

**DESIGN AND DEVELOPMENT OF A CMOS
COMPATIBLE BULK MICROMACHINED
ACCELEROMETER**

*Thesis submitted to
Indian Institute of Technology, Kharagpur
for the award of the degree*

of

Doctor of Philosophy

by
Ravindra Mukhiya

under the guidance of
Dr. Tarun K. Bhattacharyya



**DEPARTMENT OF ELECTRONICS AND ELECTRICAL
COMMUNICATION ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY, KHARAGPUR**

JULY 2010

TABLE OF CONTENTS

TITLE	i
DECLARATION	iii
CERTIFICATE OF APPROVAL	v
CERTIFICATE	vii
DEDICATION	ix
ACKNOWLEDGEMENTS	xi
LIST OF ABBREVIATIONS	xiii
LIST OF SYMBOLS	xv
ABSTRACT	xix
CONTENTS	xxi
1 INTRODUCTION	1
1.1 Introduction	3
1.2 Research Motivation	4
1.3 Research Objectives	5
1.4 Contributions of the Thesis	5
1.5 Organization of the Thesis	6

2 LITERATURE REVIEW	9
2.1 Introduction	11
2.2 MEMS Inertial Sensors	11
2.2.1 Classification of MEMS Accelerometer	12
2.2.2 Chronological Development of Piezoresistive Accelerometer	15
2.3 Prevailing Pollution Control Mechanism in Automobiles	21
2.4 Piezoresistive Property of Silicon	23
2.5 Summary	26
3 DESIGN AND SIMULATION OF A MEMS ACCELEROMETER	29
3.1 Introduction	31
3.2 Accelerometer Principle and Operation	32
3.3 Accelerometer Structure and Design	35
3.3.1 Structure	35
3.3.2 Mechanical Design and Analysis	38
3.3.3 Noise Calculation	52
3.4 FEM Simulation of Microaccelerometer	53
3.4.1 Mechanical Simulation	56
3.4.2 Damping Simulation	62
3.5 Sensing Element Design and Simulation	67
3.6 Summary	80
4 CMOS COMPATIBLE BULK MICROMACHINING	83
4.1 Introduction	85
4.2 Corner Compensation Structures	87
4.3 Experimental Details	89
4.4 Etch Morphology Study	91
4.5 Bulk Micromachining for Accelerometer Structure	99
4.6 Design Analysis and Discussions	102

4.7	Summary	104
5	FABRICATION OF THE ACCELEROMETER	107
5.1	Introduction	109
5.2	Accelerometer Description: Mechanical Structure and Sensing	110
5.3	Accelerometer Fabrication: CMOS Compatible	112
5.3.1	Planar Fabrication Process	112
5.3.2	Post-process Bulk Micromachining	116
5.3.3	Measurements of the Fabricated Device	120
5.4	Bonding and Packaging	123
5.4.1	Glass Micromachining and Bonding	123
5.4.2	Packaging	125
5.5	Summary	126
6	CHARACTERIZATION OF THE ACCELEROMETER	129
6.1	Introduction	131
6.2	Nano-Indenter and Laser Doppler Vibrometer	132
6.2.1	Nano-Indenter	132
6.2.2	Laser Doppler Vibrometer	132
6.3	Electronic Testing	133
6.4	Static Testing	135
6.5	Dynamic Testing	138
6.6	Maximum Load/Acceleration Testing	142
6.7	Comparison of Simulation and Test Results	147
6.8	Summary	147
7	DESIGN AND SIMULATION OF A FUEL CONTROL UNIT: A CASE STUDY	151
7.1	Introduction	153
7.2	Proposed Microsystem	153
7.3	Control Unit Description	155

7.4	Working Mechanism of Fuel Control Unit	159
7.5	Discrete PID Controller	160
7.6	Simulink Design	160
7.7	Working Modes of the Automobile	163
7.8	Stability Issue	164
7.9	Simulation Results	167
7.9.1	Input Simulation	167
7.9.2	Normal Acceleration Profile	168
7.9.3	Car Experiences Jerk	169
7.9.4	Repeated Asymmetric Acceleration Profile	171
7.9.5	Complex Acceleration Profile	173
7.9.6	Variable Coefficients Condition	175
7.10	Summary	177
8	CONCLUSIONS	179
8.1	Concluding Remarks	181
8.2	Scope for Future Work	184
APPENDIX-A DERIVATION FOR FREQUENCY AND TIME DOMAIN ANALYSIS		187
APPENDIX-B PUBLICATIONS FROM THE THESIS WORK		197
REFERENCES		201
CURRICULUM VITAE		211