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MODELLING, ANALYSIS AND DESIGN OF BIOELECTRONIC CIRCUITS IN VLSI

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ABSTRACT

Biological phenomena at the molecular level are being imitated by electronic circuits. The immense effectiveness and versatility of bioelectronic circuits have yielded multiple benefits to both the electronic, and the biological worlds. Advancement in technology is being made towards the design and implementation of these systems due to their extreme proficiency and extraordinary capabilities. Development of bioelectronic circuits is assisting researchers to gain deep insights into complex processes of life. These systems are classified into different categories depending on the various kinds and nature of the biological processes. Cytomorphic and neuromorphic circuits are two major classifications of the bioelectronic systems.

Cytomorphic circuits mimic the biological processes taking place inside a living cell. Activities involved in DNA-protein interactions play a vital role for the survival of living organisms. This thesis illustrates modelling and the design of the cytomorphic circuits in VLSI representing the DNA-protein interactions at the molecular level. Electronic circuits imitating neural activities are classified as neuromorphic circuits. The significance of these bioelectronic circuits cannot be denied. Hence, an effort is made in this research to model neuron-to-neuron communication process through electronic circuit components in VLSI. For an electronic representation of these phenomena, biological to electrical analogies are determined, analysed, and modelled. Circuit design validation is accomplished by comparing the circuit results with experimentally reported biological data.

The cytomorphic circuit is capable of analysing the cellular behaviour of living organisms, while the neuromorphic circuit is competent to mimic the neurological processes that are dependent on neuron-to-neuron combination such as neural DNA transcription initiation. Biological experimentation on bacteria *Escherichia coli* is carried out that validates that the cytomorphic VLSI circuit design is capable of predicting gene behaviour of living organisms. The neuromorphic circuit is fabricated using 0.13 μm IBM CMOS technology and fabrication results are illustrated in the thesis. Electronic gene oscillators and neural DNA transcription initiation circuits are illustrated as applications of the proposed VLSI bioelectronic circuit designs.

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TABLE OF CONTENTS

| | |
|---|-------------|
| ABSTRACT | ii |
| ACKNOWLEDGEMENTS | iii |
| LIST OF ABBREVIATIONS | x |
| LIST OF FIGURES | xi |
| LIST OF TABLES | xvii |
| CHAPTER 1 | 1 |
| INTRODUCTION | 1 |
| 1.1 BIOELECTRONICS | 1 |
| 1.2 MOTIVATION | 1 |
| 1.3 RESEARCH GOALS | 3 |
| 1.4 SCOPE OF THE STUDY | 3 |
| 1.5 THESIS ORGANIZATION | 4 |
| CHAPTER 2 | 6 |
| LITERATURE REVIEW | 6 |
| 2.1 INTRODUCTION | 6 |
| 2.2 CYTOMORPHIC CIRCUITS | 6 |
| 2.2.1 Biological Parameters and Electronic Circuit Analogies..... | 6 |
| 2.2.2 A Single-Gene Electronic Circuit | 7 |
| 2.2.3 Engineered Gene Circuits | 9 |
| 2.2.4 Molecular AND Gate Design | 10 |
| 2.2.5 Biochemical Feedback Mechanism of Enzyme | 10 |
| 2.3 NEUROMORPHIC CIRCUITS | 12 |

Table of Contents

| | | |
|--|---|-----------|
| 2.3.1 | Membrane Electronic Model | 13 |
| 2.3.2 | Membrane Electronic Model using Memristors | 14 |
| 2.3.3 | Synaptic Transmission Model | 15 |
| 2.3.4 | Memristor Bridge Synapse Circuit | 17 |
| 2.3.5 | VLSI Neuron Model | 18 |
| 2.4 | CONCLUSION..... | 19 |
| CHAPTER 3 | | 21 |
| ELECTRONIC CIRCUIT MODELLING OF GENE EXPRESSION MECHANISMS..... | | 21 |
| 3.1 | INTRODUCTION..... | 21 |
| 3.2 | BIOLOGICAL FUNDAMENTALS | 21 |
| 3.2.1 | Gene Expression Mechanism | 21 |
| 3.2.2 | Stages of Gene Expression | 22 |
| 3.2.3 | Transcription Control Mechanism | 25 |
| 3.3 | MATHEMATICAL MODELLING OF GENE EXPRESSION MECHANISMS | 26 |
| 3.3.1 | Equivalence between Biological Parameters and Electronic Circuit Entities | 26 |
| 3.3.2 | Analogies between Electronic Parameters and the Parameters in miRNA Gene Regulation | 27 |
| 3.3.3 | Units for Biological Circuit Entities | 32 |
| 3.4 | ELECTRONIC CIRCUIT MODEL MIMICKING GENE EXPRESSION MECHANISMS..... | 33 |
| 3.4.1 | Transcription Control Mechanism | 33 |
| 3.4.2 | Transcription, Translation and mRNA Degradation..... | 34 |
| 3.4.3 | MiRNA Synthesis | 35 |
| 3.4.4 | Protein Degradation Process..... | 35 |

Table of Contents

| | | |
|---|---|-----------|
| 3.5 | RESULTS AND DISCUSSIONS | 39 |
| 3.5.1 | Circuit Parameter Values | 39 |
| 3.5.2 | Simulation Results | 40 |
| 3.5.3 | Robustness of the Composite Gene Circuit Model..... | 42 |
| 3.5.4 | Scaling and Calibration of Axes Quantities | 44 |
| 3.5.5 | Comparison between Electronically Simulated Outputs and Experimentally Reported Data..... | 47 |
| 3.6 | CONCLUSION..... | 51 |
| CHAPTER 4 | | 53 |
| ELECTRONIC CIRCUIT MODELLING OF NEURAL SYNAPTIC TRANSMISSION PROCESS | | 53 |
| 4.1 | INTRODUCTION..... | 53 |
| 4.2 | TRANSMISSION AT SYNAPSE – BIOLOGICAL PROCESS..... | 54 |
| 4.2.1 | Presynaptic Neuron..... | 54 |
| 4.2.2 | Postsynaptic Neuron | 55 |
| 4.3 | Ca²⁺ IONS CONDUCTANCE ANALOGOUS TO MEMRISTOR..... | 57 |
| 4.3.1 | Mathematical Representation of Ca ²⁺ Ions Conductance across a Neuron Membrane | 57 |
| 4.3.2 | Voltage Controlled Memristor..... | 58 |
| 4.3.3 | Memristive System Equations for Ca ²⁺ Ions Channel | 59 |
| 4.3.4 | Implementation and Results..... | 60 |
| 4.4 | ELECTRONIC CIRCUIT MODEL FOR THE NEURAL SYNAPTIC TRANSMISSION PROCESS..... | 65 |
| 4.4.1 | ACh Synthesis | 67 |
| 4.4.2 | ACh Storage..... | 68 |

Table of Contents

| | | |
|---|---|------------|
| 4.4.3 | Chemical Synaptic Transmission Process | 68 |
| 4.4.4 | Postsynaptic Neuron Circuit Model..... | 69 |
| 4.4.5 | Concurrent Synaptic Transmissions | 70 |
| 4.5 | SIMULATION RESULTS AND DISCUSSION..... | 71 |
| 4.5.1 | Circuit Parameters and Input Voltages | 72 |
| 4.5.2 | Simulation Results | 74 |
| 4.5.3 | Monte Carlo Analysis | 79 |
| 4.6 | CONCLUSION..... | 81 |
| CHAPTER 5 | | 82 |
| BIOLOGICAL EXPERIMENTATION AND VLSI FABRICATION..... | | 82 |
| 5.1 | INTRODUCTION..... | 82 |
| 5.2 | CYTOMORPHIC CIRCUIT VALIDATION THROUGH BIOLOGICAL EXPERIMENTATION ON BACTERIA..... | 82 |
| 5.2.1 | Regulation of Gene Expression of Individual Bacteria for Environmental Changes Adaption | 83 |
| 5.2.2 | Spectrophotometric Analysis of β -galactosidase Activity | 83 |
| 5.3 | BIOLOGICAL EXPERIMENT FOR OBSERVING ESCHERICHIA COLI GENE BEHAVIOUR..... | 85 |
| 5.3.1 | Materials / Reagents..... | 85 |
| 5.3.2 | Instruments/Apparatus | 87 |
| 5.3.3 | Biological Experimental Procedure | 88 |
| 5.3.4 | Results..... | 90 |
| 5.4 | VALIDATING ELECTRONIC DESIGN BY CORRELATING CIRCUIT RESULTS WITH BIOLOGICAL EXPERIMENT OUTCOMES..... | 97 |
| 5.5 | VLSI FABRICATION OF THE NEUROMORPHIC CIRCUIT | 100 |

Table of Contents

| | | |
|---|---|------------|
| 5.5.1 | Layout and Fabrication Details..... | 101 |
| 5.5.2 | Test Setup | 103 |
| 5.5.3 | External Inputs to the Circuit..... | 103 |
| 5.5.4 | Oscilloscope Results..... | 105 |
| 5.5.5 | Circuit Design Validation..... | 107 |
| 5.6 | CONCLUSION..... | 110 |
| CHAPTER 6..... | | 111 |
| BIOELECTRONIC CIRCUITS APPLICATIONS..... | | 111 |
| 6.1 | INTRODUCTION..... | 111 |
| 6.2 | NEUROMORPHIC CIRCUIT APPLICATION..... | 111 |
| 6.2.1 | Biological Fundamental..... | 112 |
| 6.2.2 | VLSI Model of Ca ²⁺ ion Stimulated Postsynaptic DNA Transcription..... | 112 |
| 6.2.3 | Simulation Results and Discussion..... | 116 |
| 6.3 | ELECTRONIC CIRCUIT DESIGNS OF GENE – PROTEIN – MIRNA OSCILLATORS/MULTIVIBRATORS..... | 117 |
| 6.3.1 | Two Genes Oscillator Electronic Circuit..... | 117 |
| 6.3.2 | Two Genes Oscillator Simulation Results | 119 |
| 6.3.3 | Six Genes Oscillator / Multivibrator Electronic Circuit | 120 |
| 6.3.4 | Six Genes Oscillator Simulation Results | 121 |
| 6.4 | FEASIBILITY PROCEDURE FOR GENES OSCILLATOR | 126 |
| 6.4.1 | Feasibility Procedure for Two Genes Oscillator..... | 126 |
| 6.4.2 | Feasibility Procedure for Six Genes Oscillator..... | 127 |
| 6.5 | CONCLUSION..... | 130 |
| CHAPTER 7..... | | 131 |

Table of Contents

| | |
|-----------------------------------|------------|
| CONCLUSION | 131 |
| 7.1 SUMMARY..... | 131 |
| 7.2 FUTURE WORK | 133 |
| REFERENCES..... | 133 |
| APPENDIX A | 141 |
| APPENDIX B | 144 |
| APPENDIX C | 145 |
| APPENDIX D | 148 |
| LIST OF PUBLICATIONS | 153 |

LIST OF ABBREVIATIONS

| | |
|------------------|--|
| Acetyl CoA | Acetyl Coenzyme A |
| ACh | Acetylcholine |
| BiCMOS | Bipolar-CMOS |
| BJT | Bipolar Junction Transistor |
| Ca ⁺² | Calcium ion |
| CaMKIV | Ca ⁺² /calModulin-dependent protein Kinase IV |
| CAT | Choline AcetylTransferase |
| CMOS | Complementary Metal Oxide Semiconductor |
| CREB | cAMP-Responsive Element Binding Protein |
| DNA | Deoxyribonucleic acid |
| <i>E.coli</i> | Escherichia coli |
| EPC | End Plate Current |
| EPSP | Excitatory Postsynaptic Potential |
| IC | Integrated Circuit |
| Lac | Lactose |
| MATLAB | MATrix LABoratory |
| Memristor | Memory Resistor |
| miRNA | Micro Ribonucleic Acid |
| MOSFET | Metal Oxide Semiconductor Field Effect Transistor |
| mRNA | Messenger Ribonucleic Acid |
| NMOS | n-channel MOSFET |
| ONPG | <i>o</i> -nitrophenyl- β -galactoside |
| OpAmp | Operational Amplifier |
| pCREB | Phosphorylated CREB |
| PMOS | p-channel MOSFET |
| Pre-miRNA | Precursor Micro Ribonucleic Acid |
| Pri-miRNA | Primary Micro Ribonucleic Acid |
| RNA | Ribonucleic Acid |
| TiO ₂ | Titanium dioxide |
| VLSI | Very Large Scale Integration |

LIST OF FIGURES

| | |
|--|----|
| Fig. 2. 1. Electronic circuit model mimicking DNA-protein interactions of a single gene, as shown in [20] | 8 |
| Fig. 2. 2. Complete pyrimidine biosynthetic pathway as developed by Vinoth and Balaji in [18] | 11 |
| Fig. 2. 3. Electronic Model of nerve membrane proposed by Hodgkin and Huxley in [27]..... | 13 |
| Fig. 2. 4. Placement of Memristor in linear relationship of current, voltage, charge and flux as mentioned in [30] | 14 |
| Fig. 2. 5. Lissajous Figure: Frequency dependent voltage versus current graph [31]... | 15 |
| Fig. 2. 6. Memristor Bridge Neuron developed by Kim et al. in [32] | 17 |
| Fig. 2. 7. A VLSI Neuron Model proposed by Demirkol and Ozogus in [35] | 19 |
| Fig. 3. 1. Gene expression pathway with stages enclosed in square boxes, and input and output of these stages indicated by arrows. The biological representation concept is taken from [36] | 22 |
| Fig. 3. 2. miRNA synthesis pathway followed by degradation of mRNA strands. Double stranded RNA transcripts termed as pri-miRNA are transcribed from DNA which are converted into pre-miRNA by Drosha. Finally, mature miRNA (single strands) are synthesized from pre-miRNA by action of a Dicer enzyme. miRNA attacks the mRNA and degrades it. The biological representation concept is taken from [21],[43]..... | 24 |
| Fig. 3. 3. Biomolecular representation of protein degradation pathway. Protein to be degraded is targeted by the ubiquitin molecules. Ubiquitinated (marked) protein enters the proteasome where it is degraded. The biological representation concept is taken from [36]. | 25 |
| Fig. 3. 4 Electronic model of mechanisms involved in gene expression stages. All stages are highlighted with in boxes. Repressible and inducible gene regulation mechanisms are also depicted. Either repressible or inducible mechanism is selected at a time to simulate the circuit | 34 |
| Fig. 3. 5 The equivalent BiCMOS electronic circuit of the gene expression using PNP transistors. $\alpha_{rp} \gamma_{tc}$ controls the reaction rate of RNA transcription from DNA when S_1 is ON. mRNA concentration (α_{mR}) is K times RNA concentration (α_R). α_{mR} is Q1 base input voltage and its output collector voltage is synthesized protein α_p . α_p is controlled by Q2 output at collector, i.e. miRNA concentration (α_{miR}). Q2 base voltage is premiRNA concentration (α_{pre}) which depends on amount of primiRNA (α_{pri}) | |

transformed into α_{pre} by K_{drosha} . α_{pri} is transcribed from the gene with a reaction rate of α_{polyA} . Q3 and Q4 form a current source for biasing the circuit. 38

Fig. 3. 6. Simulated miRNA and protein concentrations (potentials). The dotted vertical lines indicate the simulated effect of miRNA concentration on protein. Upper plot: miRNA concentration (α_{miR}), lower plot: protein concentration after translation (α_p). Potentials are taken on x-axes, while time scales are plotted on y-axes. 40

Fig. 3. 7. Simulated final protein concentrations after translation and degradation stages. Upper plot: protein concentration after translation, lower plot: protein concentration after degradation. For protein degradation output, ubiquitin and proteasome inputs are high (1.2V), while for protein translation these inputs are low (0V)..... 41

Fig. 3. 8. Monte Carlo simulation illustrating stochastic effect of the miRNA on the protein level 43

Fig. 3. 9. Monte Carlo simulation illustrating protein concentration after translation (without degradation) and after degradation stages of gene expression. Gaussian probability distribution function is selected for the varying circuit parameters of Fig. 3.5 44

Fig. 3. 10. Inset views of electronically simulated protein and miRNA concentrations from Fig. 3.6. miRNA and protein levels are shown on left right y-axes respectively. Potentials are scaled to a biologically analogous parameter, i.e. concentration. Electrical time is also scaled to a biological time period. 46

Fig. 3. 11. Comparison between the electronically simulated and experimental biological results for miRNA (upper plot) and the protein (lower plot) concentrations. Solid lines indicate the electronic results that are generated from the electronic cytomorphic circuit of the gene expression mechanisms, while the dotted lines indicate the biologically observed results that are taken from the research mentioned in [69]. These two plots also show the effect of increasing miRNA concentration on the translated protein level. Protein level is high in the absence of miRNA. Once miRNA is transcribed, mRNA translation was affected ultimately resulting in a decrease in protein concentration..... 48

Fig. 3. 12. Comparison between the electronically simulated and experimental biological results for miRNA (upper plot) and the protein (lower plot) concentrations. Solid lines indicate the electronic results that are generated from the electronic cytomorphic circuit of the gene expression mechanisms, while the dotted lines indicate the biologically observed results that are taken from the research mentioned in [69]. These two plots also show the effect of decreasing miRNA concentration on the translated protein level. Protein level is low when miRNA level is high. When miRNA starts to decrease, mRNA translation was affected ultimately resulting in a decrease in protein concentration 49

List of Figures

Fig. 3. 13. Relative protein level from experimentally reported data as mentioned in [72],[73] with and without degradation. For observing protein level without degradation, proteasome inhibitor was injected in the cells under observation..... 51

Fig. 3. 14. Relative protein concentration output of gene expression circuit model before and after the protein degradation process 51

Fig. 4. 1. Biological representation of the neural synaptic transmission process taking place between presynaptic and postsynaptic neurons. The biological concept is taken from [28],[29],[85]..... 56

Fig. 4. 2. The Lissajous figure associated with input membrane voltage (1V, 8 Hz) and current response of memristor..... 62

Fig. 4. 3. Voltage-Current relationship at different input frequencies. Memristance is a non linear curve at low frequencies (2Hz and 5Hz) and becomes linear at a very high frequency (130 Hz) 63

Fig. 4. 4. g_{Ca} value for 1 V and 130Hz input voltage signal. Two fractional initial channel opening states, M_0 values are taken i.e. 0.1 and 0.007. 64

Fig. 4. 5. g_{Ca} value for 1.15 V and 130Hz input voltage signal. wo fractional initial channel opening states, M_0 values are taken i.e. 0.1 and 0.007. 64

Fig. 4. 6. Lissajous figures related to excitation voltage and current response of memristor equivalent to Ca^{2+} ions conductance 65

Fig. 4. 7. An electronic circuit model mimicking the neural synaptic transmission process. Stages involved in the transmission process are highlighted in square boxes. Inputs to the circuit are voltages V_{acoa} , V_{ch} and V_{Ca} analogous to acetyl coenzyme A, choline and extracellular Ca^{2+} ion concentrations respectively. Action potential input signal, V_{ap} acts as a triggering event for initiating the synaptic transmission process from presynaptic to postsynaptic neuron. Circuit output is temporally summed EPSP due to continuous pulses V_{ap} occurring at the same synapse of the presynaptic neuron membrane..... 66

Fig. 4. 8. An electronic model of the concurrent synaptic transmission process. generating spatially summed EPSP. “Syn_1” and “Syn_2” correspond to circuit model mimicking the neural synaptic transmission process (from Fig. 4.7) for synapse 1 and synapse 2 respectively. Extracellular Ca^{2+} ions concentrations for Syn_1 and Syn_2 are analogous to V_{Ca_1} and V_{Ca_2} respectively, while V_{ap_1} and V_{ap_2} are their action potential signals. Outputs EPSP1 and EPSP2 of these two synapses are added together by a non-inverting weighted summer..... 71

Fig. 4. 9. Memristor emulator [82] modified for 0.13 μm technology. It is used to model ionic conductance in the simulation of Figs 4.7 and 4.8..... 74

List of Figures

Fig. 4. 10. Lissajous figure obtained for Ca^{2+} ions conductance using the memristor emulator depicted in Fig. 4.9 75

Fig. 4. 11. Temporally summed *EPSPs* at the postsynaptic neuron. Solid line indicated the summed *EPSPs*, while the individual *EPSP* is represented by the dotted line. 76

Fig. 4. 12. Spatial summation of *EPSPs* at the postsynaptic neuron. Solid line indicated the summed *EPSPs*, while the individual *EPSP* is represented by the dotted line 77

Fig. 4.13. Circuit model simulation outputs for synaptic current at various V_m values.....78

Fig. 4.14. Data recorded from neuro-biological experimentation mentioned in [85] for synaptic current at various V_m values.....78

Fig. 4. 15. Monte Carlo analysis result for *EPSPs*' temporal summation. Memristors, capacitors and resistors in Fig. 4.7 are randomly varied by Gaussian probability distribution function..... 80

Fig. 4. 16. Monte Carlo analysis result for *EPSPs*' spatial summation. Syn_1 and Syn_2 in Fig. 4.8 are randomly varied by Gaussian probability distribution function... 80

Fig. 5. 1. Absorbance versus time for 0 – 5 minutes. 91

Fig. 5. 2. Absorbance versus time for 15 – 20 minutes..... 91

Fig. 5. 3. Absorbance versus time for 30 – 35 minutes. 92

Fig. 5. 4. Absorbance versus time for 45 – 50 minutes..... 92

Fig. 5. 5. Absorbance versus time for 60 – 65 minutes..... 93

Fig. 5. 6. Absorbance versus time for 75 – 80 minutes..... 93

Fig. 5. 7. Absorbance versus time for 90 – 95 minutes. 94

Fig. 5. 8. Rate of β -galactosidase enzyme activity for lactose, glucose and lactose + chloramphenicol..... 97

Fig. 5. 9. Predicted cellular response by electronic circuit design (solid line) for high inducer input and biologically observed *E.coli* behavior (dotted line) in presence of inducer molecule. 98

Fig. 5. 10. Predicted cellular response by electronic circuit design (solid line) for low inducer input and biologically observed *E.coli* behaviour (dotted line) in absence of inducer molecule. 99

List of Figures

Fig. 5. 11. Effect of miRNA (translation inhibitor) on protein level (solid line) and effect of chloramphenicol (translation inhibitor) on *E.coli* behaviour (solid line with marker)..... 100

Fig. 5. 12. VLSI fabricated chip photomicrograph. Different sections of the biomimetic circuits are highlighted in square boxes and labelled numerically. These labelled sections are mentioned below the diagram. 102

Fig. 5. 13. Inset view of temporal summation circuit from Fig. 5.12. 102

Fig. 5. 14. Chip connections and PGA socket 103

Fig. 5. 15. Chip output of the synaptic transmission circuit presented in Chapter 4, Fig. 4.7. Temporal Summation of *EPSPs* is observed at output pin of the chip for continuous action potential input signal. 105

Fig. 5. 16. Chip output of the *EPSP* spatial summation circuit presented in Chapter 4, Fig. 4.8. *EPSPs* are summed spatially when a single action potential pulse is applied to two different synapses..... 106

Fig. 5. 17. Temporal summation of *EPSPs* for chip output (solid line) and experimentally reported data (dotted line). The biological data is taken from [85]. Left y-axis represents postsynaptic potential amplitude obtained from oscilloscope results, while right y-axis shows the amplitude for biologically observed results. Time duration is mentioned on x-axis. 107

Fig. 5. 18. Spatial summation of *EPSPs* for electronic chip output (solid line) and experimentally reported data (dotted line). The biological data is taken from [85]. Left y-axis represents postsynaptic potential amplitude obtained from electronic results, while right y-axis shows the amplitude for biologically observed results. Time duration for electronic results is mentioned on bottom x-axis, while top x-axis shows biological time duration. 108

Fig. 5. 19. Bar chart comparison of *EPSP* summation between electronic chip results and the neurobiological data taken from [85],[123],[124]..... 109

Fig. 6. 1. Biological representation of neural DNA initiation due to synaptic transmission process and protein synthesis inside postsynaptic neuron membrane. The biological representation concept is taken from [28]...... 113

Fig. 6. 2. Electronic circuit model of the neural DNA initiation and protein synthesis inside postsynaptic membrane. 115

Fig. 6. 3. Inverse relationship between neural miRNA and neural protein. The protein is synthesized after the DNA transcription initiation in the postsynaptic neuron due to chemical synaptic transmission..... 117

Fig. 6. 4. Electronic circuit model of two genes oscillator. $V_{protein}$ represents protein output of first gene, while V_{miRNA} mimics miRNA output of second gene. $V_{protein}$ represses transcription of *gene 1* and miRNA gene through S1 and S2 NFET switches. 119

Fig. 6. 5. Oscillations observed for protein level of *gene 1* and miRNA level of the gene degrading *gene 1* mRNA. 120

Fig. 6. 6. Electronic circuit model of six genes oscillator. Switches S1, S3 and S5 control transcription of *gene 1*, *gene 2* and *gene 3* respectively. Switches S2, S4 and S4 control transcription of miRNA genes repressing *gene 1*, *gene 2* and *gene 3* at translational level respectively..... 122

Fig. 6. 7. Oscillation patterns for the concentrations of $V_{protein1}$ (upper plot) and V_{miRNA1} (lower plot), i.e., the protein synthesized from *gene 1*, and the miRNA transcripts degrading mRNA of *gene 1*. 123

Fig. 6. 8. Oscillation patterns for the concentrations of $V_{protein1}$ (upper plot) and V_{miRNA2} (lower plot), i.e., the protein synthesized from *gene 1*, and the miRNA transcripts degrading mRNA of *gene 2*. 124

Fig. 6. 9. Oscillation patterns for the concentrations of V_{miRNA2} (upper plot) $V_{protein2}$ (lower plot) and, i.e., the miRNA transcripts degrading mRNA of *gene 2*, and the protein synthesized from *gene 2*. 125

Fig. 6. 10. Oscillation patterns for the concentrations of $V_{protein2}$ (solid lines) and $V_{protein3}$ (dotted lines), i.e., the protein synthesized from *gene 2*, and the protein synthesized from *gene 3*. 125

Fig. 6. 11. A block diagram showing relationship between two genes resulting in an oscillatory network. Solid lines show gene expression control at the transcriptional stage (by the protein), while dotted lines shows gene expression control at the translational stage (by miRNA). Arrow headed line shows transcriptional induction, while flat ended lines means repression (transcriptional / translational)..... 127

Fig. 6. 12. A block diagram showing relationship among six genes resulting in an oscillatory network. Solid lines show gene expression control at the transcriptional stage (by the protein), while dotted lines shows gene expression control at the translational stage (by miRNA). Arrow headed line shows transcriptional induction, while flat ended lines means repression (transcriptional / translational)..... 129

LIST OF TABLES

| | |
|--|----|
| Table 2. 1. Summary of Gene and Electronic circuit Analogous Parameters as mentioned in [20] | 7 |
| Table 3. 1. Symbols and units for biological circuit entities utilized in electronic modelling of gene expression stages..... | 27 |
| Table 3. 2. Electronic gene expression circuit parameters and BJT π -model parameters entities analogy taken from [50] | 37 |
| Table 5. 1. Chemical components of phosphate buffer taken from [112] | 86 |
| Table 5. 2. Chemical Reagents used for <i>E.coli</i> basal medium preparation..... | 87 |
| Table 5. 3. Pipettor description taken from [105]..... | 88 |
| Table 5. 4. ΔA_{per_min} and $\beta - gal_{activity}$ measured from 0 – 90 minutes for lactose | 95 |
| Table 5. 5. ΔA_{per_min} and $\beta - gal_{activity}$ measured from 0 – 90 minutes for glucose | 96 |
| Table 5. 6. ΔA_{per_min} and $\beta - gal_{activity}$ measured from 0 – 90 minutes for lactose + chloramphenicol..... | 96 |