Winter Internship Report

On

Integrated Circuit Design using Subcircuit Feature of eSim

Submitted by

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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

SN74LS21

4.1 General Description

The SN74LS21 is a dual 4-input positive-AND gate, widely used in digital logic applications requiring high-speed operation and low power dissipation. It features two independent AND gates, each accepting four inputs and producing a high output only when all four inputs are high. Designed with Schottky-clamped TTL technology, the SN74LS21 ensures fast switching speeds and reliable operation across a range of conditions.

4.2 Key Features

- **Dual 4-Input AND Gates:** Contains two independent AND gates, each capable of handling four logic inputs.
- **Schottky Technology:** Uses Schottky transistors for faster response times and reduced power consumption.
- **TTL Compatible:** Easily integrates with other Transistor-Transistor Logic (TTL) circuits.
- **Reliable Performance:** Offers stable operation over a temperature range of 0°C to 70°C for SN74LS21 and -55°C to 125°C for SN54LS21.
- **Multiple Package Options:** Available in plastic, ceramic, and flat-pack designs to suit various application needs.

4.3 Applications

- **Digital Logic Systems:** Used in complex logic circuit designs where multiple conditions must be met before activating an output.
- **Data Processing Units:** Plays a role in arithmetic and logical computations in processors and control units.
- **Industrial Automation:** Useful in control systems requiring multiple sensor inputs to activate a process.
- **Signal Validation:** Employed in applications where multiple signals must be verified before triggering an action.

4.4 Pin Configuration

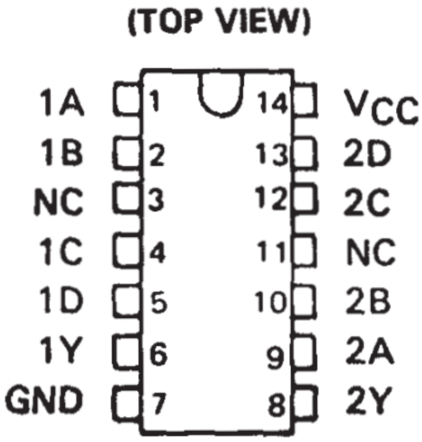


Figure 4.1: Pin of SN74LS21

4.5 IC Layout

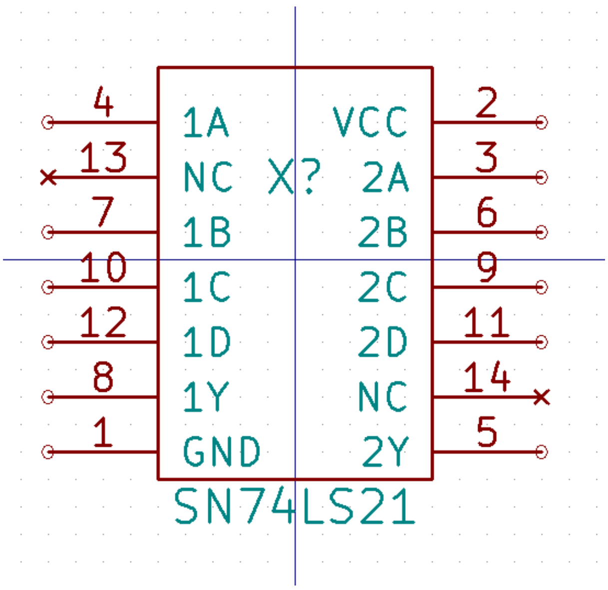


Figure 4.2: Layout of SN74LS21

4.6 Subcircuit Schematic Diagram

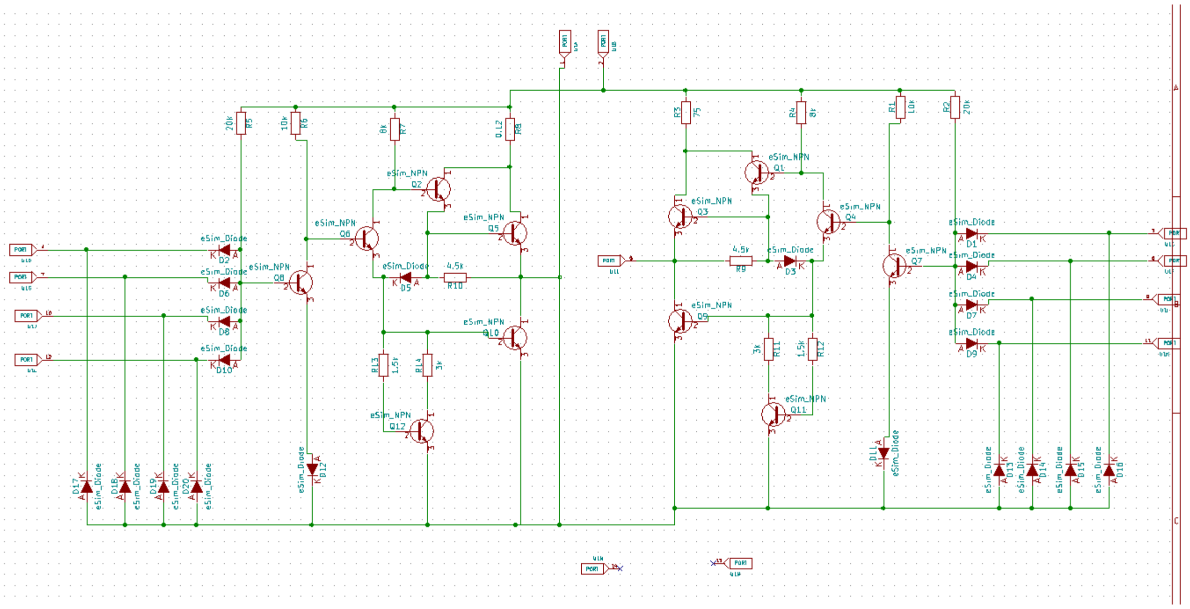


Figure 4.3: Subcircuit schematic of SN74LS21

4.7 Text Circuit

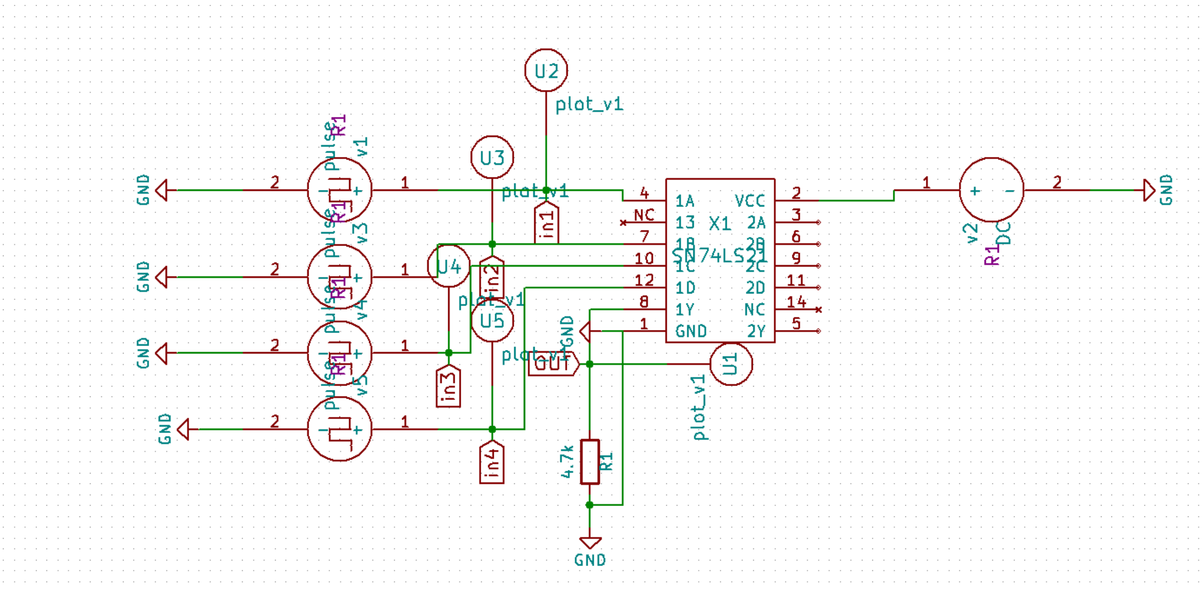


Figure 4.4: Test circuit of SN74LS21

4.8 Input Plot for LOW

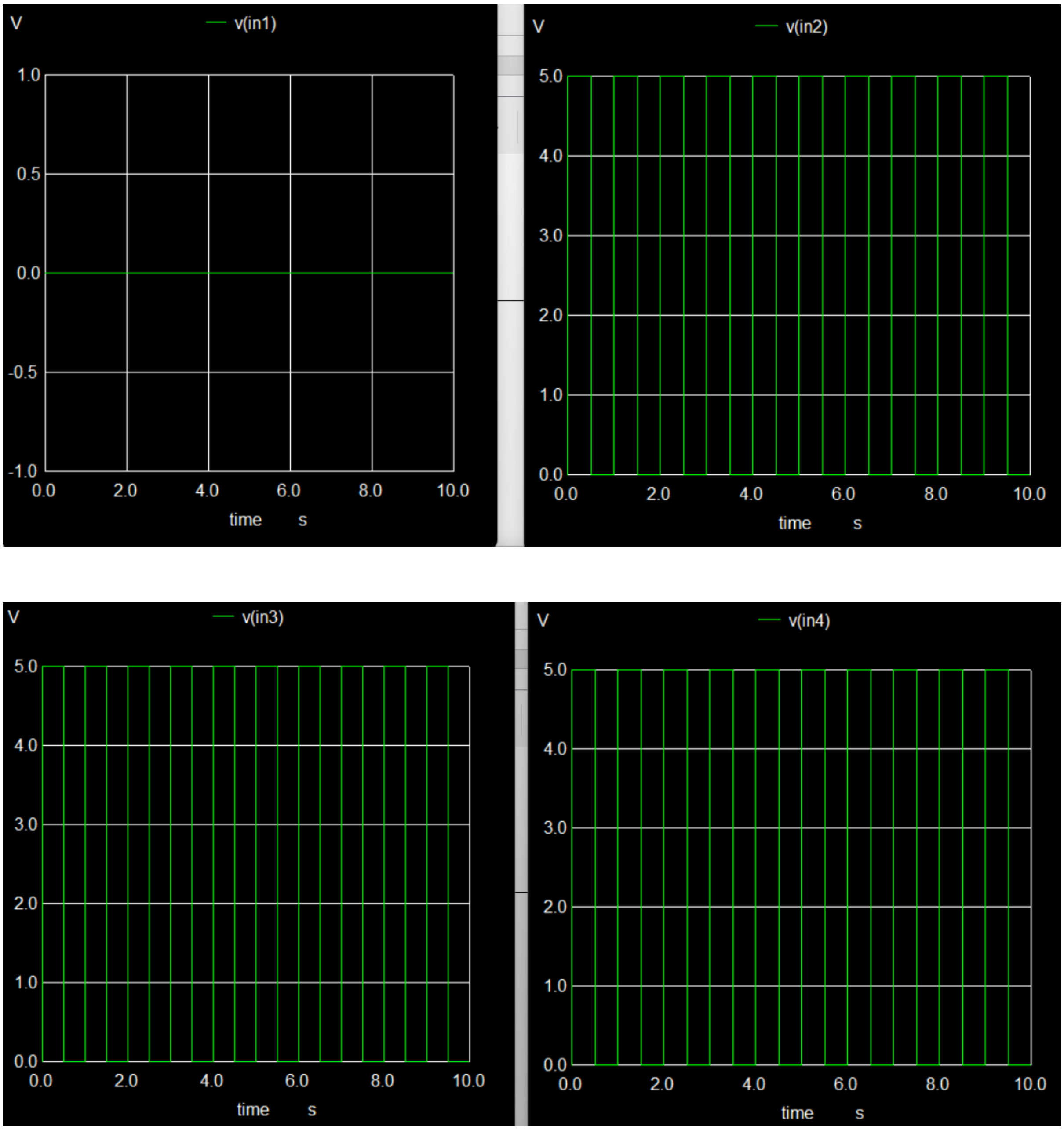


Figure 4.5: INPUTS

4.9 Output Plot for LOW

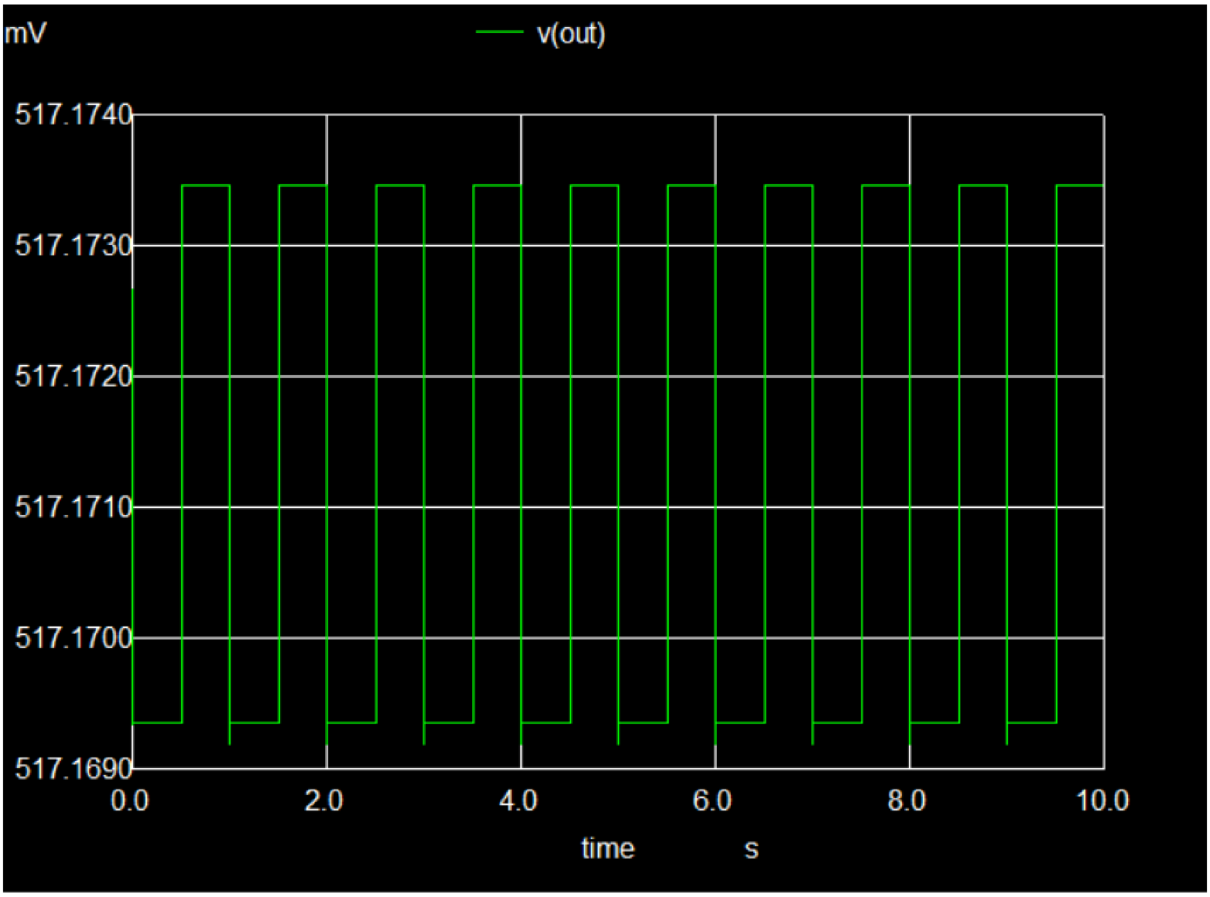
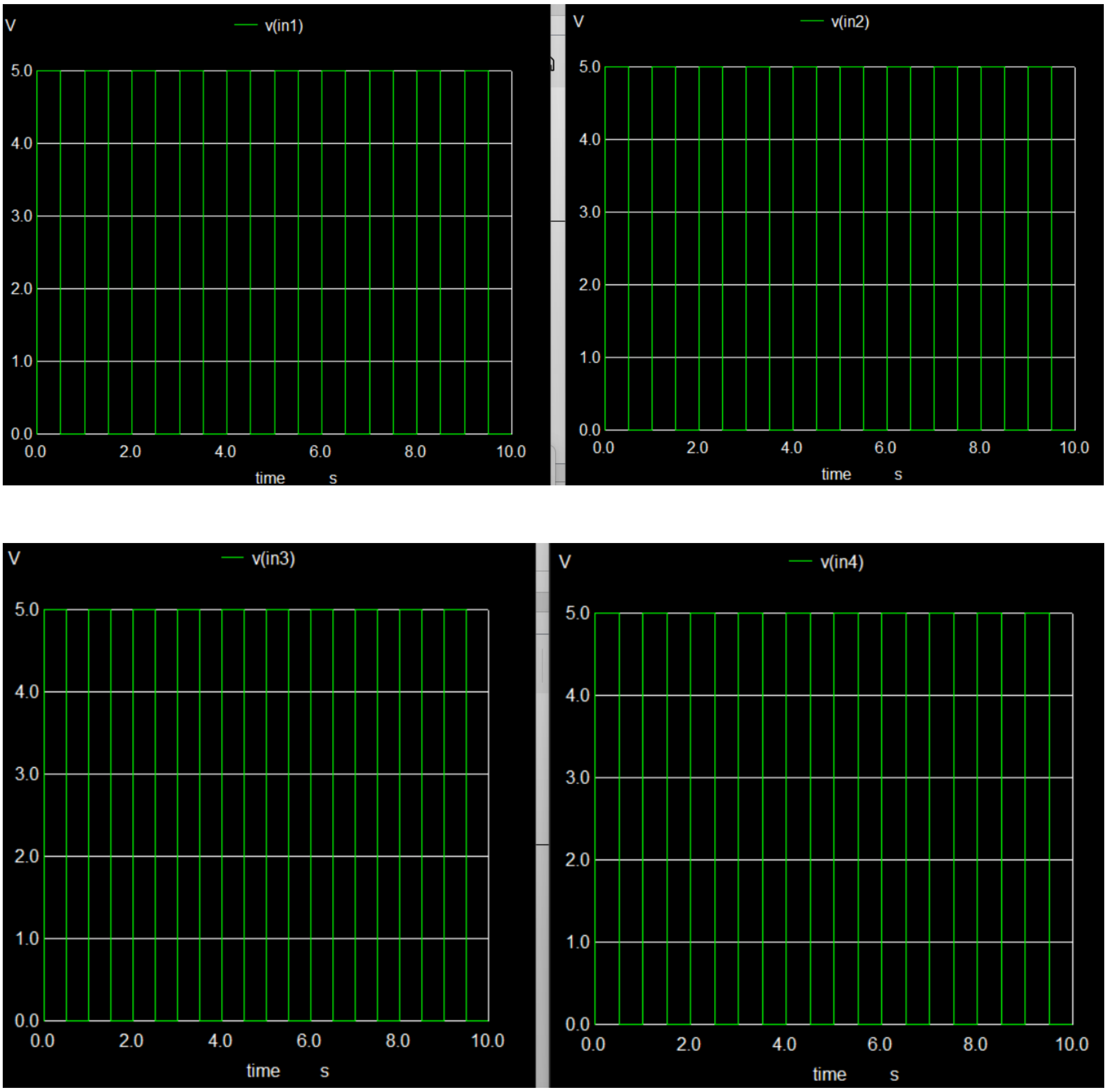


Figure 4.6: low output

4.10 Input Plot for HIGH



4.11 Output Plot for HIGH

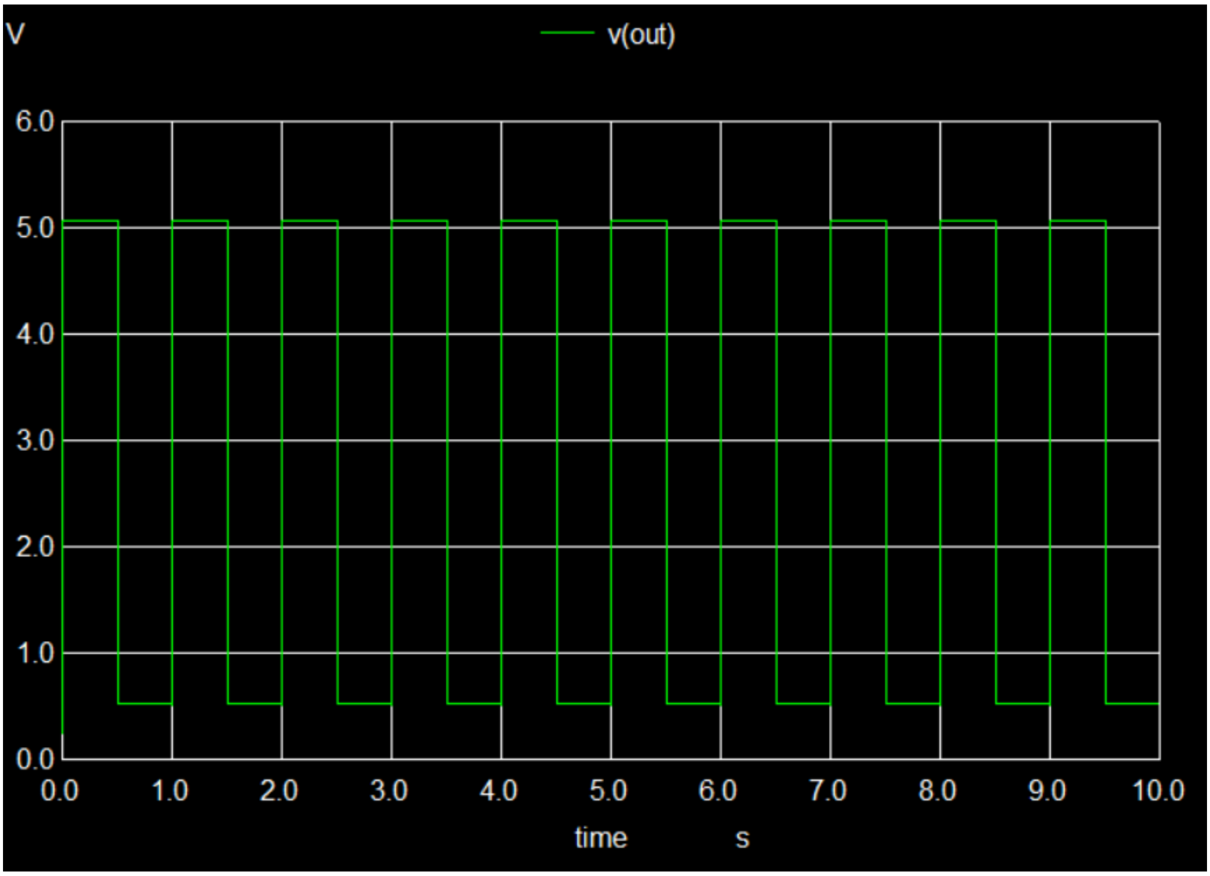


Figure 4.7: high output

Chapter 5

L604

5.1 General Description

The L604 is a high-voltage, high-current Darlington transistor array designed for driving inductive and resistive loads. It consists of eight open-collector Darlington pairs with common emitters, making it highly suitable for applications requiring high-power switching. The device integrates suppression diodes to protect against inductive voltage spikes, ensuring reliability in demanding environments.

5.2 Key Features

- **High Voltage and Current Handling:** Supports output voltages up to 90V and continuous current up to 400mA per channel.
- **Built-in Protection:** Includes suppression diodes for inductive load protection.
- **Multiple Logic Compatibility:** Interfaces seamlessly with TTL, CMOS, and DTL logic families.
- **Parallel Output Capability:** Outputs can be paralleled for increased current handling.

5.3 Applications

- **Relay and Solenoid Drivers:** Commonly used for switching high-power electromechanical devices.
- **LED and Display Drivers:** Suitable for driving large LED arrays and filament lamps.
- **Motor Control:** Used in DC motor drivers and thermal printheads.
- **Industrial Automation:** Applied in various industrial control systems requiring robust switching capabilities.

5.4 Pin Configuration

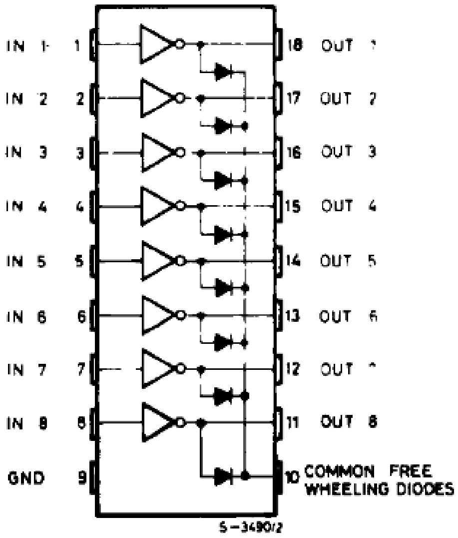


Figure 5.1: PIN of L604

5.5 IC Layout

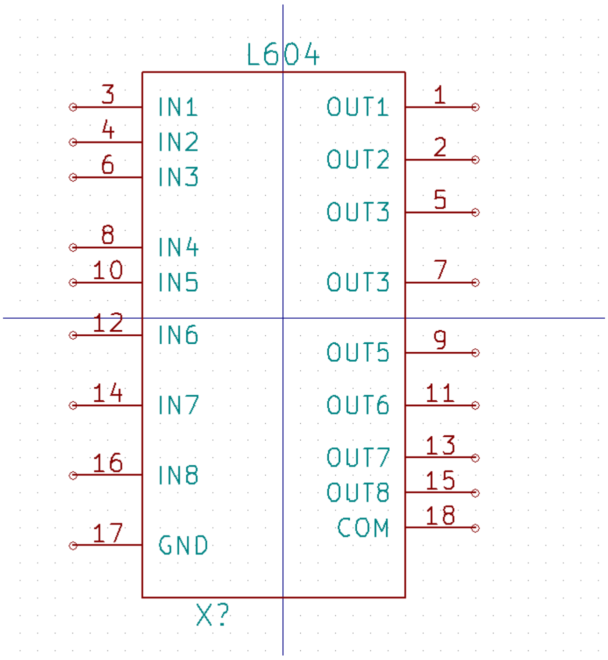


Figure 5.2: IC Layout of L604

5.6 Subcircuit Shematic Diagram

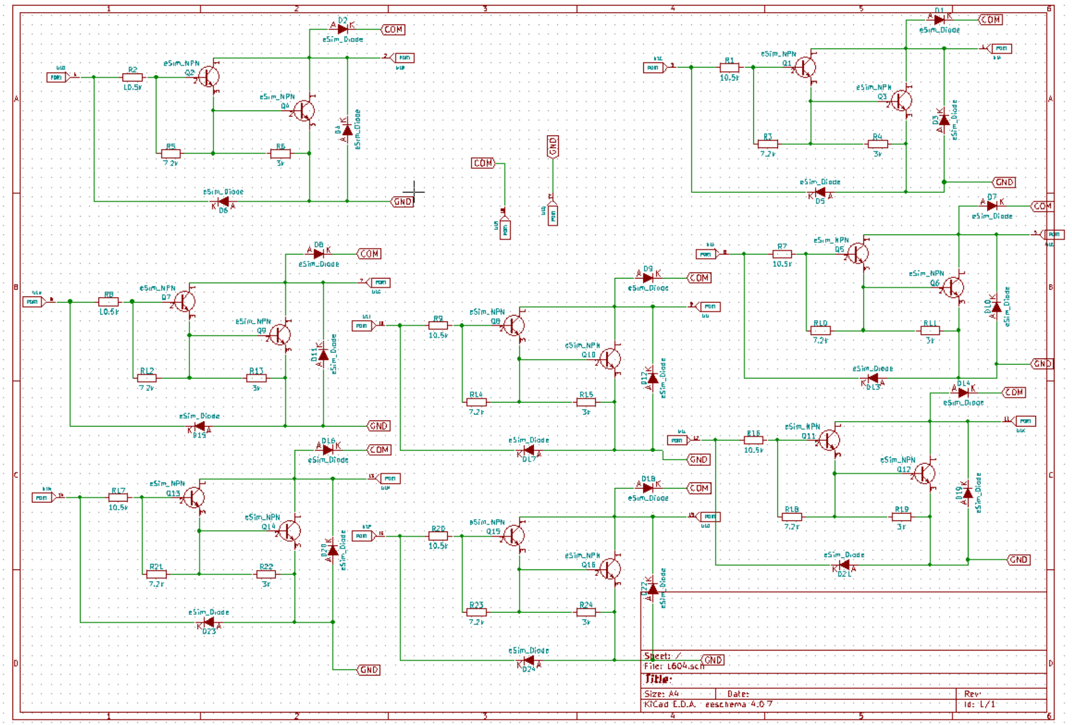


Figure 5.3: Subcircuit Schematic of L604

5.7 Test Circuit

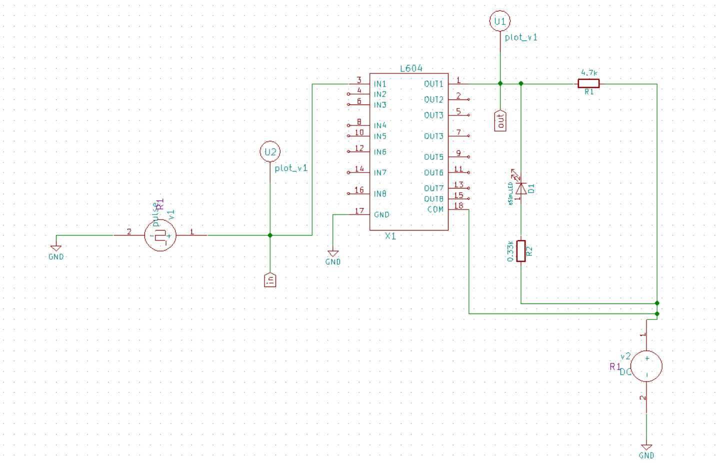


Figure 5.4: Test Circuit of L604

5.8 Input Plot

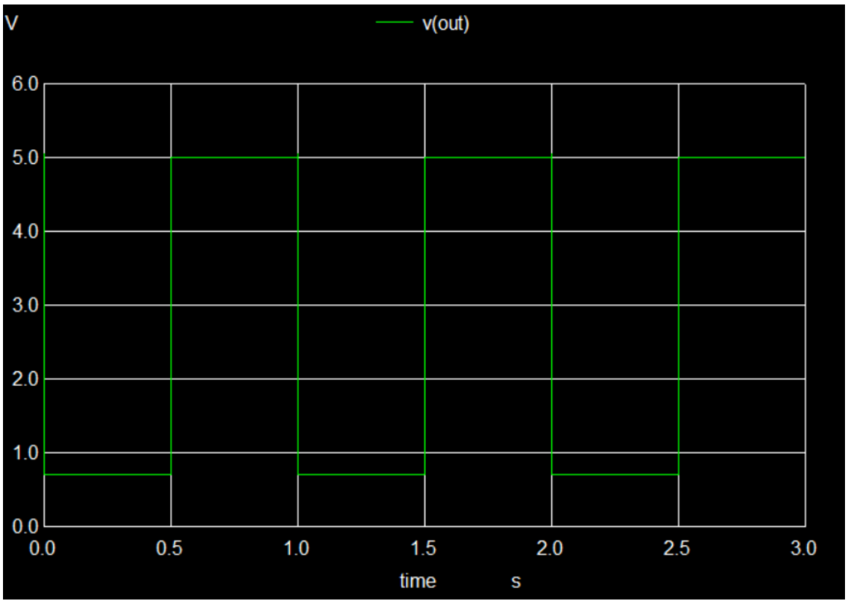


Figure 5.5: Input

5.9 Output Plot

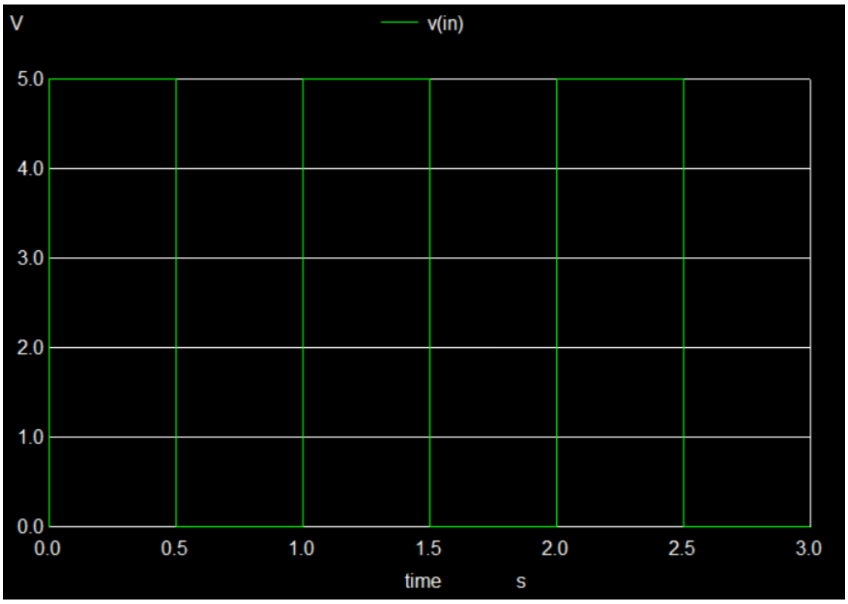


Figure 5.6: Output

Chapter 6

REF5010

6.1 General Description

The REF5010 is a high-precision, low-noise, and low-drift voltage reference designed for applications requiring excellent stability and accuracy. It offers both sourcing and sinking current capabilities with outstanding line and load regulation. The device is particularly suited for precision data acquisition systems and industrial instrumentation.

6.2 Key Features

- **High Accuracy:** Provides an initial accuracy of up to 0.025%, ensuring precise voltage regulation.
- **Low Temperature Drift:** Features a low temperature coefficient of 2.5ppm/°C (Enhanced grade), making it highly stable over varying temperatures.
- **Low Noise Operation:** Delivers an ultra-low flicker noise of 0.5µ$V_{P\text{-}P}$/V, improving signal integrity in sensitive applications.
- **Wide Input Voltage Range:** Supports an input voltage range up to 42V for enhanced flexibility.
- **High Output Drive:** Can source or sink currents up to ±10mA, making it suitable for driving various loads.
- **Extended Temperature Range:** Operates reliably from -40°C to 125°C.

6.3 Applications

- **Precision Data Acquisition Systems:** Used in high-accuracy ADCs and DACs for stable reference voltage.
- **Industrial Process Controls:** Ensures consistent and precise voltage regulation in automation systems.
- **Medical Instrumentation:** Ideal for imaging and diagnostic equipment requiring low noise and high accuracy.
- **Pressure and Temperature Transmitters:** Supports industrial sensors that require a precise reference voltage.
- **Lab and Field Instrumentation:** Suitable for test and measurement equipment that demands long-term voltage stability.

6.4 Pin Configuration

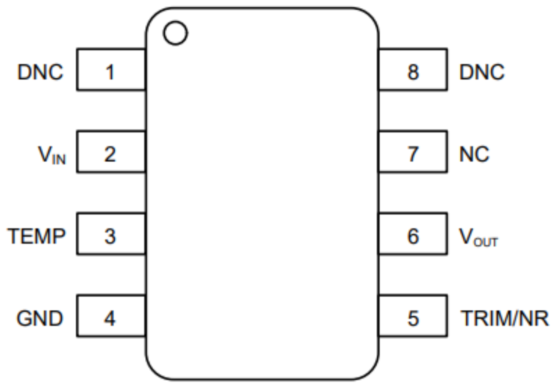


Figure 6.1: PIN of REF5010

6.5 IC Layout

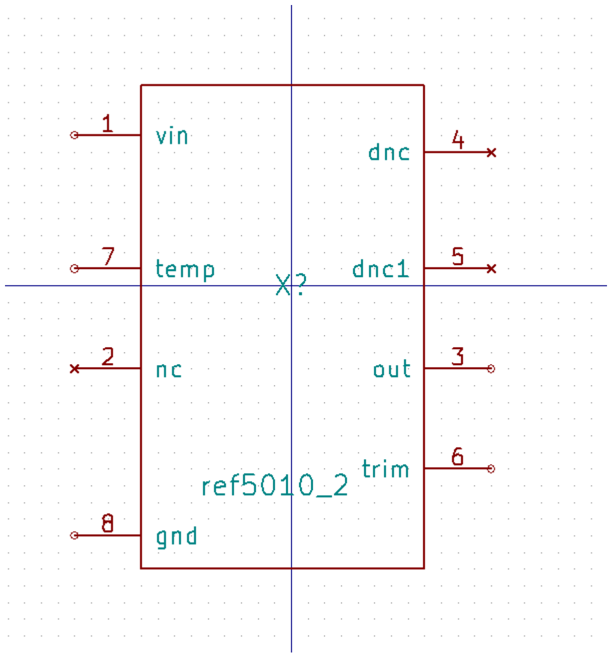


Figure 6.2: Layout of REF5010

6.6 Subcircuit Schematic

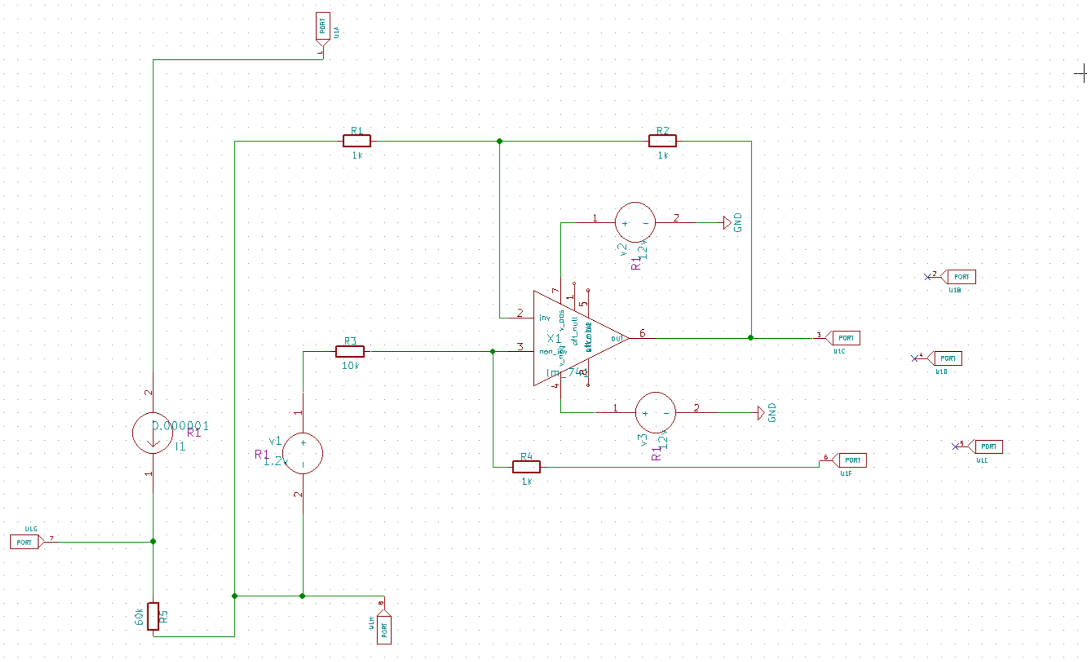


Figure 6.3: Subcircuit Schematic of REF5010

6.7 Test Circuit

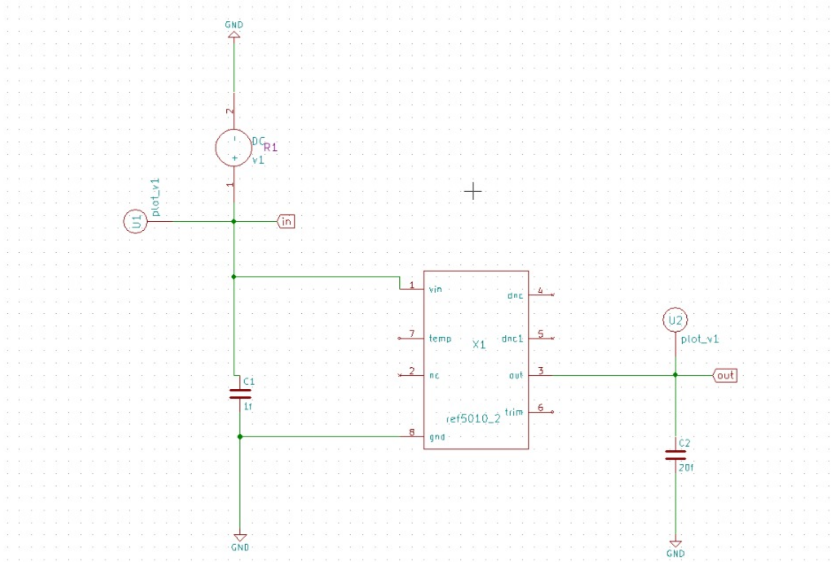


Figure 6.4: Test Circuit of REF5010

6.8 Input Plot

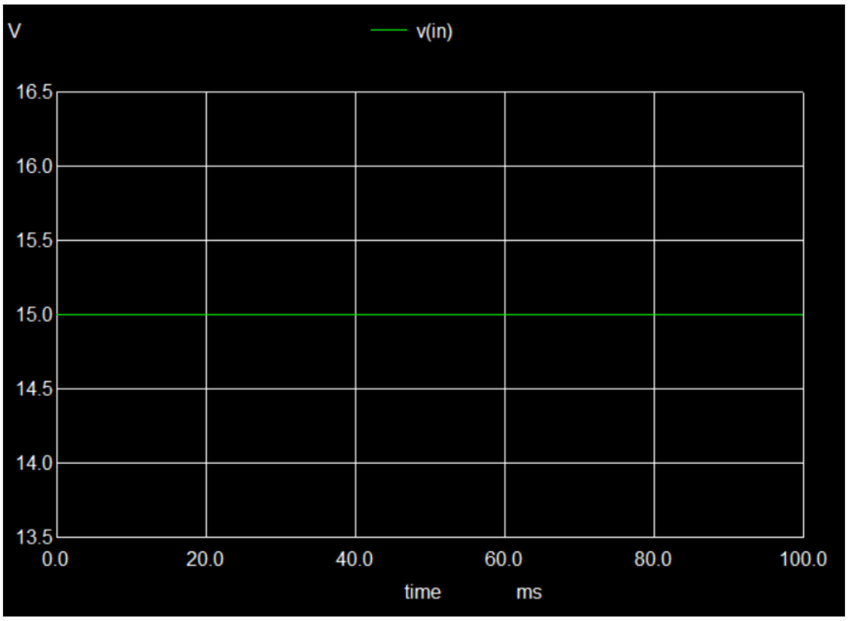


Figure 6.5: Input

6.9 Output Plot

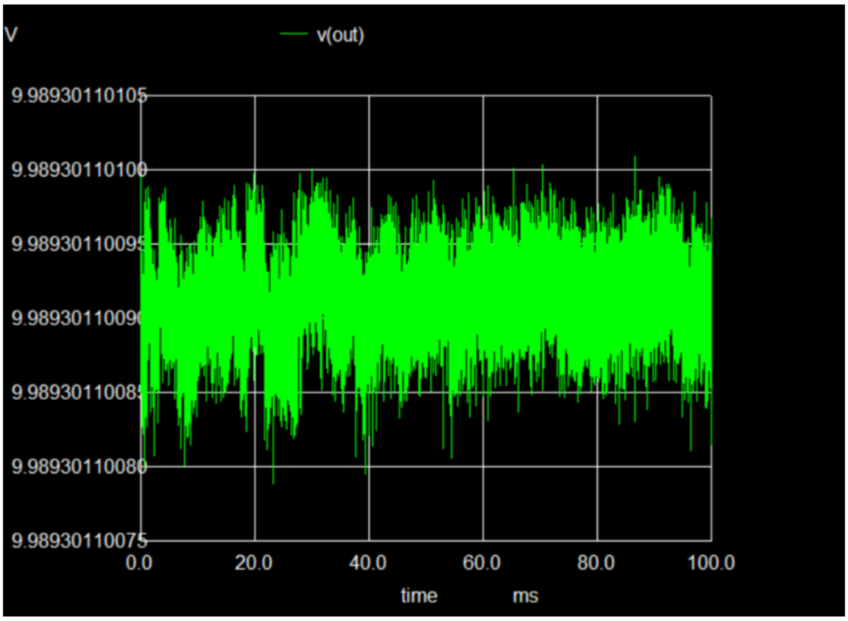


Figure 6.6: Output

Chapter 7

LM205

7.1 General Description

The LM205 is a precision voltage regulator designed to provide stable and accurate voltage regulation over a wide range of operating conditions. It features an improved biasing circuitry, which eliminates the need for a minimum load current while reducing standby current drain. This makes it ideal for high-voltage applications, ensuring reliable performance in both linear and switching regulator circuits.

7.2 Key Features

- **Adjustable Output Voltage:** Supports a regulated output voltage over a broad range.
- **High Output Current Capability:** Can deliver stable output without external pass transistors.
- **Excellent Load Regulation:** Maintains tight voltage regulation under varying loads.
- **Superior Line Regulation:** Provides minimal voltage variation with input fluctuations.
- **High Ripple Rejection:** Ensures noise-free and stable output voltage.
- **Fast Transient Response:** Adapts quickly to changes in load and input conditions.
- **Reliable Start-up:** Operates effectively under all rated load conditions.
- **Durable Package:** Designed for long-term reliability in various environmental conditions.

7.3 Applications

- **Voltage Regulation:** Ideal for precision power supply applications.
- **Switching Regulators:** Ensures stable operation in power management circuits.
- **Industrial Electronics:** Used in control systems requiring accurate voltage control.
- **Embedded Systems:** Provides reliable voltage reference for microcontroller applications.

7.4 Operating Conditions

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

7.5 Pin Configuration

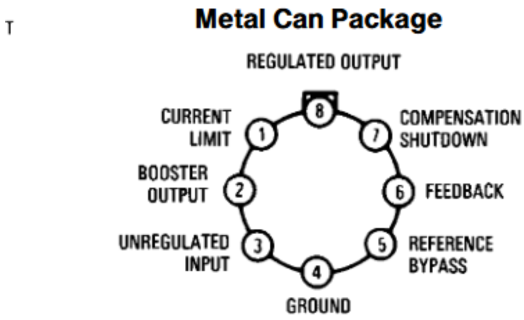


Figure 7.1: PIN of LM205

7.6 IC Layout

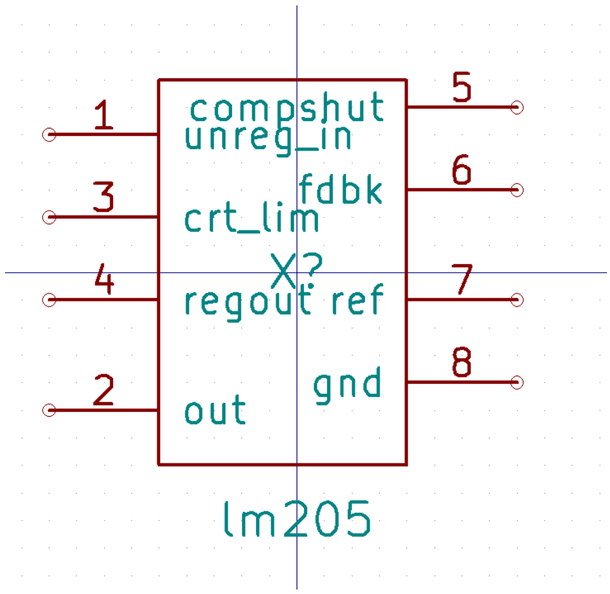


Figure 7.2: Layout of LM205

7.7 Subcircuit Schematic

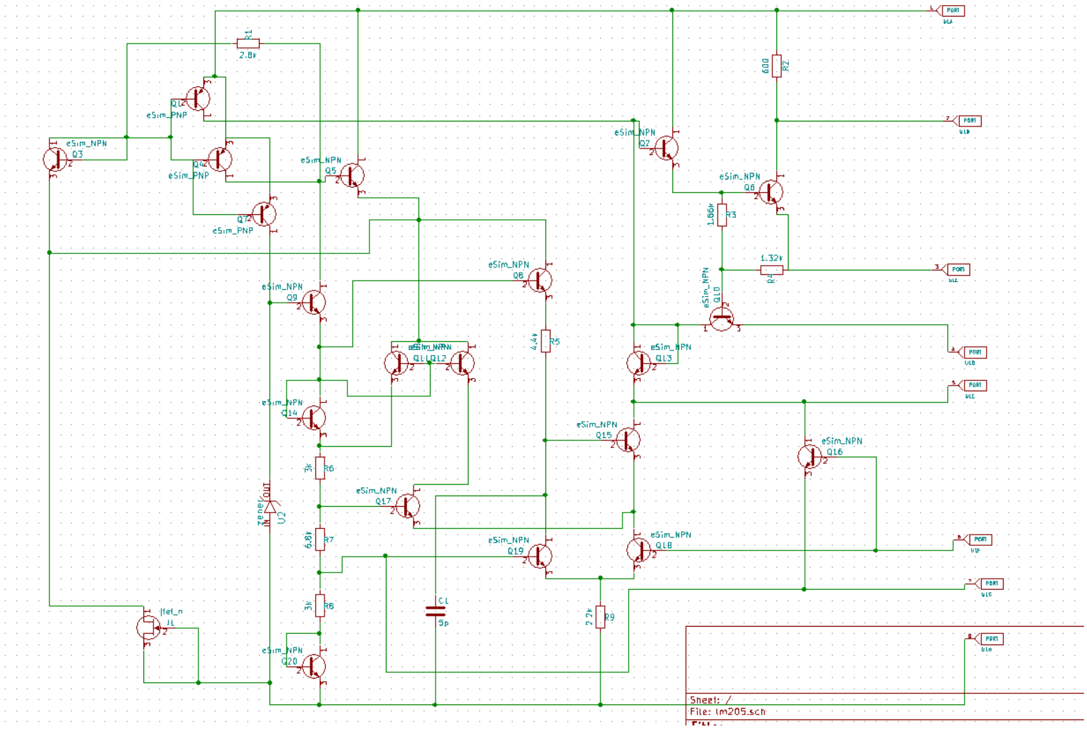


Figure 7.3: Subcircuit of LM205

7.8 Test Circuit

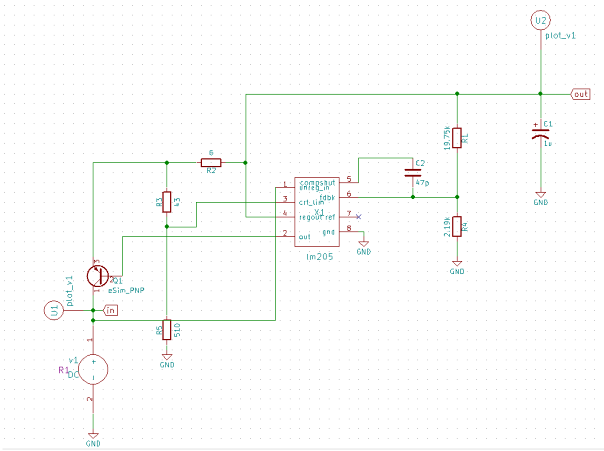


Figure 7.4: Test circuit of LM205

7.9 Input Plot

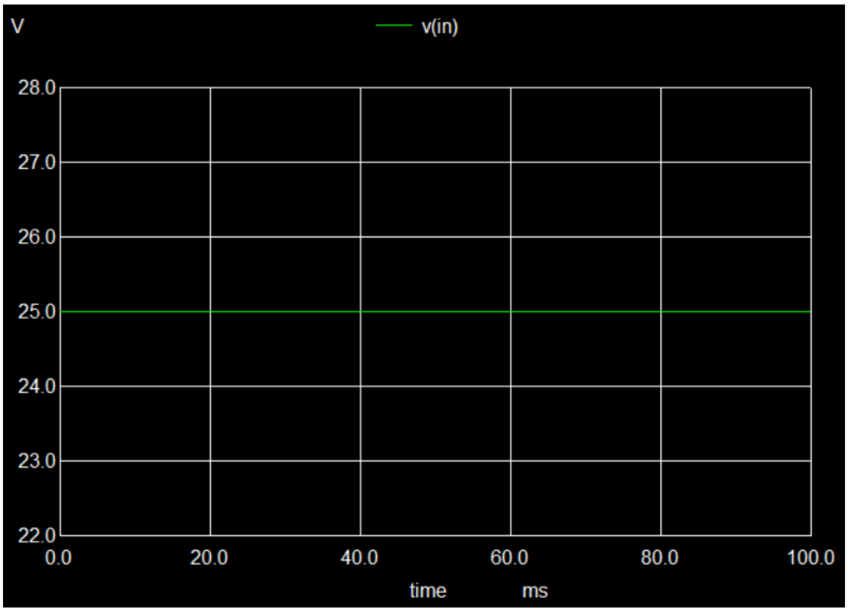


Figure 7.5: INPUT

7.10 Output Plot

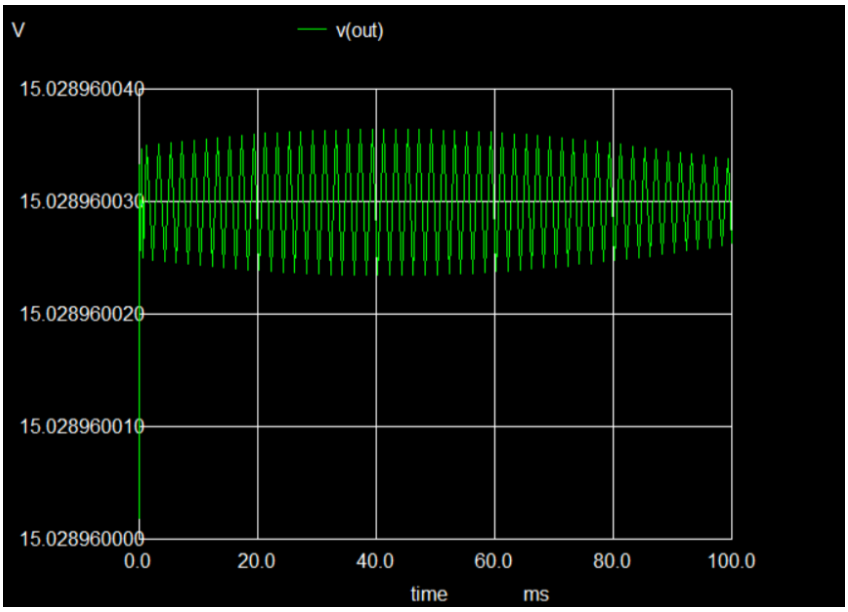


Figure 7.6: OUTPUT

Chapter 8

L603

8.1 General Description

The L603 is a high-voltage, high-current Darlington transistor array specifically designed for interfacing with 5V TTL logic circuits. It contains eight open-collector Darlington pairs with common emitters, making it ideal for driving various loads such as relays, LED displays, and stepper motors. The built-in suppression diodes provide protection for inductive load applications.

8.2 Key Features

- **Eight Darlington Transistors:** Each package contains eight high-gain Darlington pairs for efficient switching.
- **TTL Compatible Inputs:** Designed to interface directly with 5V TTL logic circuits.
- **High Output Current:** Each channel supports up to 400mA continuous current with a peak of 500mA.
- **Integral Suppression Diodes:** Built-in diodes provide protection when driving inductive loads.
- **Parallel Outputs:** Outputs can be paralleled to achieve higher current drive capability.
- **Compact DIP-18 Package:** Facilitates easy integration into PCB designs.

8.3 Applications

- **Relay and Solenoid Drivers:** Used for switching relays and solenoids in industrial control applications.
- **LED and Display Drivers:** Suitable for controlling LED segments and display panels.
- **Stepper Motor Controllers:** Commonly used in driving stepper motors in automation and robotics.
- **Thermal Printheads:** Supports applications requiring high-current switching.
- **High-Power Buffers:** Acts as a buffer for logic circuits that need high current drive capability.

8.4 Pin Configuration

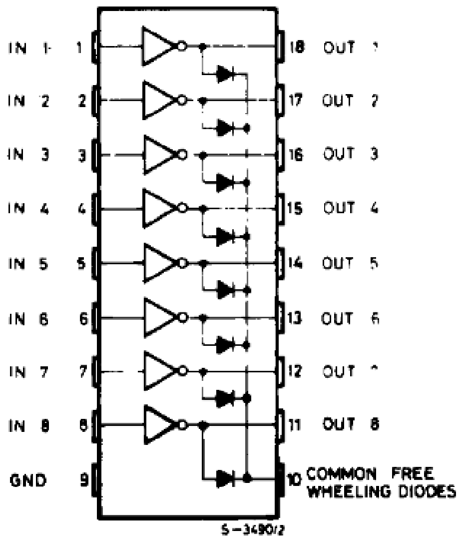


Figure 8.1: PIN of L603

8.5 IC Layout

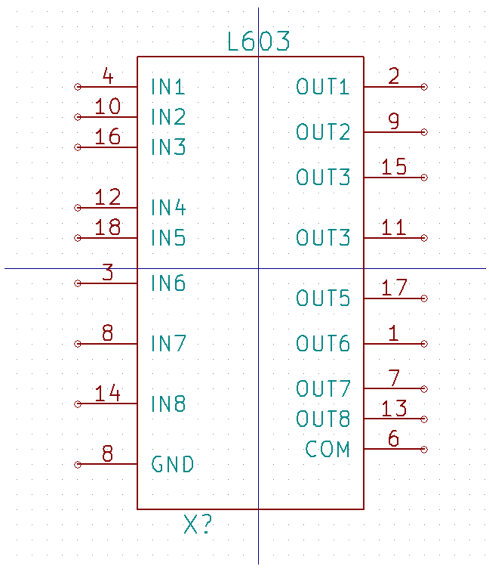


Figure 8.2: Layout of L603

8.6 Subcircuit Schematic

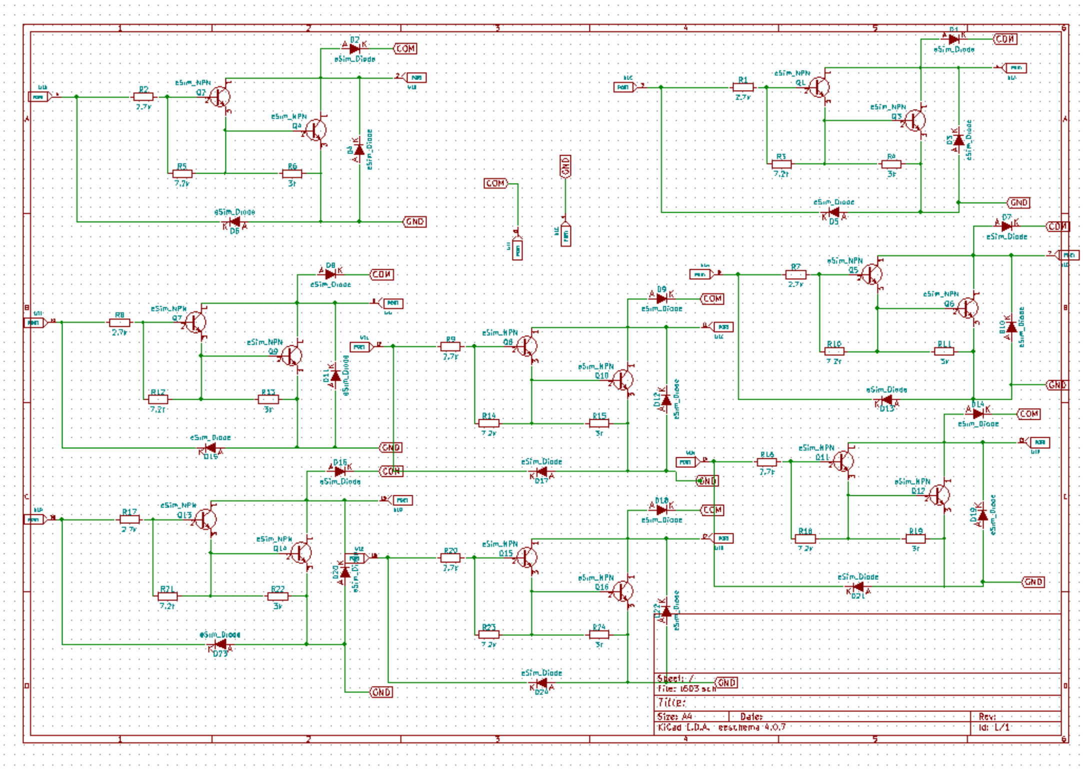


Figure 8.3: Subcircuit of L603

8.7 Test Circuit

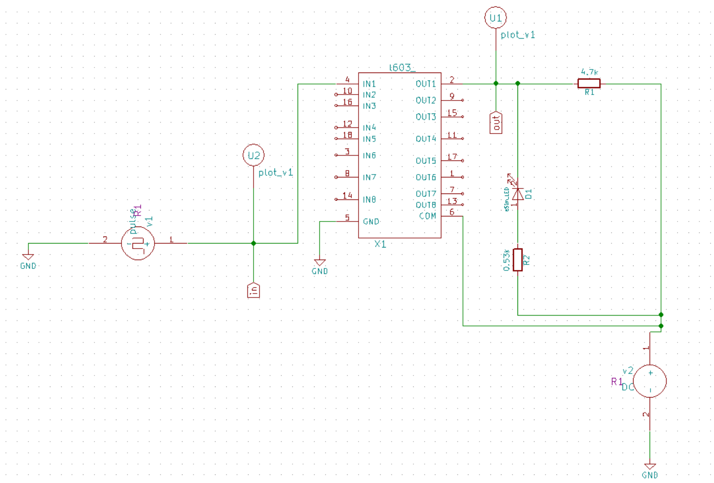


Figure 8.4: Test circuit of L603

8.8 Input Plot

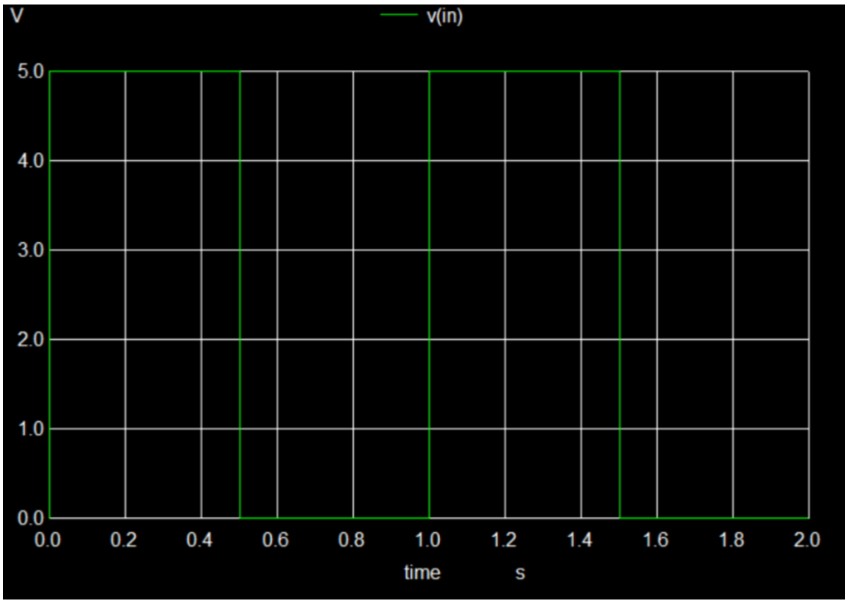


Figure 8.5: Input

8.9 Output Plot

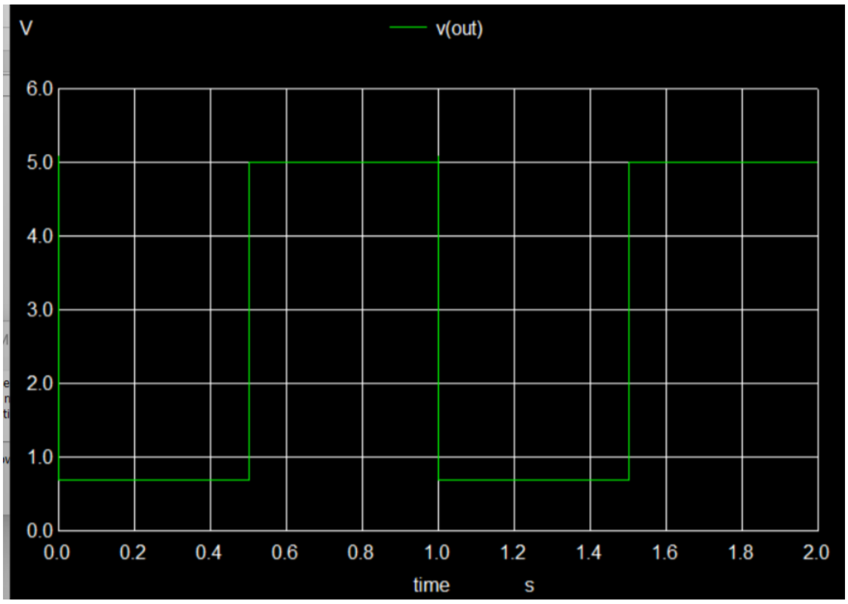


Figure 8.6: Output

Chapter 9

SN74LS09

9.1 General Description

The SN74LS09 is a quad 2-input AND gate with open-collector outputs, designed for use in logic circuits requiring wired-AND functionality. The open-collector configuration requires external pull-up resistors, allowing the device to interface with higher voltage levels or create logic functions that require active-low or active-high connections.

9.2 Key Features

- **Quad 2-Input AND Gates:** Four independent AND gates in a single package.
- **Open-Collector Outputs:** Requires pull-up resistors and allows wired-AND operation.
- **TTL Compatible:** Designed for direct interface with TTL logic.
- **Wide Operating Temperature Range:**
  - SN74LS09: 0°C to 70°C (commercial grade)
- **High Reliability:** Manufactured with dependable Texas Instruments quality and reliability.

9.3 Applications

- **Logic Circuit Design:** Used in digital logic applications that require AND logic with open-collector outputs.
- **Wired-AND Logic Implementation:** Facilitates active-low wired-OR and active-high wired-AND functions.
- **Voltage Level Shifting:** Enables interfacing between different logic voltage levels.
- **Industrial and Military Applications:** Suitable for robust environments requiring precise logic control.

9.4 Pin Configuration

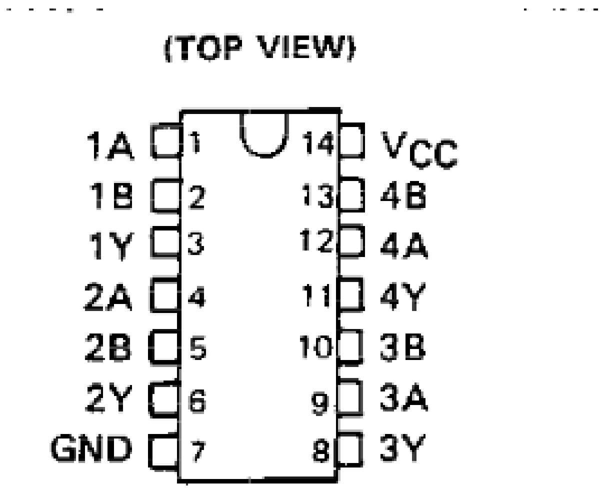


Figure 9.1: PIN of SN74LS09

9.5 IC Layout

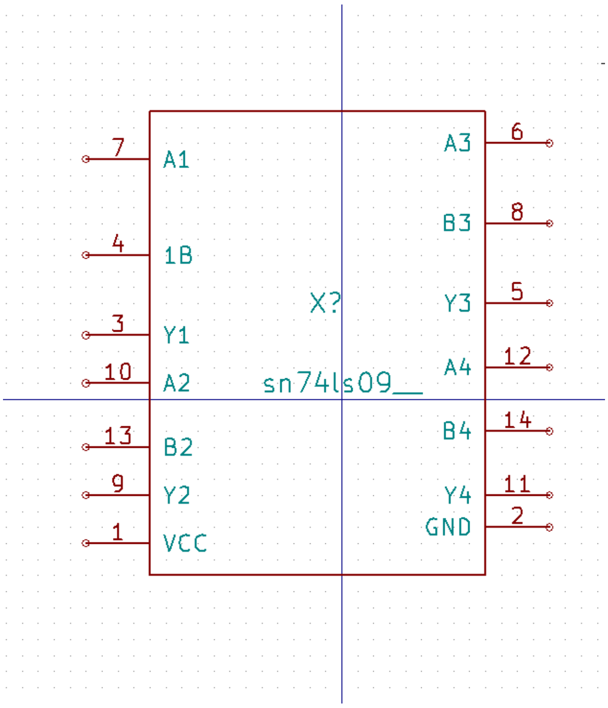


Figure 9.2: Layout of Sn74LS09

9.6 Subcircuit Schematic

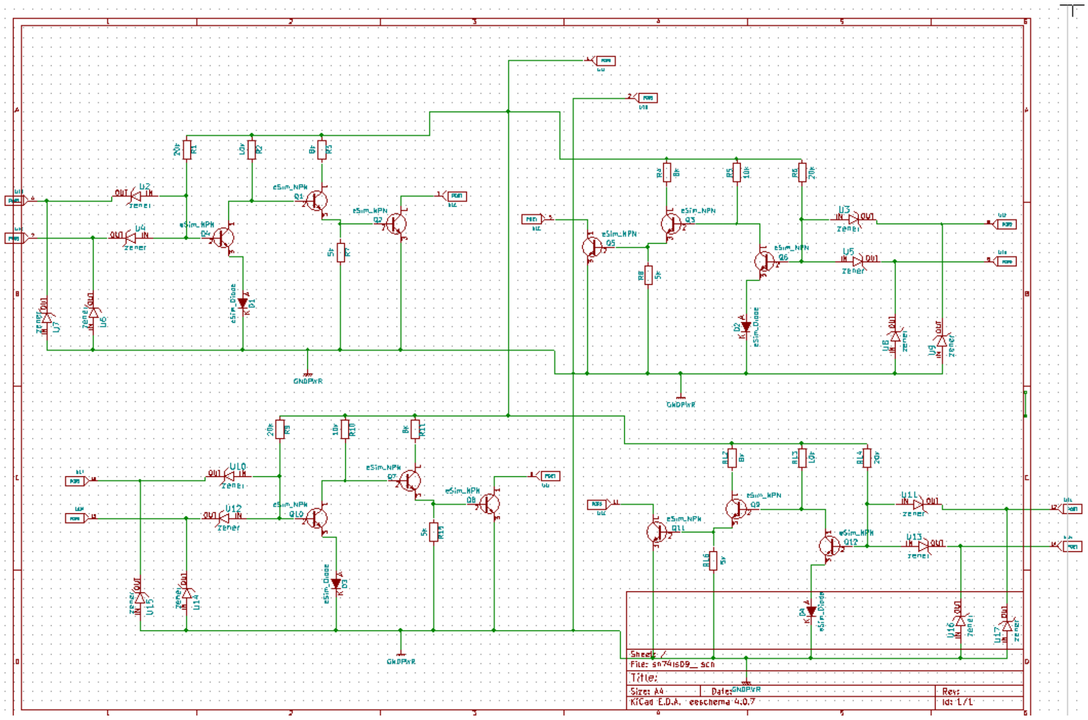


Figure 9.3: Enter Caption

9.7 Test Circuit

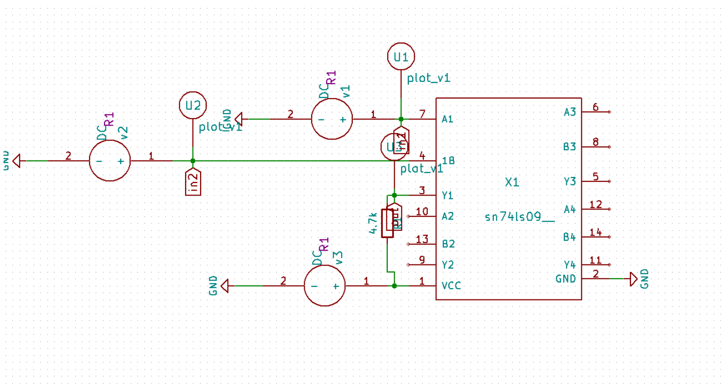


Figure 9.4: Test circuit of SN74LS09

9.8 Input Plot HIGH

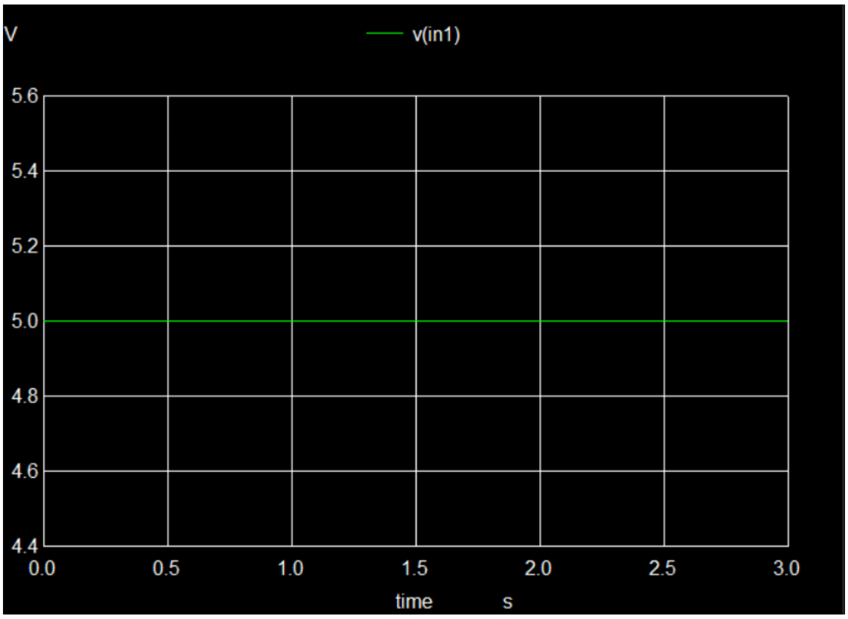


Figure 9.5: INPUT 1

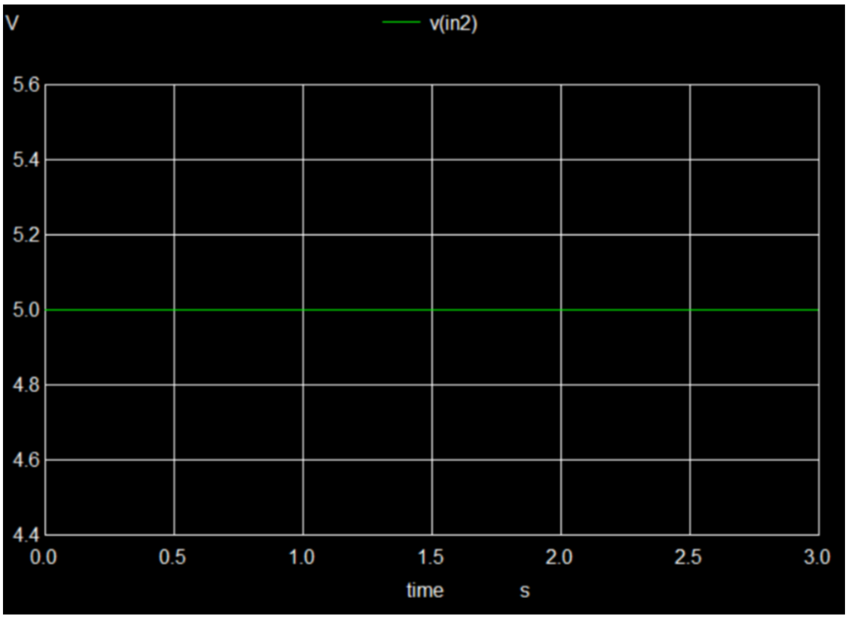


Figure 9.6: INPUT 2

9.9 Output Plot HIGH

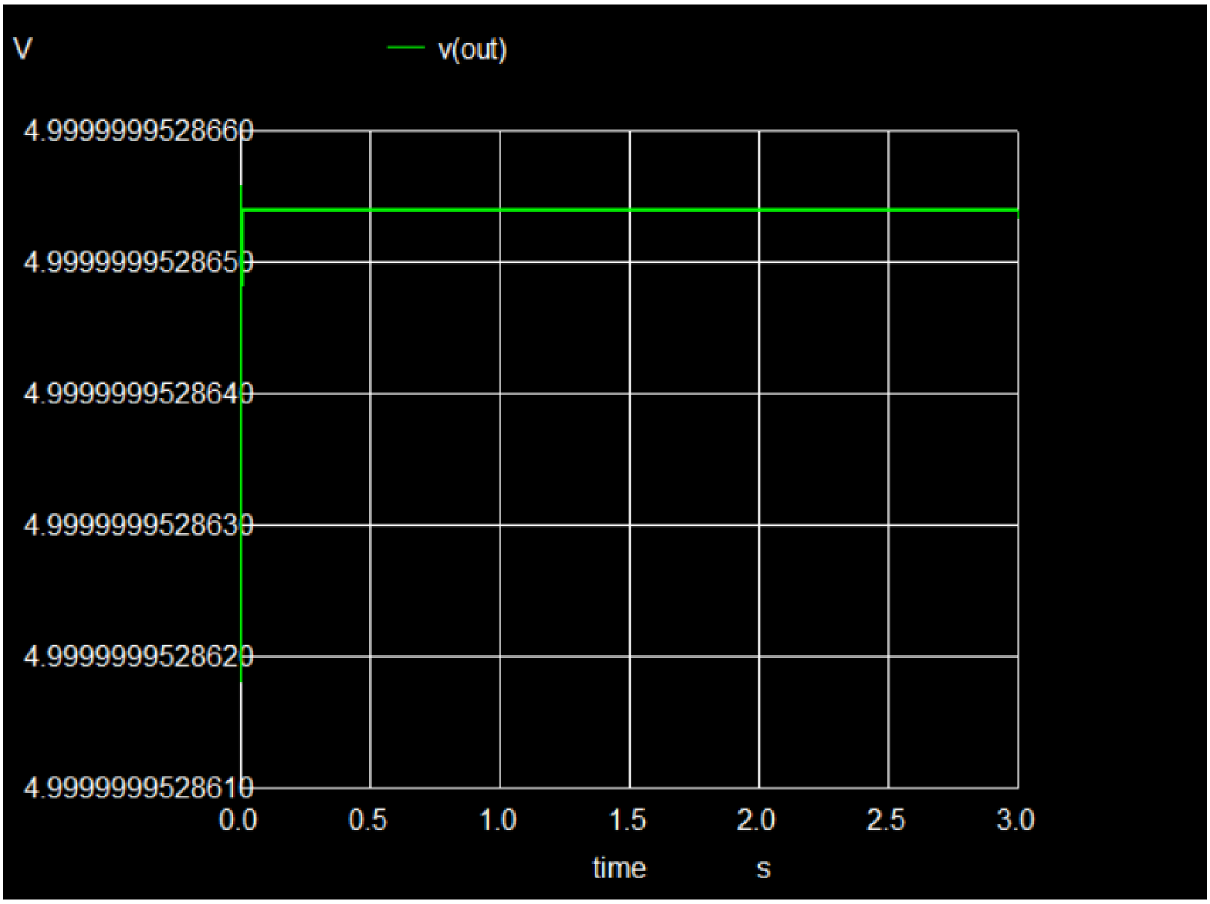


Figure 9.7: HIGH Output

9.10 Input Plot LOW

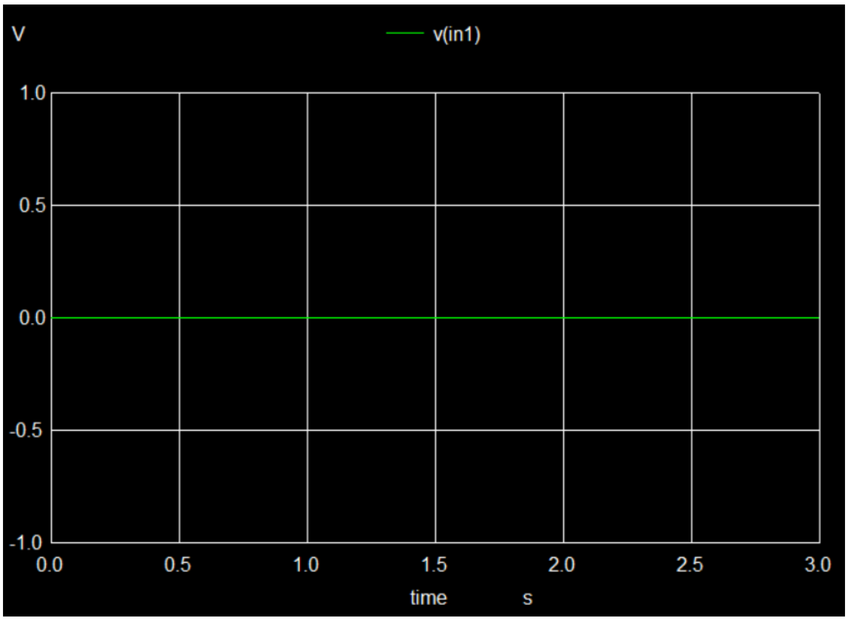


Figure 9.8: INPUT 1

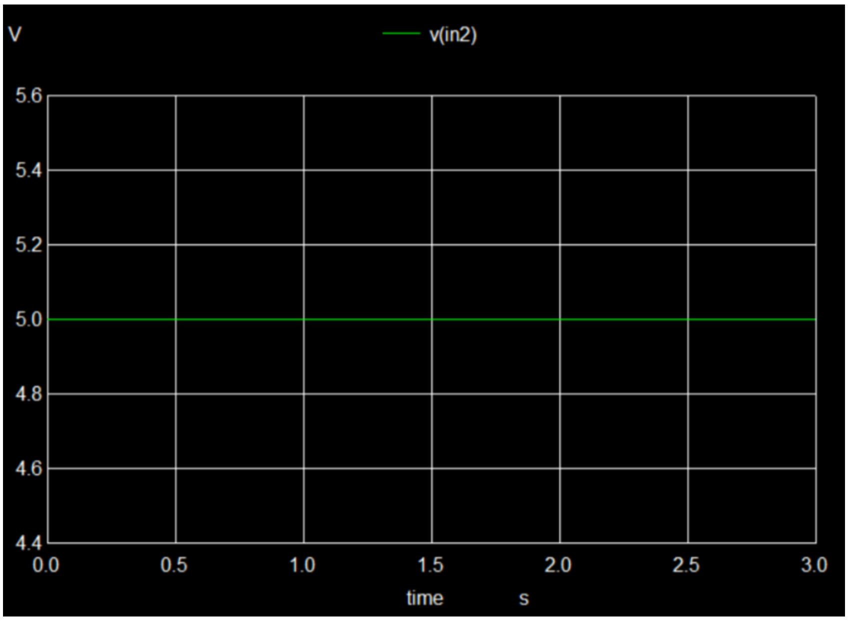


Figure 9.9: INPUT 2

9.11 Output Plot LOW

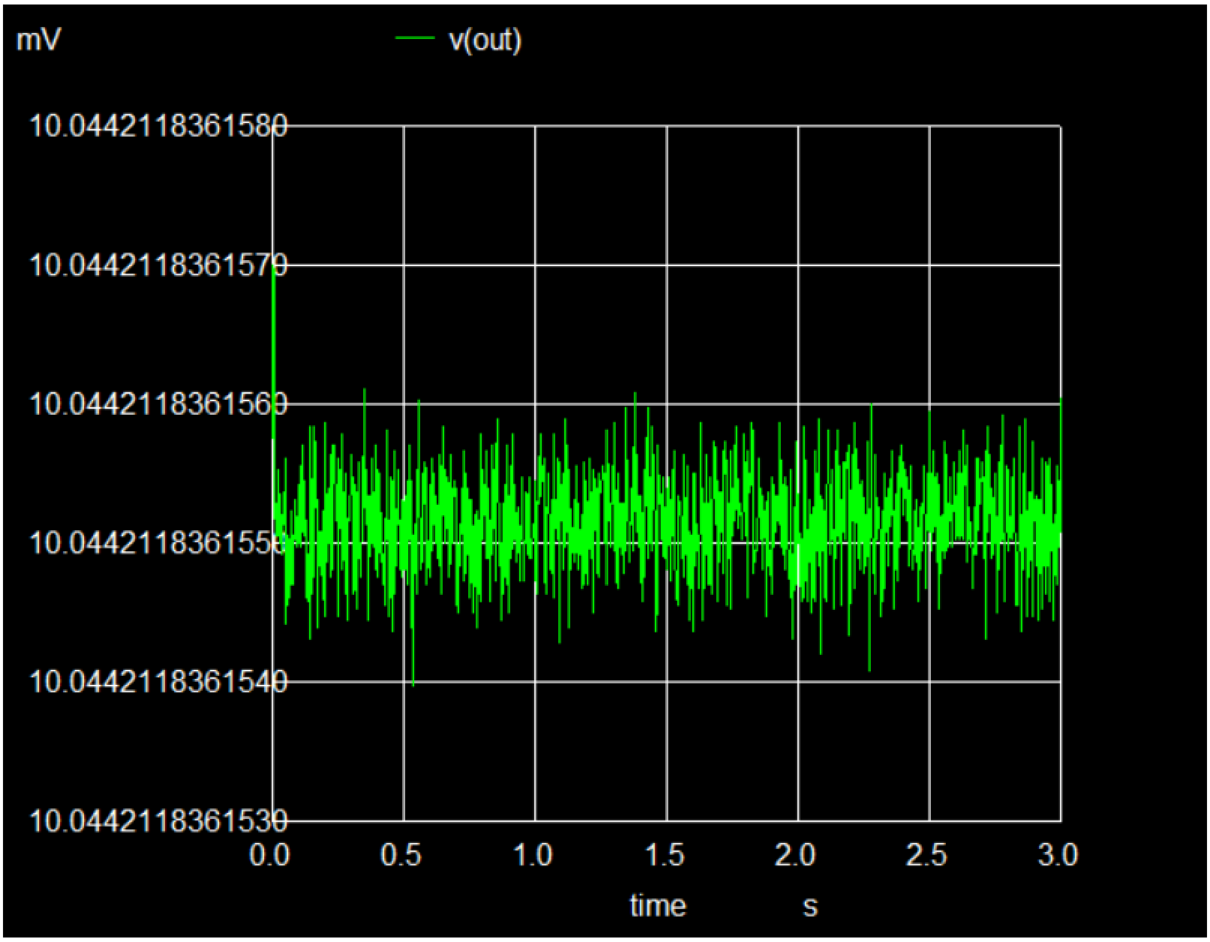


Figure 9.10: LOW Output

Chapter 10

SN55461

10.1 General Description

The SN55461 is a peripheral driver designed for high-voltage and high-current applications. It is capable of handling output currents up to 300 mA while maintaining high reliability and efficiency. This driver is suitable for various industrial and commercial applications requiring medium-speed switching and circuit flexibility.

10.2 Key Features

- **High-Voltage Outputs:** Designed to operate efficiently in high-voltage environments.
- **High-Current Capability:** Can handle up to 300 mA output current.
- **No Output Latch-Up:** Ensures stable operation even after conducting 300 mA at 30V.
- **Medium-Speed Switching:** Suitable for applications requiring moderate switching speeds.
- **Circuit Flexibility:** Allows varied applications and choice of logic functions.
- **TTL-Compatible Inputs:** Features diode-clamped inputs for direct TTL interfacing.
- **Standard Supply Voltages:** Operates within standard voltage ranges for easy integration.

10.3 Applications

- **Industrial Control Systems:** Used in automation and control applications.
- **Relay and Solenoid Drivers:** Suitable for driving inductive loads.
- **Motor Control:** Integrated into motor driving circuits for high-efficiency control.
- **Display Systems:** Utilized in high-voltage LED and segment display driving.
- **Power Management Circuits:** Supports power distribution and switching applications.

10.4 Pin Configuration

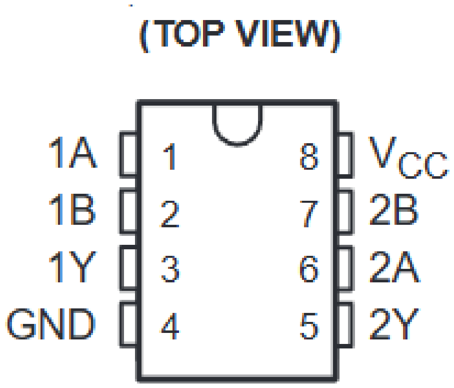


Figure 10.1: PIN of SN55461

10.5 IC Layout

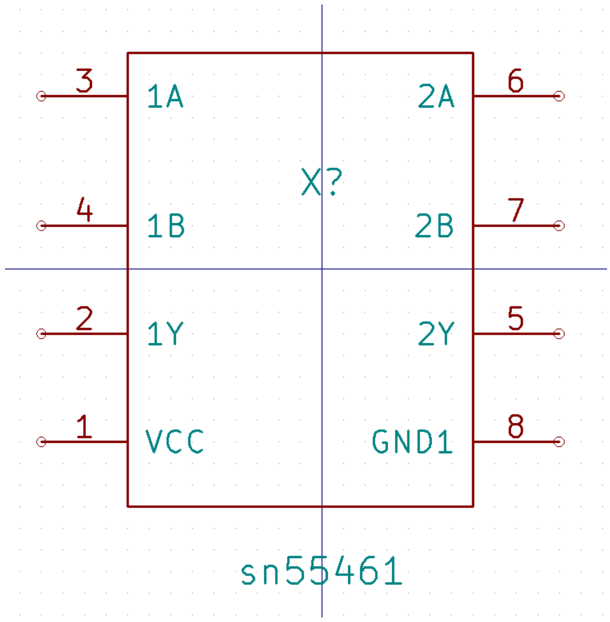


Figure 10.2: Layout of SN55461

10.6 Subcircuit Schematic

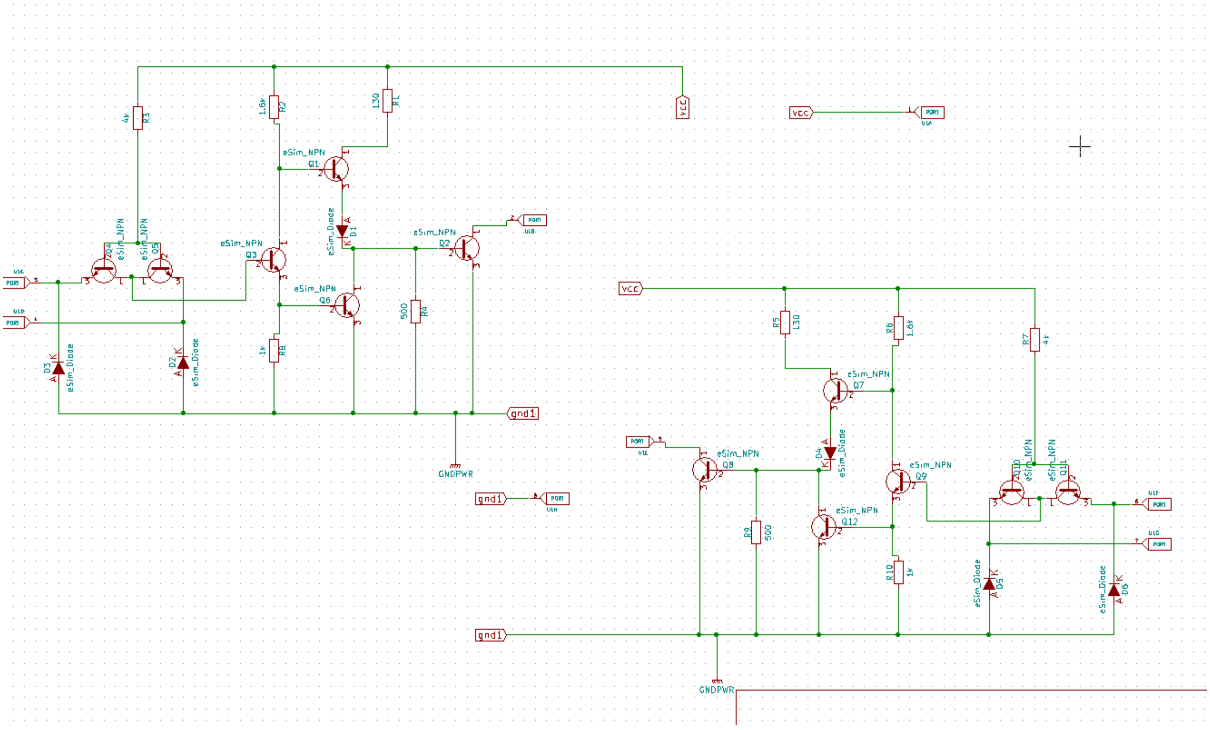


Figure 10.3: Subcircuit of SN55461

10.7 Test Circuit

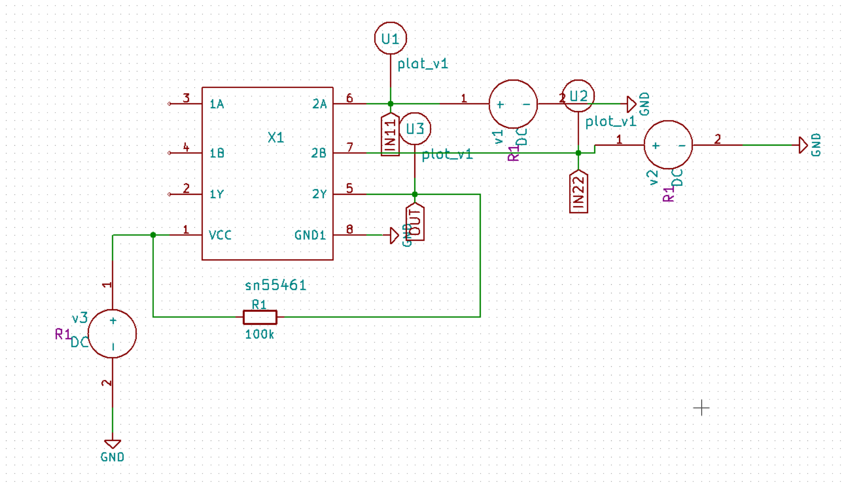


Figure 10.4: Test Circuit of SN55641

10.8 Input Plot for HIGH

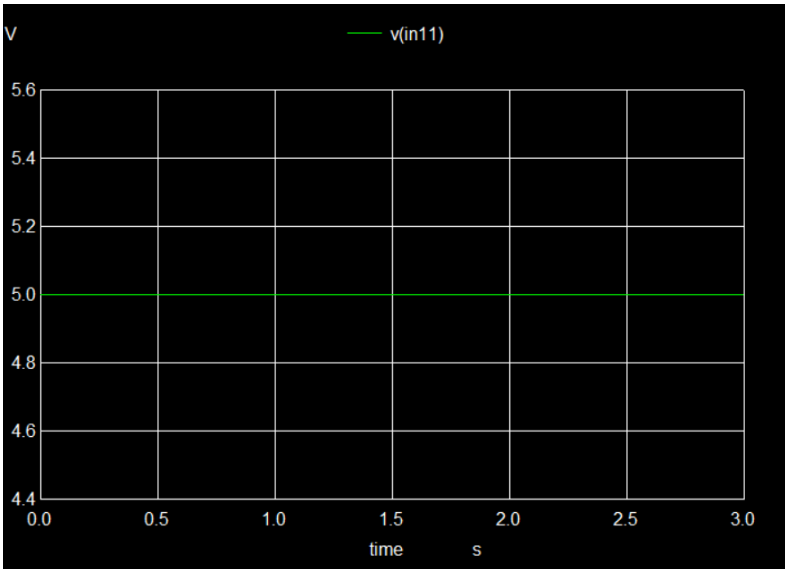


Figure 10.5: Input 1

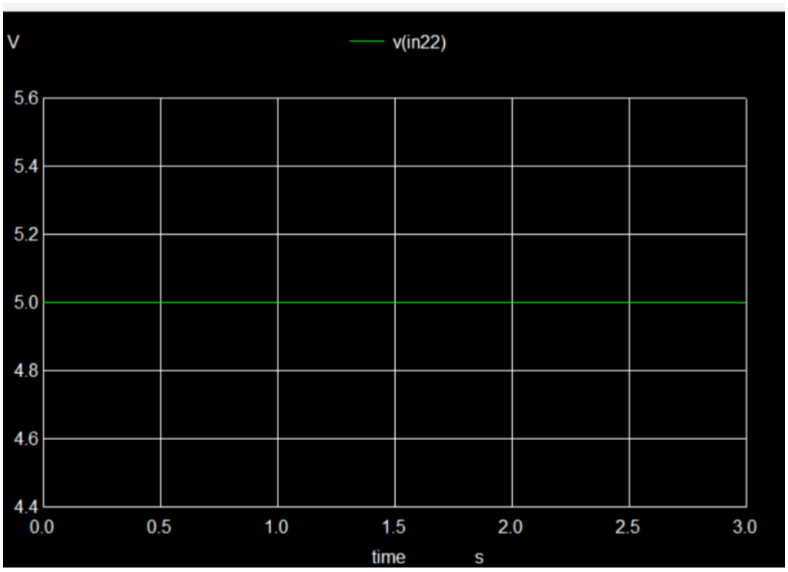


Figure 10.6: Input 2

10.9 Output Plot HIGH

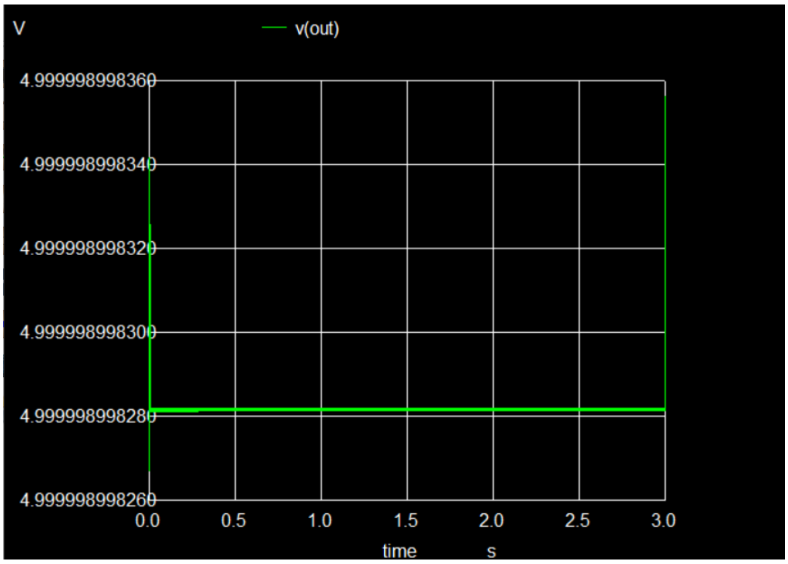


Figure 10.7: HIGH Output

10.10 Input Plot for LOW

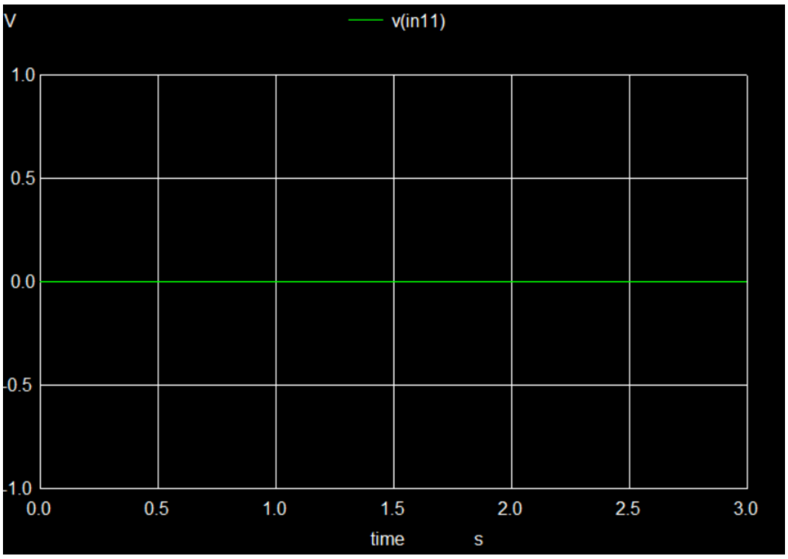


Figure 10.8: Input-1

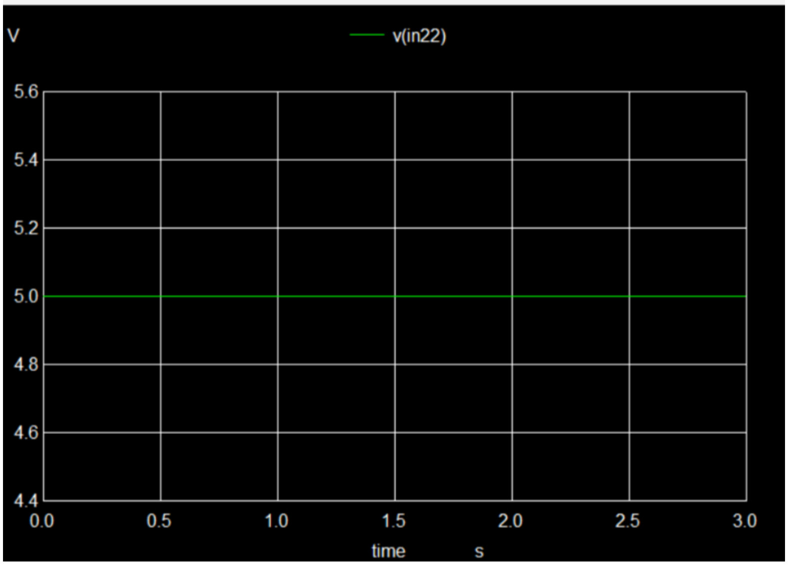


Figure 10.9: Input 2

10.11 Output Plot LOW

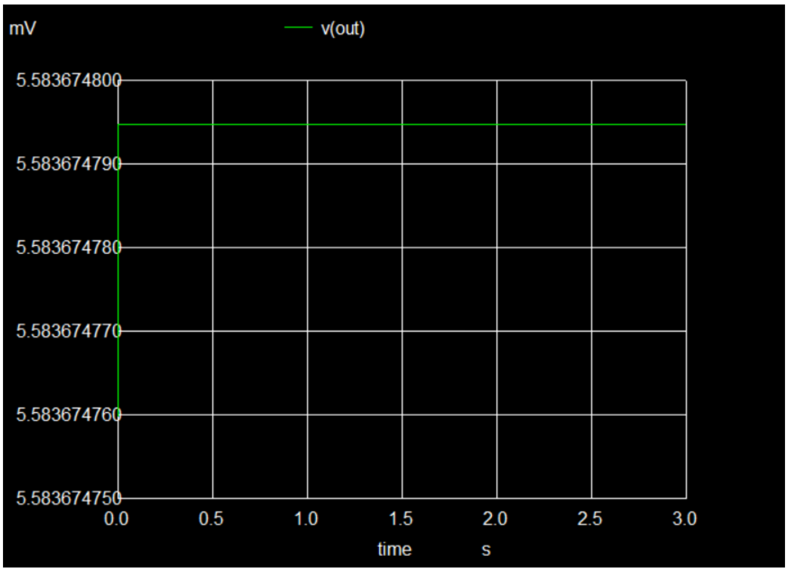


Figure 10.10: LOW Output

Chapter 11

Failed Circuits

11.1 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.

11.2 INA128

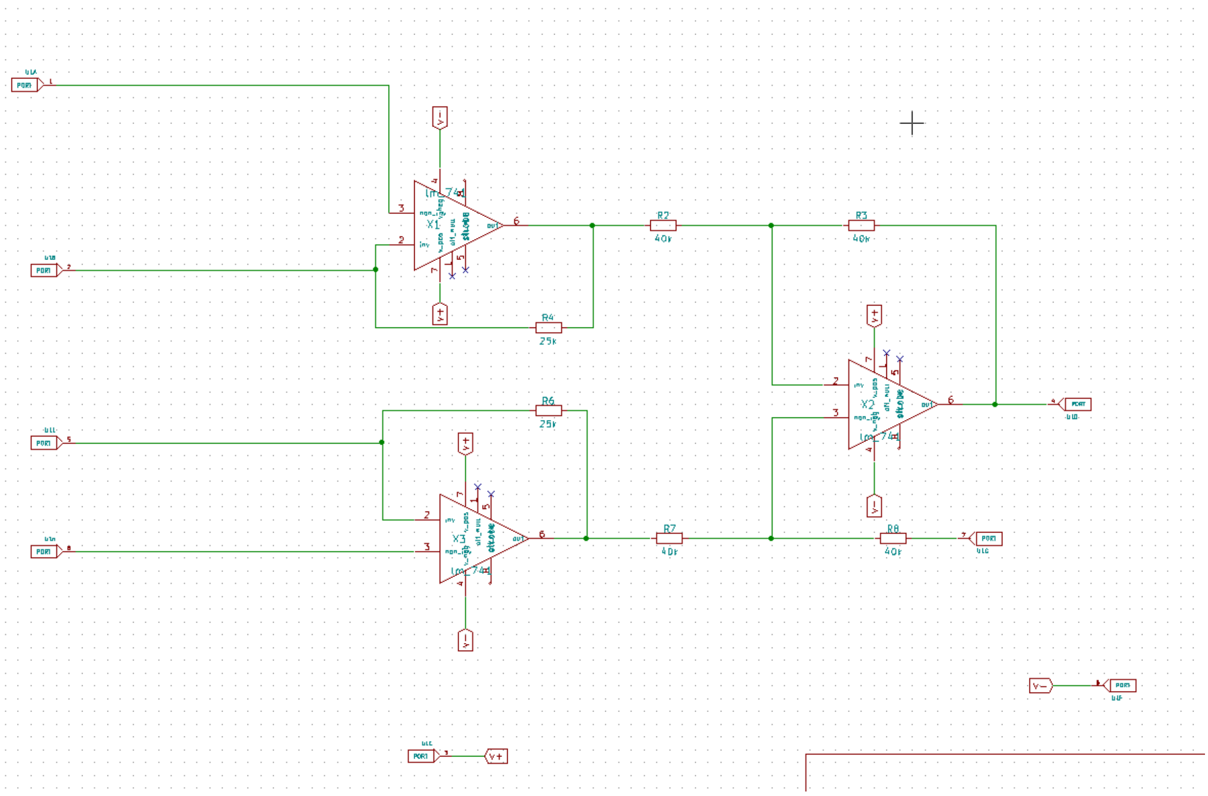


Figure 11.1: Subcircuit of INA128

Issue Description

During the simulation, the output signal exhibited significant fluctuations and noise, despite having stable input signals. Instead of a clean amplified output, the waveform displayed unexpected variations, which could indicate instability or incorrect circuit parameters.

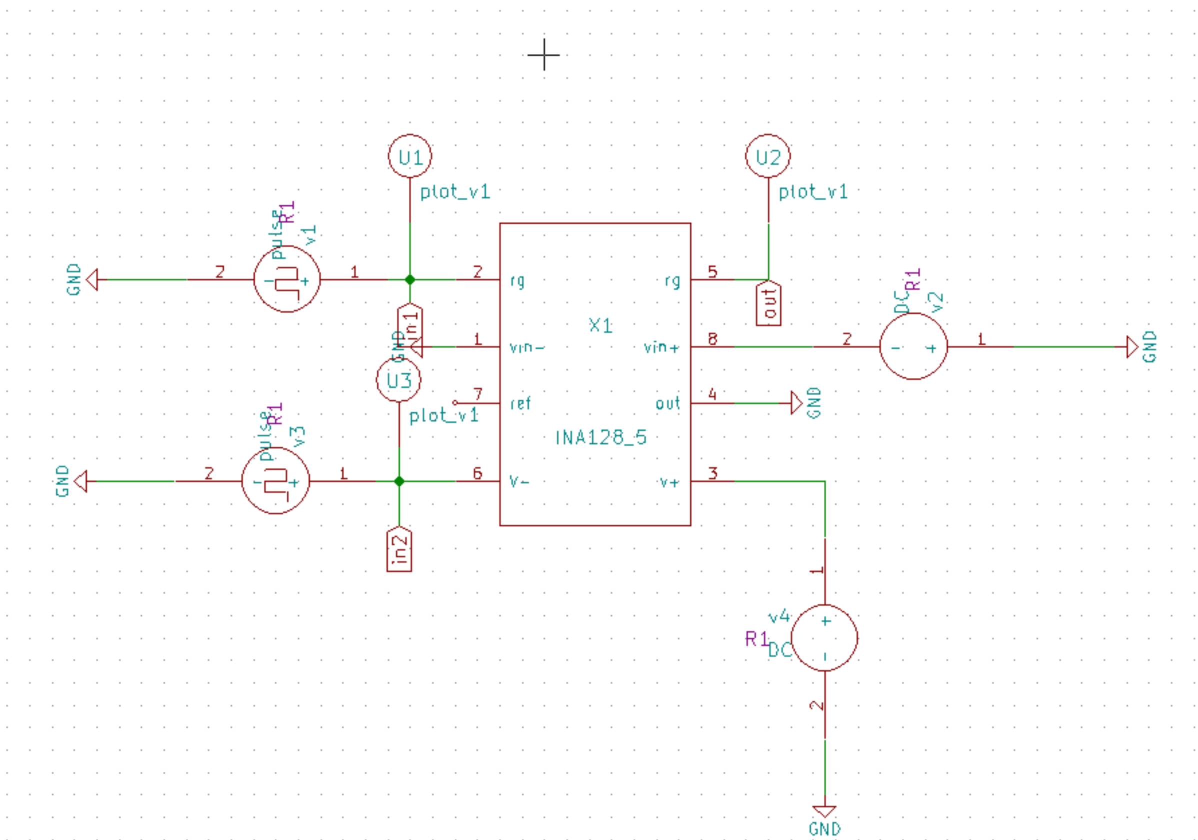


Figure 11.2: Test circuit of INA128

Chapter 12

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 13

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.

13.1 Suprraja D List of ICs

1. SN74LS21 - A dual 4-input AND gate IC
2. L604 - A Darlington transistor array IC
3. REF5010 - A low-noise, high-precision voltage reference IC
4. LM205 - A precision voltage regulator IC
5. L603 - A Darlington transistor array IC
6. SN74LS09 - A quad 2-input AND gate IC with open-collector outputs
7. SN55461 - A high-voltage, high-current peripheral driver IC

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[4] Texas Instruments, L604 Datasheet https://www.alldatasheet.com/datasheet-pdf/view/22531/STMICROELECTRONICS/L602-L604.html

[5] Texas Instruments, REF5010 Datasheet https://www.ti.com/lit/ds/symlink/ref5010.pdf?ts=1739817498351&ref_url=https%253A%252F%252Fwww.ti.com%252Fproduct%252FREF5010

[6] Texas Instruments, LM205 Datasheet https://www.alldatasheet.com/datasheet-pdf/view/132628/NSC/LM205.html

[7] Texas Instruments, L603 Datasheet https://www.alldatasheet.com/datasheet-pdf/view/22531/STMICROELECTRONICS/L602-L604.html

[8] ALL DATASHEET, SN74LS09 Datasheet https://www.alldatasheet.com/datasheet-pdf/view/543166/TI/SN74LS09.html

[9] Texas Instruments, SN55641 Datasheet https://www.alldatasheet.com/datasheet-pdf/view/28172/TI/SN55461.html

[10] Analog Devices, INA128 Datasheet https://www.ti.com/lit/ds/symlink/ina128.pdf