Semester Long Internship Spring 2026

On

Designing Integrated Circuit in eSim

Submitted by

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Chapter 1

Introduction

1.1 Background

The advancement of digital electronics and embedded systems has significantly increased the demand for efficient Electronic Design Automation (EDA) tools for circuit design, simulation, and analysis. Many commercial EDA software packages are expensive and require proprietary licenses, which limits accessibility for students, educators, and independent researchers. As a result, open-source EDA platforms have become increasingly important in academic and research environments.

eSim is an open-source EDA tool developed under the FOSSEE (Free/Libre and Open Source Software for Education) project at IIT Bombay. It integrates circuit schematic design, simulation, PCB layout, and subcircuit development into a single platform. By combining tools such as KiCad and NgSpice, eSim provides a complete environment for analog, digital, and mixed-signal circuit development.

Integrated Circuits (ICs) are fundamental components used in modern electronic systems. However, many IC models are not readily available in simulation libraries, creating the need for accurate and reusable subcircuit implementations. This project focuses on developing and testing IC subcircuits to enhance the eSim component library and support future circuit design applications.

1.2 Overview of eSim

eSim is a free and open-source Electronic Design Automation (EDA) software developed by the FOSSEE project at IIT Bombay. It provides an integrated platform for schematic creation, circuit simulation, PCB design, and analysis. The software combines several open-source tools into a unified environment, making it suitable for students, educators, researchers, and professionals.

The schematic editor in eSim allows users to design circuits using a graphical interface and a wide range of electronic components. Simulation functionality is provided through NgSpice, enabling users to perform DC, AC, transient, and mixed-signal analysis. eSim also supports PCB design through integration with KiCad, allowing schematic designs to be converted into PCB layouts.

One of the major features of eSim is its support for subcircuits. Subcircuits enable complex ICs and reusable functional blocks to be modeled using smaller internal components. This feature improves modularity and simplifies the design of larger electronic systems. The open-source nature of eSim also encourages collaborative development and contributes to accessible engineering education.

1.3 Objectives of the Project

The main objective of this project is to develop and integrate various Integrated Circuit (IC) models as subcircuits within the eSim library. These subcircuits are intended to improve the availability of reusable and accurate components for circuit design and simulation purposes.The objectives of the project are as follows:

1.To study the datasheets and functional behavior of selected Integrated Circuits.

2.To design accurate subcircuit models using the device models available in eSim.

3.To create schematic symbols and proper pin configurations for each IC.

4.To design and simulate test circuits for validating the implemented subcircuits.

5.To analyze simulation outputs and verify the functionality of the IC models.

6.To contribute verified subcircuits to the eSim library for educational and research use.

1.4 Methodology

The methodology followed in this project involved a systematic approach for developing, testing, and validating Integrated Circuit (IC) subcircuits in eSim. The process began with the selection and study of IC datasheets from standard manufacturers such as Texas Instruments, NXP, and Analog Devices. The datasheets were analyzed to understand the functional behavior, pin configuration, logic operation, and internal architecture of each IC.

After studying the datasheets, suitable ICs that were not already available in the eSim library were selected for implementation. The required subcircuits were then designed using the existing device models and components available in eSim. Care was taken to ensure that the developed models accurately matched the specifications and operational characteristics provided in the datasheets.

Once the subcircuits were created, schematic symbols and pin diagrams were generated for proper integration into the eSim environment. Test circuits were then designed to verify the functionality of each implemented IC. These test circuits were developed based on standard application circuits and truth tables available in the datasheets.

Simulation and analysis were performed using NgSpice through the eSim platform. The outputs obtained from the simulations were compared with the expected results from the datasheets to validate the correctness of the subcircuits. If any discrepancies were observed, the design was modified and tested again until satisfactory results were achieved.

Finally, the verified IC models were documented and prepared for contribution to the eSim library, making them available for future educational, research, and circuit design applications.

Chapter 2

Literature Survey

The development of Electronic Design Automation (EDA) tools has played a significant role in modern electronic circuit design and simulation. Over the years, several proprietary and open-source software platforms have been developed to support schematic creation, simulation, PCB design, and verification of analog and digital circuits. Among these, open-source EDA tools have gained increasing attention due to their accessibility, flexibility, and cost-effectiveness for educational and research purposes.

SPICE-based simulators are widely used for circuit analysis and verification. NgSpice is one of the most commonly used open-source circuit simulators for analog, digital, and mixed-signal simulation. It supports a wide range of semiconductor device models and provides accurate simulation results for electronic circuits. NgSpice serves as the simulation backend for many open-source EDA platforms, including eSim.

KiCad is another widely adopted open-source software suite for schematic capture and PCB design. It provides tools for circuit schematic development, PCB layout generation, and design rule checking. Its integration with simulation tools has improved the workflow for electronic circuit development in academic and industrial environments.

eSim, developed under the FOSSEE project at IIT Bombay, combines the capabilities of tools such as KiCad and NgSpice into a unified environment for circuit design, simulation, and PCB development.The platform has been widely used in engineering education due to its open-source nature and integrated workflow.

This project contributes to the enhancement of the eSim library by developing and validating various IC subcircuits based on manufacturer datasheets. The implemented models improve the usability of eSim for digital electronics design and provide accessible resources for students, educators, and researchers working with open-source EDA tools.

Chapter 3

Problem Statement

3.1 Problem Statement

To design and develop various analog and digital integrated circuit models in the form of sub-circuits using device model files already present in the eSim library. These IC models should be useful for future circuit design purposes by developers and users once they are successfully integrated into the eSim sub-circuit library.

3.2 Approach

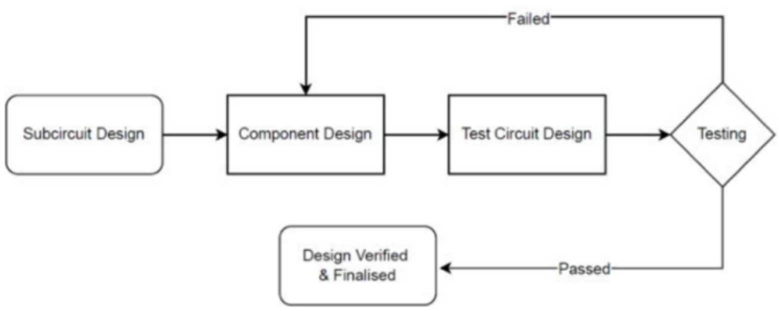

Figure 3.1: Flowchart of IC Design Approach Followed

Our approach to implementing the problem statement involved a systematic process,leveraging datasheets from leading Integrated Circuit (IC) manufacturers such as Texas Instruments, Analog Devices, and NXP Semiconductors. We focused on selecting ICs with diverse functionalities, including precision amplifiers, comparators, encoders, and audio amplifiers. The process is outlined in the following steps:

1. Analyzing Datasheets: The first step involved an in-depth review of datasheetsfor various analog and digital ICs. We aimed to identify circuits suitable for implementation in eSim that were not already present in the eSim library. This process included scrutinizing the detailed schematics of each IC, evaluating component values, and under standing truth tables. The goal was to select ICs that offered unique

functionalities or enhancements not yet covered.

2. Subcircuit Creation: After selecting appropriate ICs, we proceeded to model these as sub-circuits within eSim. We utilized the model files available in the eSim device model library and ensured that our designs adhered strictly to the specifications outlined in the official datasheets. This phase also involved creating accurate symbol and pin diagrams for each IC, in accordance with the packaging and pin descriptions provided in the datasheets. This step was crucial for ensuring the fidelity of the subcircuit models.

3. Test Circuit Design: With the sub-circuits created, we then designed and built test circuits based on the datasheets. This step was essential for verifying the functionality of each sub-circuit. We developed a series of test cases and constructed corresponding test circuits to evaluate the performance and accuracy of the implemented IC models.

4. Schematic Testing: Following the construction of test circuits, we conducted simulations to analyze the outputs. This involved generating waveforms and plots to assess the behavior of the circuits. We employed KiCad for converting designs to NgSpice netlists and utilized eSim's simulation features to perform comprehensive testing.

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

Implementation

4.1 SN7486

4.1.1 General description

The SN7486 is a quad 2-input Exclusive-OR (XOR) gate IC from the TTL logic family. It performs XOR logic operations where the output becomes HIGH when the two inputs are different. Built using TTL technology, it provides reliable high-speed performance for digital logic and arithmetic applications.

4.1.2 Key features

- Quad 2-input XOR gates

  - Standard TTL voltage operation

  - High-speed switching performance

  - Low power consumption

  - Suitable for arithmetic and parity circuits

4.1.3 Applications

- Parity generation and error detection

  - Binary addition and arithmetic circuits

  - Data comparison operations

  - Digital control and logic systems

4.1.4 Subcircuit

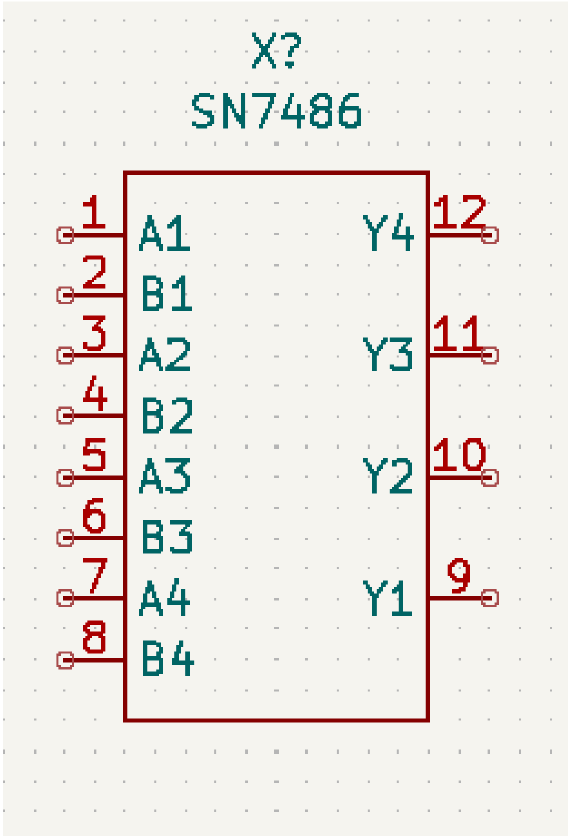

Figure 4.1: Subcircuit Diagram SN7486

4.1.5 Subcircuit Schematic Diagram

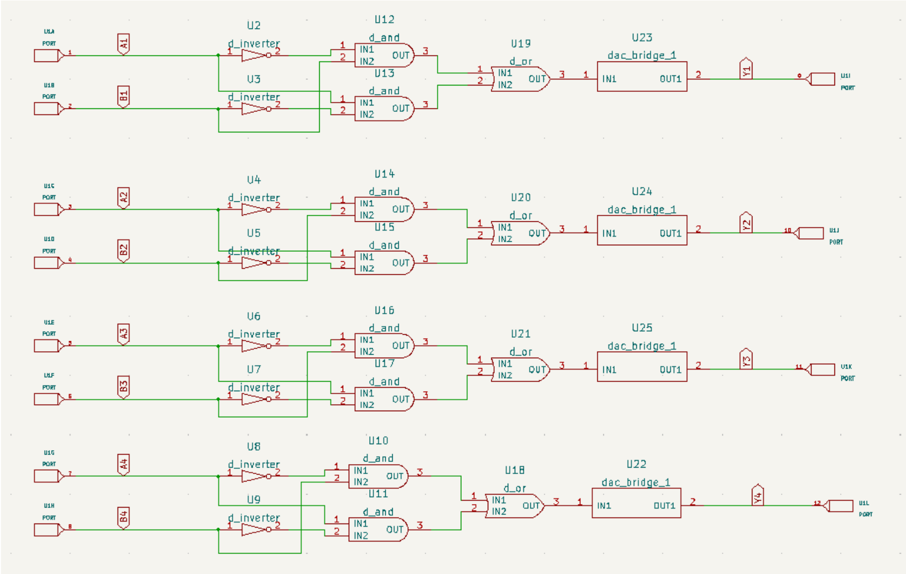

Figure 4.2: Subcircuit Schematic Diagram of SN7486

4.1.6 Test Circuit

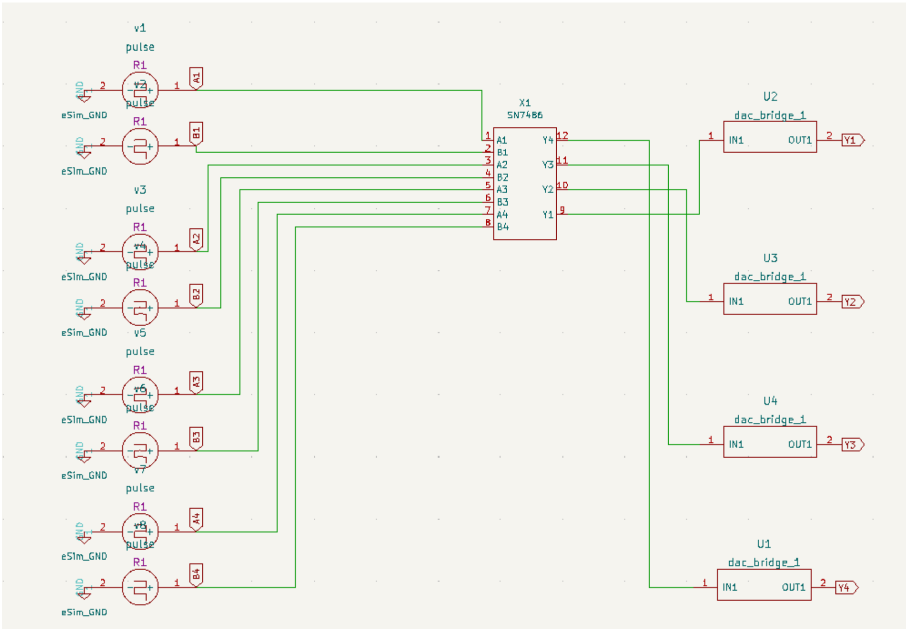

Figure 4.3: Test Circuit of SN7486

4.1.7 Function Table

A	B	Y (A⊕B)
0	0	0
0	1	1
1	0	1
1	1	0

Figure 4.4: Function Table of SN7486

4.1.8 Output Plot

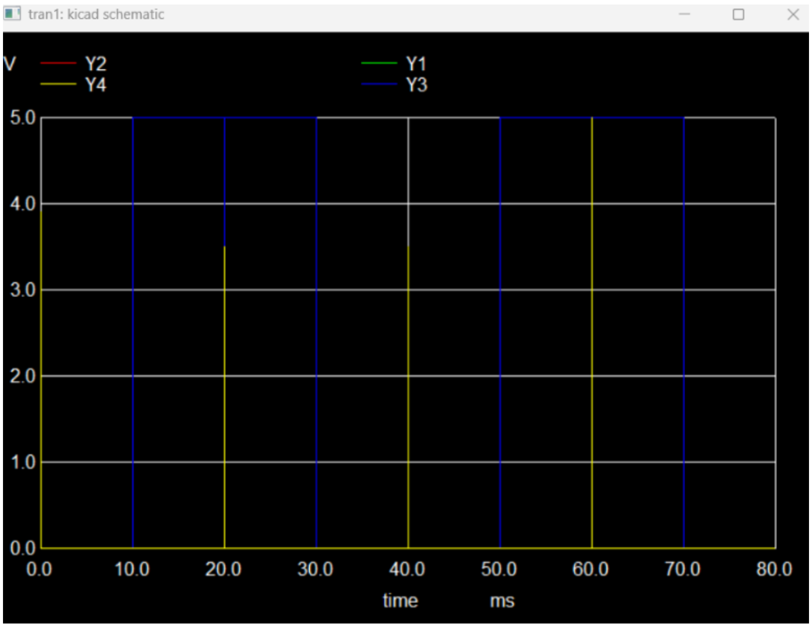

Figure 4.5: Output plot of SN7486

4.2 SN74135

4.2.1 General Description

The SN74135 is a dual 4-input NAND gate IC from the TTL logic family. It contains two independent NAND gates, each capable of performing NAND operations on four input signals. Built using TTL technology, it provides reliable switching performance for digital logic applications.

4.2.2 Key Features

- Dual 4-input NAND gates

  - Standard TTL voltage operation

  - High-speed switching performance

  - Reliable TTL logic compatibility

  - Suitable for combinational logic circuits

4.2.3 Applications

- Digital logic implementation

  - Signal gating and control circuits

  - Combinational logic design

  - Data processing and control systems

4.2.4 Subcircuit

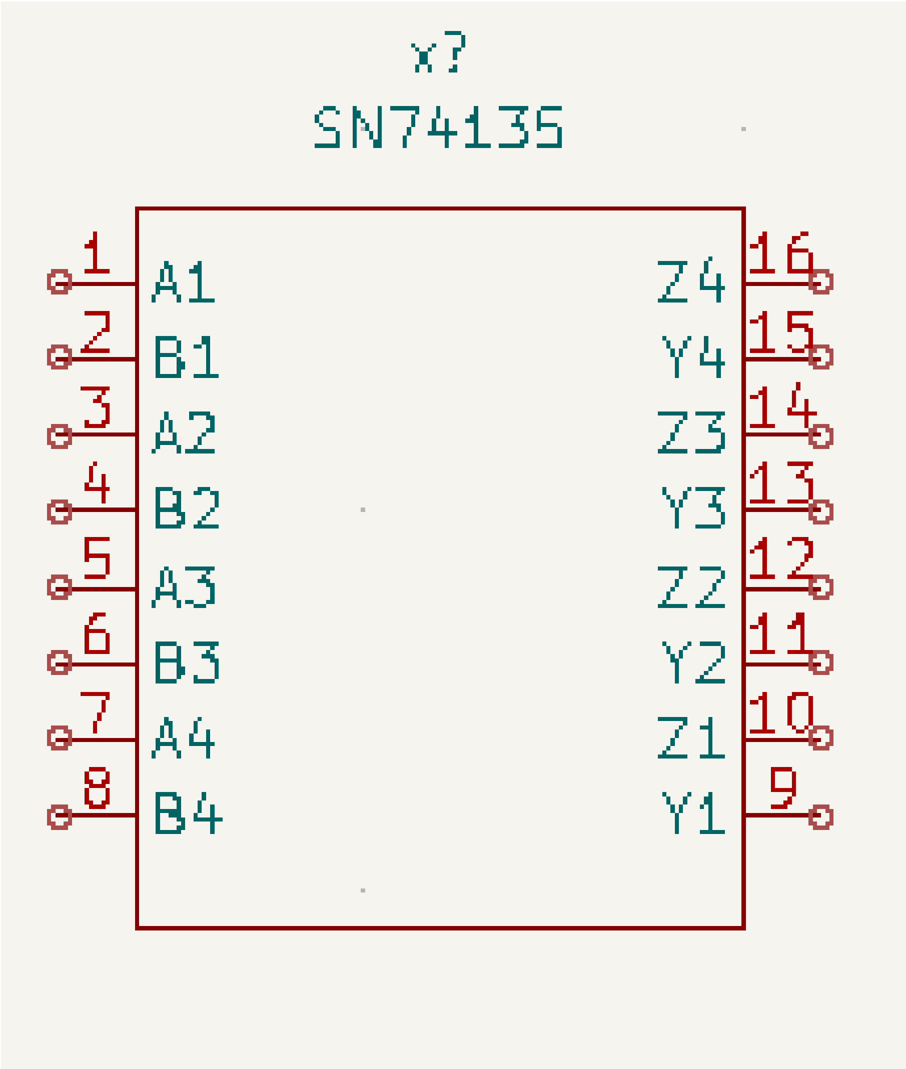

Figure 4.6: Subcircuit Diagram of SN74135

4.2.5 Subcircuit Schematic Diagram

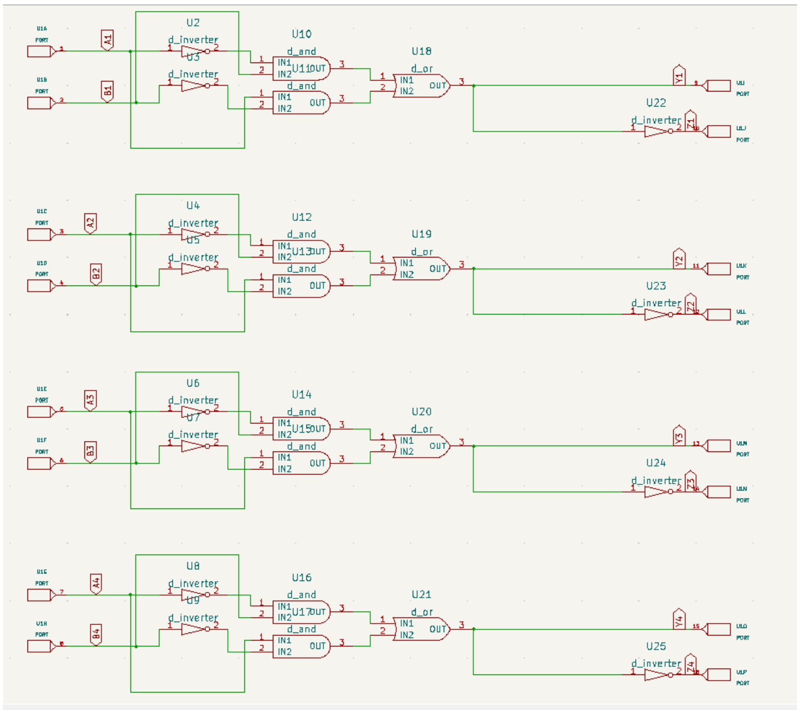

Figure 4.7: Subcircuit Schematic Diagram of SN74135

4.2.6 Test Circuit

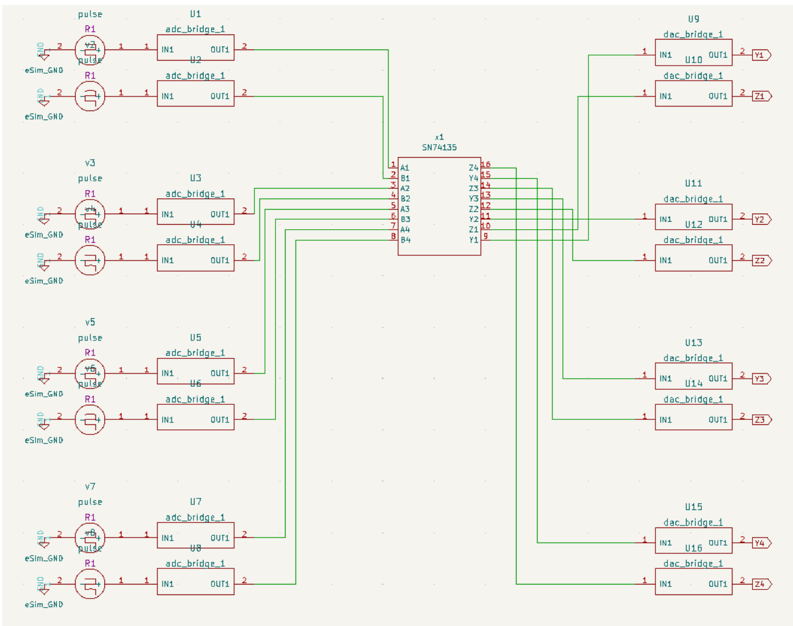

Figure 4.8: Test Circuit of SN74135

4.2.7 Function Table

A	B	C	Y
0	0	0	1
0	1	0	0
1	0	0	0
1	1	0	1
0	0	1	0
0	1	1	1
1	0	1	1
1	1	1	0

Figure 4.9: Function Table of SN74135

4.2.8 Output Plot

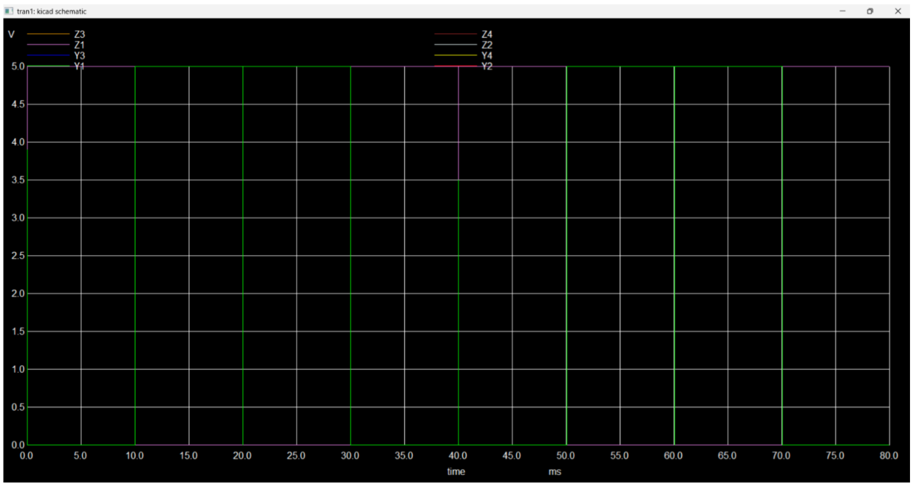

Figure 4.10: Output plot of SN74135

4.3 SN74688

4.3.1 General Description

The SN74688 is an 8-bit magnitude comparator IC from the TTL logic family. It compares two 8-bit binary inputs and provides an output indicating whether the two data words are equal. Built using TTL technology, it offers reliable high-speed performance for digital comparison applications.

4.3.2 Key Features

- 8-bit magnitude comparator

  - Equality comparison of two binary inputs

  - Standard TTL voltage operation

  - High-speed switching performance

  - Cascadable for larger comparison systems

4.3.3 Applications

- Digital data comparison

  - Address matching in memory systems

  - Error detection and verification

  - Control and decision-making circuits

4.3.4 Subcircuit

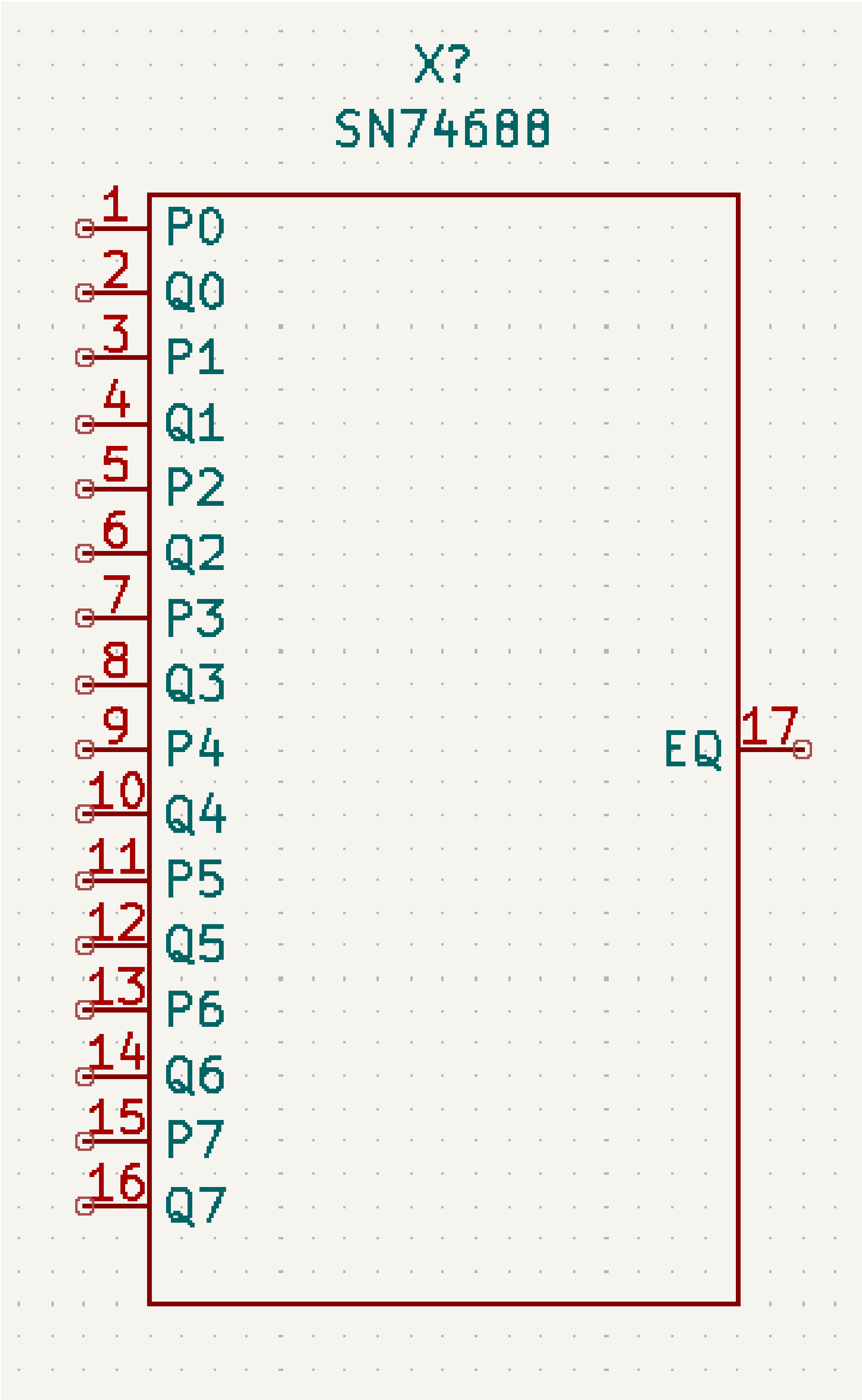

Figure 4.11: Subcircuit Diagram of SN74688

4.3.5 Subcircuit Schematic Diagram

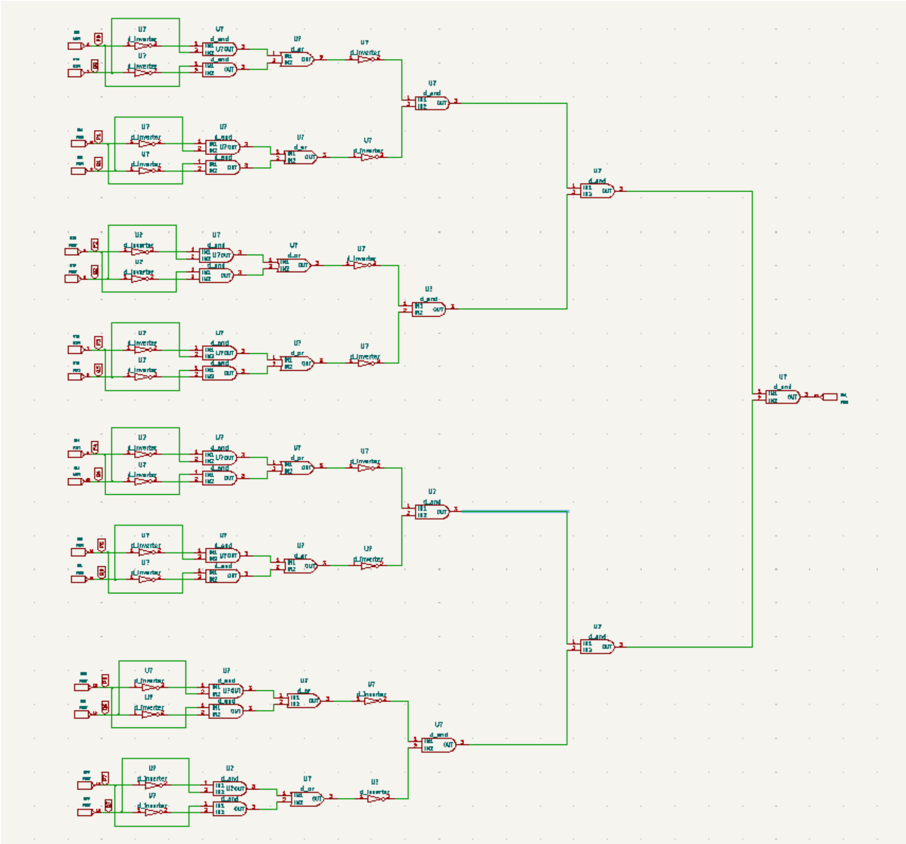

Figure 4.12: Subcircuit Schematic Diagram of SN74688

4.3.6 Test Circuit

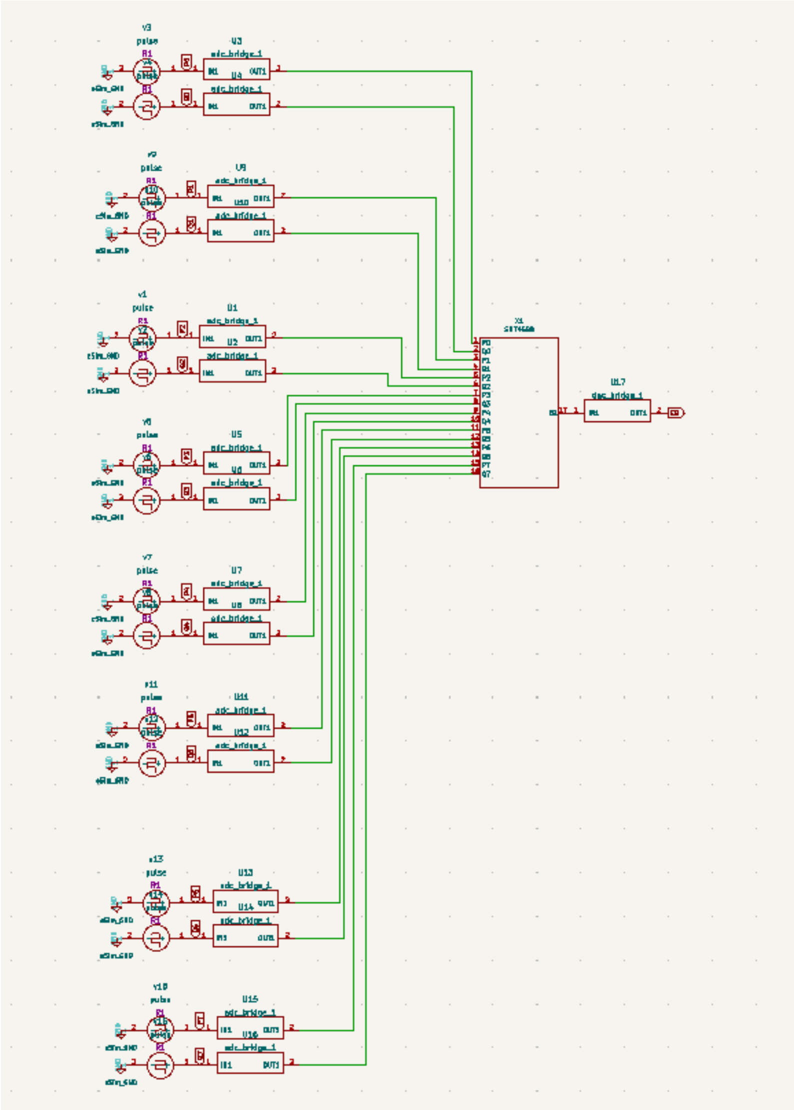

Figure 4.13: Test Circuit of SN74688

4.3.7 Function Table

Ḡ (Enable)	P vs Q	P=Q Output
H (disabled)	X	H
L (enabled)	P ≠ Q	H
L (enabled)	P = Q	L

Figure 4.14: Function Table of SN74688

4.3.8 Output Plot

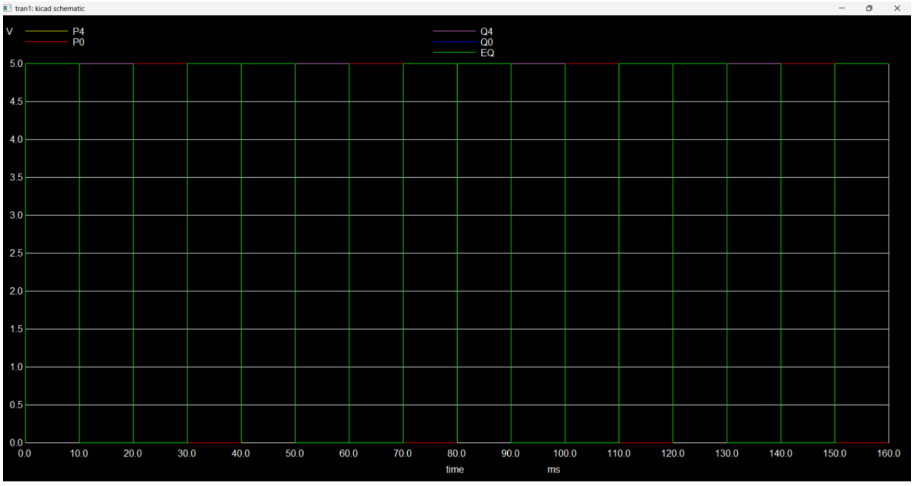

Figure 4.15: Output plot of SN74688

4.4 SN74386

4.4.1 General Description

The SN74386 is a quad 2-input Exclusive-OR (XOR) gate IC from the TTL logic family. It contains four independent XOR gates that perform Exclusive-OR operations on pairs of input signals. Built using TTL technology, it provides reliable high-speed performance for digital logic and arithmetic applications.

4.4.2 Key Features

- Quad 2-input XOR gates

  - Standard TTL voltage operation

  - High-speed switching performance

  - Reliable TTL logic compatibility

  - Suitable for arithmetic and parity operations

4.4.3 Applications

- Binary addition circuits

- Parity generation and error detection

- Data comparison operations

- Digital logic and control systems

4.4.4 Subcircuit

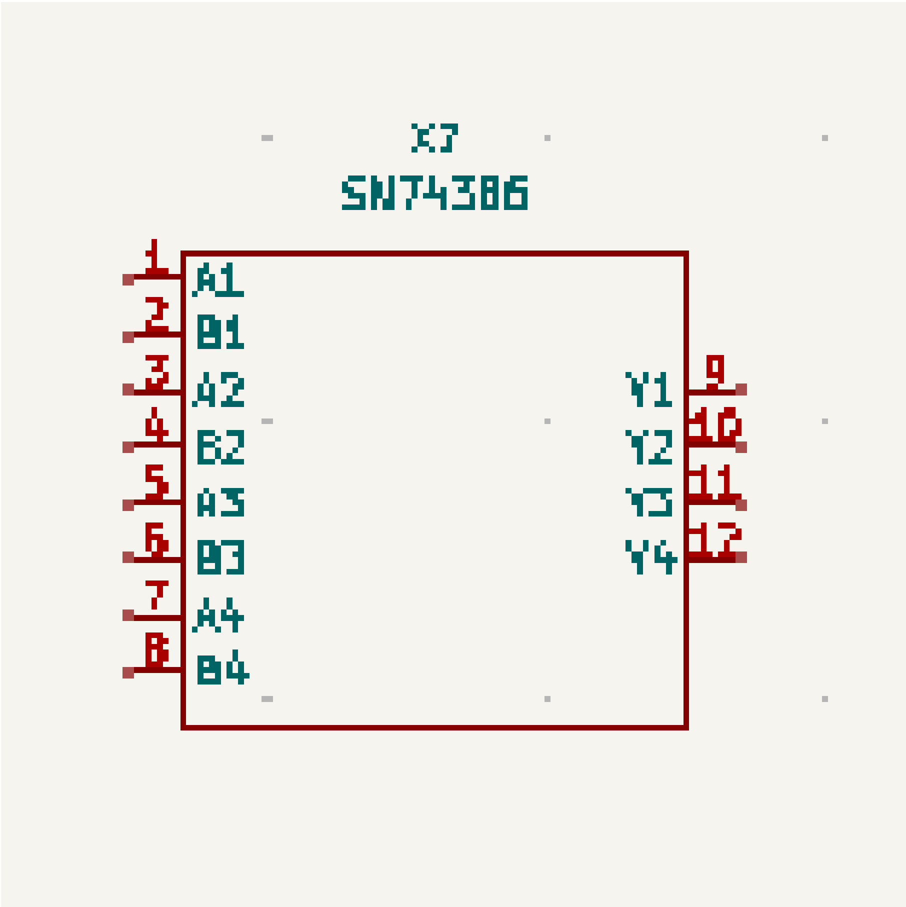

Figure 4.16: Subcircuit Diagram of SN74386

4.4.5 Subcircuit Schematic Diagram

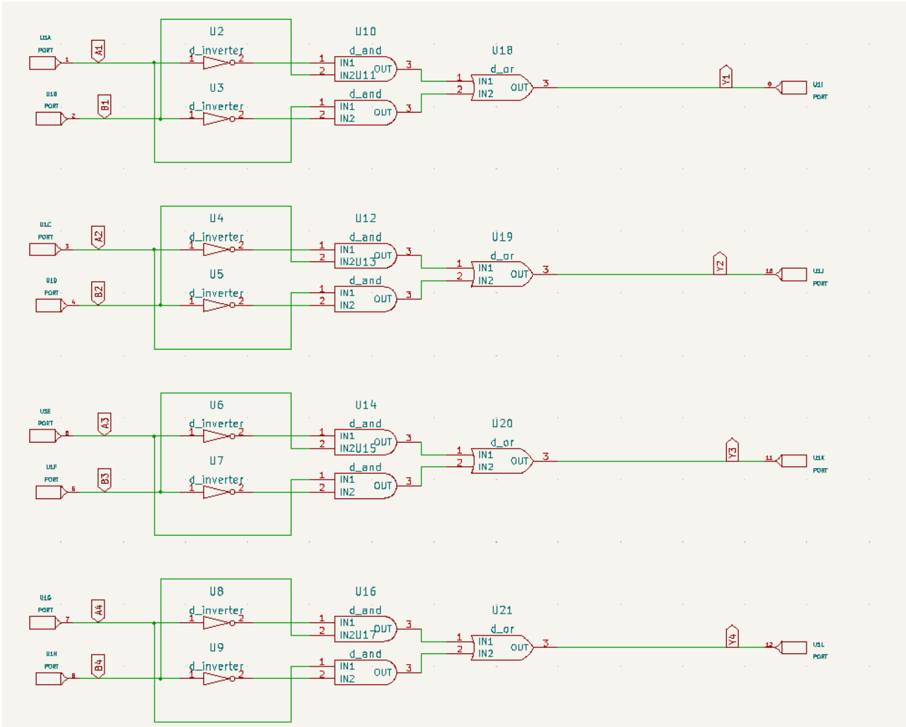

Figure 4.17: Subcircuit Schematic Diagram of SN74386

4.4.6 Test Circuit

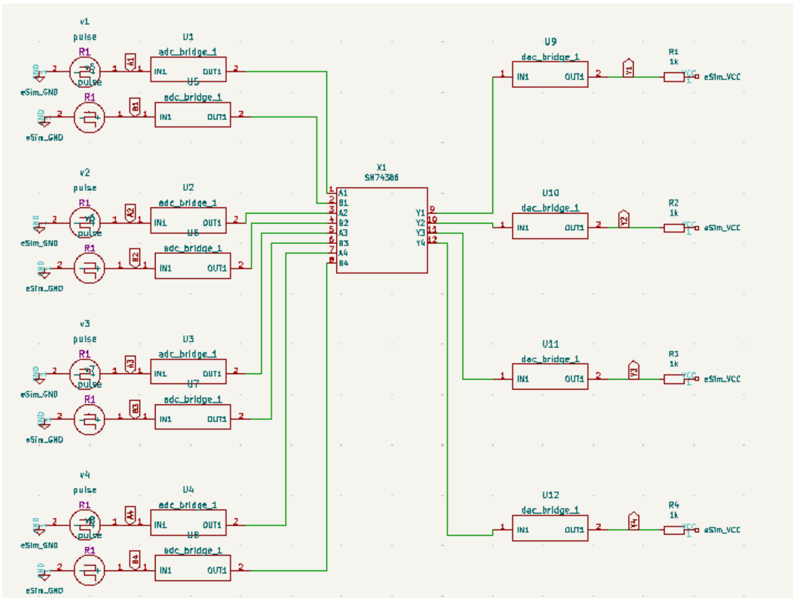

Figure 4.18: Test Circuit of SN74386

4.4.7 Function Table

A	B	Y (XNOR)
0	0	1
0	1	0
1	0	0
1	1	1

Figure 4.19: Function Table of SN74386

4.4.8 Output Plot

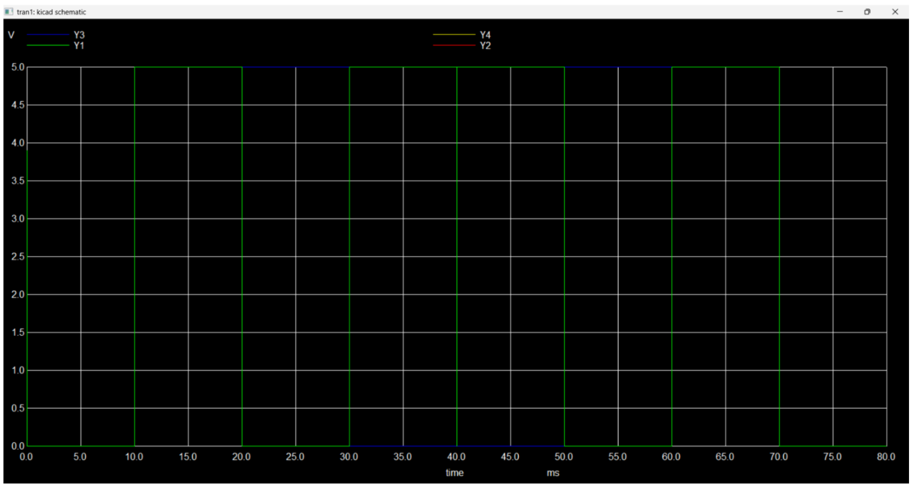

Figure 4.20: Output plot of SN74386

4.5 74LS240

4.5.1 General Description

The 74LS240 is an octal inverting buffer and line driver IC from the Low-Power Schottky (LS) TTL family. It contains eight inverting buffers with two active-LOW enable inputs for controlled data transmission. Built using LS TTL technology, it provides reliable high-speed performance for buffering and driving digital signals.

4.5.2 Key Features

- Octal inverting buffer/line driver

  - Two active-LOW enable inputs

  - Low-power Schottky TTL operation

  - High-speed switching performance

  - Suitable for bus-oriented applications

4.5.3 Applications

- Data buffering and signal driving

  - Bus-oriented systems

  - Memory address driving

  - Digital signal isolation and control

4.5.4 Subcircuit

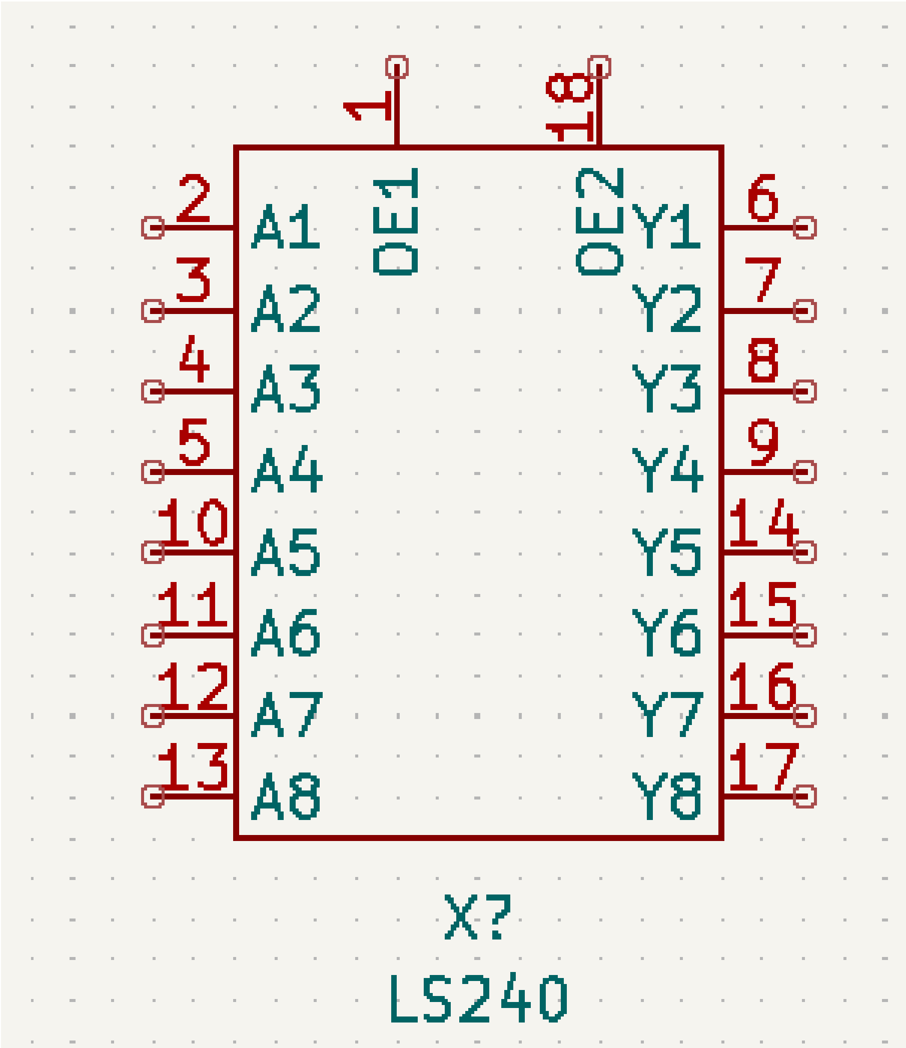

Figure 4.21: Subcircuit Diagram of 74LS240

4.5.5 Subcircuit Schematic Diagram

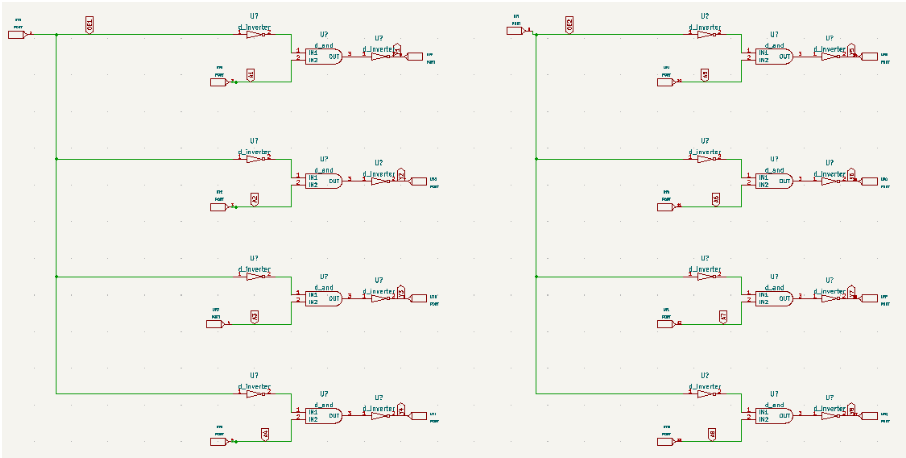

Figure 4.22: Subcircuit Schematic Diagram of 74LS240

4.5.6 Test Circuit

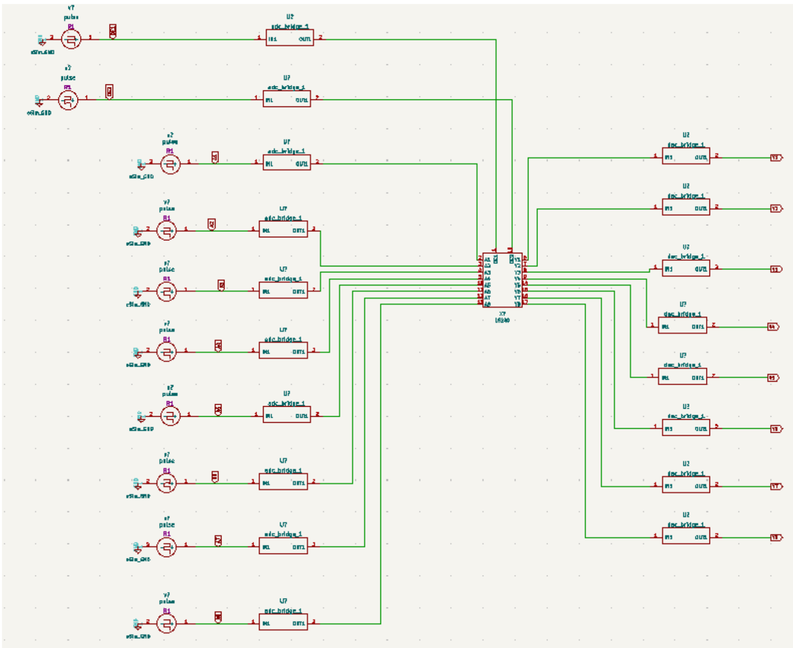

Figure 4.23: Test Circuit of 74LS240

4.5.7 Function Table

$\bar{G}$ (Output Enable)	A (Input)	Y (Output)
L	L	H
L	H	L
H	X	Z

Figure 4.24: Function Table of 74LS240

4.5.8 Output Plot

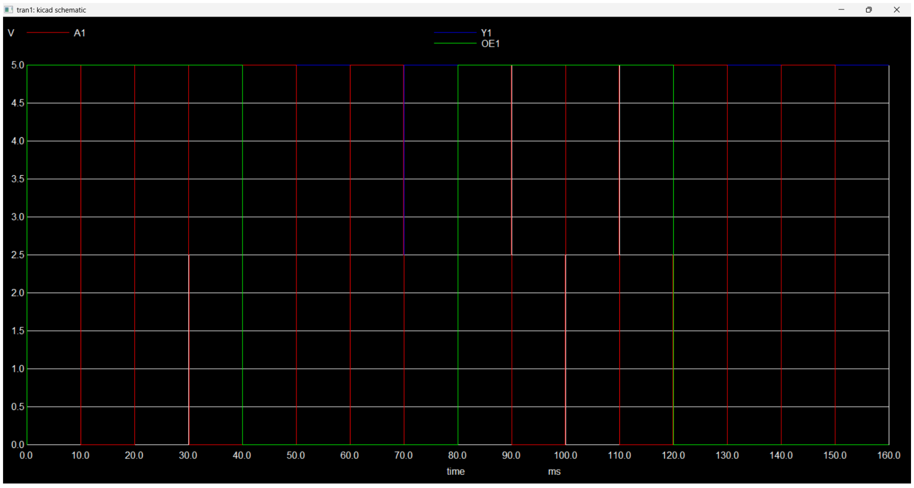

Figure 4.25: Output plot of 74LS240

4.6 SN74H87

4.6.1 General Description

The SN74H87 is a hexadecimal buffer/driver IC from the TTL logic family. It is designed to provide signal buffering and data transmission with improved driving capability for digital systems. Built using TTL technology, it offers reliable high-speed performance for interfacing and signal control applications.

4.6.2 Key Features

- Hexadecimal buffer/driver configuration

- Standard TTL voltage operation

- High-speed switching performance

- Improved signal driving capability

- Suitable for digital interfacing applications

4.6.3 Applications

- Data buffering and signal driving

- Digital interfacing circuits

- Control and transmission systems

- Bus and logic signal applications

4.6.4 Subcircuit

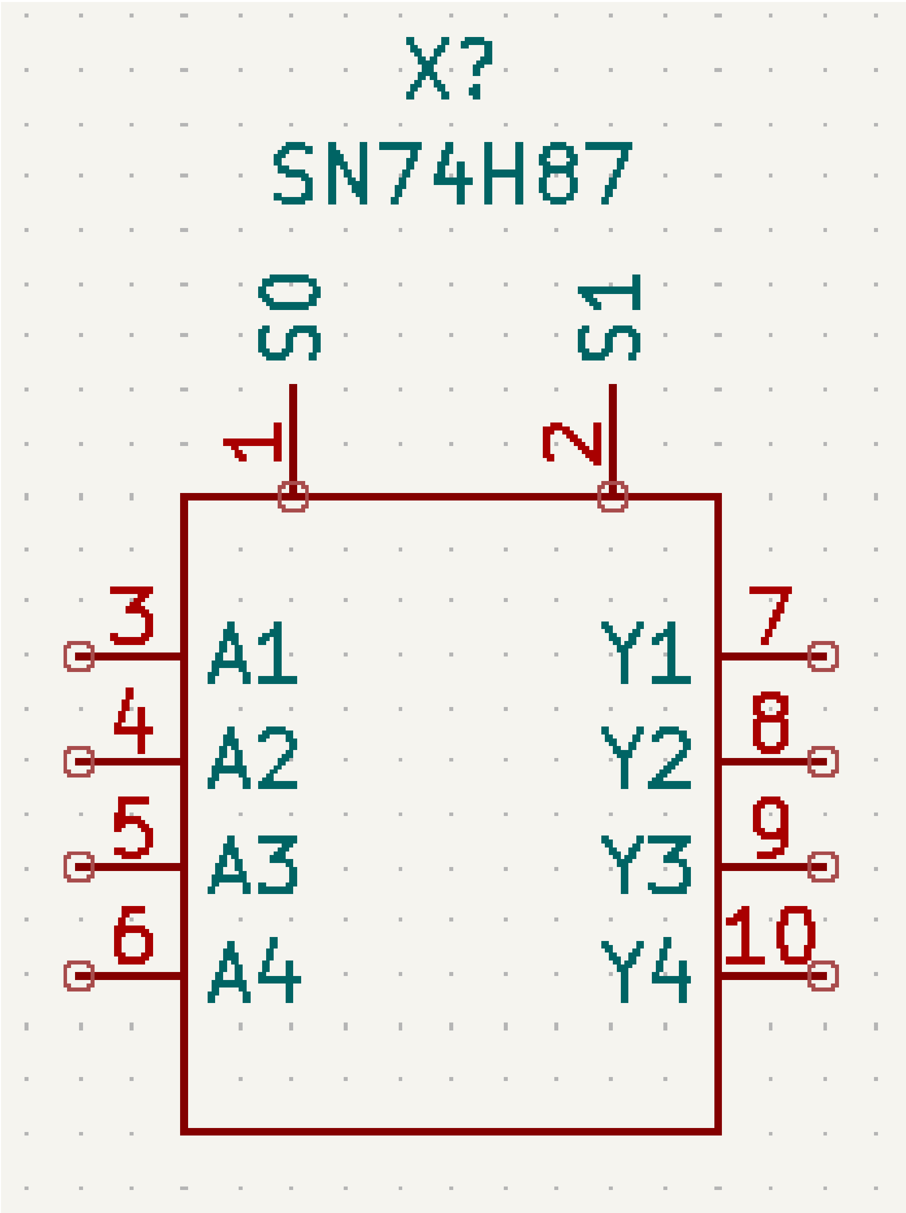

Figure 4.26: Subcircuit Diagram of SN74H87

4.6.5 Subcircuit Schematic Diagram

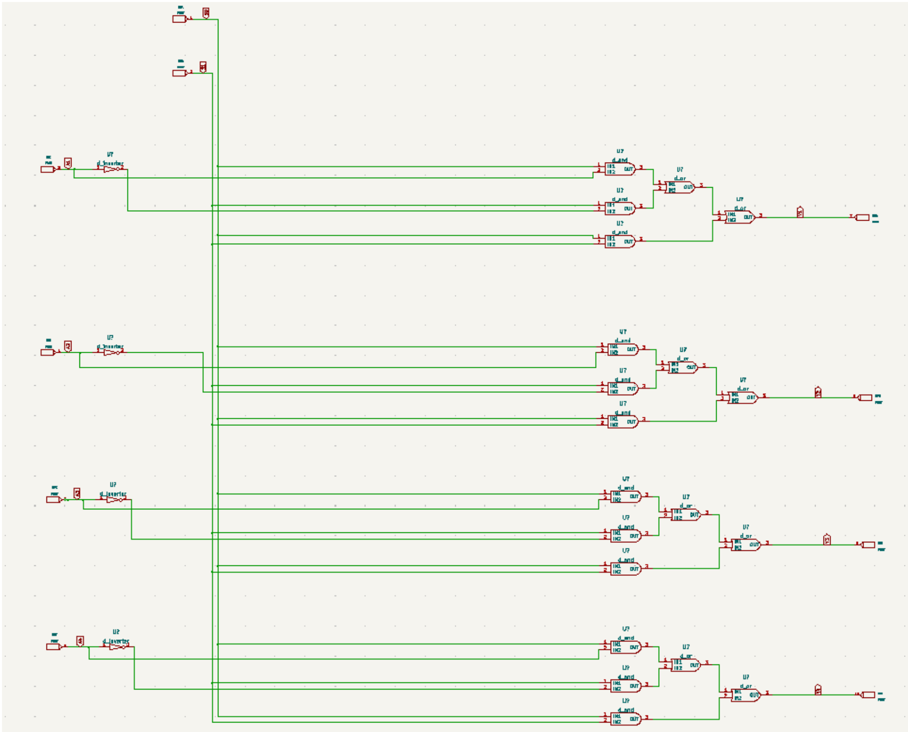

Figure 4.27: Subcircuit Schematic Diagram of SN74H87

4.6.6 Test Circuit

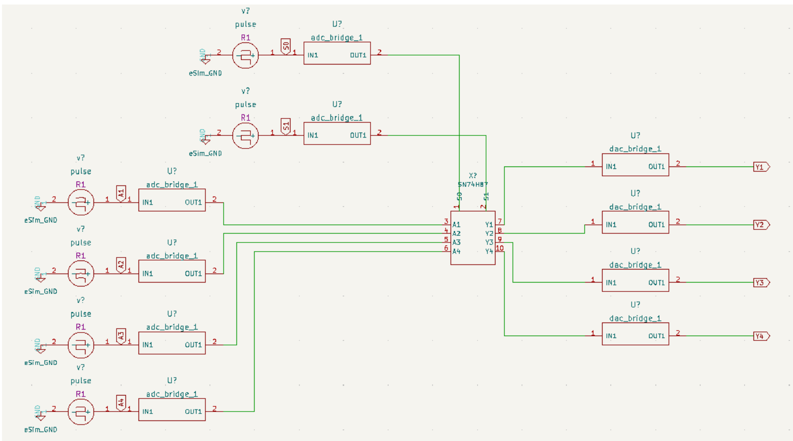

Figure 4.28: Test Circuit of SN74H87

4.6.7 Function Table

S1	S0	Output Y
0	0	0 (All zeros)
0	1	1 (All ones)
1	0	A (True — output = input)
1	1	Ā (Complement — output = inverted input)

Figure 4.29: Function Table of SN74H87

4.6.8 Output Plot

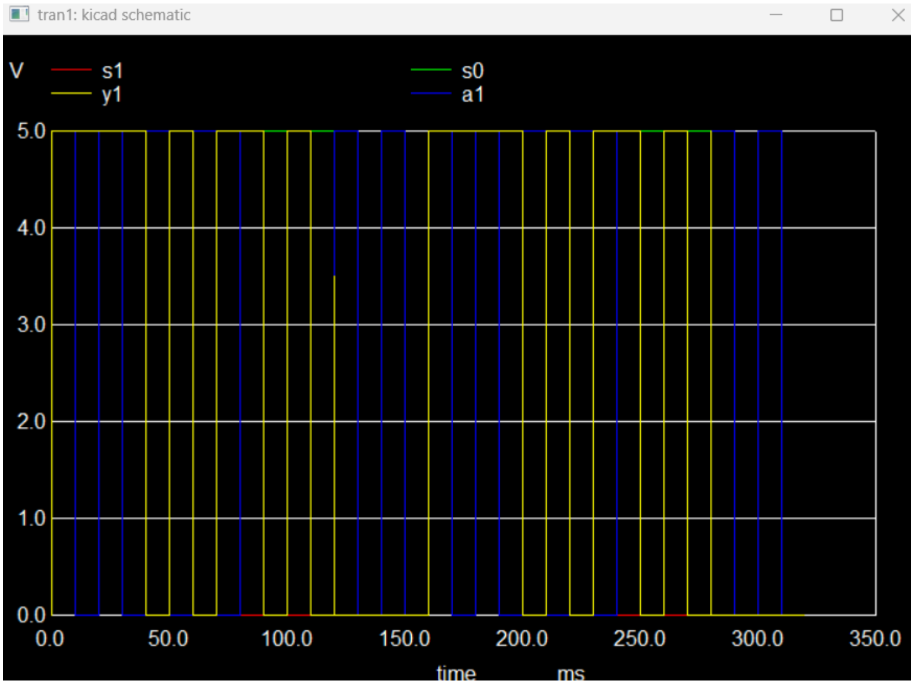

Figure 4.30: Output plot of SN74H87

4.7 SN74LS55

4.7.1 General Description

The SN74LS55 is a dual 2-wide 2-input AND-OR-INVERT gate IC from the Low-Power Schottky (LS) TTL family. It combines AND, OR, and inversion logic functions within a single package, making it suitable for implementing complex combinational logic circuits. Built using LS TTL technology, it provides reliable high-speed performance with reduced power consumption.

4.7.2 Key Features

- Dual AND-OR-INVERT gate structure

  - Low-Power Schottky TTL operation

  - High-speed switching performance

  - Reduced power consumption

  - Suitable for combinational logic implementation

4.7.3 Applications

- Combinational digital logic circuits

  - Logic control systems

  - Signal processing applications

  - Arithmetic and decision-making circuits

4.7.4 Subcircuit

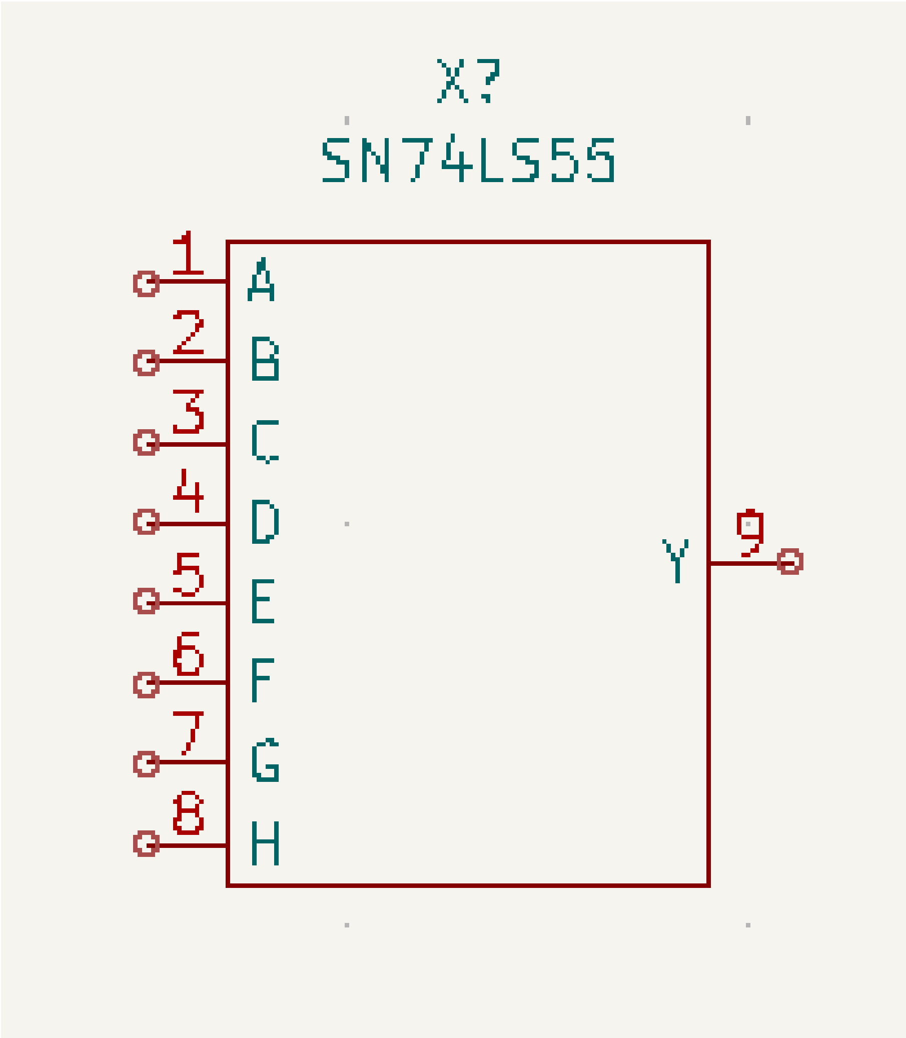

Figure 4.31: Subcircuit Diagram of SN74LS55

4.7.5 Subcircuit Schematic Diagram

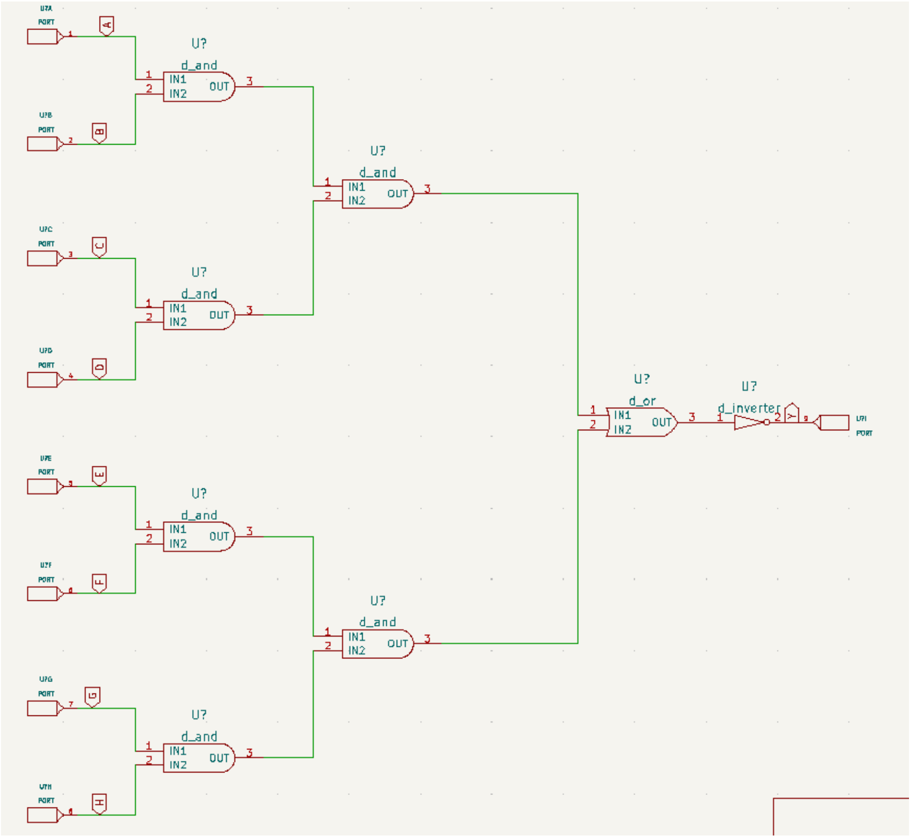

Figure 4.32: Subcircuit Schematic Diagram of SN74LS55

4.7.6 Test Circuit

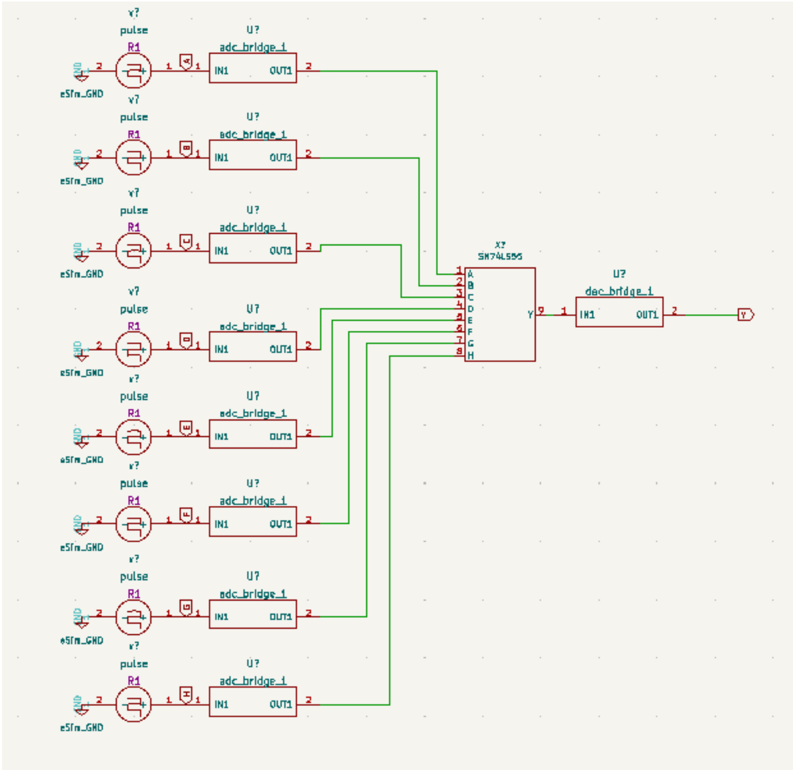

Figure 4.33: Test Circuit of SN74LS55

4.7.7 Function Table

A·B·C·D	E·F·G·H	Y (Output)
0	0	1
0	1	0
1	0	0
1	1	0

Figure 4.34: Function Table of SN74LS55

4.7.8 Output Plot

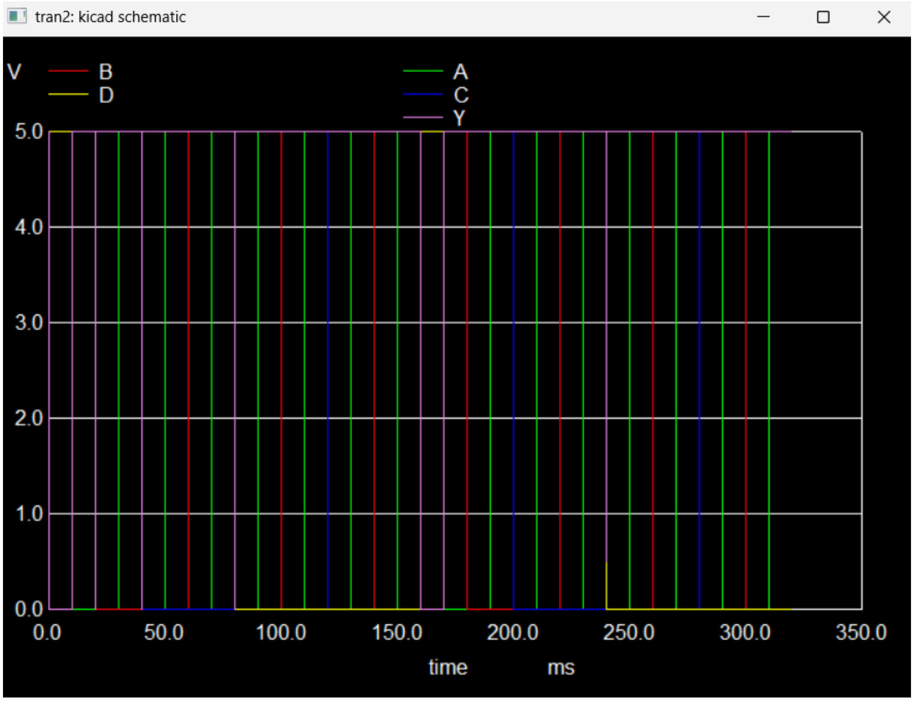

Figure 4.35: Output plot of SN74LS55

4.8 SN7458

4.8.1 General Description

The SN7458 is a dual AND-OR gate IC from the TTL logic family. It combines multiple AND and OR logic functions within a single package, enabling efficient implementation of combinational logic circuits. Built using TTL technology, it provides reliable high-speed performance for digital applications.

4.8.2 Key Features

- Dual AND-OR gate configuration

- Standard TTL voltage operation

- High-speed switching performance

- Compact combinational logic implementation

- Suitable for digital logic applications

4.8.3 Applications

- Combinational logic circuits

  - Arithmetic and control systems

  - Signal processing applications

  - Digital decision-making circuits

4.8.4 Subcircuit

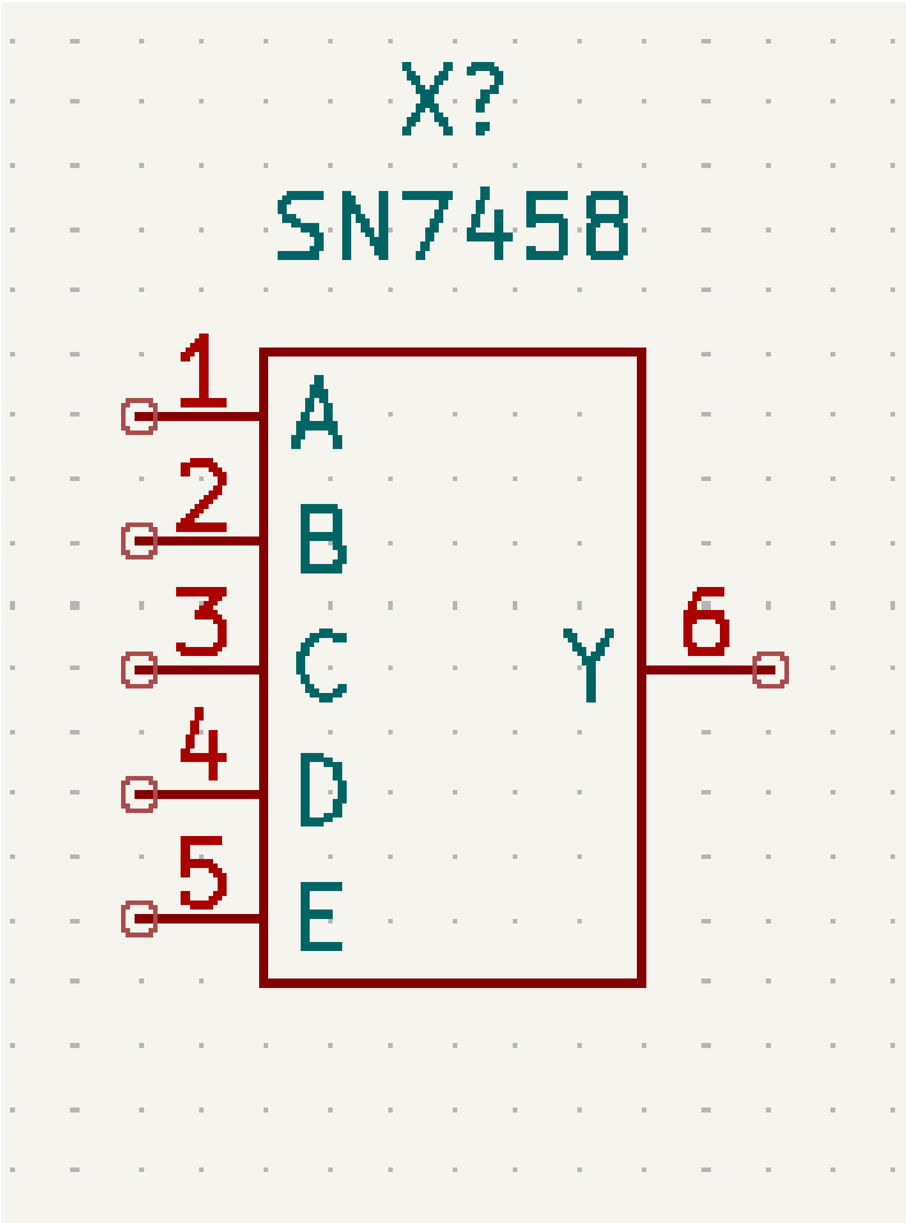

Figure 4.36: Subcircuit Diagram of SN7458

4.8.5 Subcircuit Schematic Diagram

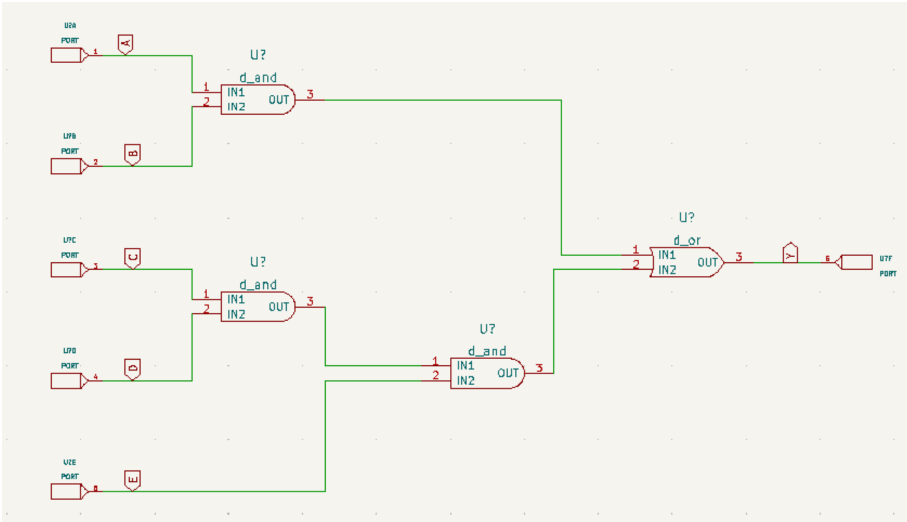

Figure 4.37: Subcircuit Schematic Diagram of SN7458

4.8.6 Test Circuit

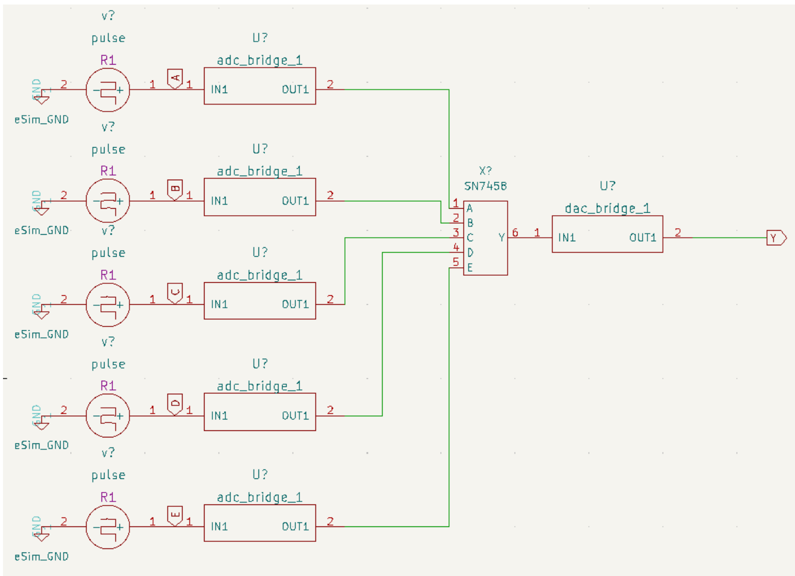

Figure 4.38: Test Circuit of SN7458

4.8.7 Function Table

A	B	C	D	E	F	Y1
1	1	1	X	X	X	1
X	X	X	1	1	1	1
others						0

Figure 4.39: Function Table of SN7458

4.8.8 Output Plot

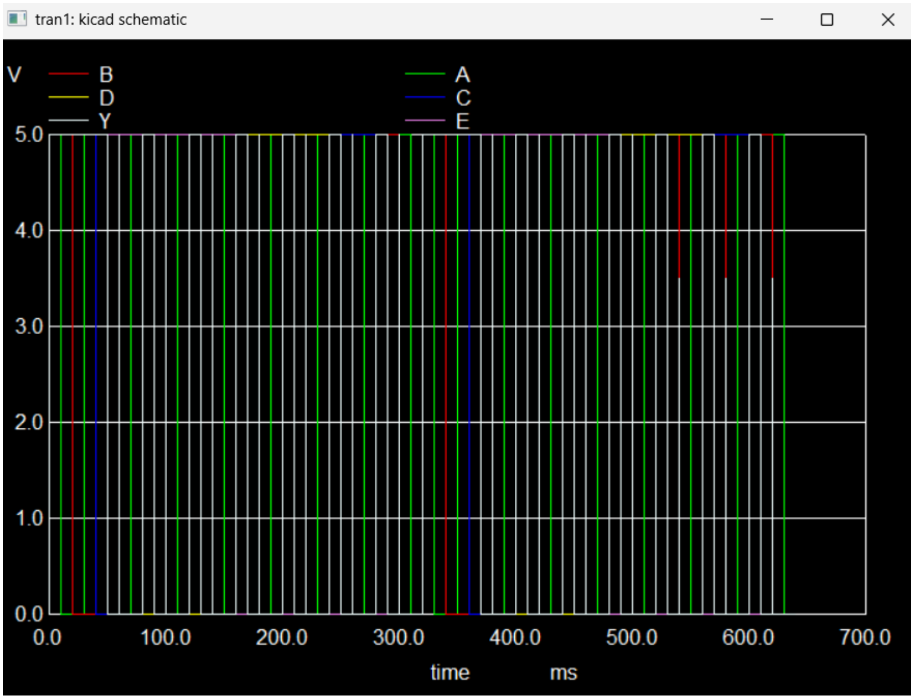

Figure 4.40: Output plot of SN7458

4.9 SN7482

4.9.1 General Description

The SN7482 is a 2-bit binary full adder IC from the TTL logic family. It performs binary addition of two 2-bit words along with carry input and produces sum and carry outputs. Built using TTL technology, it provides reliable high-speed performance for arithmetic and digital processing applications.

4.9.2 Key Features

- 2-bit binary full adder

- Carry input and carry output support

- Standard TTL voltage operation

- High-speed switching performance

- Suitable for arithmetic logic circuits

4.9.3 Applications

- Binary addition circuits

- Arithmetic logic units (ALUs)

- Digital computation systems

- Data processing and control circuits

4.9.4 Subcircuit

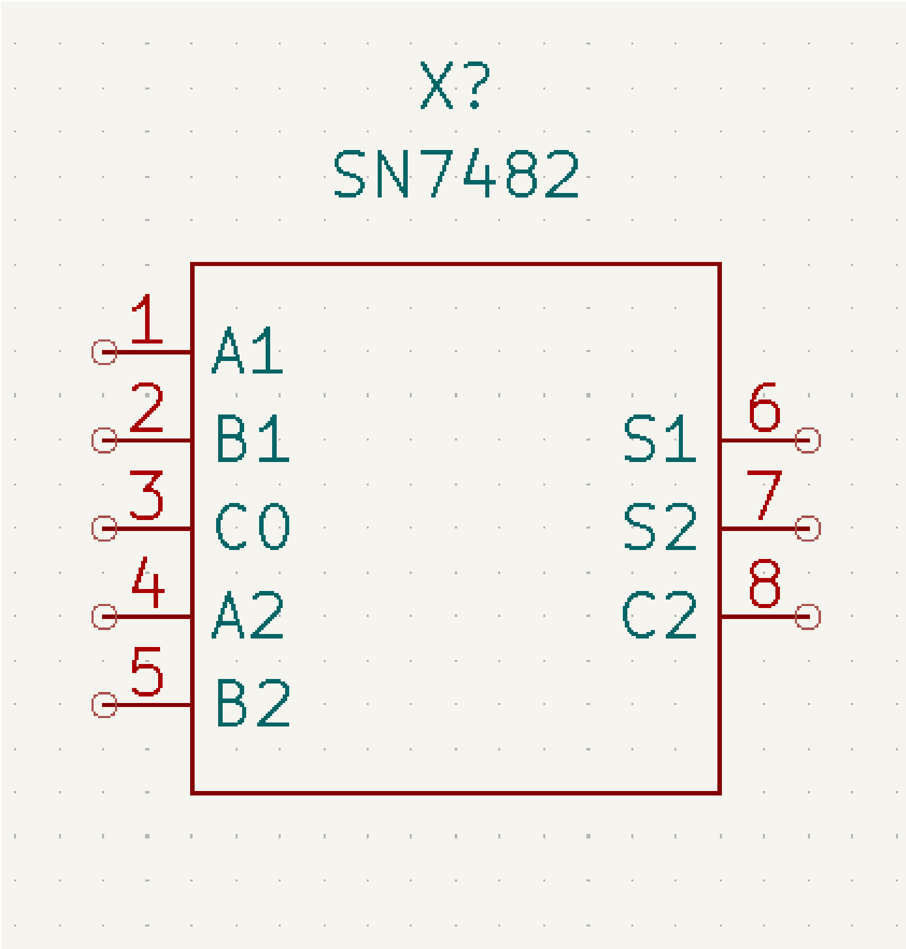

Figure 4.41: Subcircuit Diagram of SN7482

4.9.5 Subcircuit Schematic Diagram

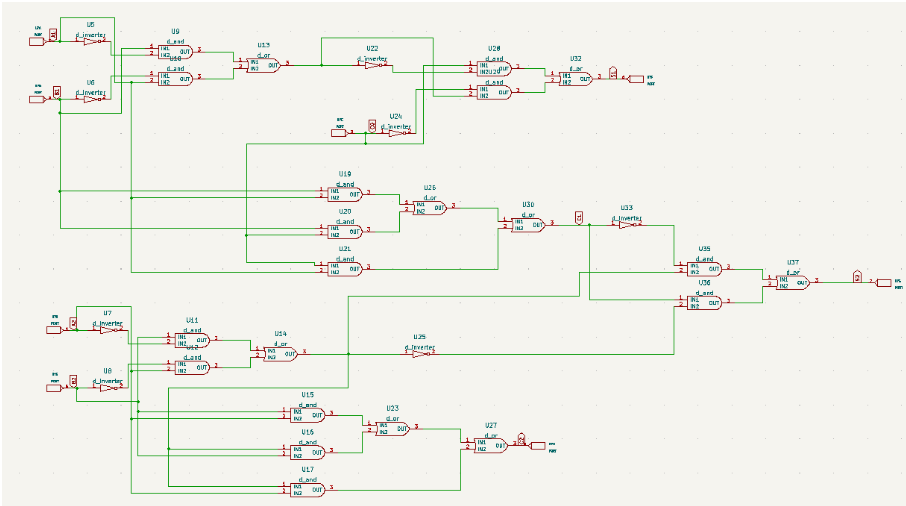

Figure 4.42: Subcircuit Schematic Diagram of SN7482

4.9.6 Test Circuit

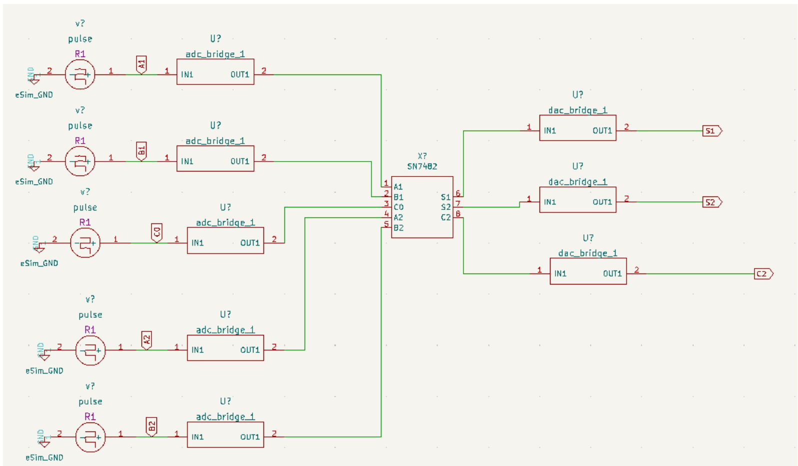

Figure 4.43: Test Circuit of SN7482

4.9.7 Function Table

C0	A1	B1	A2	B2	Σ1	Σ2	C2
0	0	0	0	0	0	0	0
0	1	0	0	0	1	0	0
0	0	1	0	0	1	0	0
0	1	1	0	0	0	1	0
0	0	0	1	0	0	1	0
0	0	0	1	1	0	0	1
1	1	1	1	1	0	0	1

Figure 4.44: Function Table of SN7482

4.9.8 Output Plot

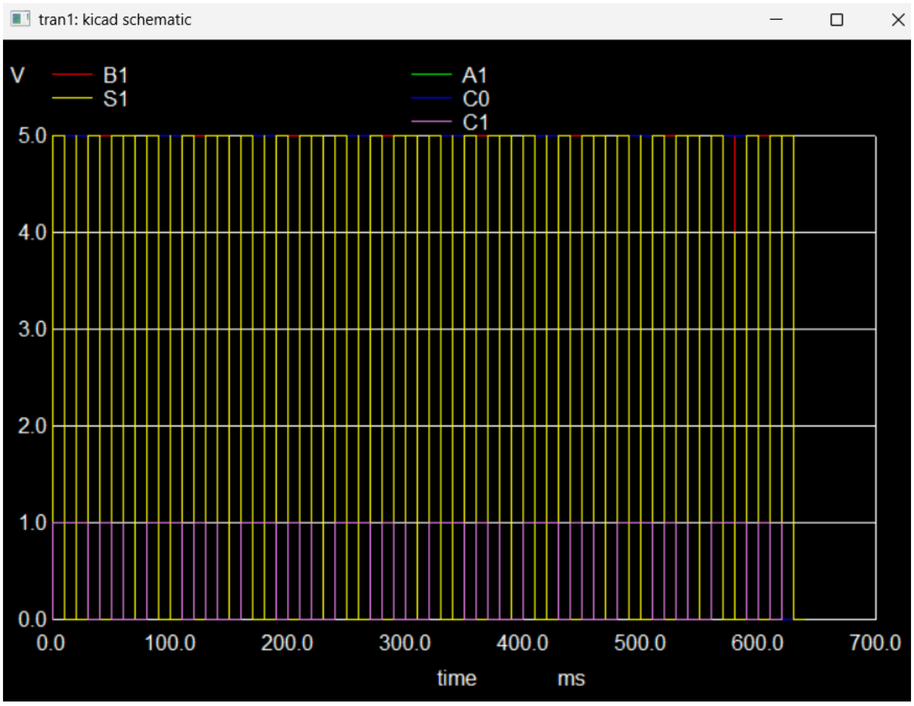

Figure 4.45: Output plot 1 of SN7482

4.9.9 Output Plot

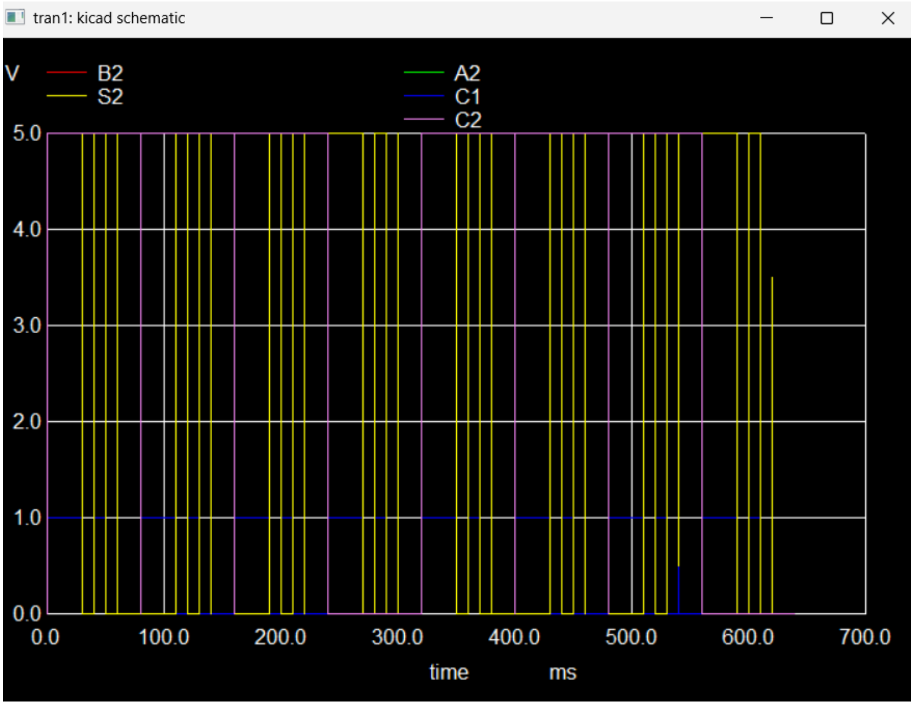

Figure 4.46: Output plot 2 of SN7482

4.10 SN7485

4.10.1 General Description

The SN7485 is a 4-bit magnitude comparator IC from the TTL logic family. It compares two 4-bit binary numbers and provides outputs indicating whether one number is greater than, less than, or equal to the other. Built using TTL technology, it offers reliable high-speed performance for digital comparison applications.

4.10.2 Key Features

- 4-bit binary magnitude comparator

  - Provides A ¿ B, A = B, and A ¡ B outputs

  - Standard TTL voltage operation

  - High-speed switching performance

  - Cascadable for larger comparison systems

4.10.3 Applications

- Digital data comparison

  - Arithmetic and logic systems

  - Address comparison circuits

  - Control and decision-making systems

4.10.4 Subcircuit

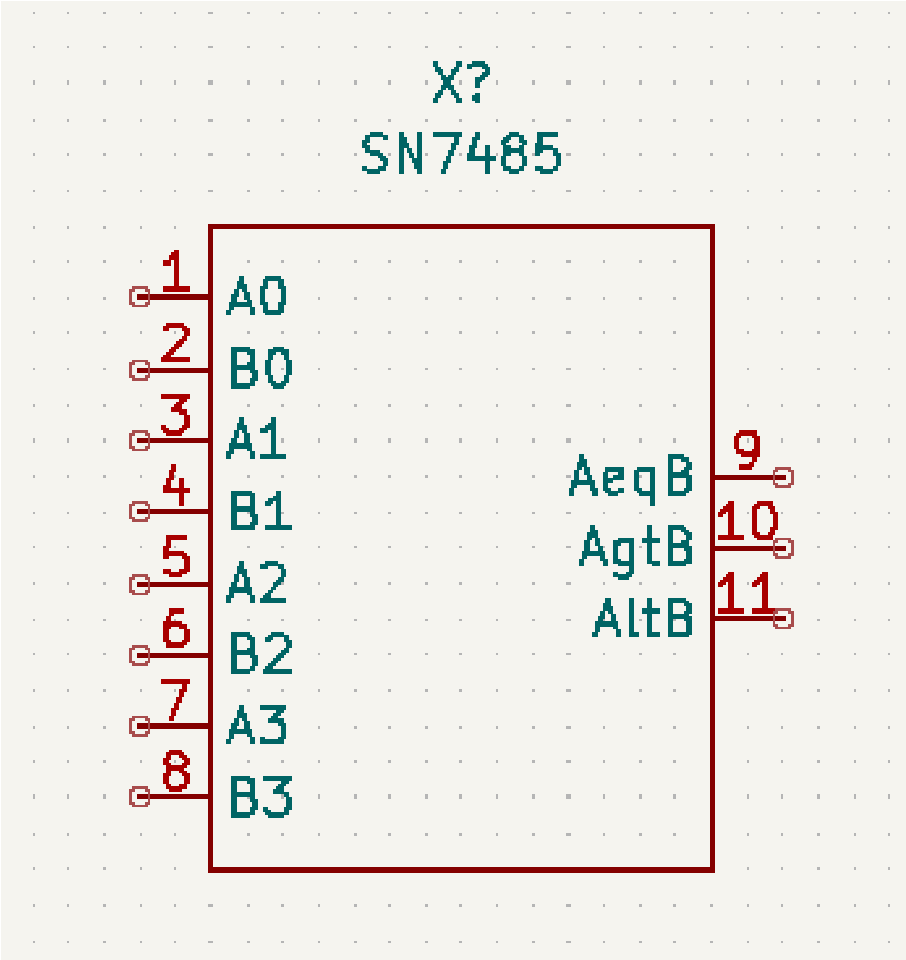

Figure 4.47: Subcircuit Diagram of SN7485

4.10.5 Subcircuit Schematic Diagram

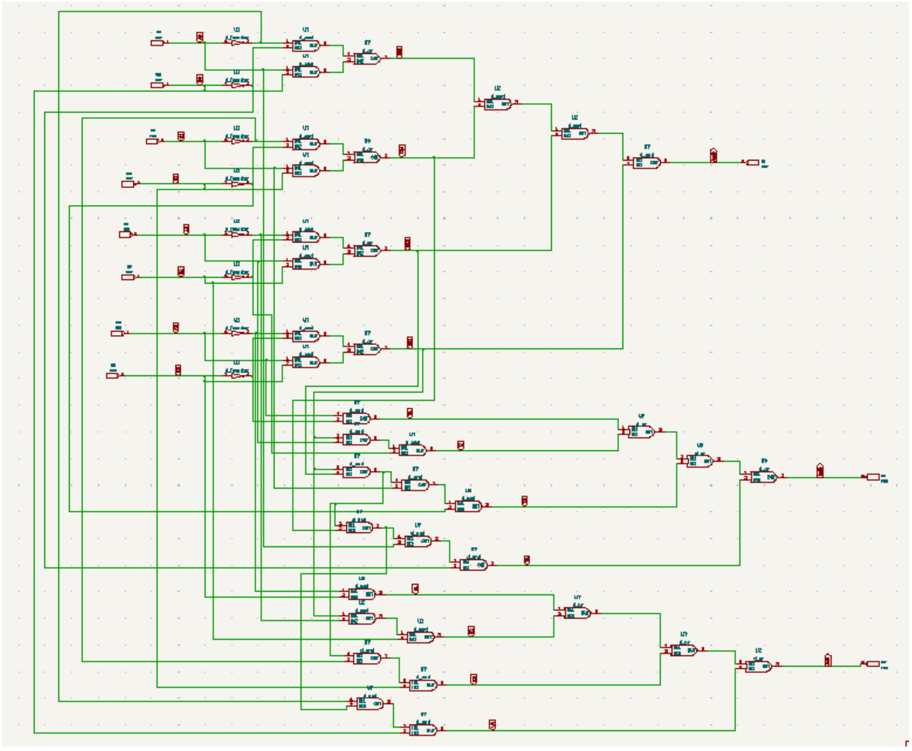

Figure 4.48: Subcircuit Schematic Diagram of SN7485

4.10.6 Test Circuit

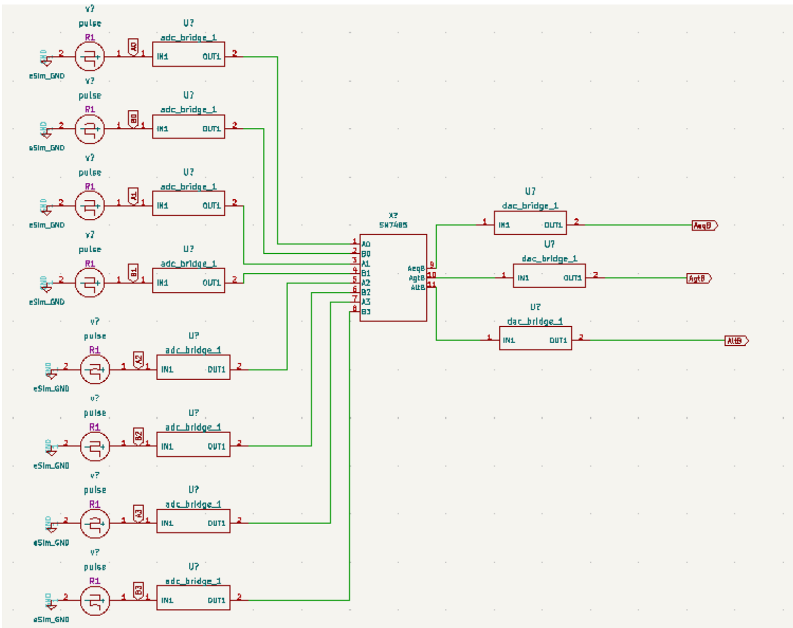

Figure 4.49: Test Circuit of SN7485

4.10.7 Function Table

A3 A2 A1 A0	B3 B2 B1 B0	A>B	A=B	A<B
0000	0000	0	1	0
0001	0000	1	0	0
0010	0100	0	0	1
0110	0110	0	1	0
1001	0111	1	0	0
0101	1010	0	0	1

Figure 4.50: Function Table of SN7485

4.10.8 Output Plot

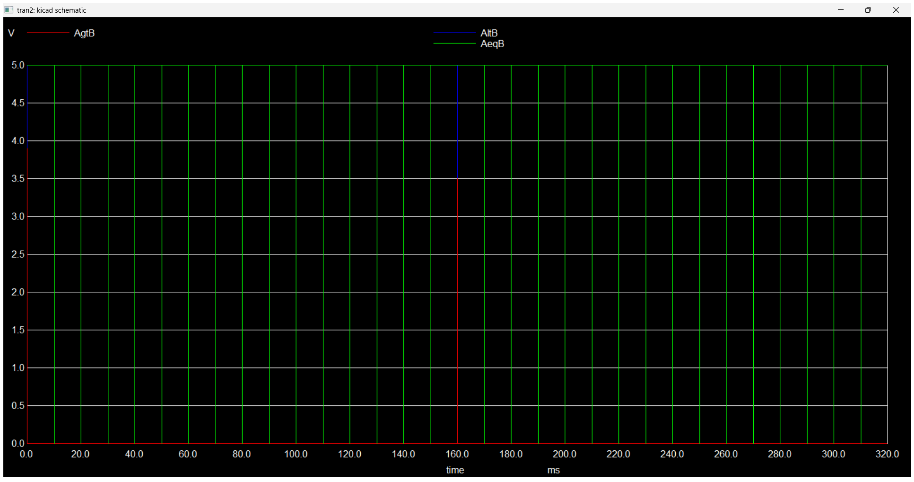

Figure 4.51: Output plot of SN7485

Chapter 5

Conclusion and Future Scope

The project successfully fulfilled its objective of contributing a diverse set of accurately modeled digital logic ICs to the eSim subcircuit library. Each IC was implemented based on its official datasheet and rigorously tested through appropriate simulation testbenches to ensure its functional correctness and reliability. The contributions include a variety of fundamental digital components such as Adders, Encoders, Decoders, Multiplexers, Flip-Flops, Latches, Comparators, and Display Drivers.

These digital IC models serve as essential building blocks for designing and simulating complex digital systems, making them valuable resources for students, educators, and researchers using eSim. By integrating these verified models into the eSim library, the project has enhanced the platform's capability to support real-world digital logic design and experimentation.

This initiative not only reinforces the importance of open-source EDA tools in academic and research settings but also lays the groundwork for future developments. As the eSim device model library continues to grow, we anticipate a broader adoption among the engineering community and the creation of increasingly sophisticated circuits. The outcomes of this project thus represent a meaningful step forward in strengthening the ecosystem of accessible, open-source circuit simulation tools.

Chapter 6

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