# Declaration

I, **Biswajit Das**, hereby declare that the present thesis, entitled **"Modeling and Simulation of Extracellular Space and its Role in Signal Transmission"**, is the record of work done by me under the supervision of Prof. Soumik Roy, Professor, Department of Electronics and Communication Engineering, Tezpur University, Tezpur. The contents of the thesis represent my original works that have not been previously submitted for any Degree/Diploma/Certificate in any other University or Institutions of Higher Education.

This thesis is being submitted to Tezpur University for the Degree of Doctor of Philosophy in Electronics and Communication Engineering.

Place: Tezpur University, Tezpur

Date: 19/06/2025

Biswajit Das

(Biswajit Das)

# TEZPUR UNIVERSITY

*(A Central University Established by an Act of Parliament)*

**Napaam, Tezpur-784028, Sonitpur, Assam, India**

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## Certificate

This is to certify that the thesis entitled, "**Modeling and Simulation of Extracellular Space and its Role in Signal Transmission**", submitted to the School of Engineering, Tezpur University in partial fulfillment for the award of the degree of Doctor of Philosophy in Electronics and Communication Engineering is a record of research work carried out by **Mr. Biswajit Das** under my supervision and guidance.

All help received by him from various sources have been duly acknowledged.

No part of this thesis has been submitted elsewhere for award of any other degree.

19/06/2025

(*Supervisor*)

Prof. Soumik Roy

Professor

Department of ECE

School of Engineering, Tezpur University

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## Certificate of the External Examiner

This is to certify that the thesis entitled **"Modeling and Simulation of Extracellular Space and its Role in Signal Transmission"** submitted by **Mr. Biswajit Das,** Department of Electronics & Communication Engineering, School of Engineering, Tezpur University in partial fulfilment for the award of the degree of Doctor of Philosophy in Electronics & Communication Engineering has been examined by us on 19.06.2025 and found to be satisfactory.

The committee recommends for the award of the degree of Doctor of Philosophy.

**Supervisor**

19/06/2025

**(Prof. Soumik Roy)**

**External Examiner**

( )

**Date:**_____

**Date:**_____

# Acknowledgment

First and foremost, I express my deepest gratitude to my esteemed supervisor, **Prof. Soumik Roy**, for his unwavering support, expertise, and mentorship. His encouragement, insightful feedback, and patience have been instrumental in shaping the direction of this research and in fostering my growth as a scholar.

I extend my heartfelt appreciation to the members of my thesis committee, **Prof. Partha Pratim Sahu** and **Dr. Biplob Mondal**, for their valuable insights, constructive critiques, and thoughtful suggestions. Their rigorous examination and insightful comments have significantly enhanced the quality of this work. I am immensely grateful to all the individuals and institutions that have contributed to the completion of this doctoral thesis. Their support, guidance, and encouragement have been invaluable throughout this journey.

I am thankful to **Tezpur University** for providing me with the necessary resources, research facilities, and a stimulating academic environment that enabled me to conduct this research effectively. I extend my heartfelt appreciation to the **lab technician and staff** for their invaluable support, dedication, and expertise, which significantly contributed to the success of this thesis.

I would like to express my gratitude to **my family** for their unconditional love, unwavering support, and understanding throughout my academic journey. Their belief in my abilities has been a constant source of motivation and strength. I am grateful to my friends and colleagues for their camaraderie, encouragement, and countless stimulating discussions. Their diverse perspectives have broadened my horizons and enriched my research.

My sincere thanks go to my amazing friends and lab partners, whose cooperation and support have been crucial to finishing my thesis successfully. Your combined efforts have produced a stimulating and motivating atmosphere that has greatly improved the caliber of this study**.** My lab partners, **Dr. Satyabrat Malla Bujar Baruah, Mr. Uddipan Hazarika, Mr. Bidyut Bikash Borah, Mr. Rajkumar Joydev Borah, Ms. Sneha Singh and all other lab partners from M.Tech and B.Tech** deserve special recognition. Your commitment to the common goals of our study, your attitude of cooperation, and your readiness to

share expertise have been helpful. Our lab's synergy has been a driving force, creating an atmosphere that encourages creative problem-solving and inventive thinking.

I would like to extend my deepest thanks to my companions **Reetom Borkotoky, Padum Chetry, Debarun Chakraborty, Vickey Sharma, Nivaj Gogoi, Ashish Kashyap, Subhankar Chakraborty, Awanish Singh, Souvick Roy** whose presence brought color and excitement to this journey. Without you, the path would have been dulled and monotonous, but your energy, humor, and unwavering camaraderie turned every moment into an adventure worth cherishing.

I would also like to thank my dear friends from the department **Sujay Amarprit, Ritayan, Suhriday, Deepamoni, Arpita, Anjana,** for your support and mutual amusement, the study process has become not just manageable but joyful.

It is often said that a hostel is a second home, and in this spirit, I would like to express my heartfelt gratitude to my **hostel mates from Saraighat C V Raman Men's Hostel**. Your unwavering support, camaraderie, and readiness to lend a helping hand have made this journey truly memorable. Thank you for always being there in times of need and for creating a sense of belonging that I will forever cherish.

Last but not least, I extend my heartfelt appreciation to all those whose names may not be mentioned here but have played a role in my academic and personal development. Completing this thesis would not have been possible without the combined efforts and support of all these individuals and institutions, and I am deeply grateful for their contributions, who bestowed all his blessings on me.

Biswajit Das

Dedicated to my

Parents and my Grandmother (Aita).....

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# Nomenclature

## Symbols:

| | |
|---|---|
| $Na^+$ | Sodium Ions |
| $K^+$ | Potassium Ions |
| $Ca^{2+}$ | Calcium Ions |
| $Cl^-$ | Chlorine Ions |
| $C_m$ | Total Membrane Capacitance |
| $c_m$ | Characteristic Membrane Capacitance |
| $G_{Na}$ | Sodium Conductance |
| $G_k$ | Potassium Conductance |
| $G_l$ | Maximum Leakage Conductance |
| $g_{Na}$ | Maximum Sodium Conductance |
| $g_k$ | Maximum Potassium Conductance |
| $g_l$ | Leakage Conductance |
| $E_{Na}$ | Equilibrium Potential of Sodium Ions |
| $E_k$ | Equilibrium Potential of Potassium Ions |

| | |
|---|---|
| $E_l$ | Equilibrium Potential of Leakage Ions |
| $I_T$ | Transmembrane Current |
| $I_{Na}$ | Sodium Current |
| $I_k$ | Potassium Current |
| $I_l$ | Leakage Current |
| $I_i$ | Internal Current |
| $I_e$ | External Current |
| $I_a$ | Axial Current |
| $R_m$ | Total Membrane Resistance |
| $R_a$ | Total Axial Resistance |
| $m^3$, h | Activation Variable of Sodium Ions |
| $n^4$ | Activation Variable of Potassium Ions |
| $\alpha$, $\beta$ | Rate Constants |
| $r_m$ | Characteristic Membrane Resistance |
| $R_i$ | Volumetric Internal Resistance of the Nerve Fiber |
| $R_e$ | Volumetric Extracellular Space Resistance |
| $r_i$ | Characteristic Internal Resistance of the Nerve Fiber |

| | |
|---|---|
| $r_e$ | Characteristic Extracellular Space Resistance |
| $V_i$ | Internal Potential of the Nerve Fiber |
| $V_e$ | Potential of the Extracellular Space |
| $V_m$ | Resting Membrane Potential |
| $A$ | Area |
| $d$ | Myelin Thickness |
| $\epsilon$ | Permittivity of the Material |
| $\epsilon_0$ | Permittivity of Free Space |
| $\epsilon_r$ | Relative Permittivity |
| $\frac{dV_m}{dt}$ | Rate of Change of Membrane Potential |
| $D_i$ | Internal Diameter of the Nerve Fiber |
| $D_e$ | Diameter of the Extracellular Space |
| $l$ | Length of the Fiber / Physical length of the segment under consideration |
| $V_{mnode1}$ | Membrane Potential of the Initial Node of Ranvier |
| $V_{mnode2}$ | Membrane Potential of the Next Node of Ranvier |
| $I_{prop1}$ | Current Received at the Adjacent Myelinated Segment |
| $I_{prop2}$ | Current Leaving the Myelinated Segment |

| | |
|---|---|
| $I_{delivered}$ | Current Delivered at the Fiber's Outlet |
| $I_{inj}$ | Injected Current |
| $I_{loss}$ | Propagation Loss |
| $R_p(V_m)$ | Rescue Protein Voltage |
| $K_{Rescue}$ | Rescue Protein Coefficient |
| $V_{m,Original}$ | Membrane Potential for Non Mutated (Original) State |
| $V_{m,mutated}$ | Membrane Potential for Mutated State |

# Abbreviation:

| | |
|---|---|
| AP | Action Potential |
| CNS | Central Nervous System |
| PNS | Peripheral Nervous System |
| ATP | Adenosine Triphosphate |
| ECS | Extracellular Space |
| ECM | Extracellular Matrix |
| CSD | Cortical Spreading Depression |
| LFP | Local Field Potential |
| EEG | Electroencephalogram |
| EcoG | Electro-Corticogram |
| NCV | Nerve Conduction Velocity |
| H-H | Hodgkin-Huxley |

| | |
|---|---|
| MCV | Motor Nerve Conduction Velocity |
| MS | Multiple Sclerosis |
| CMV | Cytomegalovirus |
| OPCs | Oligodendrocyte Precursor Cells |
| BDNF | Brain Derived Neurotrophic Factor |
| GABA | Gamma-Aminobutyric Acid |
| BBB | Blood Brain Barrier |
| AIS | Axon Initial Segment |
| Nav | Voltage Gated Sodium Channel |
| CAMs | Cell Adhesion Molecules |
| SCN | Sodium Voltage Gated Genes |
| KCN | Potassium Voltage Gated Genes |
| MT2 | Metallothionein-2 |
| PM22 | Peripheral Myelin Protein 22 |
| ZBP1 | Zipcode Binding Protein 1 |
| GEFS+ | Genetic Epilepsy with Febrile Seizure Plus |