Winter Internship Report

On

Integrated Circuit Design using Subcircuit Feature of eSim

Submitted by

Subikeesh M

Under the guidance of

Prof. Kannan M. Moudgalya
Chemical Engineering Department
IIT Bombay

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Acknowledgment

We extend our sincere gratitude to the **FOSSEE, IIT Bombay** team for providing us with this incredible opportunity to work on designing and integrating multiple sub-circuits in eSim. This experience has been immensely valuable, giving us hands-on exposure to open-source EDA tools for circuit simulation and a deeper understanding of their real-world applications.

We are profoundly grateful to **Prof. Kannan M. Moudgalya** for his unwavering support and guidance throughout this fellowship. Our heartfelt thanks also go to our mentors, **Mr. Sumanto Kar, Ms. Usha Vishwanathan**, and **Ms. Vineeta Ghavri**, whose expertise and continuous encouragement helped us overcome challenges and successfully complete our project.
This internship has been a transformative learning experience, equipping us with crucial skills and insights that will be invaluable in our future careers. Being part of the **FOSSEE** initiative has been a truly rewarding journey, and we deeply appreciate the knowledge and practical exposure we have gained. As aspiring professionals in the semiconductor field, we consider this internship a significant milestone in our professional growth.

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Chapter 1

Introduction

FOSSEE and eSim: Pioneering Open-Source EDA Solutions

The **Free/Libre and Open Source Software for Education (FOSSEE)** project, headquartered at **IIT Bombay**, is a significant initiative under the **National Mission on Education through Information and Communication Technology (ICT)**, Ministry of Education, Government of India. Its primary mission is to minimize dependence on proprietary software in academia by advocating for the adoption of open-source alternatives.

One of FOSSEE's flagship projects is **eSim**, an open-source Electronic Design Automation (EDA) tool tailored for circuit design, simulation, analysis, and PCB design. eSim integrates various open-source software packages, including KiCad, Ngspice, GHDL, OpenModelica, Verilator, Makerchip, and the SkyWater SKY130 Process Design Kit (PDK). This integration offers users a comprehensive platform for designing and simulating electronic circuits without the financial burden associated with proprietary tools.

eSim provides a range of features:

- **Schematic Creation**: Utilize KiCad's *eeschema* editor to craft and modify circuit schematics.
- **PCB Layout Design**: Design intricate PCB layouts and generate Gerber files using KiCad's *cvpcb* package.
- **Simulation and Analysis**: Convert KiCad netlists to Ngspice netlists for detailed circuit simulation and analysis.
- **Mixed-Signal Simulation**: Incorporate both analog and digital components in simulations, facilitated by tools like GHDL and Verilator.
- **Model and Subcircuit Builder**: Add or edit device models and subcircuits seamlessly.
- **Cross-Platform Support**: Compatible with both Ubuntu and Windows operating systems.

Through eSim, FOSSEE empowers educational institutions, researchers, and industry professionals to transition from expensive proprietary EDA tools to a cost-effective, open-source solution, thereby fostering innovation and collaboration in the field of electronic design.

1.1 eSim

eSim, created by the FOSSEE project at IIT Bombay, is a versatile open-source software tool for circuit design and simulation. It combines various open-source software packages into one cohesive platform, making it easier to design, simulate, and analyze electronic circuits. This tool is particularly useful for students, educators, and professionals who need an affordable and accessible alternative to proprietary software.

eSim offers features for schematic creation, circuit simulation, and PCB design, and includes an extensive library of components. The Subcircuit feature is a significant enhancement, enabling users to design complex circuits by integrating simpler subcircuits. Through eSim, FOSSEE promotes the use of open-source solutions in engineering education and professional fields, encouraging innovation and collaboration.

1.2 NgSpice

NgSpice is an open-source SPICE simulator for electric and electronic circuits. It can simulate various circuit elements, including JFETs, bipolar and MOS transistors, passive elements (R, L, C), diodes and other devices, all interconnected in a netlist.

Digital circuits are also simulated, ranging from single gates to complex circuits, including combinations of analog, digital, and mixed-signal circuits. NgSpice offers a wealth of device models for active, passive, analog, and digital elements. Users input their circuits as netlists, and the output is one or more graphs of currents, voltages, and other electrical quantities, or saved in a data file

1.3 Makerchip

Makerchip is a platform that offers convenient and accessible tools for digital circuit design. It provides both browser-based and desktop-based environments for coding, compiling, simulating, and debugging Verilog designs. Makerchip supports a combination of open-source and proprietary tools, ensuring a comprehensive range of capabilities.

Users can simulate Verilog/SystemVerilog/Transaction-Level Verilog code in Makerchip. eSim is interfaced with Makerchip using a Python-based application called Makerchip-App, which launches the Makerchip IDE. Makerchip aims to make circuit design easy and enjoyable for users of all skill levels. The platform provides a userfriendly interface, intuitive workflows, and a range of helpful features that simplify the design process and enhance the overall user experience.

The main drawback of these open-source tools is that they are not comprehensive. While some are capable of PCB design (e.g., KiCad), others focus on simulations (e.g., gEDA). To the best of our knowledge, there is no open-source software that combines circuit design, simulation, and layout design in one platform. eSim addresses this gap by integrating all these capabilities.

Chapter 2

Features of eSim

The objective behind the development of eSim is to provide an open-source EDA solution for electronics and electrical engineers. The software is capable of performing schematic creation, PCB design, and circuit simulation (analog, digital, and mixedsignal). It also provides facilities to create new models and components. Thus, eSim offers the following features:

1. Schematic Creation: eSim provides an easy-to-use graphical interface for drawing circuit schematics, making it accessible for users of all levels. Users can drag and drop components from the library onto the schematic, simplifying the design process. Comprehensive editing tools allow for easy modification of schematics, including moving, rotating, and labeling components.

2. Circuit Simulation: eSim supports SPICE (Simulation Program with Integrated Circuit Emphasis), a standard for simulating analog and digital circuits. Users can perform various types of analysis such as transient, AC, and DC, providing insights into circuit behavior over time and frequency. An integrated waveform viewer helps visualize simulation results, aiding in the analysis and debugging of circuit designs.

3. PCB Design: The PCB layout editor allows users to place components and route traces with precision. eSim includes DRC (Design Rule Check) capabilities to ensure that the PCB design adheres to manufacturing constraints and electrical rules. Users can generate Gerber files, which are standard for PCB fabrication, directly from their designs.

4. Subcircuit Feature: This feature enables users to create complex circuits by integrating smaller, simpler subcircuits, promoting modular and hierarchical design approaches. Subcircuits can be reused in different projects, saving time and effort in redesigning common circuit elements.

5. Open Source Integration: eSim integrates several open-source tools like KiCad, NgSpice, and GHDL, providing a comprehensive suite for electronic design automation. Being open-source, eSim is free to use, making advanced circuit design tools accessible without the need for expensive licenses.

Chapter 3

Abstract

The objective of this internship was to design and develop various integrated circuits (ICs) using the Subcircuit Builder Method in eSim. This involved modeling the ICs with eSim library files and subsequently simulating them with different circuits. The goal was to expand the eSim Subcircuit Library for future use, enhancing its utility and application in both educational and practical scenarios.

3.1 Approach

- Identify and research an integrated circuit (IC) that is not currently available in the eSim library.
- Obtain and study the datasheet of the selected IC thoroughly.
- Carefully examine the schematic provided in the datasheet.
- Accurately recreate the schematic in eSim using the Subcircuit Builder Method.
- Model the IC in eSim, ensuring all parameters and configurations match those in the datasheet.
- Simulate the integrated circuit within eSim, testing it with various circuits to verify its functionality.
- Document the process and results to contribute to the future use and expansion of the eSim Subcircuit Library.

If the simulated outputs deviated from expected results, it signaled potential errors in the schematic. In such instances, we revisited the design phase to identify and correct discrepancies. The iterative process of debugging and re-testing continued until the test cases produced satisfactory results. Once the IC models met the desired performance criteria, they were deemed successful, marking the completion of the design process

Chapter 4

SN74LS07

4.1 General Description

These hex buffers and drivers feature high-voltage open-collector outputs to interface with high-level circuits or for driving high-current loads. They are also characterized for use as buffers for driving TTL inputs. The SN74LS07 devices have a rated output voltage of 30 V. The maximum sink current is 40 mA. These circuits are compatible with most TTL families. Inputs are diode-clamped to minimize transmissionline effects, which simplifies design. Typical power dissipation is 140 mW, and average propagation delay time is 12 ns

4.2 Key Features

- **High-Voltage Output Capability:** sink current from up to 30V external supplies.
- **TTL-Compatible Inputs:** Designed to interface easily with other TTL logic families.
- **High Output Current Capability:** Can sink up to 40 mA per output pin
- **Wide Operating Temperature Range:** Typically from 0°C to 70°C, suitable for commercial-grade applications.

4.3 Applications

- **Driving LEDs:** Commonly used in status indicators or digital display drivers.
- **Relay Driving:** Can be used to switch small relays directly due to its output current capability.
- **Logic Isolation:** Isolate the logic signal from the power supply of the load.
- **Level Shifting:** Ideal for converting TTL (5V) logic to control higher voltage devices.

4.4 Pin Configuration

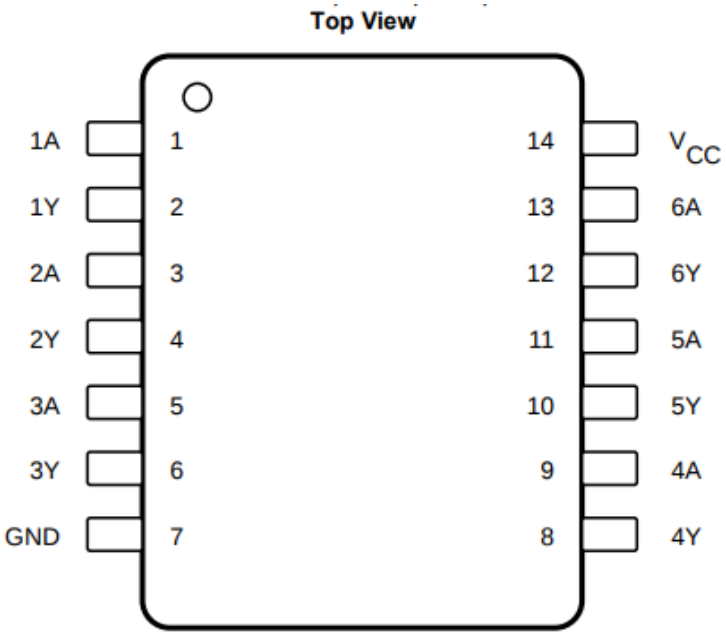

Figure 4.1: Pin of SN74LS07

4.5 IC Layout

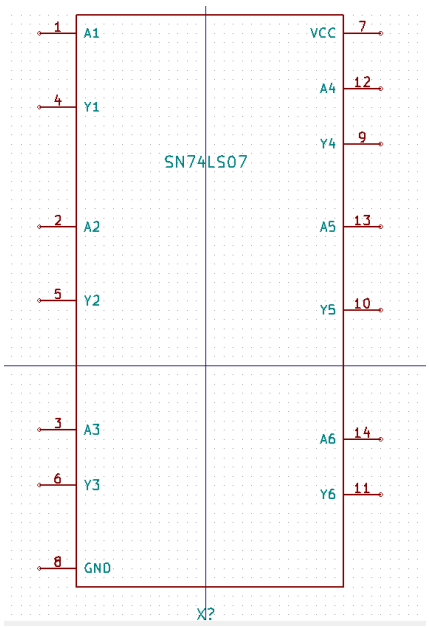

Figure 4.2: Layout of SN74LS07

4.6 Subcircuit Schematic Diagram

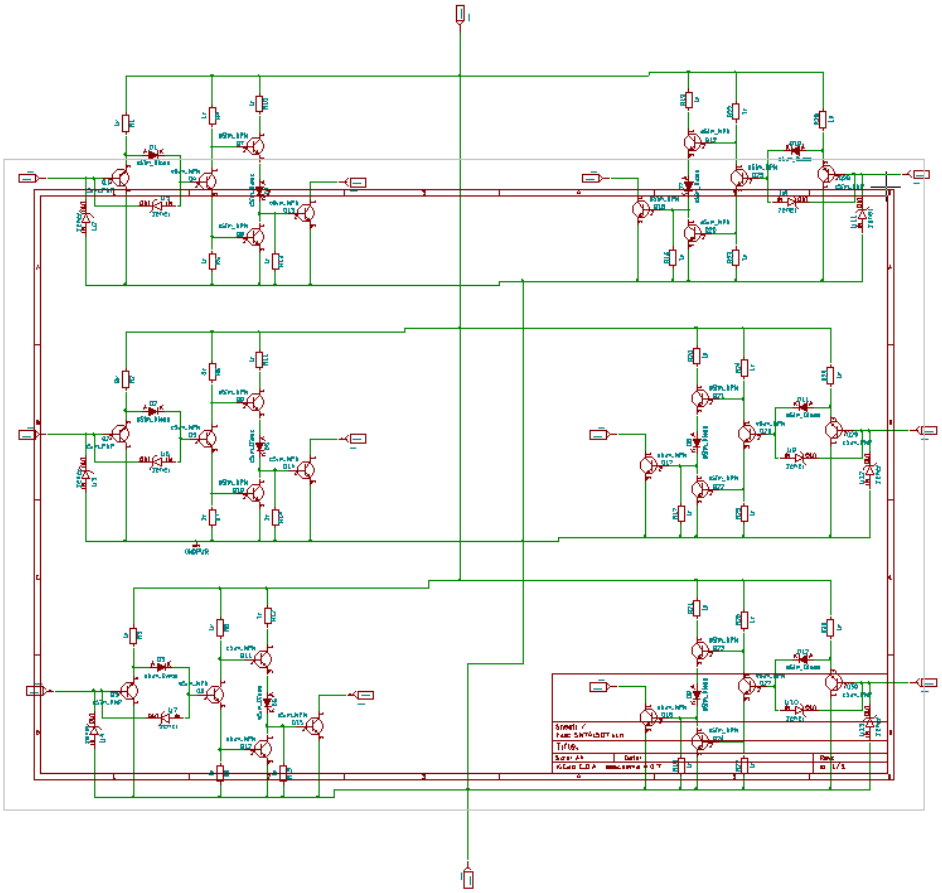

Figure 4.3: Subcircuit Schematic of SN74LS07

4.7 Text Circuit

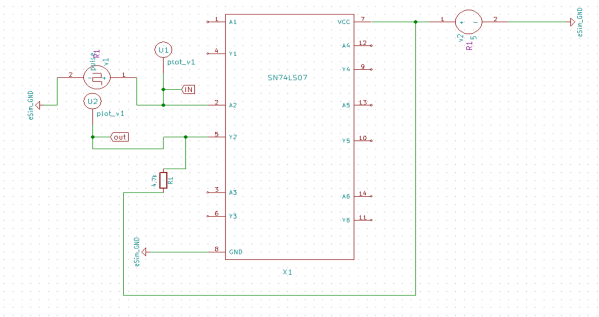

Figure 4.4: Test Circuit of SN74LS07

4.8 Input Plot for LOW Input Voltage

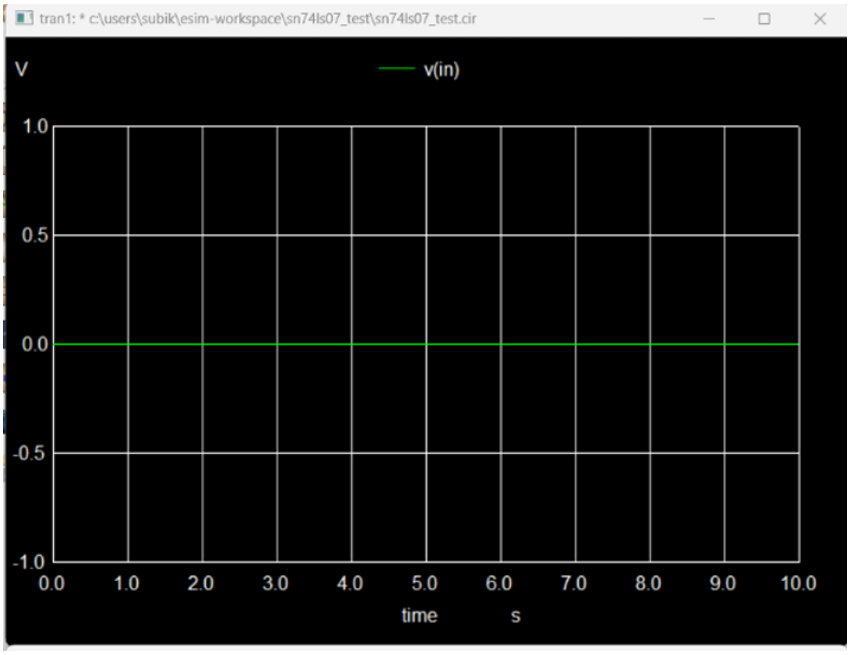

Figure 4.5: Input low

4.9 Output Plot for LOW Input Voltage

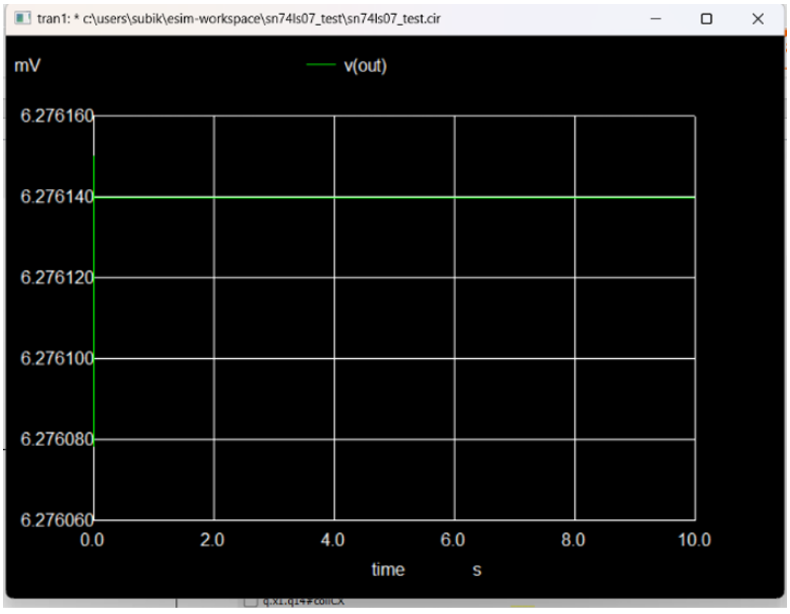

Figure 4.6: Output Low

4.10 Input Plot for High Input Voltage

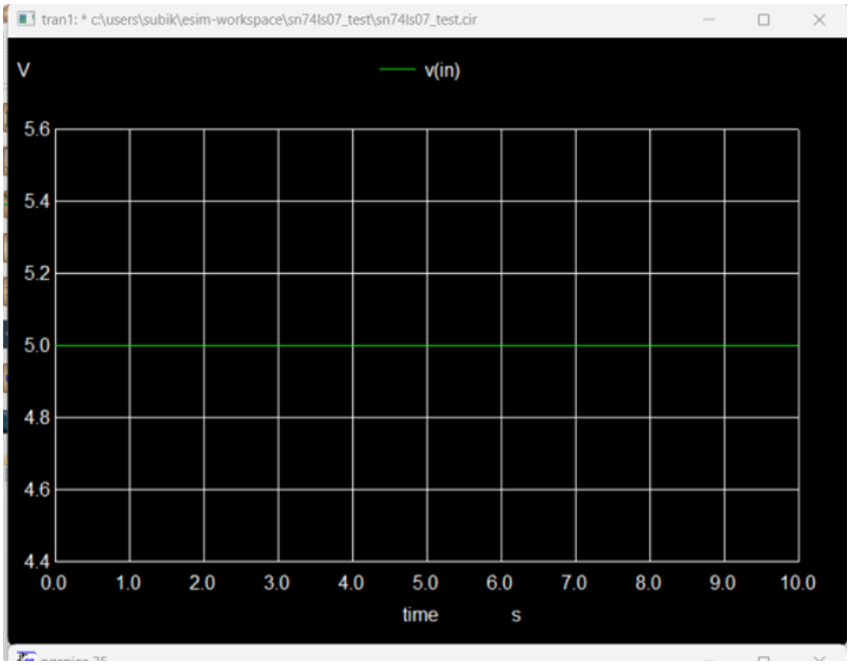

Figure 4.7: Input High

4.11 Output Plot for High Voltage

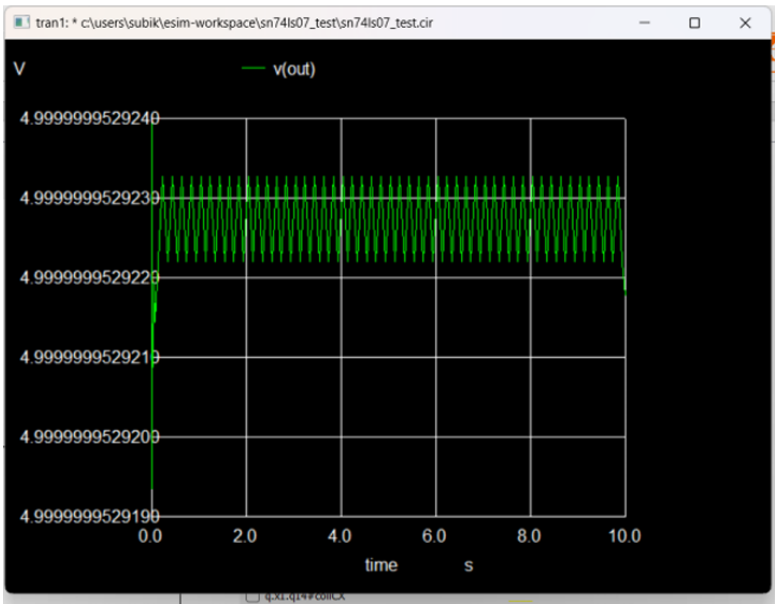

Figure 4.8: Output High

Chapter 5

CD4049UB

5.1 General Description

The CD4049UB and CD4050B devices are inverting and noninverting hex buffers, and feature logic-level conversion using only one supply voltage (VCC). The input-signal high level (VIH) can exceed the VCC supply voltage when these devices are used for logiclevel conversions. These devices are intended for use as CMOS to DTL or TTL converters and can drive directly two DTL or TTL loads.

5.2 Key Features

- **Hex Inverter Configuration:** Contains six independent inverters in a single package.
- **Voltage Range:** Operates from 3V to 15V
- **High Noise Immunity:** Typically 100 percent noise margin of the supply voltage
- **Standard CMOS Logic Levels:** TTL-compatible input logic levels when powered at 5V
- **Low Power Consumption:** Uses CMOS technology, resulting in very low static power dissipation

5.3 Applications

- **Signal Inversion / Logic Level Inversion:** Acts as a basic logic inverter in digital circuits.
- **Oscillator Circuits:** Commonly used in RC or LC oscillator configurations.
- **Waveform Shaping:** Used for waveform generation and signal conditioning.

5.4 Pin Configuration

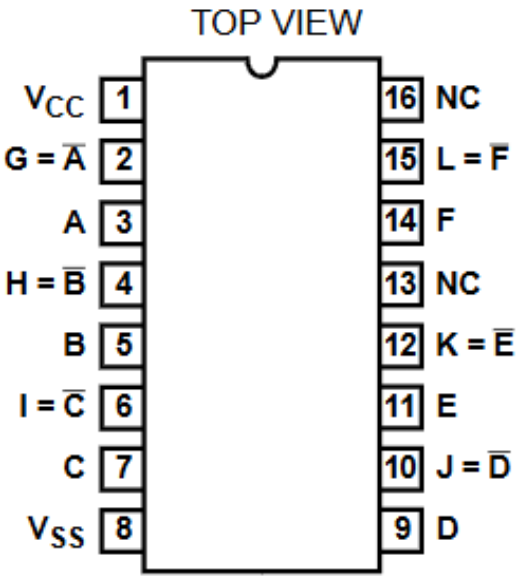

Figure 5.1: Pin of CD4049UB

5.5 IC Layout

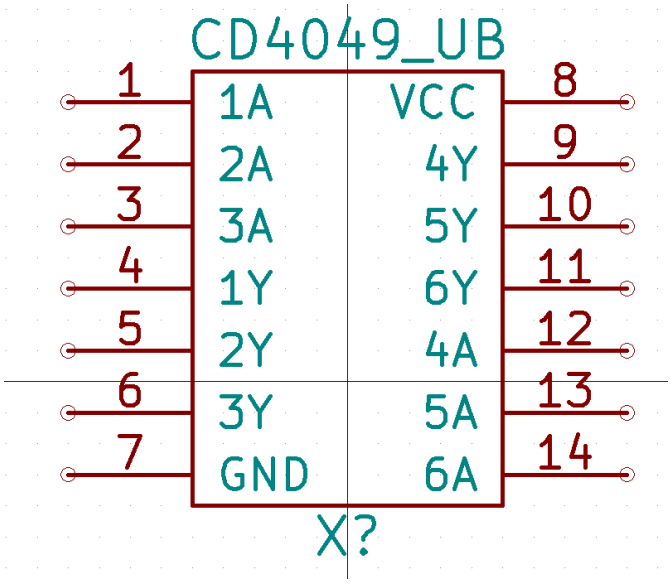

Figure 5.2: IC Layout of CD4049UB

5.6 Subcircuit Shematic Diagram

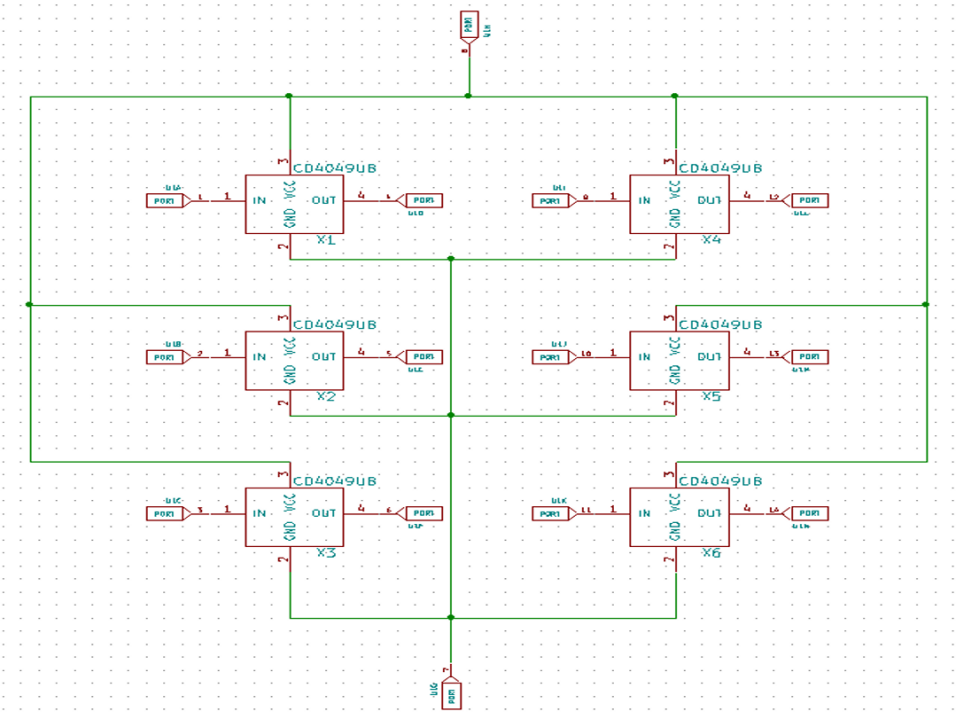

Figure 5.3: Subcircuit of CD4049UB

5.7 Subcircuit Single Unit

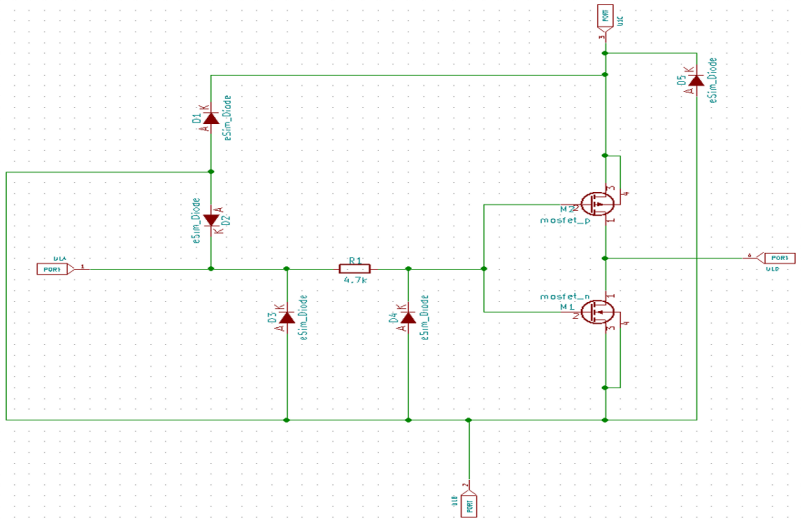

Figure 5.4: Single Unit of CD4049UB

5.8 Test Circuit

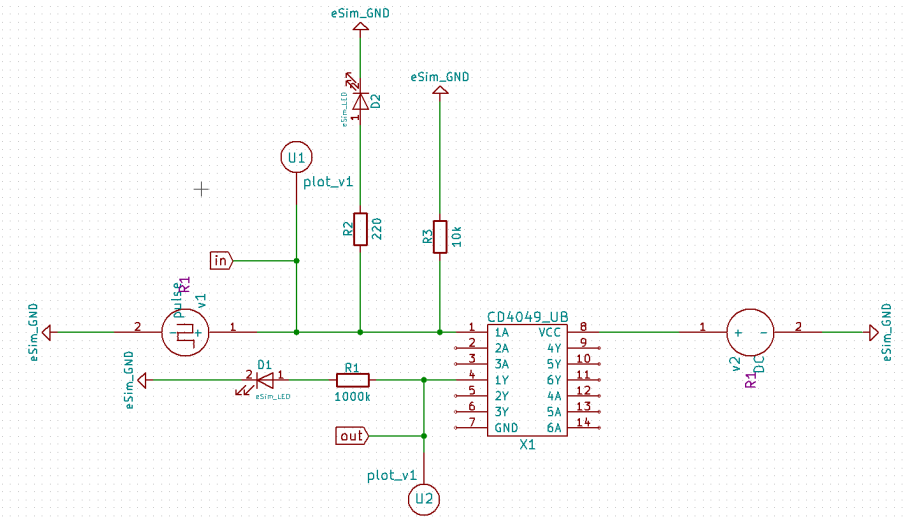

Figure 5.5: Test Circuit of CD4049UB

5.9 Input Plot

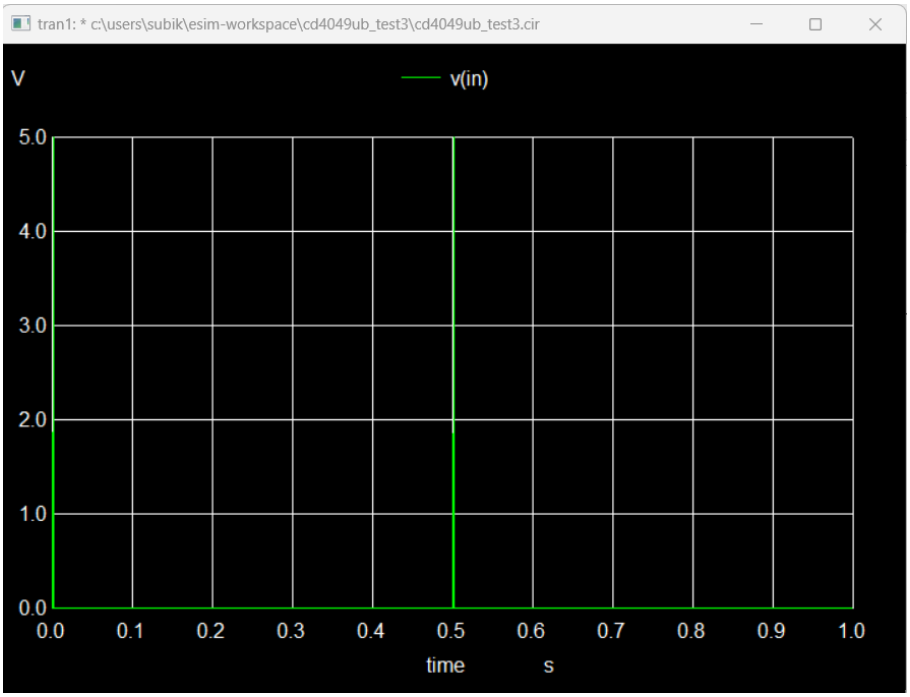

Figure 5.6: Input

5.10 Output Plot

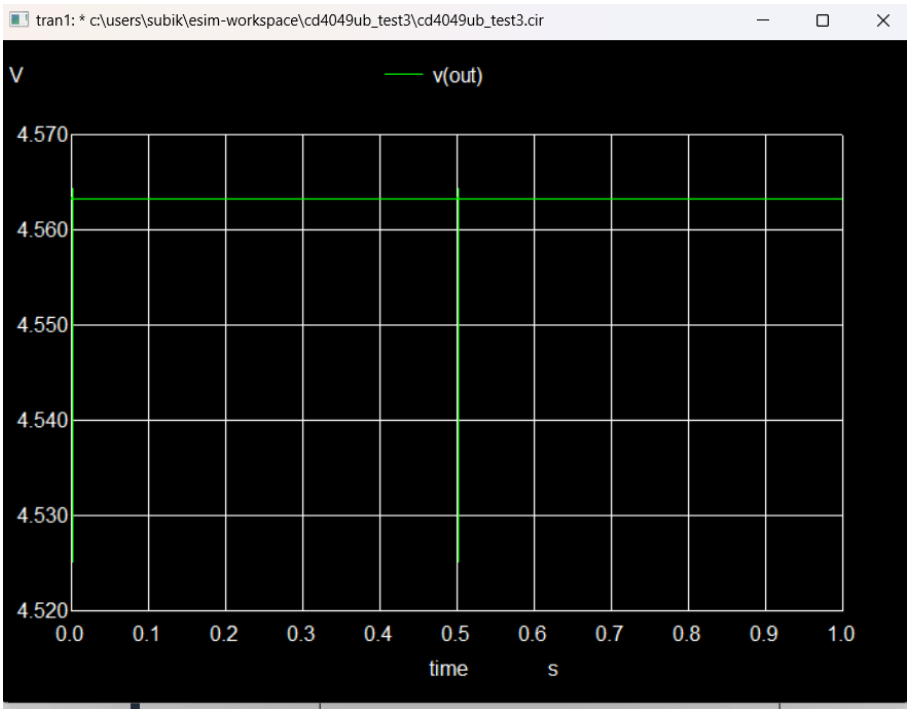

Figure 5.7: Output

Chapter 6

SN54LS40

6.1 General Description

The SN54LS40 is a dual 4-input NAND gate built using Low Power Schottky TTL technology, offering high-speed logic operation with reduced power consumption. Each gate performs a logic NAND function and is ideal for applications that require reliable and efficient digital logic processing. The device is particularly suited for industrial and military-grade systems, where extended temperature ranges and robust performance are essential.

6.2 Key Features

- **TTL-Compatible Logic Levels:** Fully compatible with standard TTL devices for seamless integration.
- **Low Power Consumption:** Uses Low Power Schottky (LS) technology to reduce power usage while maintaining speed.
- **High-Speed Operation:** Fast switching times, making it suitable for high-performance digital systems.
- **Extended Temperature Range:** Designed for military and industrial applications, operates across –55°C to +125°C.
- **Improved Noise Margin:** Robust design provides reliable logic levels in noisy environments.

6.3 Applications

- **Logic Control Circuits:** Used in digital control systems where complex logic conditions need to be evaluated using NAND logic.
- **Industrial Automation:**Suitable for industrial-grade logic systems that require robust and reliable logic operations under extreme conditions.
- **Timing and Clock Generation:** Can be used in timing circuits by combining with other logic gates, flip-flops, and oscillators.
- **LED Logic Indicators:** Can control logic-driven LED displays to indicate system states based on multiple input conditions.
- **Embedded System Interfaces:** Useful in embedded boards for digital signal routing, gating, and enabling circuits.

6.4 Pin Configuration

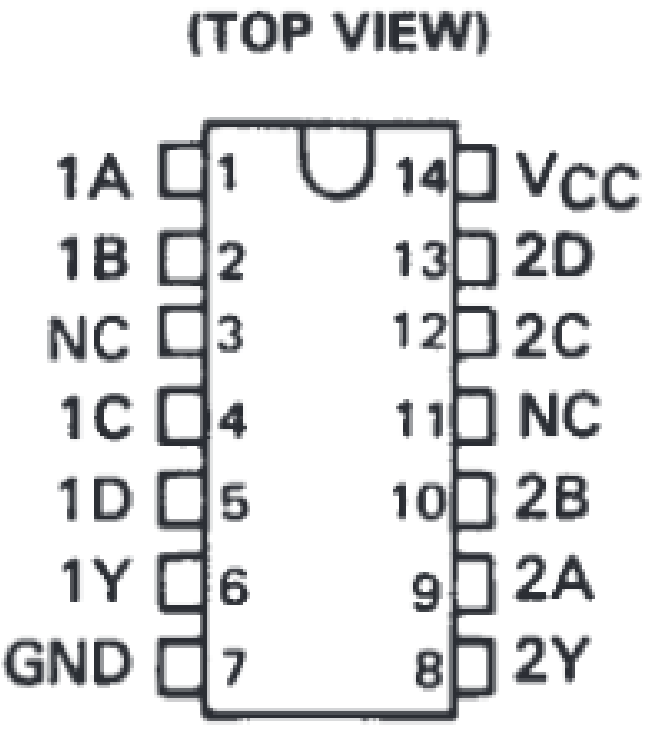

Figure 6.1: Pin Configuration of SN54LS40

6.5 IC Layout

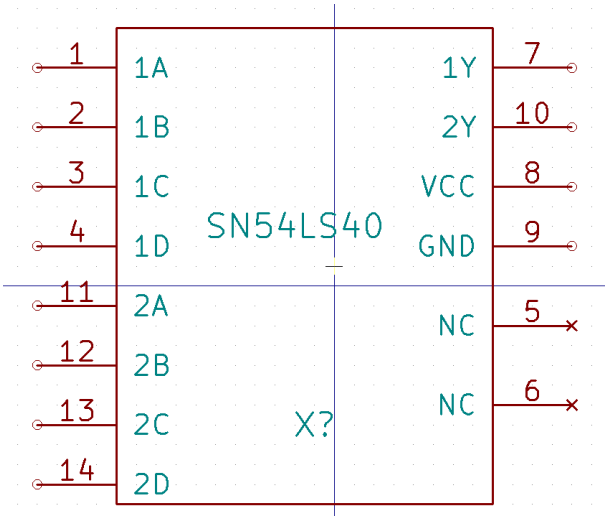

Figure 6.2: IC Layout of SN54LS40

6.6 Subcircuit Schematic

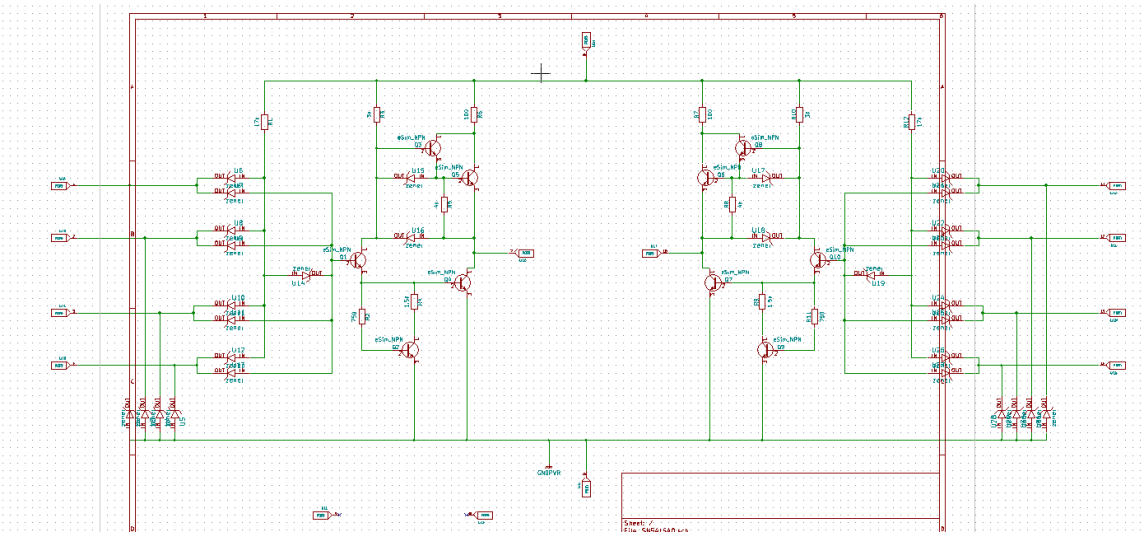

Figure 6.3: Subcircuit of SN50LS40

6.7 Test Circuit

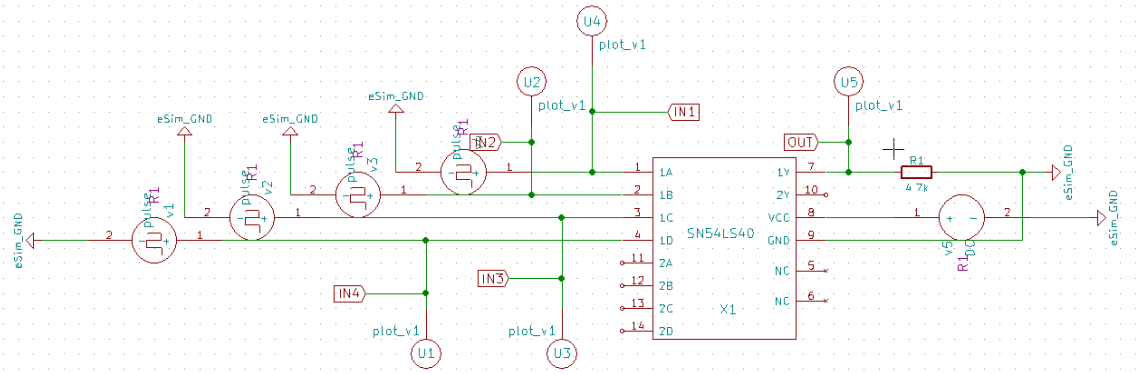

Figure 6.4: Test Circuit of SN54LS40

6.8 Input Plot 1 for Low Input

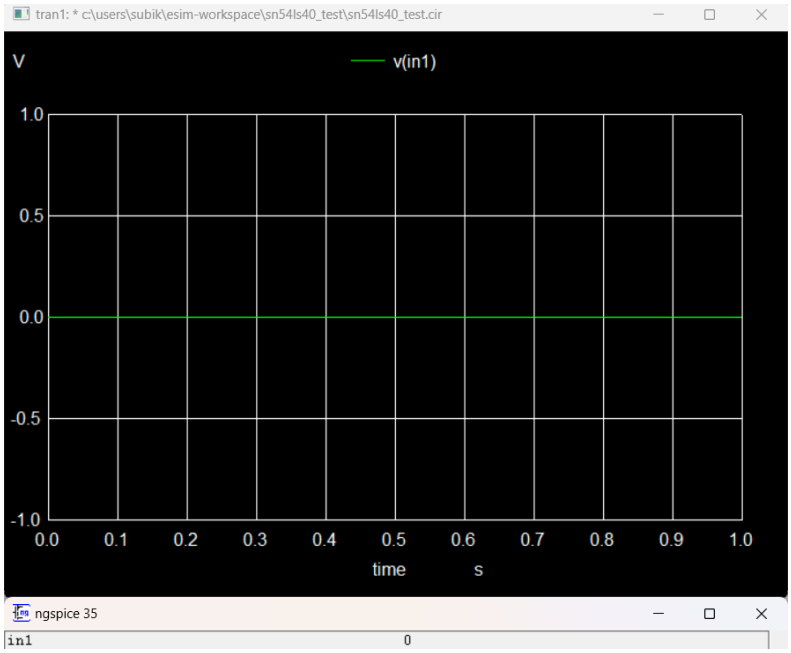

Figure 6.5: Input Plot 1 for Low Input

6.9 Input Plot 2 for Low Input

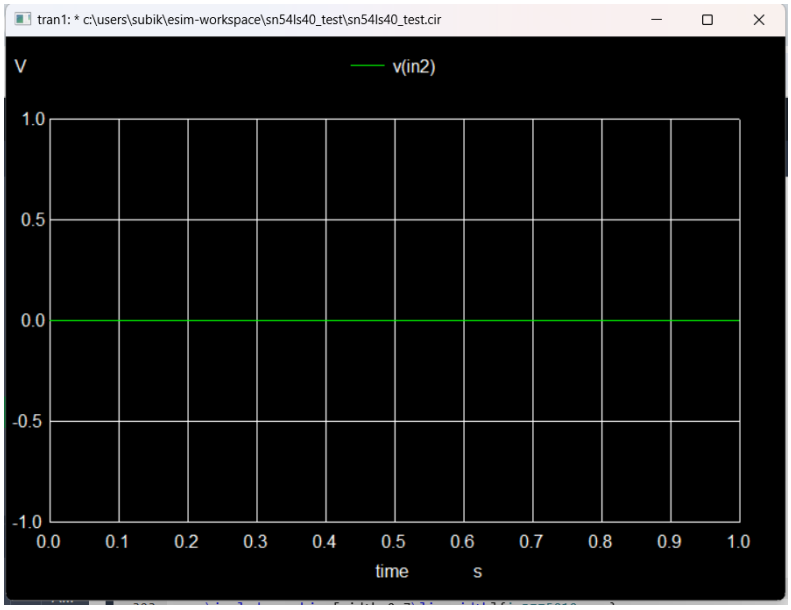

Figure 6.6: Input Plot 2 for Low Input

6.10 Input Plot 3 for Low Input

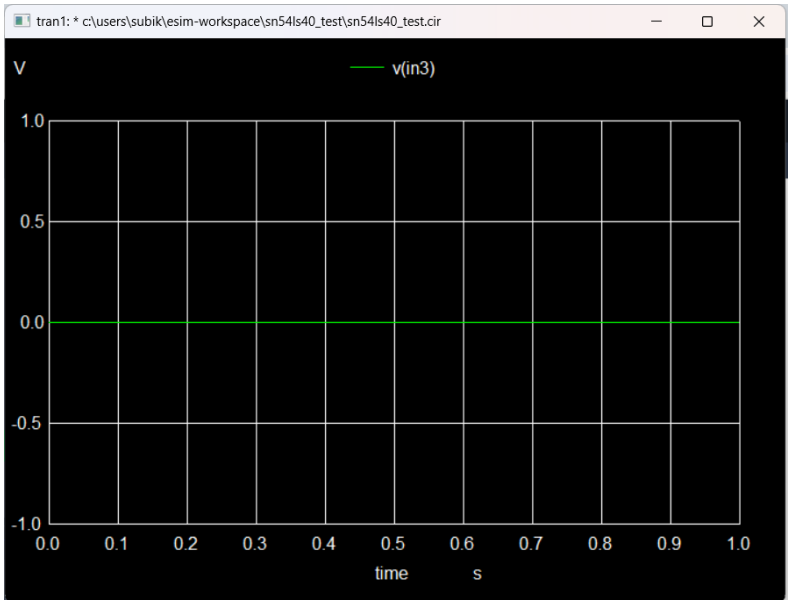

Figure 6.7: Input Plot 3 for Low Input

6.11 Input Plot 4 for Low Input

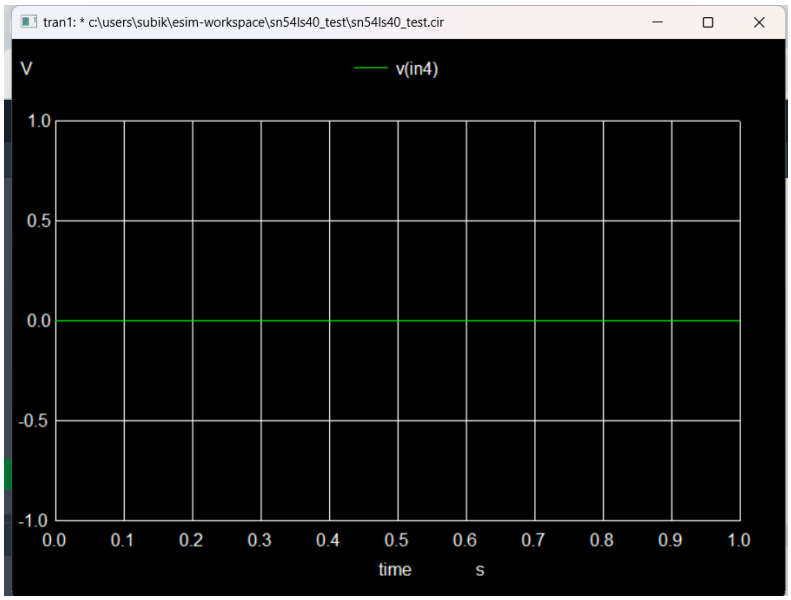

Figure 6.8: Input Plot 4 for Low Input

6.12 Output Plot for Low Input

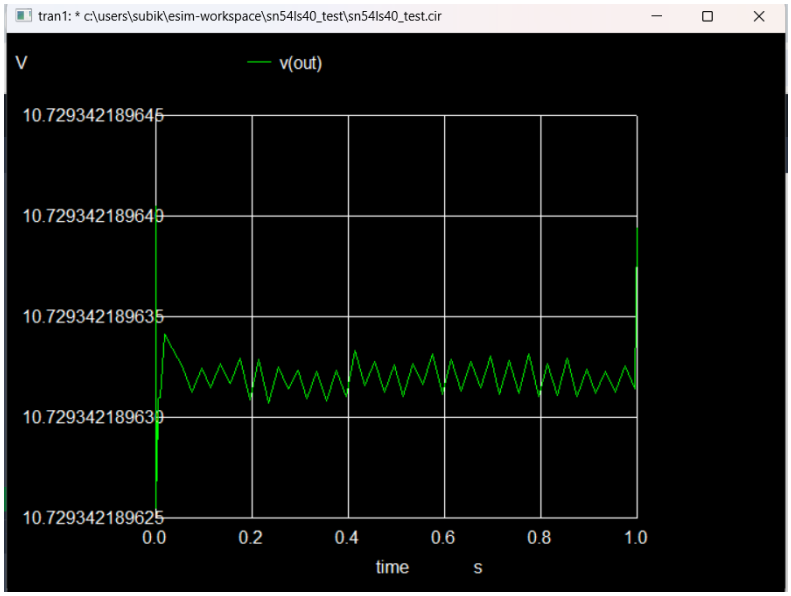

Figure 6.9: output Plot for Low Input

6.13 Input Plot 1 for High Input

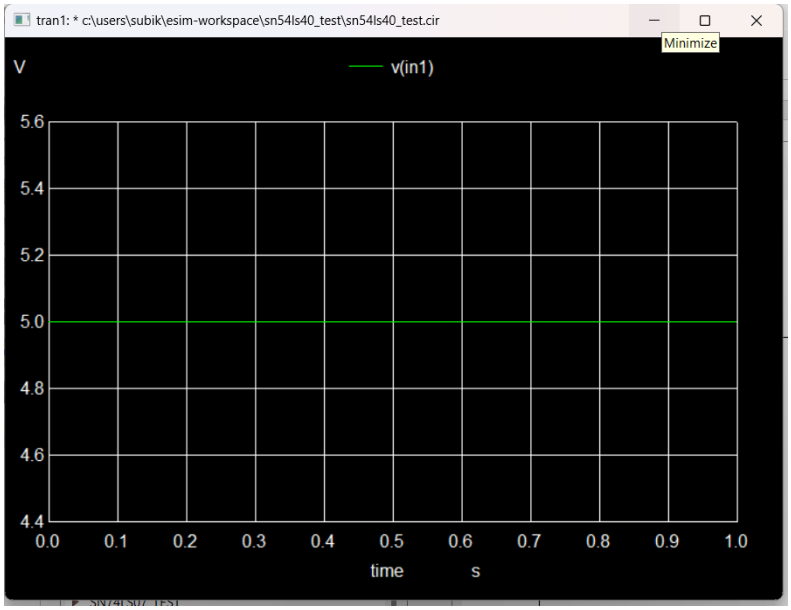

Figure 6.10: Input Plot 1 for High Input

6.14 Input Plot 2 for High Input

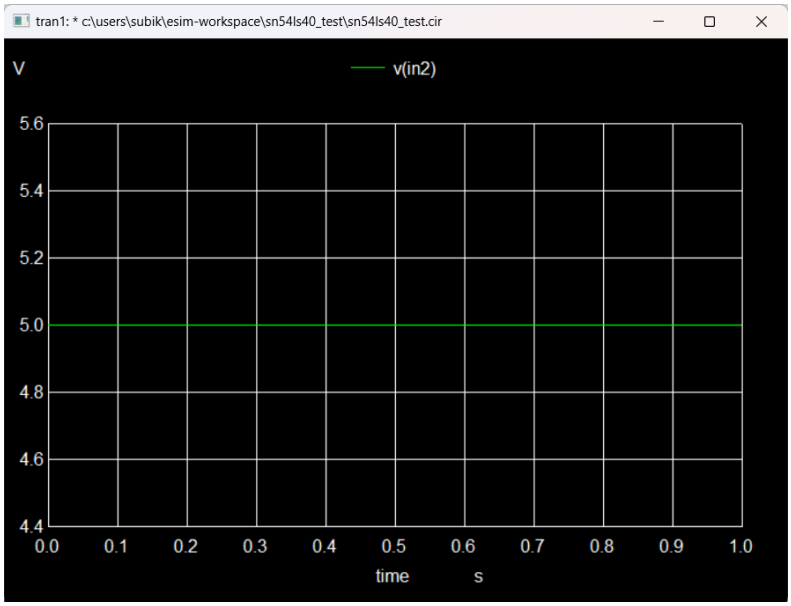

Figure 6.11: Input Plot 2 for High Input

6.15 Input Plot 3 for High Input

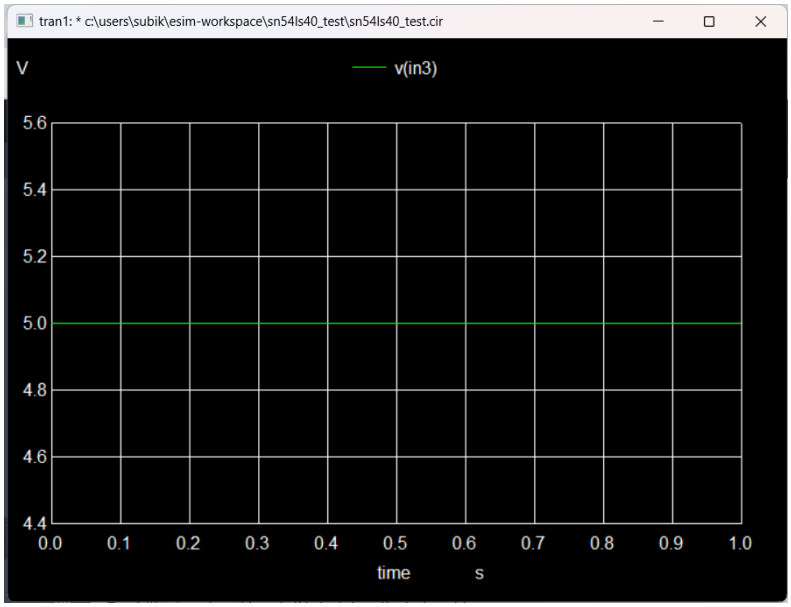

Figure 6.12: Input Plot 3 for High Input

6.16 Input Plot 4 for High Input

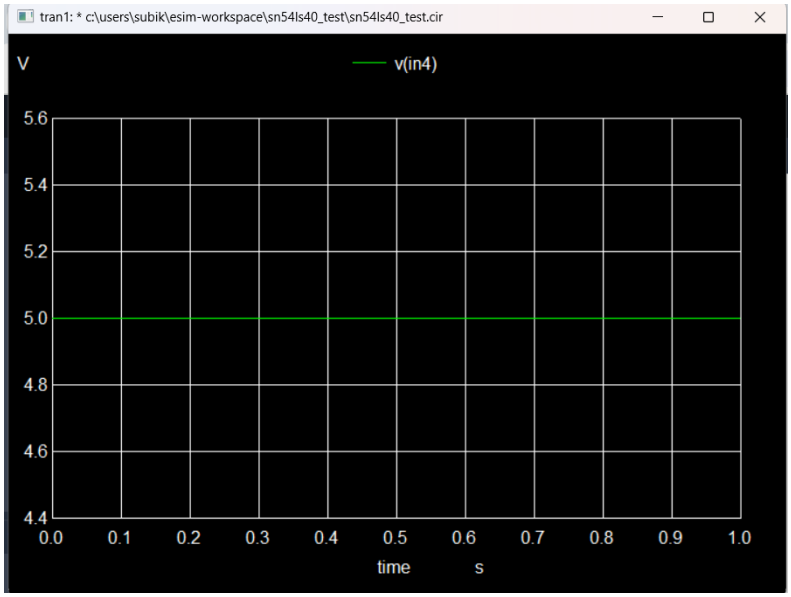

Figure 6.13: Input Plot 4 for High Input

6.17 Output Plot for High Input

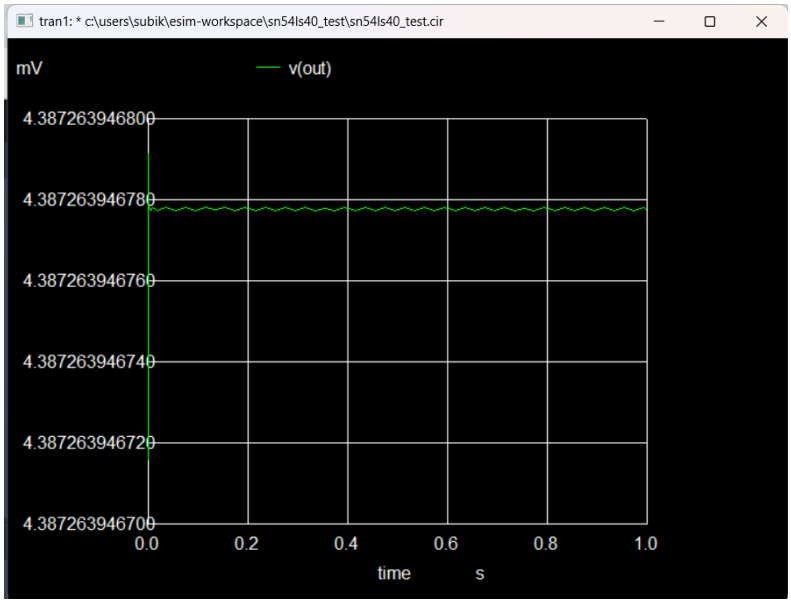

Figure 6.14: Output Plot for High Input

Chapter 7

SN5402

7.1 General Description

The SN5402 is a dual 4-input positive-NAND gate designed for high-speed digital logic operations in demanding environments. Built with Schottky TTL technology, it offers fast switching times and reliable performance across a wide temperature range. The device is optimized for military and industrial applications, delivering consistent logic functionality under harsh operating conditions.

7.2 Key Features

- **Dual 4-Input NAND Gates:** Provides two independent logic gates with four inputs each for flexible digital design.
- **High-Speed Operation:** Delivers fast logic transitions suitable for timing-critical applications.
- **Schottky TTL Technology:** Offers improved speed and reduced power consumption.
- **Wide Operating Temperature Range:** Designed for military and industrial use, functioning reliably from $-55°C$ to $125°C$.
- **TTL-Compatible Inputs and Outputs:** Seamlessly integrates with other standard TTL logic families.

7.3 Applications

- **Digital Control Systems:** Used to implement logic-based decision-making in industrial and embedded systems.
- **Combinational Logic Circuits:** Ideal for constructing custom logic functions using NAND gates.
- **Timing and Clocking Logic:** Supports pulse generation, signal conditioning, and clock logic.
- **Safety and Interlock Mechanisms:** Ensures certain conditions are met before a process is enabled.
- **Signal Gating and Routing:** Controls the flow of digital signals in communication or processing circuits.

7.4 Operating Conditions

- **Temperature Range:** Designed to function across a wide range of temperatures.

7.5 Pin Configuration

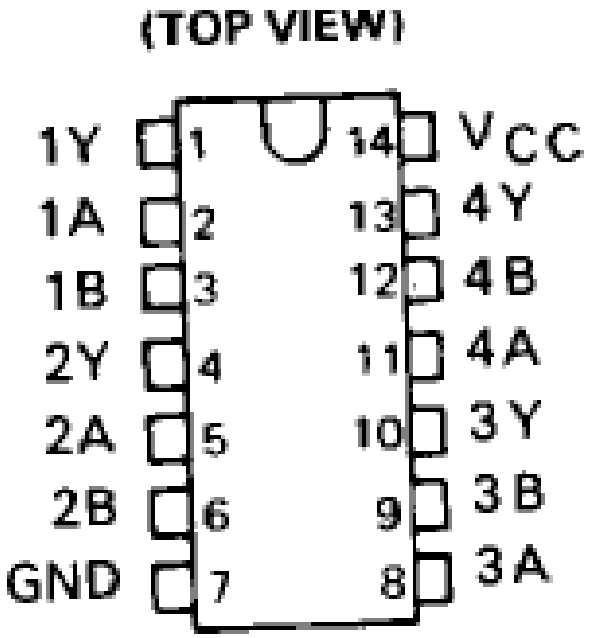

Figure 7.1: Pin Configuration of SN5402

7.6 IC Layout

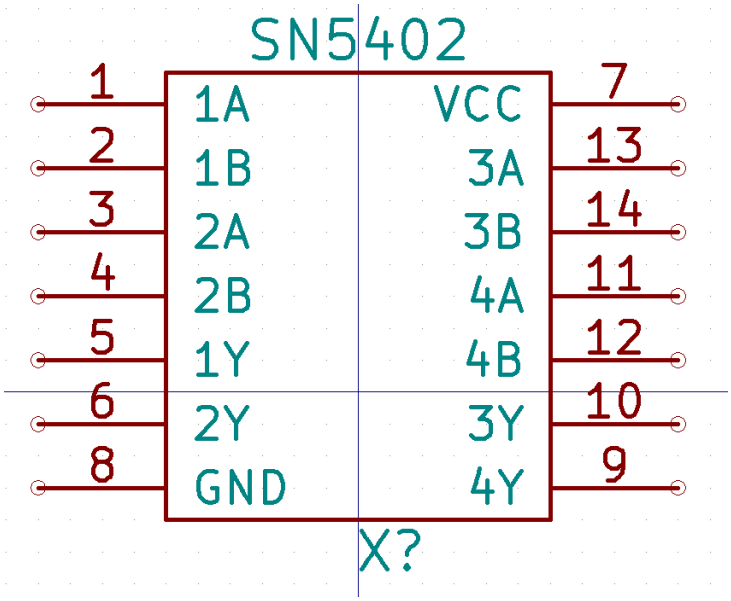

Figure 7.2: IC Layout of SN5402

7.7 Subcircuit Schematic

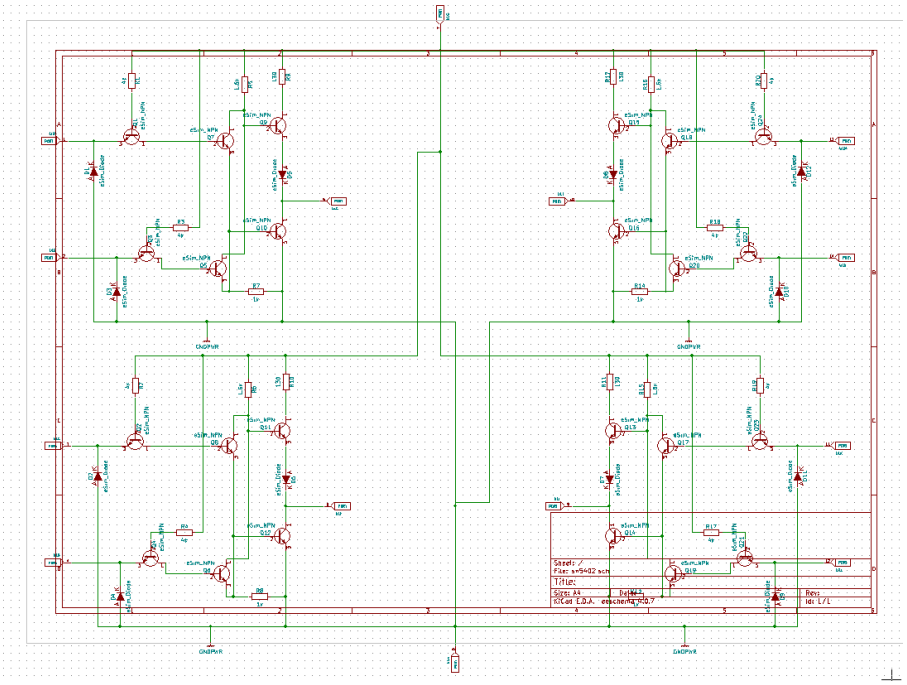

Figure 7.3: Subcircuit of SN5402

7.8 Test Circuit

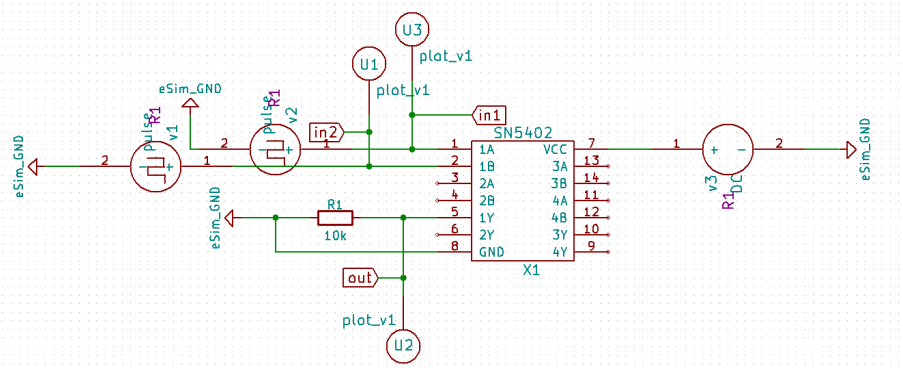

Figure 7.4: Test Circuit of SN5402

7.9 Input Plot 1 for Low Input

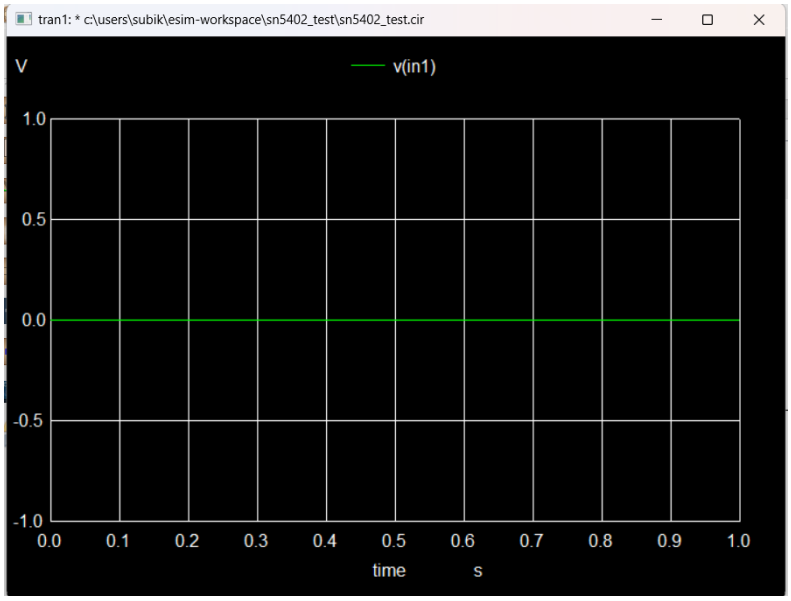

Figure 7.5: Input Plot 1 for Low Input

7.10 Input Plo 2 for Low Input

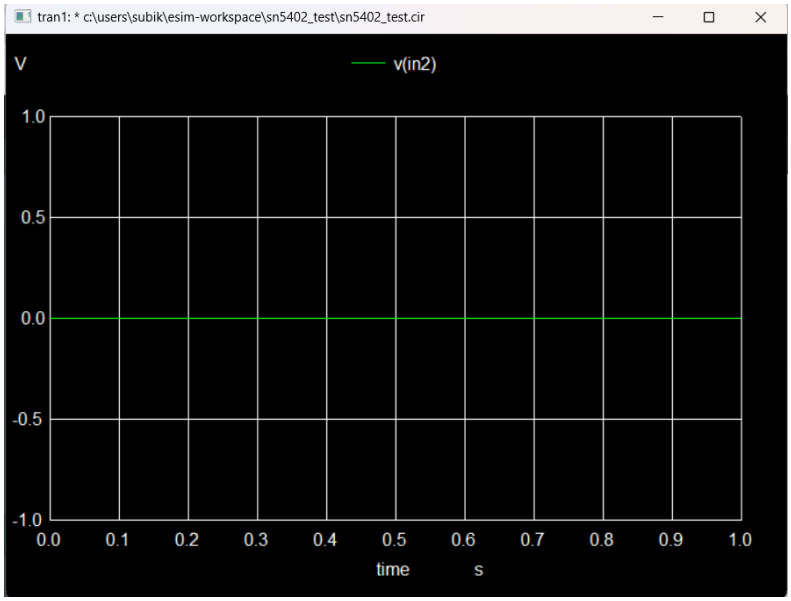

Figure 7.6: nput Plot 2 for Low Input

7.11 Output Plot for Low Input

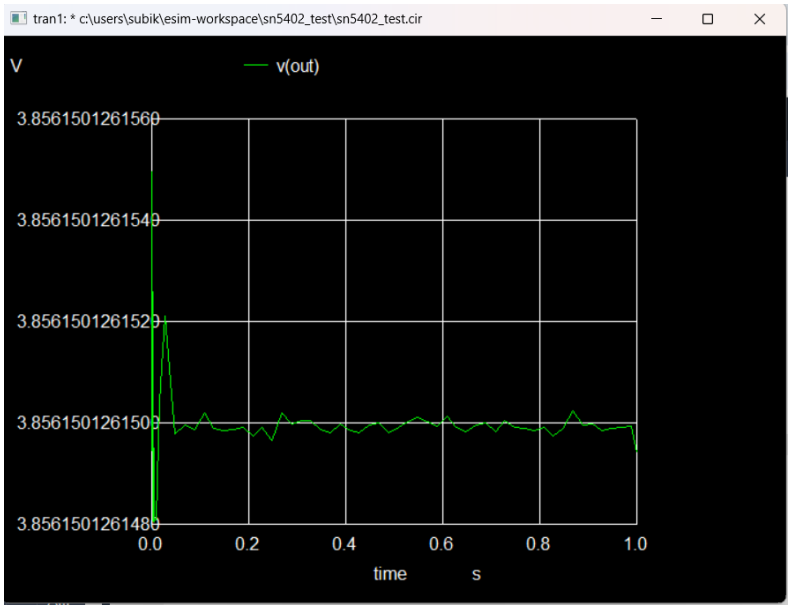

Figure 7.7: Output Plot for Low Input

7.12 Input Plot 1 for High Input

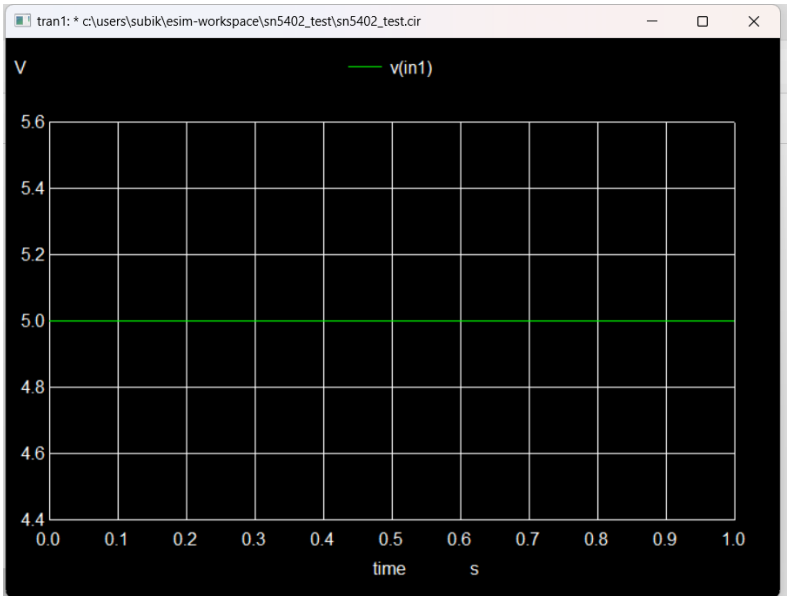

Figure 7.8: Input Plot 1 for High Input

7.13 Input Plot 2 for High Input

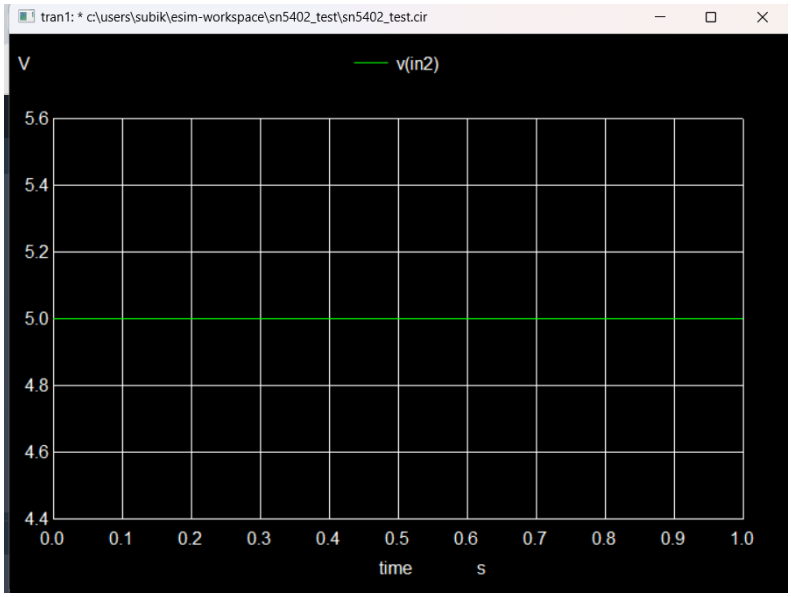

Figure 7.9: Input Plot 2 for High Input

7.14 Output Plot for High Input

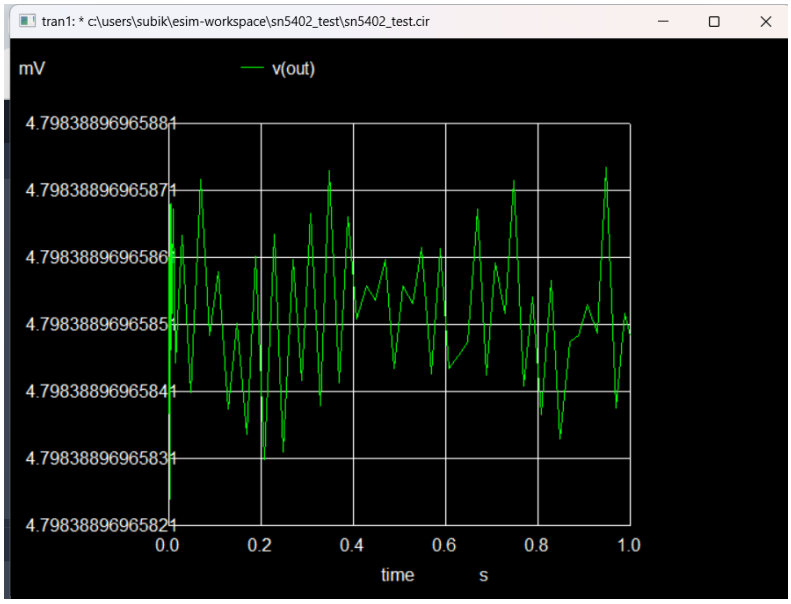

Figure 7.10: Output Plot for High Input

Chapter 8

SN74LS00

8.1 General Description

The SN74LS00 is a quad 2-input NAND gate IC built using Low Power Schottky TTL technology, optimized for high-speed and low-power digital applications. It contains four independent NAND gates with standard TTL-compatible inputs and outputs, making it easy to integrate into logic circuits. The device is ideal for performing basic logic functions in control systems, computing circuits, and signal processing.

8.2 Key Features

- **Quad 2-Input NAND Gates:** Contains four independent NAND gates in a single package.
- **Low Power Schottky Technology:** Ensures fast switching speeds with reduced power consumption.
- **TTL-Compatible Inputs and Outputs:** Easily interfaces with other TTL logic families.
- **Wide Supply Voltage Range:** Operates reliably within standard TTL voltage levels.
- **High Noise Immunity:** Provides stable operation in noisy digital environments.

8.3 Applications

- **Logic Gate Implementation:** Used to build custom logic circuits using basic NAND functions.
- **Digital Control Systems:** Ideal for decision-making logic in embedded and automation systems.
- **Signal Timing and Conditioning:** Supports pulse shaping and delay circuits.
- **Combinational Logic Design:** Forms the foundation of complex logic blocks and truth table implementation.
- **Arithmetic and Logic Units (ALUs):** Serves as a building block in mathematical and logical processing circuits.

8.4 Pin Configuration

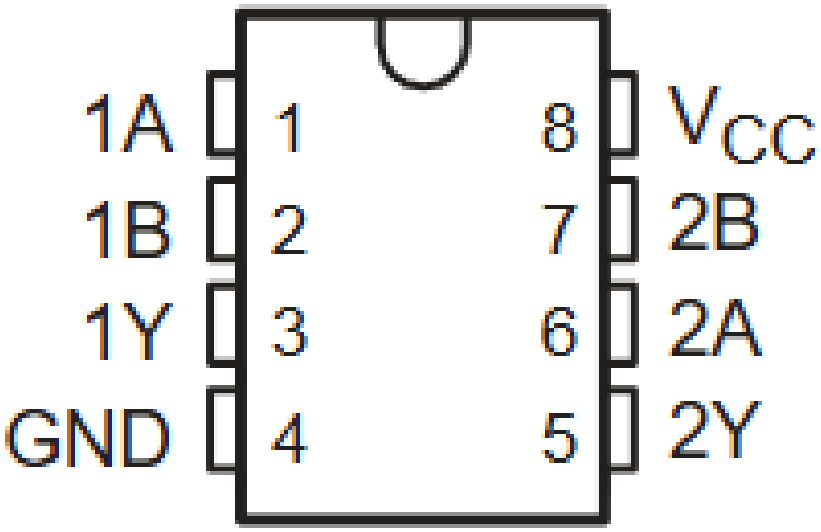

Figure 8.1: Pin Configuration of SN74LS00

8.5 IC Layout

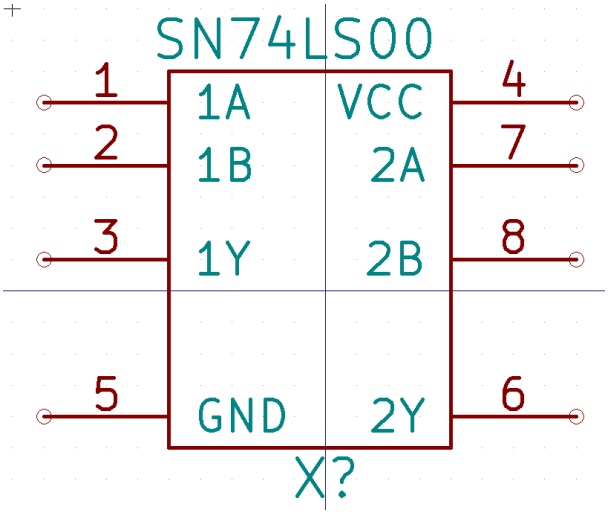

Figure 8.2: IC Layout of SN74LS00

8.6 Subcircuit Schematic

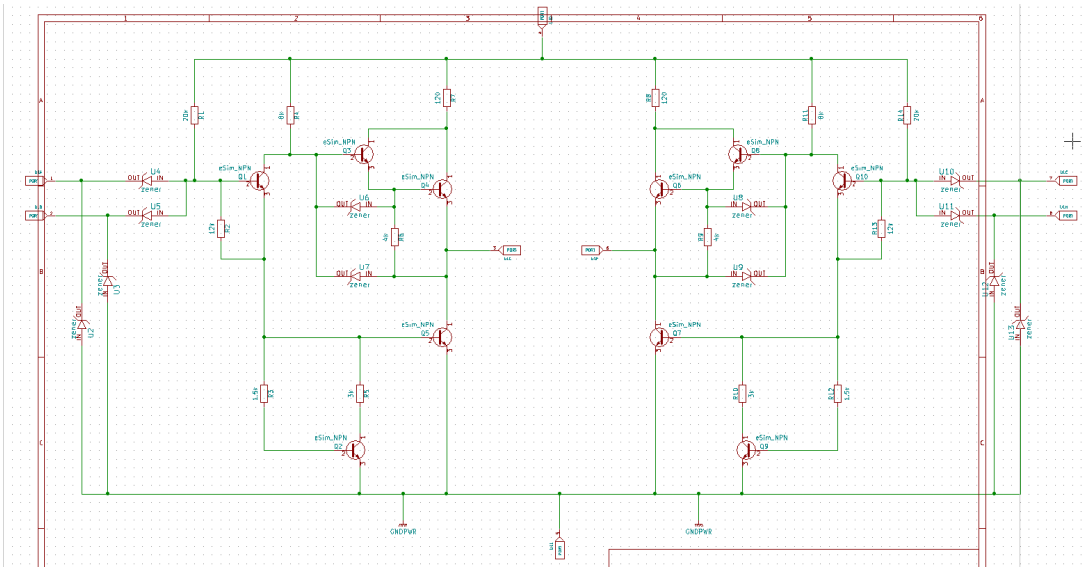

Figure 8.3: Subcircuit Schematic of SN74LS00

8.7 Test Circuit

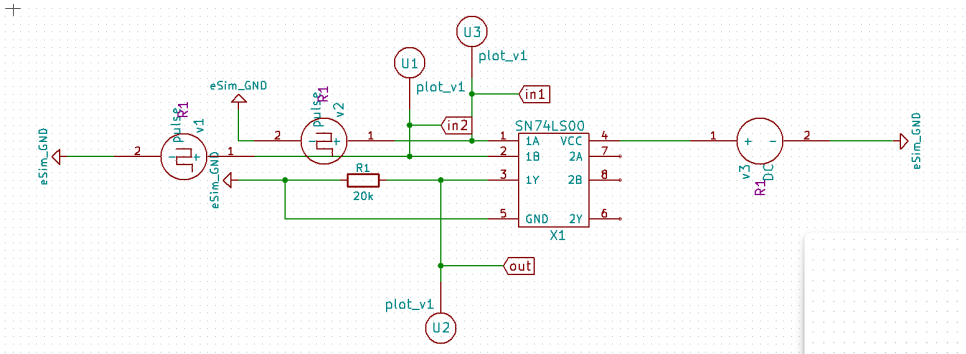

Figure 8.4: Test Circuit of SN74LS00

8.8 Input Plot 1 for Low Input

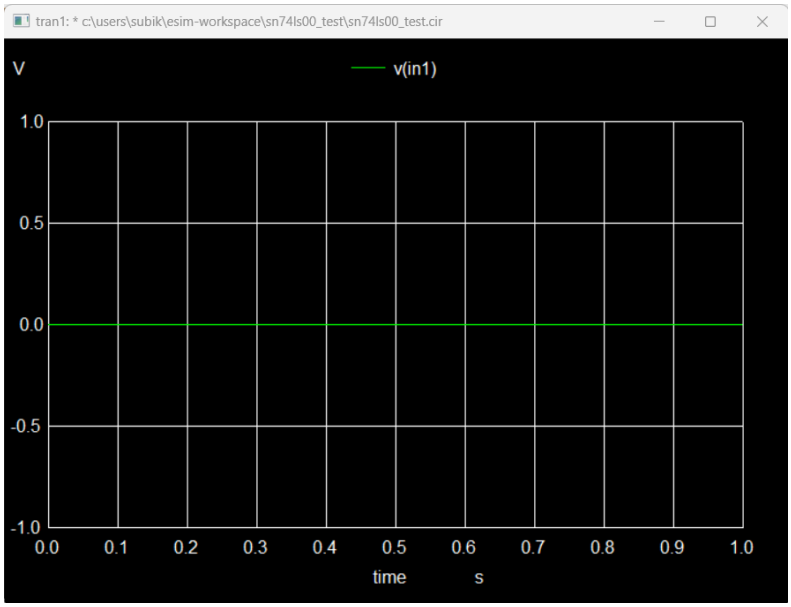

Figure 8.5: Input Plot 1 for Low Input

8.9 Input Plot 2 for Low Input

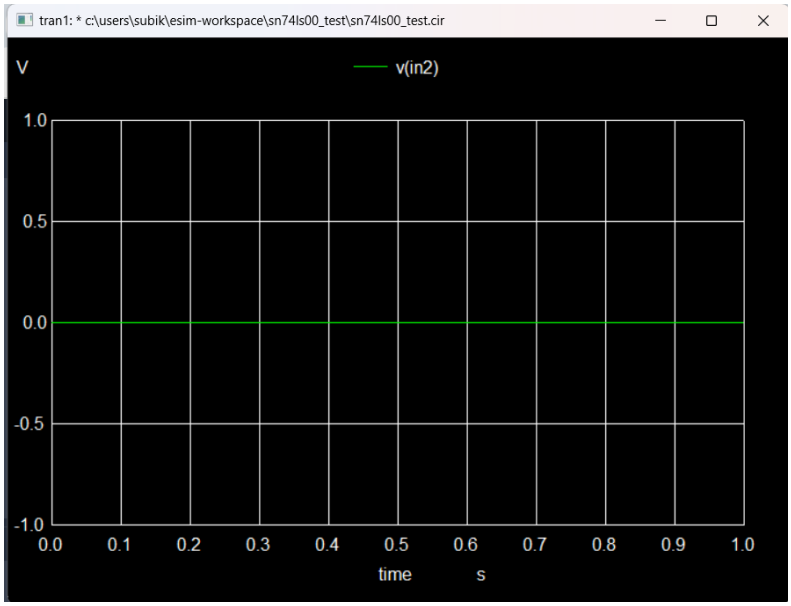

Figure 8.6: Input Plot 2 for Low Input

8.10 Output Plot for Low Input

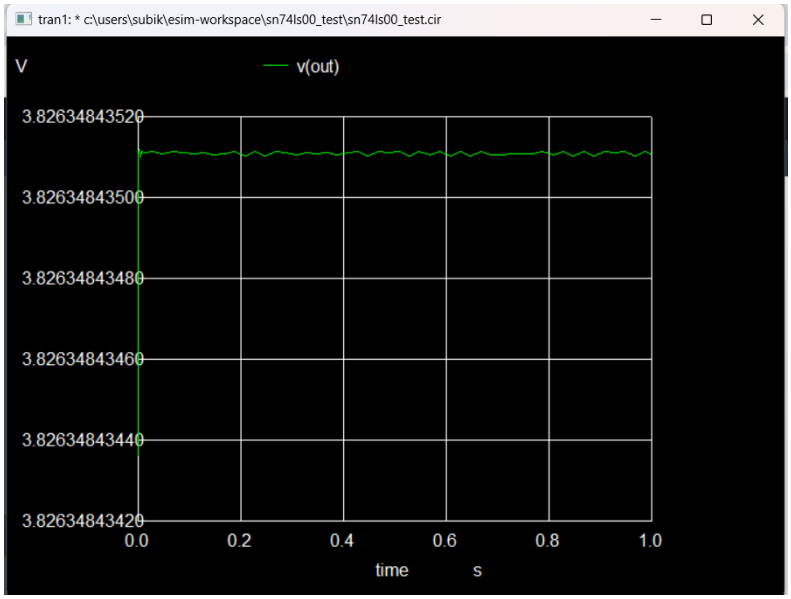

Figure 8.7: Output Plot for Low Input

8.11 Input Plot 1 for High Input

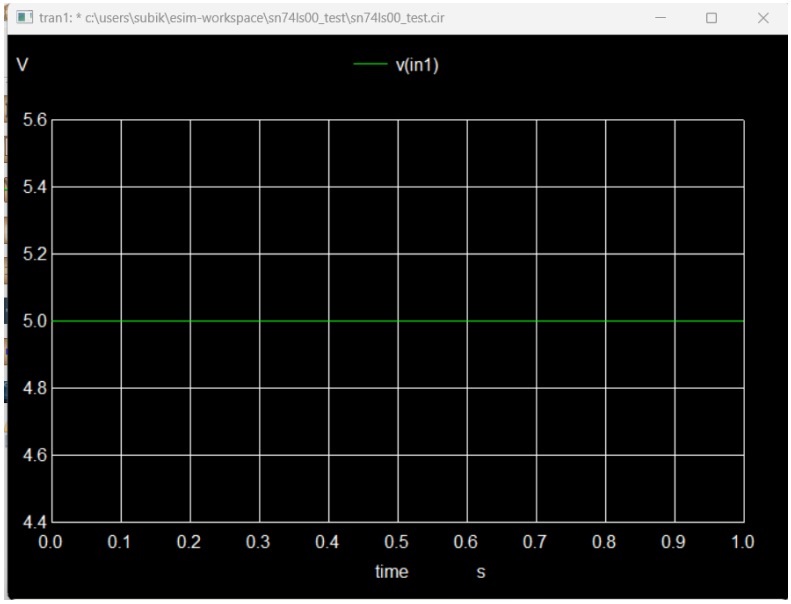

Figure 8.8: Input Plot 1 for High Input

8.12 Input Plot 2 for High Input

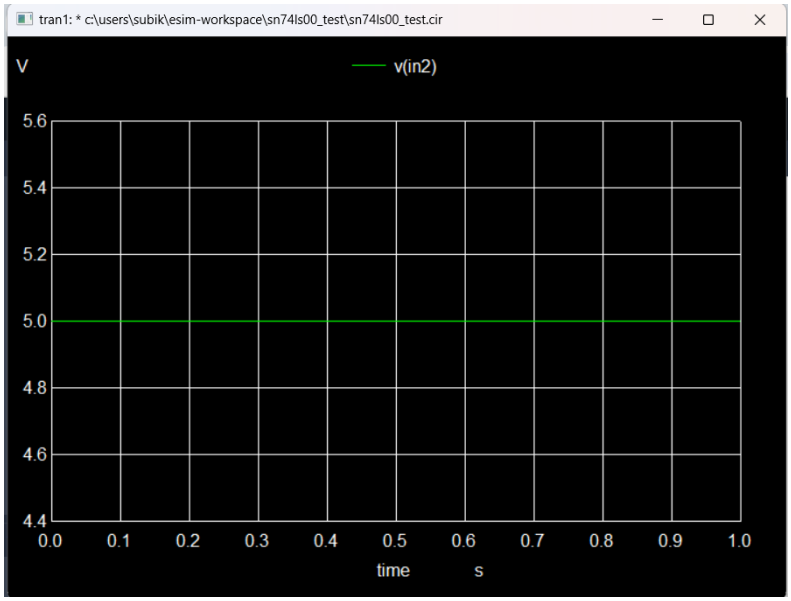

Figure 8.9: Input Plot 2 for High Input

8.13 Output Plot for High Input

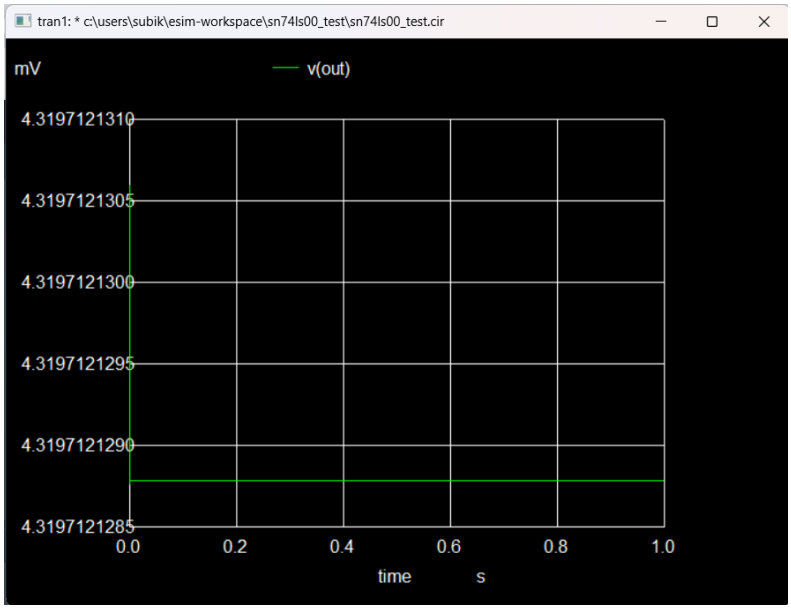

Figure 8.10: Output Plot for High Input

Chapter 9

Failed Circuits

9.1 Overview

In this section, we discuss circuits that did not perform as expected during testing.Understanding the reasons for these failures helps in diagnosing issues and improving circuit design. Each failed circuit is analyzed to identify the potential causes of failure and to suggest corrective measures.

9.2 LF444

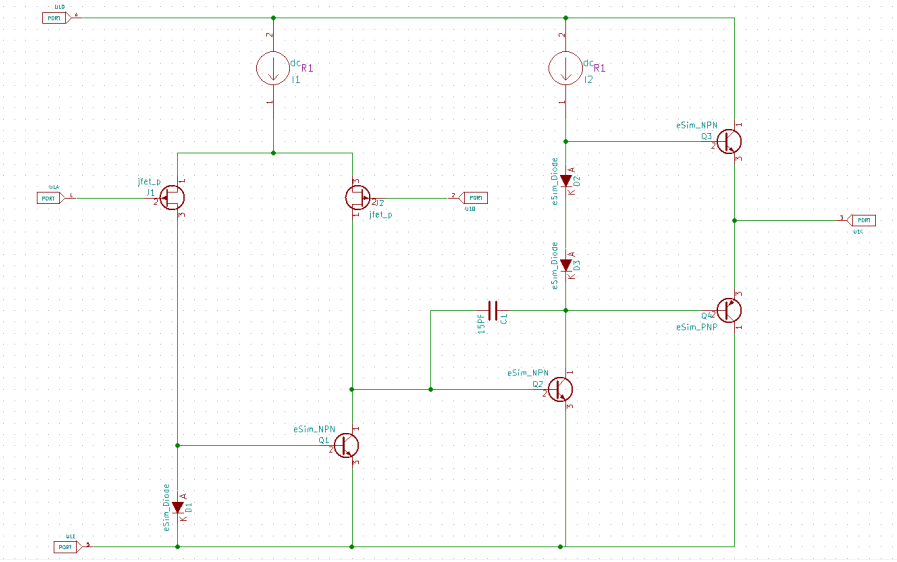

Figure 9.1: Subcircuit of LF444

Issue Description

While simulating the LF444 op-amp in eSim, I encountered issues such as unstable output behavior and convergence errors. These problems were primarily due to the absence of essential external passive components and improper power supply connections. Initially, the simulation would either fail to converge or produce unrealistic output waveforms. After analyzing the circuit, I added appropriate bypass capacitors to the power rails and ensured correct biasing and load connections. With these adjustments, the simulation stabilized, and the op-amp performed as expected.

9.3 Test Circuit

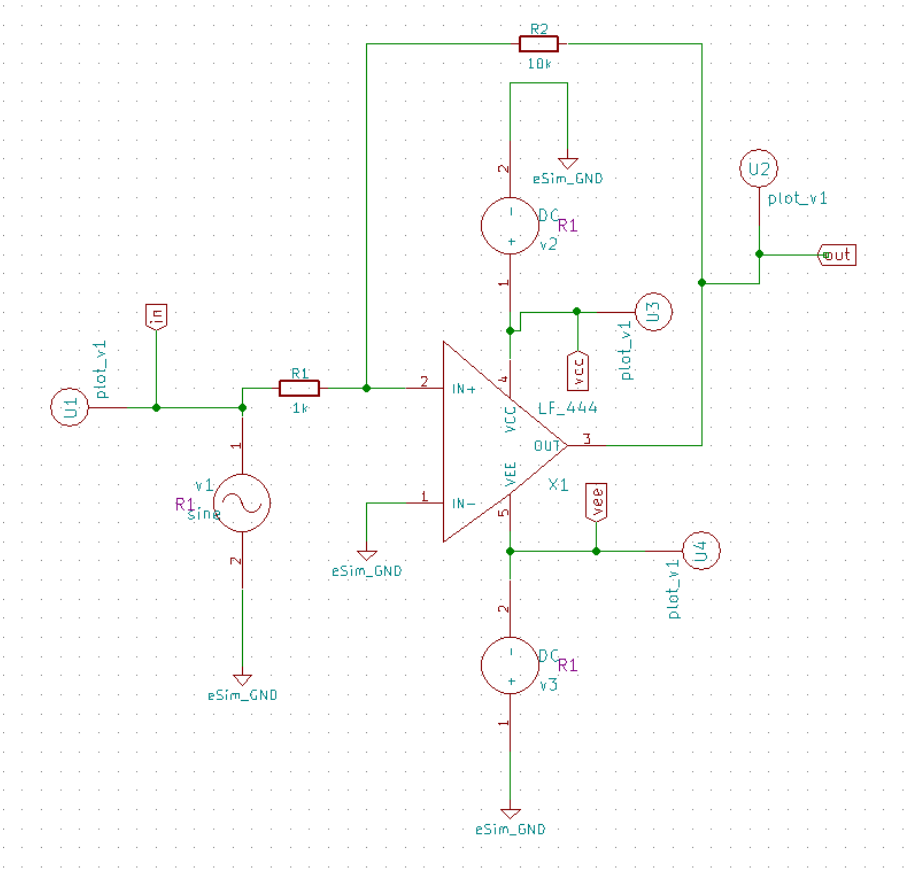

Figure 9.2: Test Circuit of LF444

Chapter 10

Conclusion and Future Scope

The project achieved its objective of developing a wide range of subcircuits for both Analog and Digital Integrated Circuits, with each IC model meticulously crafted based on the specifications provided in their official datasheets. Through rigorous testing and verification using corresponding test circuits, these IC models were validated for accuracy and functionality. The components developed under this fellowship encompass fundamental circuit elements such as Operational Amplifiers (Op-Amps), Voltage Regulators, Precision Rectifiers, Schmitt Triggers, Differential Amplifiers, Instrumentation Amplifiers, Comparators, Multiplexers, De-Multiplexers, and various Logic Gate ICs. These models are now ready for integration into the eSim subcircuit library, providing a robust resource for developers, students, and researchers. The inclusion of these models in the eSim library will significantly enhance the tool's capabilities, enabling users to easily incorporate these fundamental ICs into their own projects and circuit designs. Looking ahead, this project sets the foundation for the continued expansion of eSim's device model library. We anticipate that more such ready-to-use IC models will be developed, broadening the scope of available components and further empowering the eSim community. This ongoing development will not only aid in academic and research endeavors but also contribute to the growing ecosystem of open-source electronic design automation (EDA) tools.

Chapter 11

Circuits Contribution

This chapter lists all the Integrated Circuits (ICs) contributed during the fellowship. Each IC has been carefully modeled and tested, and is now part of the eSim library. The contributions include both analog and digital ICs, covering a wide range of functionalities.

11.1 Subikeesh M List of ICs

1. SN74LS07 – A hex buffer/driver IC with open-collector outputs for interfacing and level shifting
2. CD4049UB – A hex inverting buffer IC with high input impedance and CMOS technology
3. SN54LS40 – A dual 4-input NAND gate IC with extended temperature range support
4. SN5402 – A dual 4-input NAND gate IC for military and industrial applications
5. SN74LS00 – A quad 2-input NAND gate IC built with low power Schottky TTL technology

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[2] eSim Official Website https://esim.fossee.in/

[3] Texas Instruments, SN74LS07 Datasheet. https://www.ti.com/lit/ds/symlink/sn74ls07.pdf

[4] Texas Instruments, CD4049UB Datasheet. https://www.ti.com/lit/ds/symlink/cd4049ub.pdf

[5] Texas Instruments, SN54LS40 Datasheet. https://eeshop.unl.edu/pdf/74ls40.pdf

[6] Texas Instruments, SN5402 Datasheet. https://www.ti.com/lit/ds/symlink/sn5402.pdf

[7] Texas Instruments, SN74LS00 Datasheet. https://www.ti.com/lit/ds/symlink/sn74ls00.pdf