Indian Institute of Technology Bombay

fossee better education

eSim Semester Long Internship (Autumn) 2025

On

IC Integration and Subcircuit Creation

Submitted by

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Acknowledgment

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I would also like to thank my internal mentors, **Mr. Varad Patil**, **Ms. Shanthi Priya K**, and **Mr. Aditya M**, for their valuable guidance, coordination, and technical inputs during the internship. Their mentorship contributed significantly to the clarity, progress, and successful execution of the work.

This internship has been an enriching learning experience, allowing me to work closely with open-source EDA tools, develop IC subcircuits in **eSim**, and gain exposure to real-world circuit modeling and simulation workflows. The knowledge acquired during this period will undoubtedly support my future academic and professional pursuits.

Finally, I would like to thank my friends **Anish Khapare**, **Sakshi Pandey**, and **Manwantha Krishnan** for their motivation, encouragement, and unwavering support throughout this journey. This internship has been an important milestone in my academic and professional development, and I am truly grateful to everyone who contributed to making it a rewarding and memorable experience.

Contents

Chapter 1

Introduction

The FOSSEE (Free/Libre and Open Source Software for Education) project, an initiative by IIT Bombay, is part of the National Mission on Education through ICT (NMEICT), Ministry of Education, Government of India. The primary goal of FOSSEE is to promote the use of Free and Open Source Software (FOSS) tools in academia and research, offering an affordable and transparent alternative to expen- sive proprietary software. FOSSEE supports a wide range of open-source software including eSim, Scilab, OpenFOAM, Python, R, OpenModelica, DWSIM, and others. Through its various projects, internships, and fellowships, FOSSEE provides students, educators, and researchers an opportunity to contribute to the development and enhancement of these tools. The project not only encourages practical learning and skill development but also aims to foster a collaborative ecosystem where individuals can contribute meaning- fully to the open-source community. By integrating FOSS into academic curricula and research, FOSSEE empowers institutions across India to achieve greater self- reliance and innovation in STEM education.

1.1 eSim

eSim (Electronic Simulation) is a free and open-source Electronic Design Au- tomation (EDA) tool developed as part of the FOSSEE (Free/Libre and Open

Source Software for Education) project at IIT Bombay. It is created with the aim of providing a viable open-source alternative to widely used proprietary software in the field of circuit design and simulation, such as OrCAD, PSpice, and LTspice.[1] The tool brings together the power of multiple open-source platforms—most notably KiCad for schematic capture and PCB design, and Ngspice for circuit simulation—into a single integrated environment. eSim is designed to support the entire workflow of electronics development, from circuit design to simulation, offering users a comprehensive platform for learning and innovation. eSim is particularly well-suited for academic institutions, students, and researchers, as it eliminates the dependency on expensive licensed soft-

ware. Its development is aligned with the larger objective of the FOSSEE project: to promote self-reliance, accessibility, and transparency in technical education through the use of open-source tools. By adopting eSim, users gain exposure to industry-relevant design processes using freely available resources. It enables hands-on experience with modern EDA methodologies and encourages active learning and experimentation. Moreover, it supports the open-source philosophy by allowing users to contribute back to its development, ensuring continuous improvement and community-driven innovation. In an educational context, eSim plays a crucial role in fostering practical elec- tronics skills. It enables learners to explore circuit behavior, verify designs through simulation, and even move towards prototyping through PCB layout generation—all within a unified, license-free platform. This makes eSim a valuable asset for engi- neering curricula and student projects.

1.2 NgSpice

NgSpice is an open-source circuit simulator integrated into eSim for performing ana- log and mixed-signal simulations. Based on the SPICE simulation engine, NgSpice supports DC, AC, transient, and parametric analyses, making it suitable for ana- lyzing a wide range of circuits. [2] It serves as the simulation backend in eSim, enabling users to simulate circuits de- signed using schematic editors like KiCad.Ngspice has become an essential resource in education and research, enabling learners and engineers to simulate and test cir- cuits efficiently, without relying on proprietary software.

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 should be capable of performing schematic creation, PCB design, and circuit simulation (analog, digital, and mixed-signal). It should provide 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 automa-

tion. Being open-source, eSim is free to use, making advanced circuit design tools accessible without the need for expensive licenses.

Chapter 3

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 in the future for circuit designing purposes by developers and users, once they get successfully integrated into the eSim subcircuit library.

3.1 Approach

Our approach to implementing the problem statement began with examining datasheets from prominent Integrated Circuit (IC) manufacturers such as Texas Instruments, Analog Devices, and NXP Semiconductors. we selected ICs that offer a diverse range of functionalities, including precision amplifiers, comparators, encoders, and audio amplifiers. After building the subcircuits, we tested them to verify basic circuit configurations using NgSpice simulations. The step-by-step roadmap of this process is outlined below :

1. Analysing Datasheet: The primary step is to browse through various analog and digital IC datasheets, and hence find suitable circuits to implement in eSim, that are not previously included into the eSim library. Check for the detailed schematic of the IC's and once the component values and the truth table is ascertained, then finalise the IC to be created.

2. Subcircuit creation: After deciding the IC, we start modeling it as a subcircuit in eSim, using the model files present in the eSim device model library only. The design is strictly according to the information given in the official data-sheets of the ICs.This step also includes building the Symbol/Pin diagram of the IC according to the packaging and pin description given in the data-sheets only.

3. Test circuit design: Once the component of the IC is ready, now we can build the test circuits, according to the data-sheets. In this step we build the test cases and test circuits using the component IC.

4. Schematic testing and verification: Once the test circuits are ready, now it's time to simulate the test circuits so that the output can be obtained in the form of waveforms and plots. Here we take help of KiCad to NgSpice conversion and Simulation feature in eSim If the output of the test circuit is not as per expectation, this implies that the test case has failed, and there is some error in the schematic. In such cases we go back to the design phase of the IC or the test circuits, to look for possible errors and then repeat the testing process again after making required changes. Once the expected output of the test cases are correct and satisfy the expected results, then in such a case the IC is declared successfully working. The test case has been verified and the designing process is complete.

Chapter 4

Digital ICs

4.1 SN74HCT139: 2 to 4 Line Decoder

The SN74HCT139 is a high-speed dual 2-to-4 line decoder/demultiplexer belonging to the HCT (High-speed CMOS, TTL-compatible) logic family. It contains two independent decoders, each having two select inputs (A, B), an active-LOW enable input (G), and four active-LOW outputs (Y0–Y3). When the enable input is LOW, one of the four outputs is selected based on the binary combination of the select inputs, while the remaining outputs remain HIGH. When the enable input is HIGH, all outputs are forced HIGH.

The device operates with a 5 V supply and provides TTL-compatible input thresholds, making it suitable for interfacing with TTL logic while offering the low power consumption and high noise immunity of CMOS technology. The SN74HCT139 is widely used in address decoding, memory selection, data routing, and control signal generation in digital systems. It is available in standard 16-pin packages and is designed for reliable operation over a wide range of industrial and educational applications.

4.1.1 IC Layout

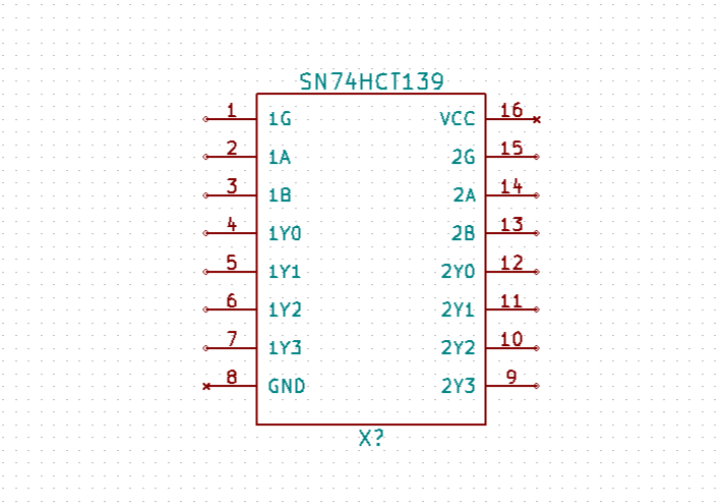

Figure 4.1: Pin Diagram of SN74HCT139

4.1.2 Function Table

Table 8-1. Function Table

INPUTS(1)			OUTPUTS(2)			
$\overline{G}$	SELECT					
	B	A	Y0	Y1	Y2	Y3
H	X	X	H	H	H	H
L	L	L	L	H	H	H
L	L	H	H	L	H	H
L	H	L	H	H	L	H
L	H	H	H	H	H	L

(1) H = High Voltage Level, L = Low Voltage Level, X = Don't Care
(2) H = Driving High, L = Driving Low, Z = High Impedance State

Figure 4.2: Function Table of SN74HCT139

4.1.3 Subcircuit Schematic Diagram

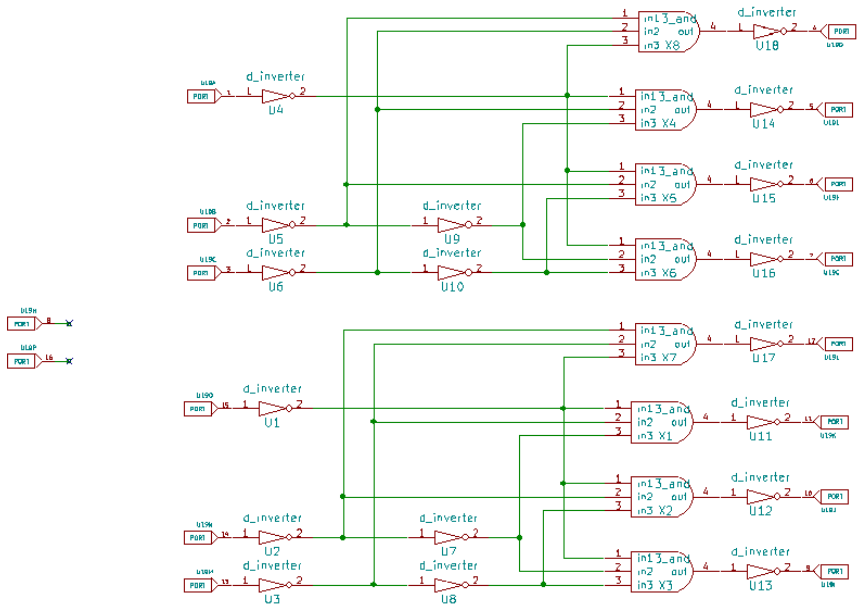

Figure 4.3: Subcircuit Schematic Diagram of SN74HCT139

4.1.4 Test Circuit

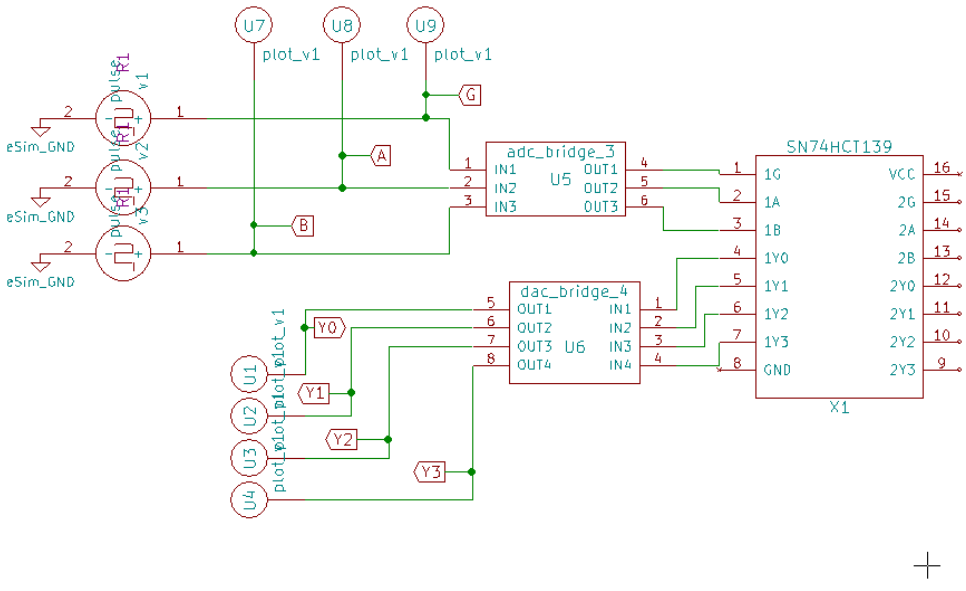

Figure 4.4: Test Circuit of SN74HCT139

4.1.5 Input and Output Plots

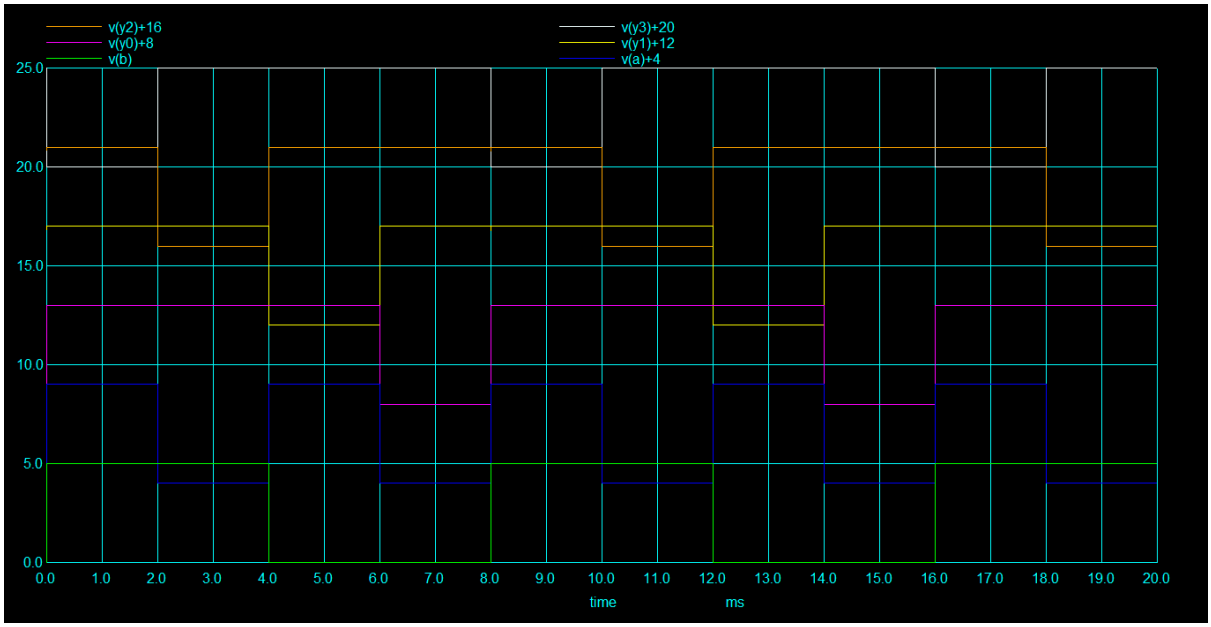

Figure 4.5: Plots of SN74HCT139

Chapter 5

Digital ICs

5.1 74HC08: Quad 2-Input AND Gate

The 74HC08 is a quad 2-input AND gate integrated circuit belonging to the 74HC (High-speed CMOS) logic family. It contains four independent AND gates, each performing the logical AND operation on two input signals. The output of each gate is HIGH only when both inputs are HIGH; otherwise, the output remains LOW.

The IC operates over a wide supply voltage range (2 V to 6 V), offering low power consumption, high noise immunity, and fast switching speed compared to standard TTL devices. The 74HC08 is commonly used in digital logic circuits, including control systems, data gating, signal masking, and combinational logic design. It is available in standard 14-pin packages and is suitable for a wide range of industrial, educational, and embedded system applications.

5.1.1 IC Layout

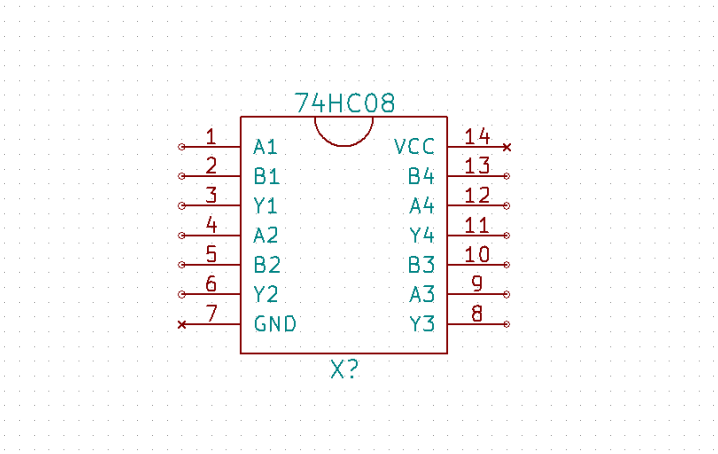

Figure 5.1: Pin Diagram of 74HC08

5.1.2 Function Table

FUNCTION TABLE

Inputs		Output
A	B	Y
L	L	L
L	H	L
H	L	L
H	H	H

Figure 5.2: Function Table of 74HC08

5.1.3 Subcircuit Schematic Diagram

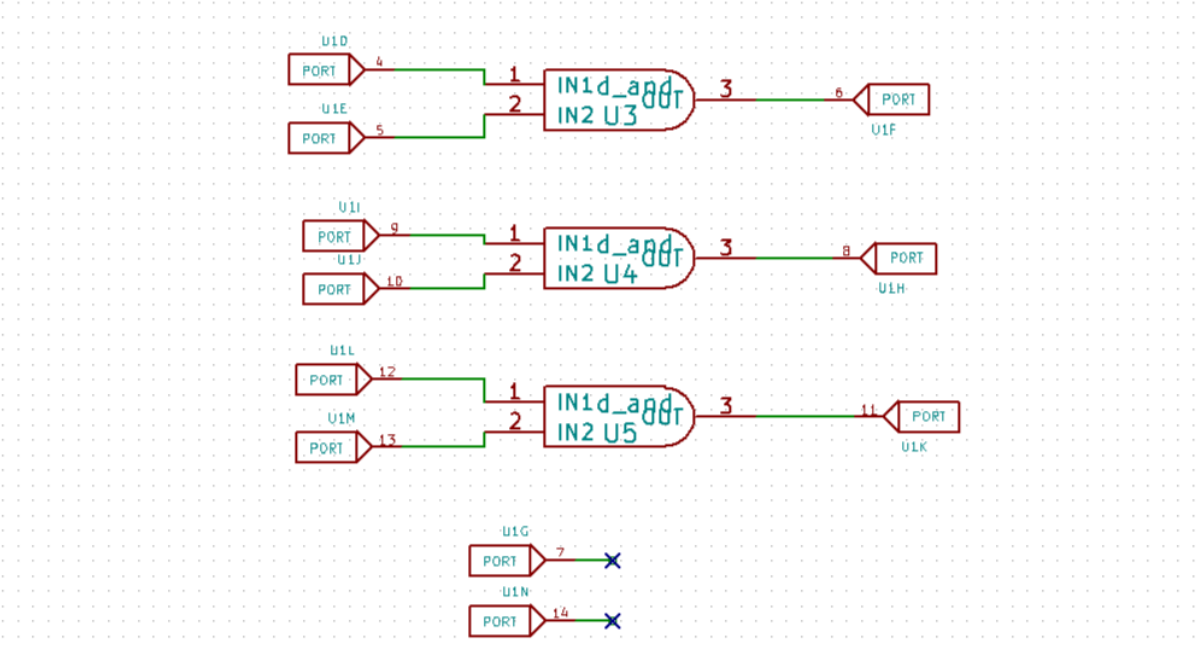

Figure 5.3: Subcircuit Schematic Diagram of 74HC08

5.1.4 Test Circuit

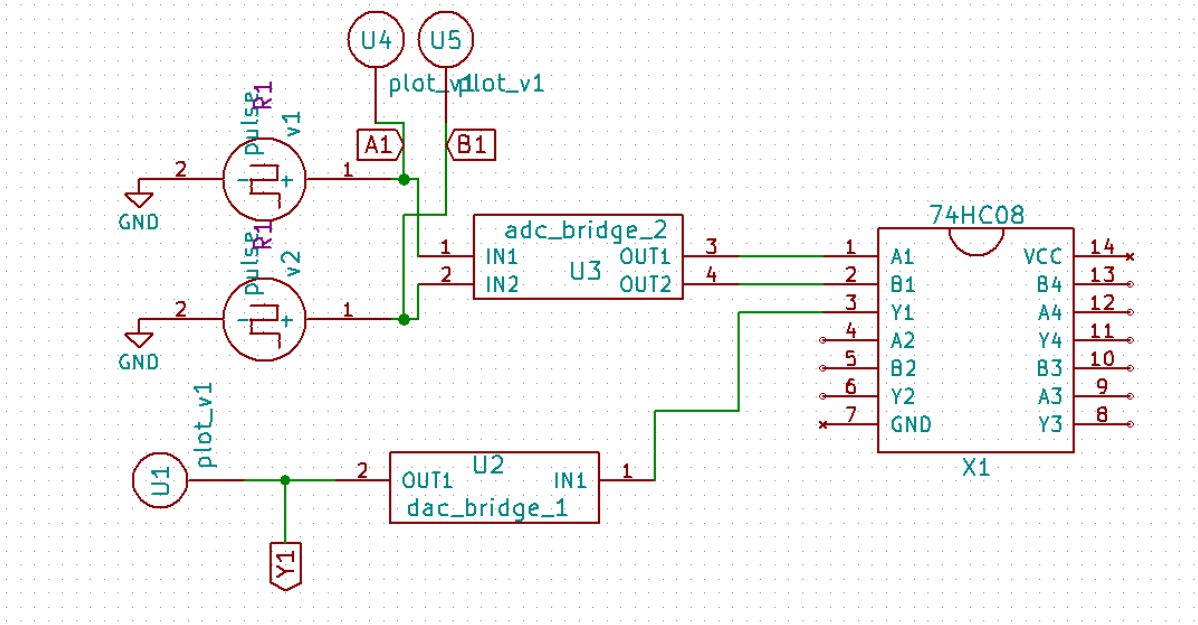

Figure 5.4: Test Circuit of 74HC08

5.1.5 Input and Output Plots

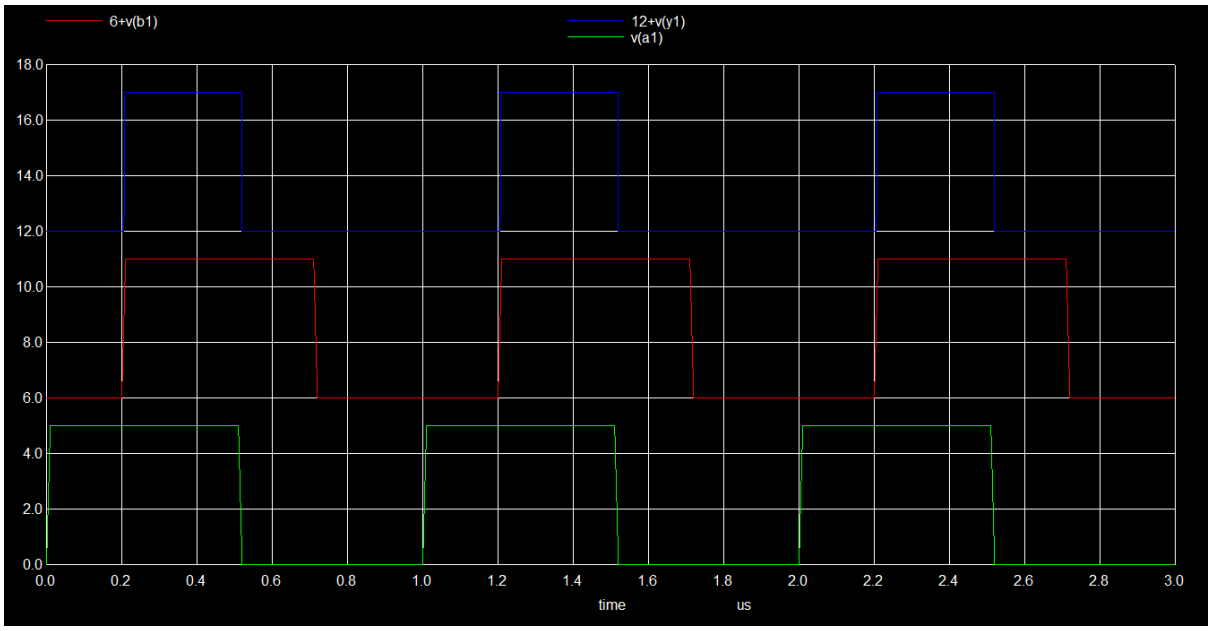

Figure 5.5: Plots of 74HC08

Chapter 6

Digital ICs

6.1 74HC32: Quad 2-Input OR Gate

The 74HC32 is a quad 2-input OR gate integrated circuit from the 74HC (High-speed CMOS) logic family. It consists of four independent OR gates, each performing the logical OR operation on two input signals. The output of each gate is HIGH when at least one of the inputs is HIGH, and LOW only when both inputs are LOW.

The IC operates over a supply voltage range of 2 V to 6 V, providing low power consumption, high noise immunity, and high-speed switching performance. The 74HC32 is widely used in combinational logic circuits, signal combining, control logic, and decision-making circuits in digital systems. It is available in standard 14-pin packages and is suitable for industrial, educational, and embedded applications.

6.1.1 IC Layout

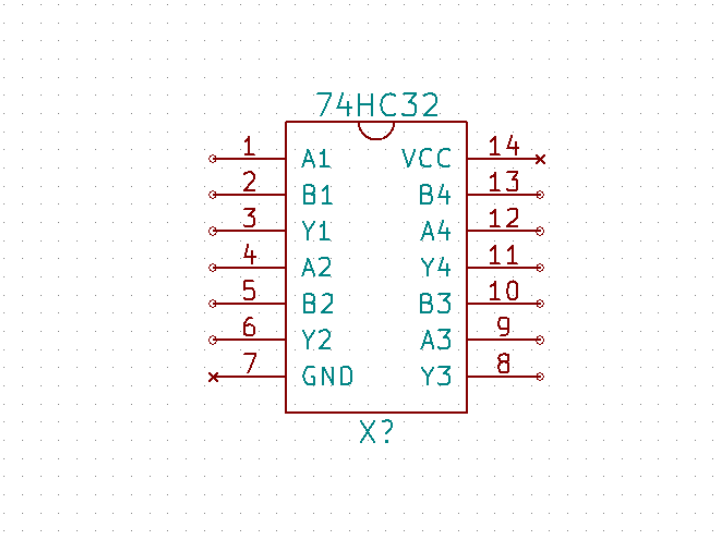

Figure 6.1: Pin Diagram of 74HC32

6.1.2 Function Table

INPUTS		OUTPUT
A	B	Y
L	L	L
H	X	H
X	H	H

Figure 6.2: Function Table of 74HC32

6.1.3 Subcircuit Schematic Diagram

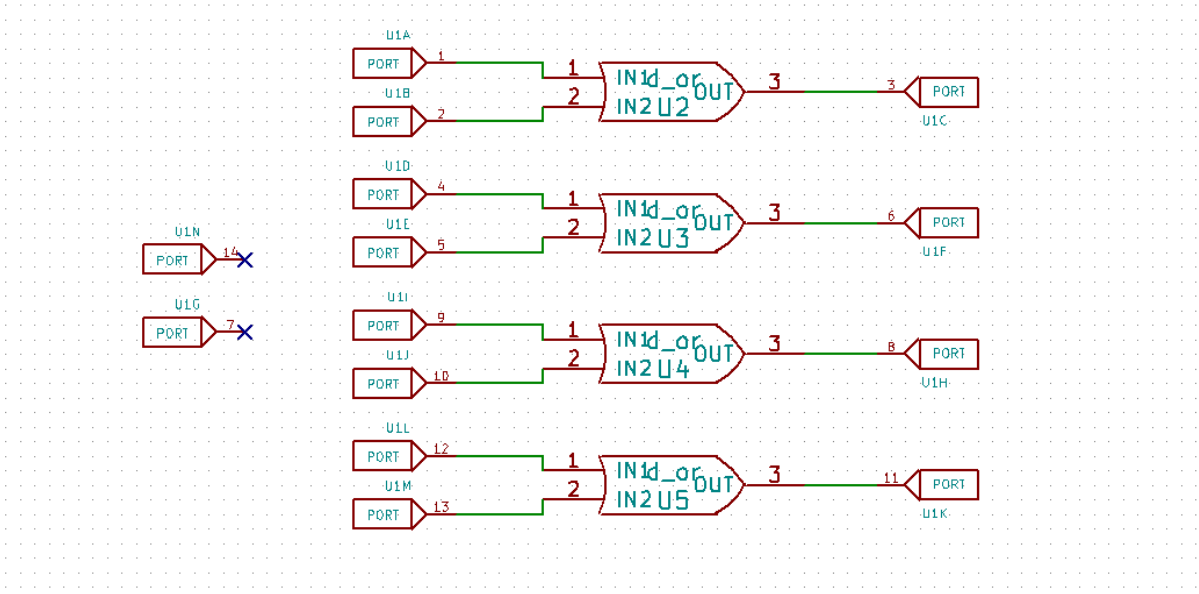

Figure 6.3: Subcircuit Schematic Diagram of 74HC32

6.1.4 Test Circuit

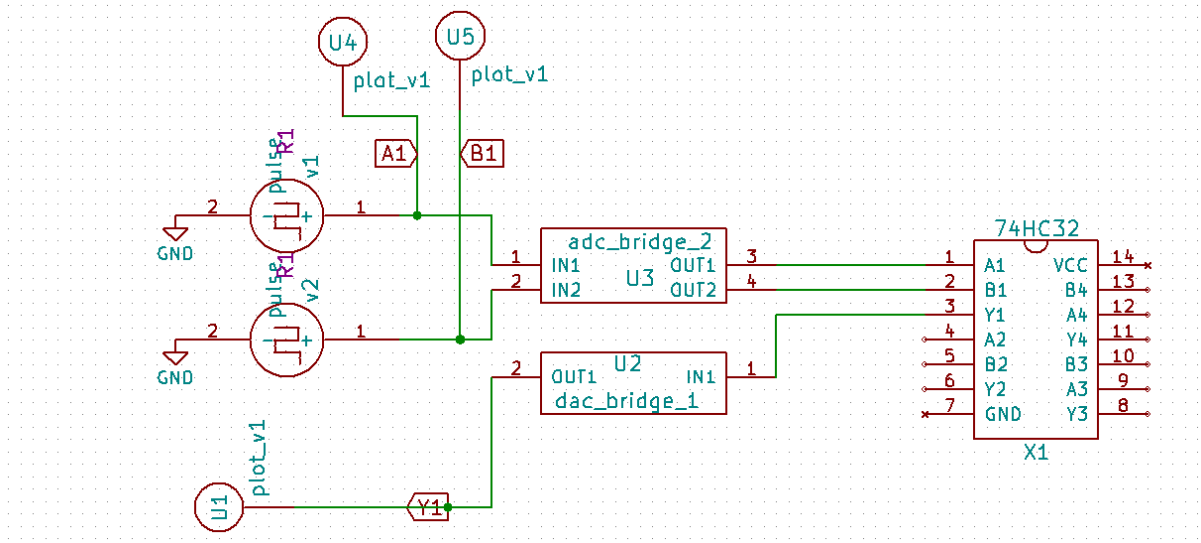

Figure 6.4: Test Circuit of 74HC32

6.1.5 Input and Output Plots

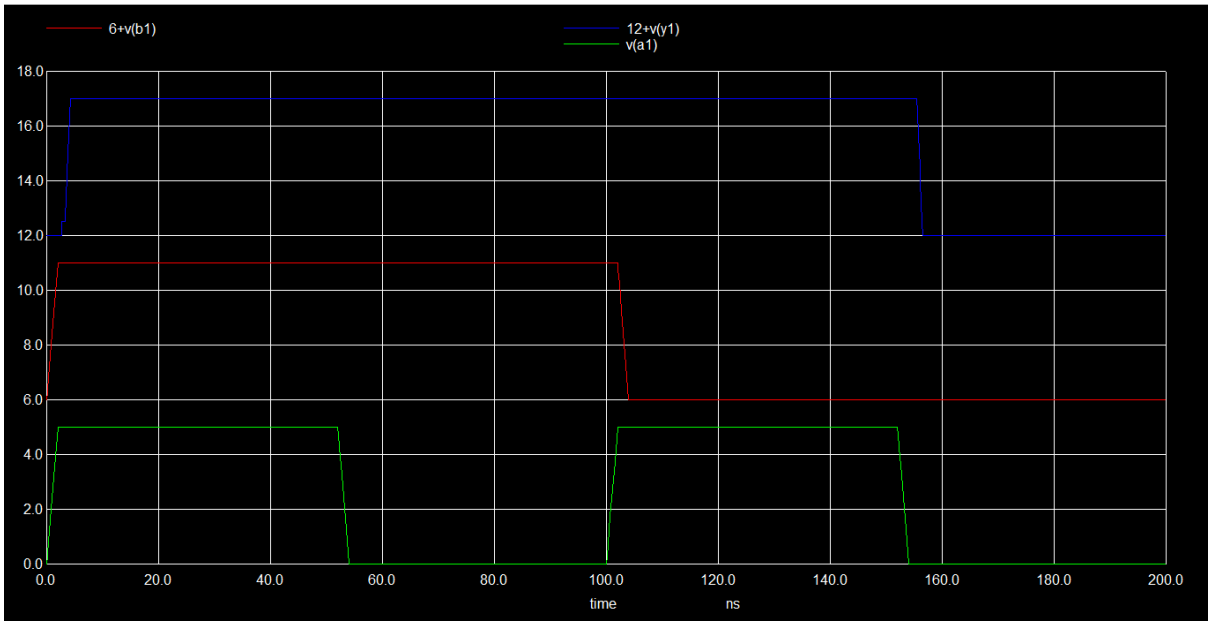

Figure 6.5: Plots of 74HC32

Chapter 7

Digital ICs

7.1 M74HC42: BCD to Decimal Decoder

The M74HC42 is a BCD-to-decimal decoder integrated circuit from the 74HC (High-speed CMOS) logic family. It accepts a 4-bit Binary-Coded Decimal (BCD) input and decodes it into one of ten active-LOW outputs (Y0–Y9). For any valid BCD input combination (0000 to 1001), exactly one output is driven LOW while all other outputs remain HIGH. For invalid BCD codes (1010 to 1111), all outputs remain HIGH.

The device operates with a supply voltage range of 2 V to 6 V, providing low power consumption, high noise immunity, and fast switching performance typical of CMOS logic. The M74HC42 is commonly used in numeric displays, digital counters, address decoding, and control logic applications. It is available in standard 16-pin packages and is suitable for industrial, educational, and embedded digital systems.

7.1.1 IC Layout

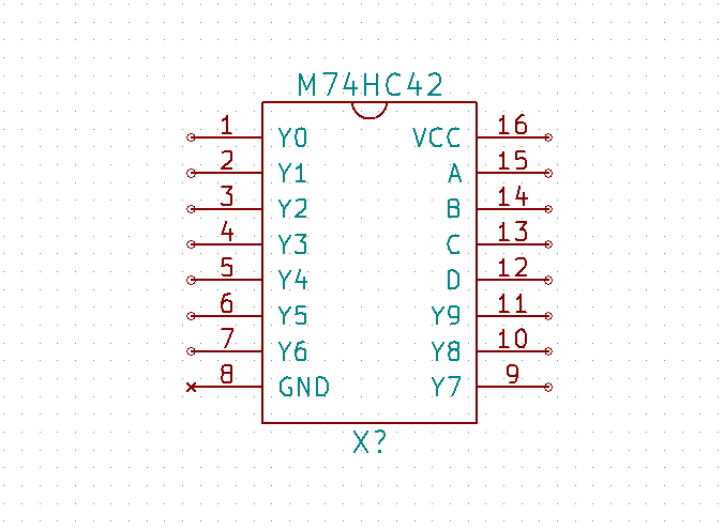

Figure 7.1: Pin Diagram of M74HC42

7.1.2 Function Table

Code no	BCD inputs				Decimal outputs									
	D	C	B	A	$\overline{Y}_0$	$\overline{Y}_1$	$\overline{Y}_2$	$\overline{Y}_3$	$\overline{Y}_4$	$\overline{Y}_5$	$\overline{Y}_6$	$\overline{Y}_7$	$\overline{Y}_8$	$\overline{Y}_9$
0	L	L	L	L	L	H	H	H	H	H	H	H	H	H
1	L	L	L	H	H	L	H	H	H	H	H	H	H	H
2	L	L	H	L	H	H	L	H	H	H	H	H	H	H
3	L	L	H	H	H	H	H	L	H	H	H	H	H	H
4	L	H	L	L	H	H	H	H	L	H	H	H	H	H
5	L	H	L	H	H	H	H	H	H	L	H	H	H	H
6	L	H	H	L	H	H	H	H	H	H	L	H	H	H
7	L	H	H	H	H	H	H	H	H	H	H	L	H	H
8	H	L	L	L	H	H	H	H	H	H	H	H	L	H
9	H	L	L	H	H	H	H	H	H	H	H	H	H	L
10	H	L	H	L	H	H	H	H	H	H	H	H	H	H
11	H	L	H	H	H	H	H	H	H	H	H	H	H	H
12	H	H	L	L	H	H	H	H	H	H	H	H	H	H
13	H	H	L	H	H	H	H	H	H	H	H	H	H	H
14	H	H	H	L	H	H	H	H	H	H	H	H	H	H
15	H	H	H	H	H	H	H	H	H	H	H	H	H	H

Figure 7.2: Function Table of M74HC42

7.1.3 Subcircuit Schematic Diagram

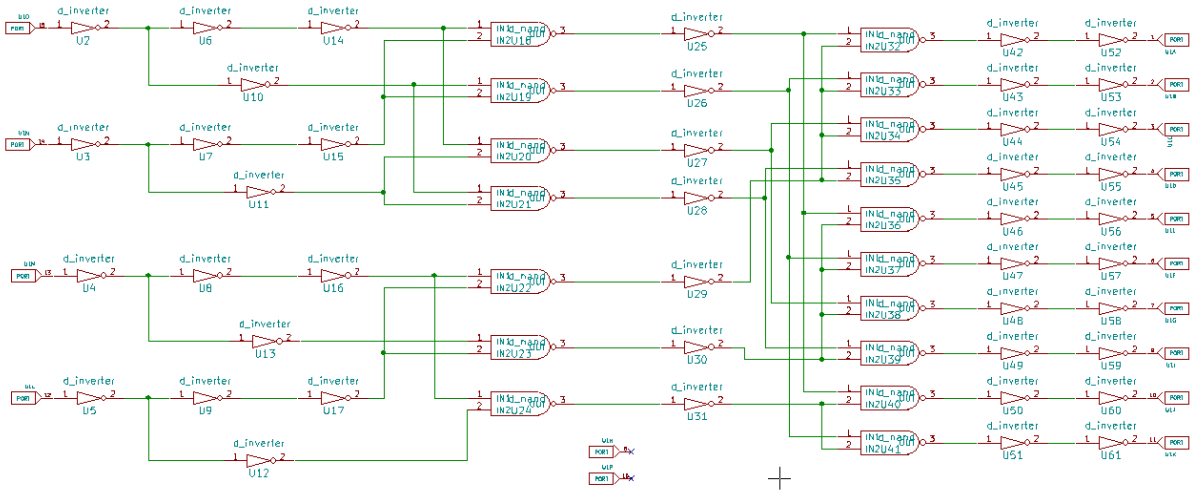

Figure 7.3: Subcircuit Schematic Diagram of M74HC42

7.1.4 Test Circuit

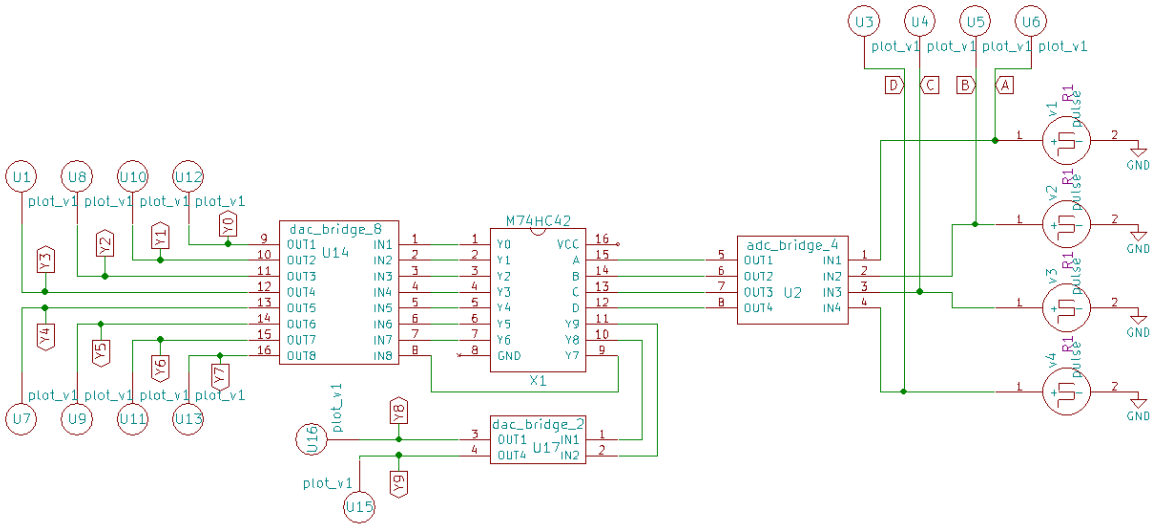

Figure 7.4: Test Circuit of M74HC42

7.1.5 Input and Output Plots

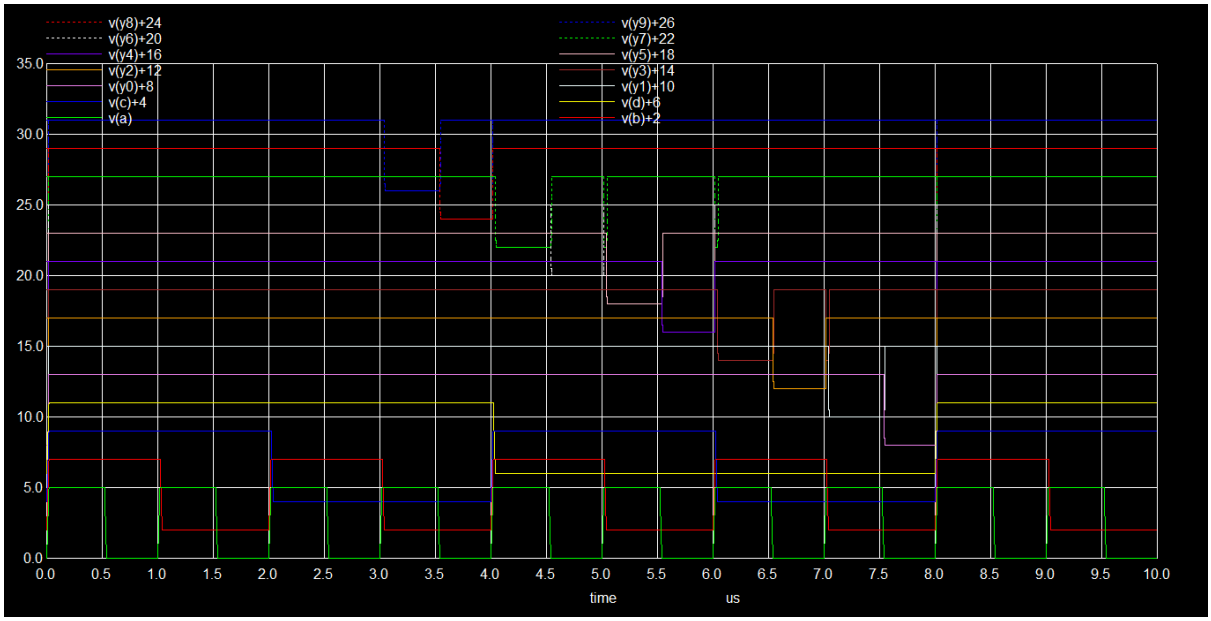

Figure 7.5: Plots of M74HC42

Chapter 8

Digital ICs

8.1 SN74LVC1T45: Single-Bit Dual-Supply Bus Transceiver

The SN74LVC1T45 is a single-bit dual-supply bus transceiver designed for bidirectional voltage-level translation between different logic voltage domains. It supports automatic or direction-controlled data transfer through a dedicated DIR (direction) control input, allowing data to flow from port A to port B or from port B to port A. An output enable (OE) input places both ports in a high-impedance state when disabled, enabling bus isolation.

The device operates with two independent supply voltages, typically VCCA = 1.65 V to 5.5 V and VCCB = 1.65 V to 5.5 V, making it suitable for interfacing between low-voltage logic (such as 1.8 V or 3.3 V) and 5 V systems. It features low propagation delay, high-speed performance, and low power consumption, and supports over-voltage tolerant I/Os. The SN74LVC1T45 is widely used in level shifting, microcontroller and FPGA interfacing, and mixed-voltage digital systems, and is available in compact single-gate packages suitable for space-constrained designs.

8.1.1 IC Layout

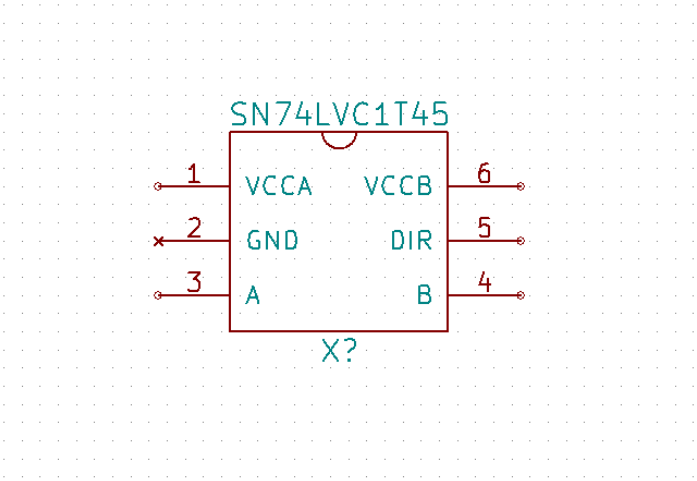

Figure 8.1: Pin Diagram of SN74LVC1T45

8.1.2 Function Table

INPUT DIR	OPERATION
L	B data to A bus
H	A data to B bus

(1) Input circuits of the data I/Os always are active.

Figure 8.2: Function Table of SN74LVC1T45

8.1.3 Subcircuit Schematic Diagram

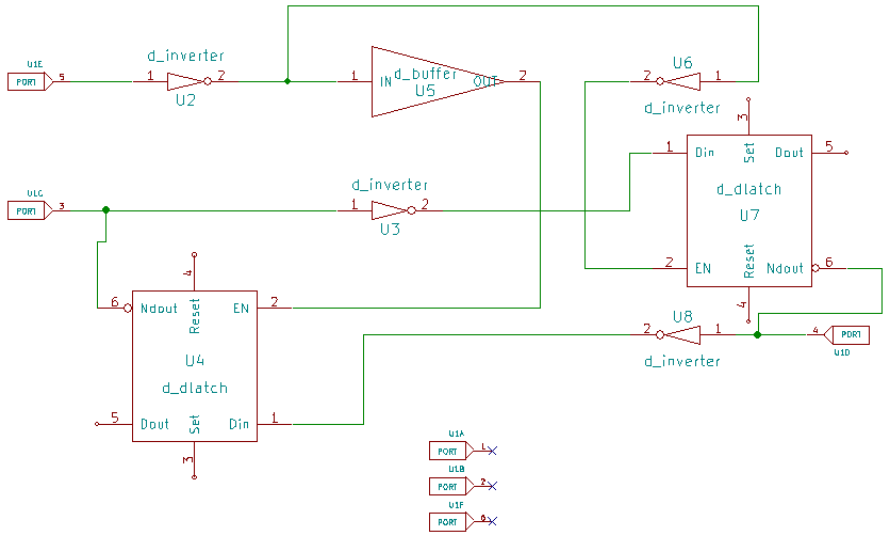

Figure 8.3: Subcircuit Schematic Diagram of SN74LVC1T45

8.1.4 Test Circuit

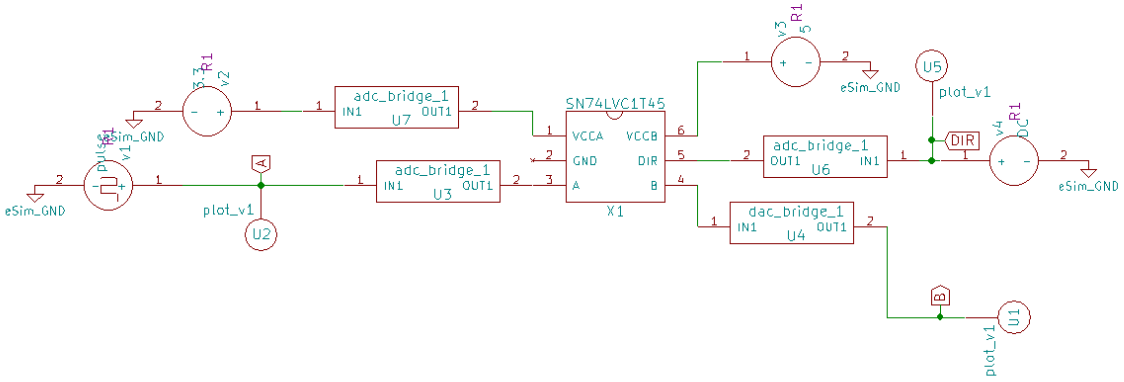

Figure 8.4: Test Circuit of SN74LVC1T45

8.1.5 Input and Output Plots

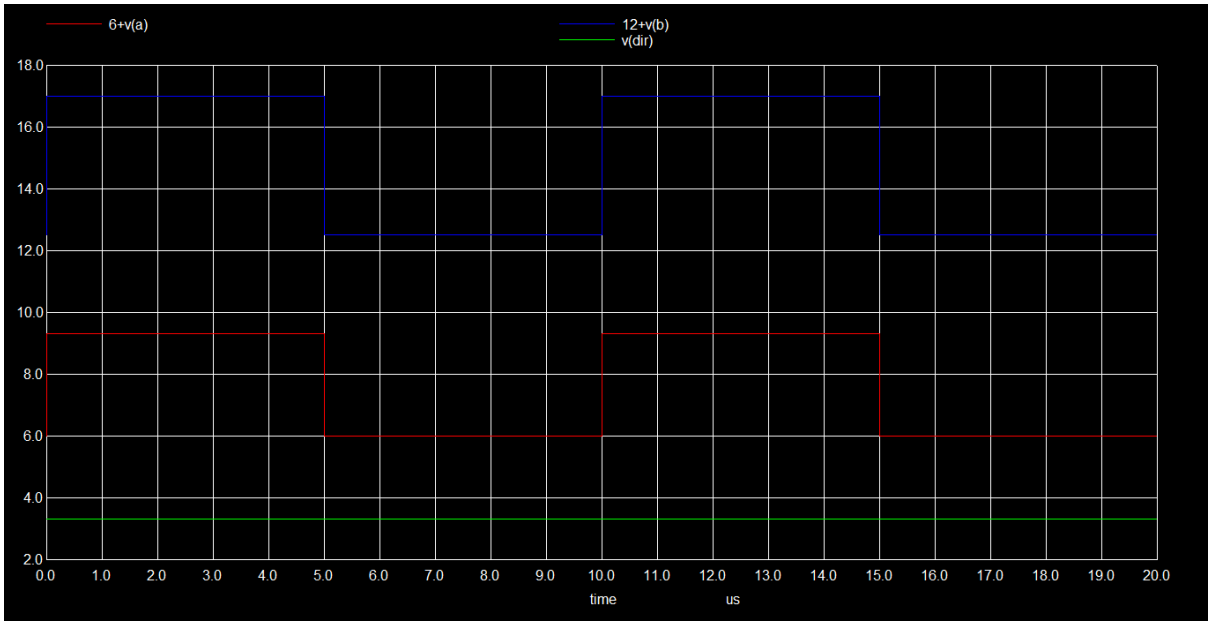

Figure 8.5: Plots of SN74LVC1T45

Chapter 9

Digital ICs

9.1 MC74HC11A: Triple 3-Input AND Gate

The MC74HC11A is a triple 3-input AND gate integrated circuit from the 74HC (High-speed CMOS) logic family. It integrates three independent AND gates, each accepting three input signals. The output of each gate goes HIGH only when all three inputs are HIGH; if any input is LOW, the output remains LOW.

The IC operates over a supply voltage range of 2 V to 6 V, providing low power consumption, high noise immunity, and fast switching speed typical of CMOS logic. The MC74HC11A is widely used in combinational logic design, control logic, signal gating, and digital systems. It is available in standard 14-pin packages and is suitable for industrial, educational, and embedded applications.

9.1.1 IC Layout

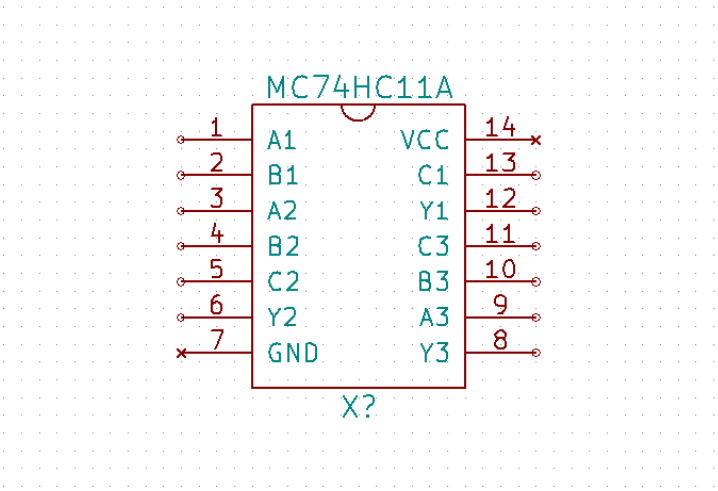

Figure 9.1: Pin Diagram of MC74HC11A

9.1.2 Function Table

FUNCTION TABLE

Inputs			Output
A	B	C	Y
L	X	X	L
X	L	X	L
X	X	L	L
H	H	H	H

Figure 9.2: Function Table of MC74HC11A

9.1.3 Subcircuit Schematic Diagram

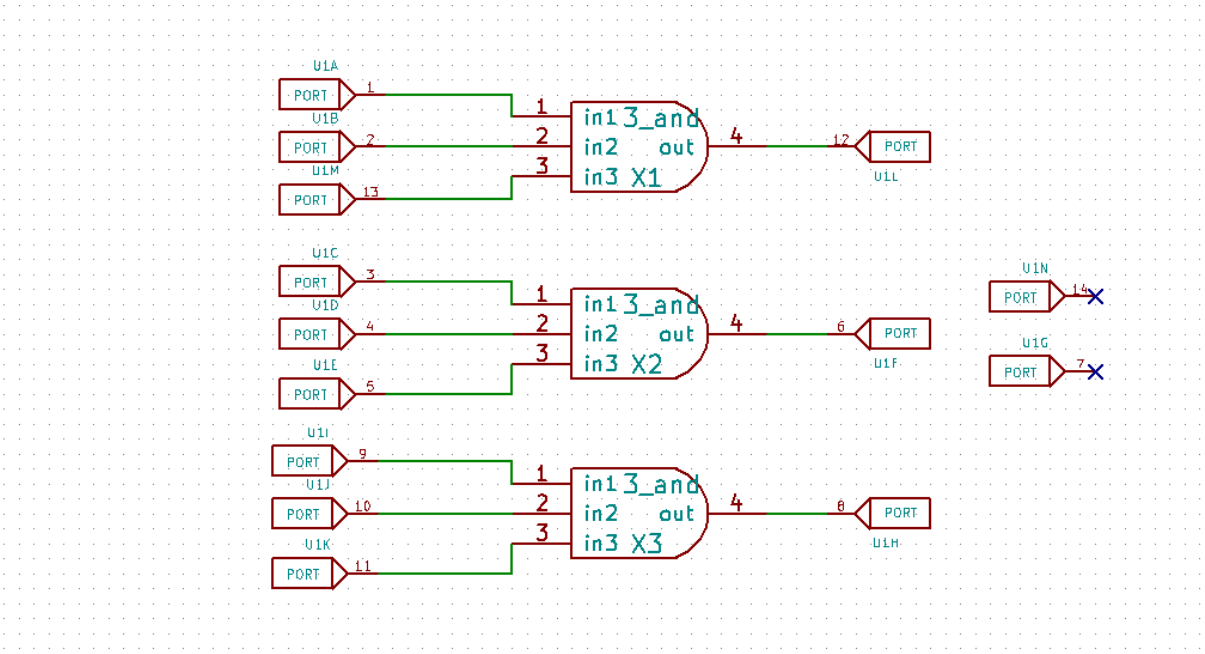

Figure 9.3: Subcircuit Schematic Diagram of MC74HC11A

9.1.4 Test Circuit

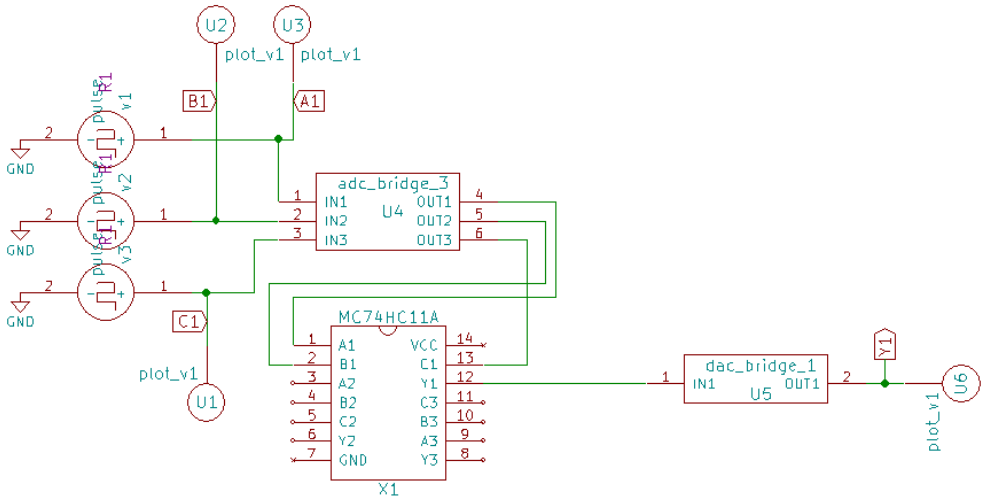

Figure 9.4: Test Circuit of MC74HC11A

9.1.5 Input and Output Plots

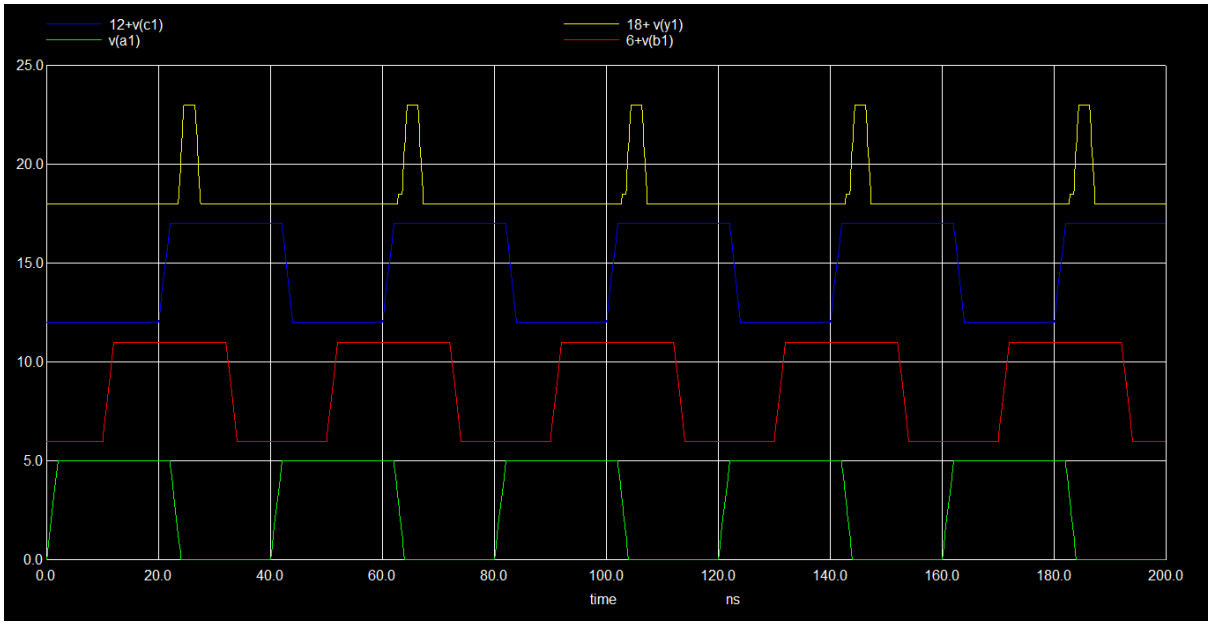

Figure 9.5: Plots of MC74HC11A

Chapter 10

Digital ICs

10.1 74HC10: Triple 3-Input NAND Gate

The 74HC10 is a triple 3-input NAND gate integrated circuit from the 74HC (High-speed CMOS) logic family. It contains three independent NAND gates, each with three input terminals. The output of each gate is LOW only when all three inputs are HIGH; if any input is LOW, the output remains HIGH.

The device operates over a supply voltage range of 2 V to 6 V, offering low power consumption, high noise immunity, and fast switching performance characteristic of CMOS logic. The 74HC10 is commonly used in combinational logic circuits, control logic, signal inversion and gating, and digital system design. It is available in standard 14-pin packages and is suitable for industrial, educational, and embedded applications.

10.1.1 IC Layout

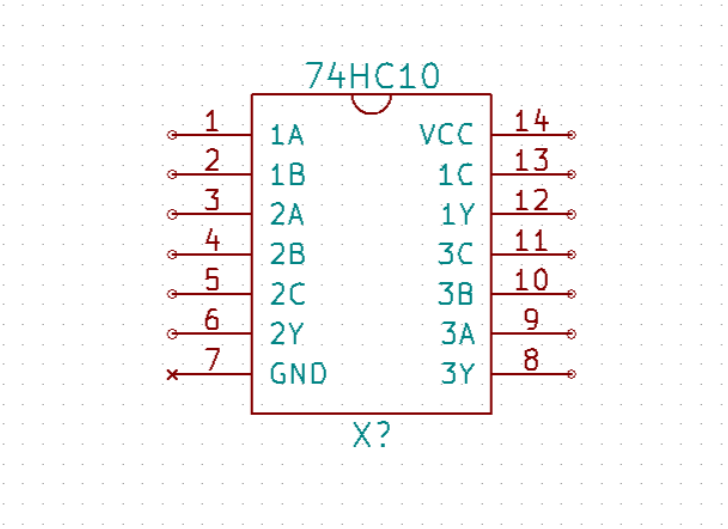

Figure 10.1: Pin Diagram of 74HC10

10.1.2 Function Table

INPUTS			OUTPUT
A	B	C	Y
H	H	H	L
L	X	X	H
X	L	X	H
X	X	L	H

Figure 10.2: Function Table of 74HC10

10.1.3 Subcircuit Schematic Diagram

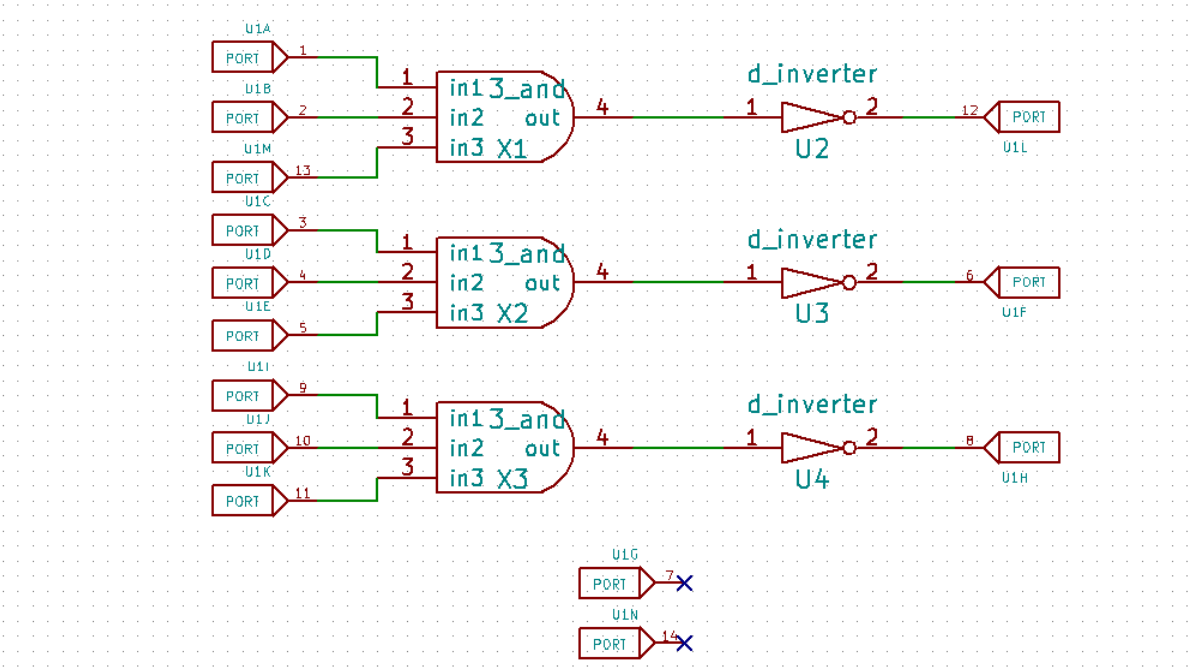

Figure 10.3: Subcircuit Schematic Diagram of 74HC10

10.1.4 Test Circuit

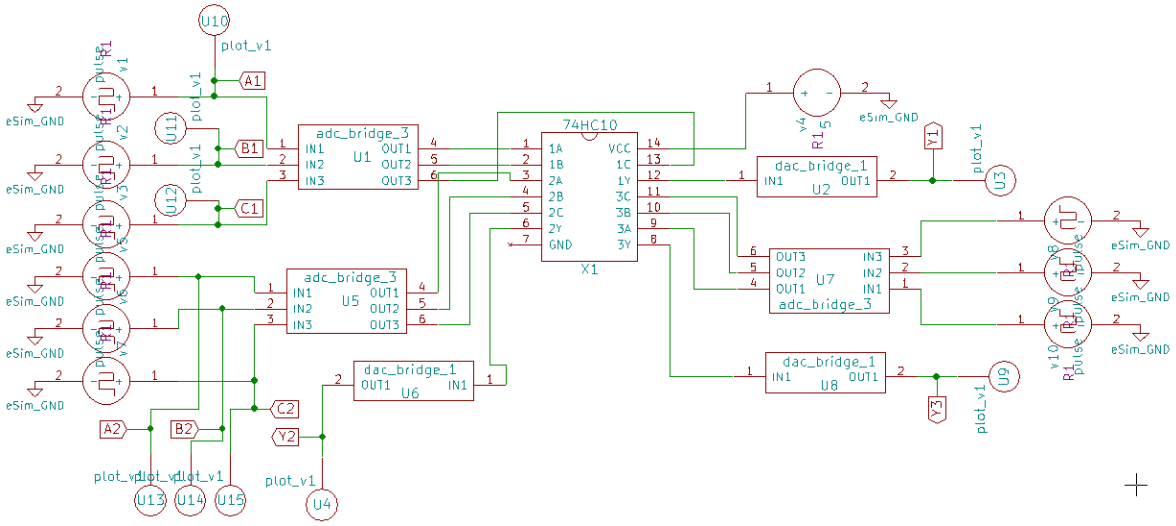

Figure 10.4: Test Circuit of 74HC10

10.1.5 Input and Output Plots

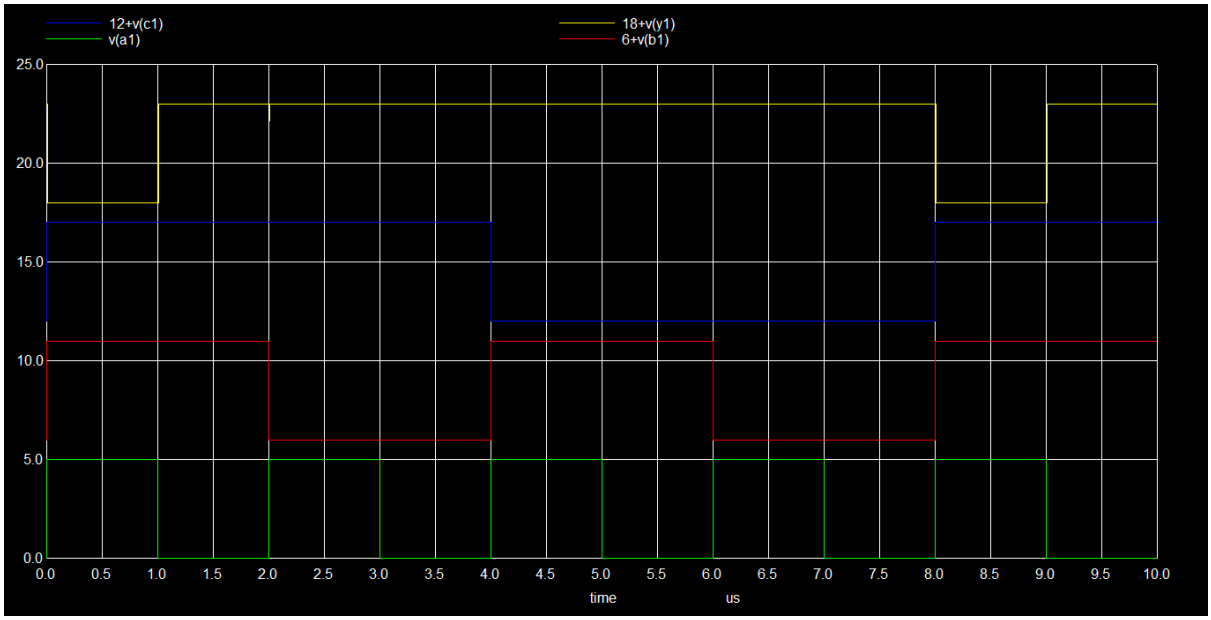

Figure 10.5: Plots of 74HC10

Chapter 11

Analog ICs

11.1 CA3000: Transistor Array for DC Amplification

The CA3000 is a DC amplifier designed for the amplification of low-level direct-current and low-frequency signals. It is primarily used in applications where accurate amplification of slowly varying or steady-state signals is required. The amplifier provides high input impedance, which minimizes loading effects on the signal source, and good DC stability, ensuring reliable operation over time.

The CA3000 is commonly employed in sensor signal conditioning, instrumentation circuits, measurement systems, and control applications where precise DC signal amplification is essential. Its design allows for low offset drift and stable gain, making it suitable for educational, laboratory, and industrial analog circuits.

11.1.1 IC Layout

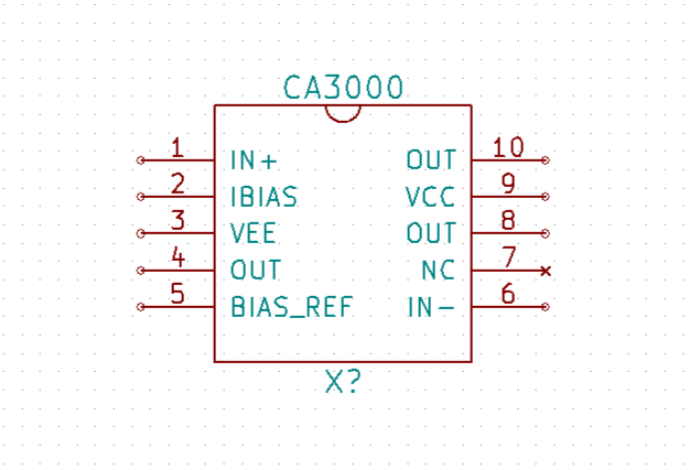

Figure 11.1: Pin Diagram of CA3000

11.1.2 Subcircuit Schematic Diagram

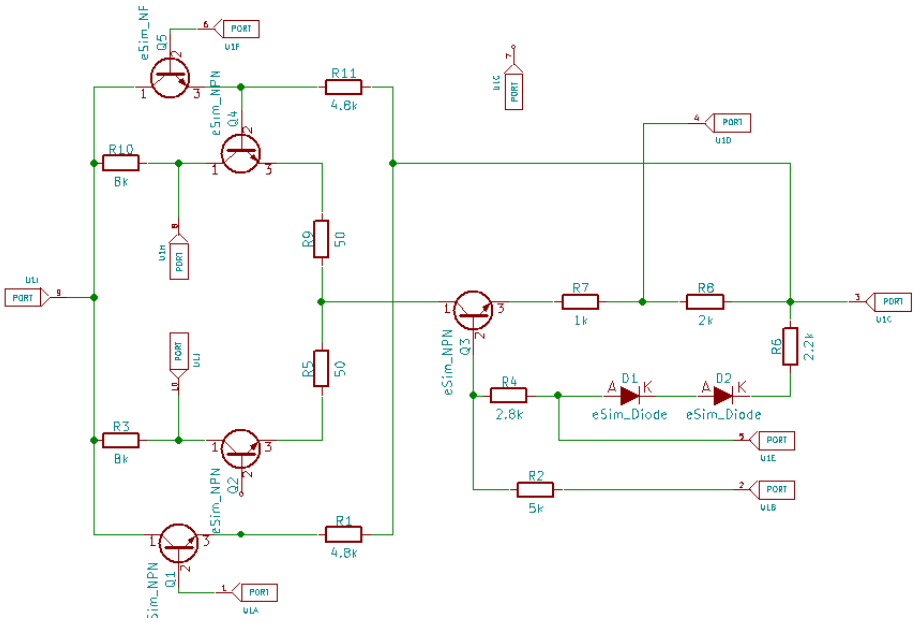

Figure 11.2: Subcircuit Schematic Diagram of CA3000

11.1.3 Test Circuit

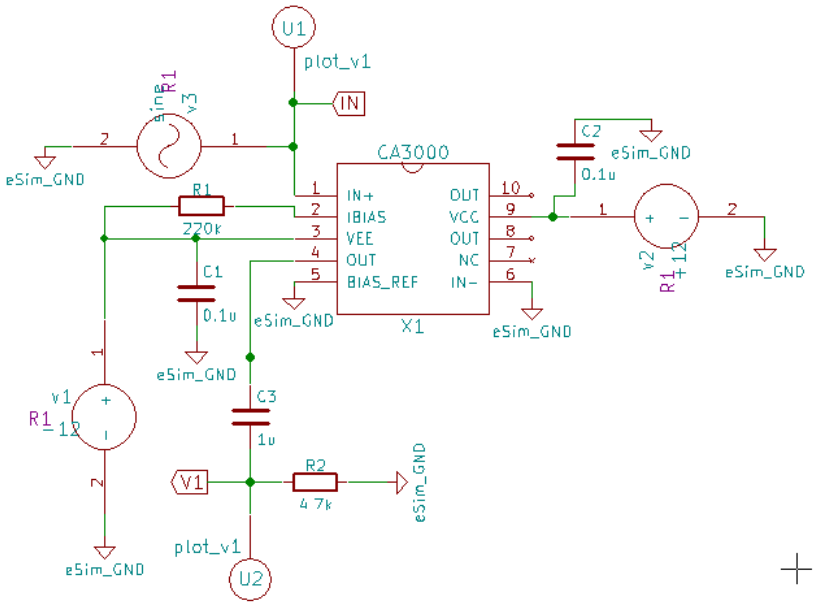

Figure 11.3: Test Circuit of CA3000

11.1.4 Input and Output Plots

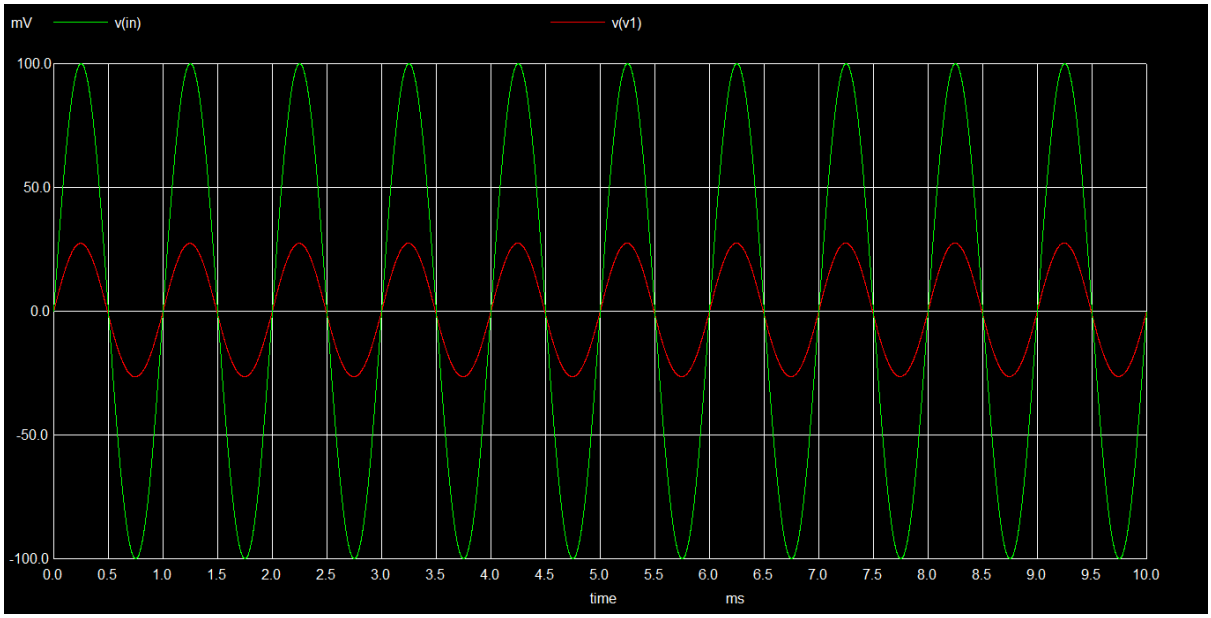

Figure 11.4: Plots of CA3000

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