

Contents

Acknowledgment	iii
Abstract	v
Abbreviations and Symbols	xi
1 Introduction	1
2 Fundamentals	7
2.1 Medical Background	7
2.1.1 Anatomy of the Human Heart	7
2.1.2 Electrical Conduction System of the Heart	9
2.1.3 Cardiac Arrhythmia	12
2.1.4 Pacemaker Treatment	15
2.2 Measurement of the Cardiac Activity	16
2.2.1 Electrocardiography	16
2.2.2 Cardiomechanical Signals	18
2.3 Capacitive Electrocardiography	20
2.3.1 Electrode Types and Coupling Impedance	21
2.3.2 Obstacles of Capacitive ECG	25
2.3.3 Applications	30
3 Physiological Motion Artifacts and Their Measurement	33
3.1 Motivation and Overview	33
3.2 Mathematical Model for Motion Artifacts	34
3.2.1 Electrode Model	34
3.2.2 Effect of Time-Variant Components	35
3.2.3 Resulting Artifacts	36
3.3 Physiological Motion Artifacts	37
3.3.1 Hypothesis	38
3.3.2 Supporting Examples in the Literature	41
3.3.3 Preliminary Study for BCG Influence	42
3.4 Measurement System for the Coupling Impedance	45
3.4.1 Design Constraints	47
3.4.2 BCG Measurement	48
3.4.3 Impedance Measurement	49
3.5 System Evaluation in Vitro	52
3.5.1 Performance Under Static Load	53
3.5.2 Dynamic Characteristics	54

3.6	Summary	57
4	Results and Analysis of Physiological Motion Artifacts	59
4.1	Motivation and Overview	59
4.2	Methods	60
4.2.1	Study on Healthy Subjects	60
4.2.2	Post-processing and Metrics	61
4.3	Evaluation of the Correlation Model	67
4.3.1	Correlation in Time Domain	69
4.3.2	Correlation in Frequency Domain	71
4.3.3	Artifact Consistency	74
4.3.4	Correlation Strength	75
4.4	Electrode Impedance Mismatch	77
4.4.1	Mismatch Factor	77
4.4.2	Deterioration of CMRR	79
4.5	Summary	82
5	Utilization of Time-Variant Coupling Impedance	85
5.1	Motivation and Overview	85
5.2	Amplitude Modulation in Capacitive ECG	86
5.2.1	Electrode Model with Modulated Impedance	86
5.2.2	Analytical Solution of the System	87
5.2.3	Validation in Numerical Simulations	89
5.2.4	Crossover in the Coupling Impedance	92
5.3	System Description for Physical Simulations	93
5.3.1	Proposed Electrode Prototype	93
5.3.2	Measurement Setup and Amplifier	96
5.3.3	Physical Test Setup	97
5.4	Validation on the Test Bench	98
5.4.1	Proof-of-Concept Measurement	98
5.4.2	Modeling of the mECG Amplitude	99
5.4.3	Experimental Validation	99
5.5	Influence of System Parameters	101
5.5.1	Textile Material	102
5.5.2	Contact Pressure	104
5.5.3	Modulation Frequency	106
5.6	Summary	107
6	Extension of the cECG to Patients with Cardiac Pacemakers	111
6.1	Motivation and Overview	111

6.2	Multichannel Capacitive ECG Measurement	112
6.2.1	Capacitive ECG Car Seat	113
6.2.2	Morphology of Pacemaker Spikes	115
6.3	Clinical Trial on Pacemaker Patients	117
6.3.1	Measurement Protocol	117
6.3.2	Reference System and Data Annotation	120
6.4	Data Evaluation	122
6.4.1	Spike Detection Algorithm	122
6.4.2	Evaluation Metrics	124
6.4.3	Channel Fusion	125
6.5	Results and Discussions	127
6.5.1	Signal Quality in cECG Channels	128
6.5.2	Multichannel Measurement of Pacemaker Spikes	128
6.5.3	Detection Efficiency	131
6.5.4	Factors Influencing Detection Score	133
6.6	Summary	136
7	Conclusion and Outlook	139
A	Publications	143
	Bibliography	147