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Design and implementation of a multi-channel temperature sensing system using RTD PT100 for Real-time data acquisition and display

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ملخص: تعتبر قياسات درجات الحرارة بدقة وفي الوقت الحقيقي ضرورية في العديد من المجالات العلمية والصناعية. RTD يقدم هذا المقال العلمي تصميم وتنفيذ نظام كشف درجات الحرارة متعدد القنوات باستخدام أجهزة استشعار يدمج النظام تقنيات متقدمة لتكييف الإشارة ودوائر أمامية تناظرية عالية الدقة واكتساب البيانات المستندة إلى PT100. المتحكم المدمج لتمكين اكتساب البيانات في الوقت الحقيقي لدرجات الحرارة من قنوات متعددة. بالإضافة إلى ذلك، يتم تطوير واجهة عرض سهلة الاستخدام لتوفير تصور فوري للقراءات المكتسبة لدرجات الحرارة. يتم تقييم أداء النظام من خلال تجارب المعايرة، مما يدل على قدرته على توفير قراءات درجات حرارة دقيقة وموثوقة. تسهم هذه البحث في مجال تقنية قياس درجات الحرارة وتقدم حلاً عملياً للتطبيقات التي تتطلب مراقبة درجات الحرارة متعددة القنوات في الوقت الحقيقي وعرضها. **كلمات المفاتيح :**

Résumé : La mesure précise et en temps réel de la température est essentielle dans de nombreux domaines scientifiques et industriels. Cette étude présente la conception et la mise en œuvre d'un système de mesure de température à canaux multiples utilisant des capteurs RTD PT100. Le système intègre des techniques avancées de conditionnement du signal, des circuits analogiques à haute précision en amont et une acquisition de données basée sur un microcontrôleur pour permettre l'acquisition en temps réel des données de température à partir de plusieurs canaux. De plus, une interface conviviale est développée pour fournir une visualisation instantanée des lectures de température acquises. Les performances du système sont évaluées à travers des expériences de calibration, démontrant sa capacité à fournir des mesures de température précises et fiables. Cette recherche contribue au domaine de la technologie de mesure de température et offre une solution pratique pour les applications nécessitant une surveillance simultanée de la température à plusieurs canaux et un affichage en temps réel. **Mots clés :** RTD ; STM32 ; PT100 ; PCB .

Abstract: Accurate and real-time temperature measurement is essential in numerous scientific and industrial domains. This scientific article presents the design and implementation of a multi-channel temperature sensing system utilizing RTD PT100 sensors. The system incorporates advanced signal conditioning techniques, high-precision analog front-end circuitry, and microcontroller-based data acquisition to enable real-time temperature data acquisition from multiple channels. Additionally, a user-friendly display interface is developed to provide instantaneous visualization of the acquired temperature readings. The system's performance is evaluated through calibration experiments, demonstrating its capability to provide accurate and reliable temperature measurements. This research contributes to the field of temperature sensing technology and offers a practical solution for applications requiring simultaneous multi-channel temperature monitoring and real-time display.

Keywords : RTD ; STM32; PT100 ; PCB.

List of acronyms and abbreviations

CS: Chip Select

CLK: Clock

I2C: Inter-Integrated Circuit

LCD: Liquide Cristal Display

LTDC: or LCD-TFT Liquid Crystal Display - Thin Film Transistor

MCU: Microcontroller

MISO: Master INPUT Slave OUTPUT

MOSI: Master OUTPUT slave INPUT

PCB: Printed Circuit Board

PCBA: PCB Assemble

PLC: programmable Logic Controller

RTD: Resistance Temperature Detector

SPI: Serial peripheral interface

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General Introduction

The mastery of industrial processes requires the acquisition of physical variables of various types, such as temperature, flow rate, pressure, concentration, chemical concentrations, and velocities. Measurement and control instruments collect this data and convert it into exploitable standard signals, which are then processed to meet the requirements of the given environment and the needs specified in a specifications document.

Our project aims to develop a reliable and competitive temperature controller. It is centered around the STM32 as the main calculator and must be able to acquire temperature, process data such as setting an alarm threshold or a threshold for activating ventilation, display temperature, and allow the user to make modifications to the system. The objective is to use our system for the protection of motor windings or other components.

The report will be organized in accordance with specifications formulated by the company DOOFAS, in which all the tasks of this work could be carried out.

In the first chapter, we present the development boards, the temperature sensors, namely the 4-wire Pt100 temperature sensor used in the project, and the display types.

The second chapter focuses on the development and integration of the display card and the RTD card. We discuss the specific components, circuitry, and programming involved in realizing these cards.

Third chapter we delve into the design and realization of the printed circuit board (PCB). We explore the layout, wiring, and considerations taken to ensure an efficient and reliable PCB design for our temperature controller system.

The final chapter covers the comprehensive testing process conducted for both the hardware and software aspects of the temperature controller system. We discuss the methodologies employed, the obtained results, and analyze the system's performance and accuracy.

Chapter 1 Display interface and the pt100 sensor

1.1 Introduction

In this chapter, we will explore the utilization of RTD PT100 sensors and display technologies in various applications. RTD PT100 sensors provide accurate temperature measurements, while displays serve as visual interfaces for monitoring and controlling processes. We will delve into the benefits and applications of these technologies, highlighting their significance in achieving precise temperature monitoring and enhancing operational efficiency. our choice of temperature sensor, the Pt100 3-wire probe.

1.2 State of the art on development boards

There are many development boards available that offer various functionalities such as analog/digital acquisition, digital processing, and more. The most commonly used boards include :

1.2.1 Arduino Uno

This model has been around for several years, but it remains an excellent starting point for discovering the field of embedded electronics. Equally at ease in home designs as in professional prototypes, the Arduino Uno is built around the Atmel ATmega328 processor, has 14 digital I/Os, 6 analog inputs, and is programmed using the Arduino IDE software. [6]

1.2.2 Texas Instruments AM3359

This is a powerful platform built around the Sitara AM335x ARM Cortex A8 processor. This implies vast processing capacity (not to mention that it runs Windows) but, more importantly, the presence of a PRU (Programmable Real-time Unit) makes this board a good introduction to real-time communication technologies. [2]

1.2.3 STMicroelectronics STM32

STM32 is a family of 32-bit microcontrollers produced by STMicroelectronics. These microcontrollers are based on the ARM Cortex-M processor architecture and are widely used in a variety of embedded applications, including industrial control, consumer electronics, and automotive applications. The STM32 family includes a wide range of microcontrollers with different features and capabilities, including different CPU speeds, memory sizes, and peripherals. They are available in various package types, such as LQFP, BGA, and QFN, to suit different application requirements. One of the notable features of the STM32 family is the presence of a rich set of peripherals, including ADCs, DACs, timers, communication interfaces (UART, SPI, I2C, USB), and many more. These peripherals can be used to implement a wide range of functionality, such as analog and digital signal processing, motor control, communication protocols, and user interfaces. STM32 microcontrollers are often programmed using the C programming language, with development tools provided by STMicroelectronics and other third-party vendors. The microcontrollers can also be programmed using graphical development tools, such as STM32CubeIDE, which provides a comprehensive set of tools for developing, debugging, and deploying applications for the STM32 family. [3]

1.2.4 Raspberry Pi 3

This is one of the most powerful boards on the market, with a 1.2 GHz 64-bit quad-core ARM Cortex-A53 processor that offers very high performance. It also integrates 802.11n Wireless LAN and Bluetooth 4.1. [4]

1.2.5 Freedom Board

The Freedom Board is an inexpensive development board for the Kinetis MCU family. You can add sensors, power management expansion kits, and other open-source boards. They also have a large community that makes development easier. [5]

Based on thorough research, it has been determined that the STM32 platform stands out as the optimal choice due to its exceptional reliability, competitive pricing, and robust community support.

1.3 Temperature sensors

In embedded systems, there is a constant need for higher performance and more features in a smaller form factor. This requires system designers to monitor the overall temperature to ensure safety and protect the systems. The trend of sensor data-logging further drives the need for temperature measurement to not only measure system or environmental conditions, but to compensate for temperature-sensitive components and maintain accuracy of the total system. [7]

The main temperature sensor used in the industry described below:

1.3.1 Thermocouple

A thermocouple or thermoelectric couple (TEC) is a pair of materials in physics, whose Seebeck effect, discovered in 1821 by the German physicist Thomas Johann Seebeck, is used for temperature measurement. They are inexpensive and allow measurement over a wide range of temperatures. The main limitation is the accuracy obtained. It is relatively difficult to obtain measurements with an uncertainty of less than 0.1 C. [7]

1.3.2 Thermometry by resistance

Thermometry by resistance uses, as its name suggests, the variation in the resistance of a material according to temperature. This variation in resistance can be observed with both metals (in which case we refer to them as resistance temperature detectors or RTDs) as well as oxides (in which case we refer to them as thermistors Table.I.1 gives us a comparison between the three temperature sensors already presented, according to: temperature scale, accuracy, linearity, sensitivity and cost. [1]

1.3.3 Thermometry by diodes and transistors

The principle is based on the variation of the voltage across a semiconductor and the current flowing through it as a function of temperature, expressed by the following relationship: $I=I_0.exp(qV/kT)$. Two temperature sensors based on this principle can be mentioned: the AD590 or the LM35. Sensors using diodes and transistors have the advantage of being easy to manufacture and use, inexpensive, and very linear. However, due to their design, they have a limited measuring range (-50C to 150C) and can be affected by a magnetic field,

which makes them unreliable in an industrial environment. As a first conclusion on temperature sensors, the choice of RTDs appears to be the best choice for the

realization of a digital temperature relay, and in addition, in all the consulted research, it is found that platinum RTDs are the most commonly used in industry. [1]

Criteria :	Thermocouple	RTD	thermistor
Temp scale :	267C to 2316C	-240C to 649C	-100C to 500C .
Accuracy :	Good	Optimal	Good
Linearity :	Better	Optimal	Good
Sensitivity :	Good	Better	Optimal
Cost :	Optimal	Good	Better

TABLE 1.1: comparison between temperature sensors [7]

1.4 Platinum RTD

The platinum RTDs (Resistance Temperature Detectors) are sensors commonly used in industry. Their principle is based on the temperature variation of the electrical resistance of a platinum conductor, according to known and stable characteristics described by the IEC 751 and DIN 43760 standards. These sensors can be used in temperature ranges beyond -200 to 800C. The main models encountered are Pt100, Pt500, and Pt1000, indicating their nominal electrical resistances at 0C. For example, for the most common Pt100 model, the electrical resistance at 0C is 100 ohms. It is for its widespread use in the industry that the Pt100 probe was chosen as the sensor for the Mihrar4 project. Figure 1.1 below shows the three-wire Pt100 probe. [7]



FIGURE 1.1: pt100.

1.4.1 PT100 connexion mode

There are three types of Pt100 probe on the market and the difference depends on the mode of connection : "2-wire" mode, "3-wire" mode and "4-wire" mode.

a. 2-wire mode : The simplest approach does not require any measurement accuracy as long as the effect induced by the resistance of the connection cables becomes of the same order of magnitude as the desired accuracy. Unless considered as a systematic error, a standard AWG24 cable (85 ohms/km) introduces a gross error of about 0.4°C for a Pt1000 sensor. The diagram for this mode is indicated by (A) in Figure 1.2.

b. 3-wire mode : This mode often provides a precision that is widely sufficient for long wiring distances. The principle of this connection mode is based on the assumption that the 3 connection wires have the same electrical resistance value. For example, for an AWG18 cable (21 ohms/km) with a good electrical interface, the error should be around 0.4°C for 100 meters of cable. The diagram of this mode is indicated by (B) in Figure 1.2.

c. 4-wire mode : This theoretically represents the circuit that provides the best accuracy since the voltage measurement is made directly at the active part of the sensor with a low impedance interface, and therefore the resistance of the connection cables no longer contributes to the measurement error. However, in practice, it is not preferred due to cost and other factors. The diagram of this mode is shown as (C) in Figure 1.2. [26]

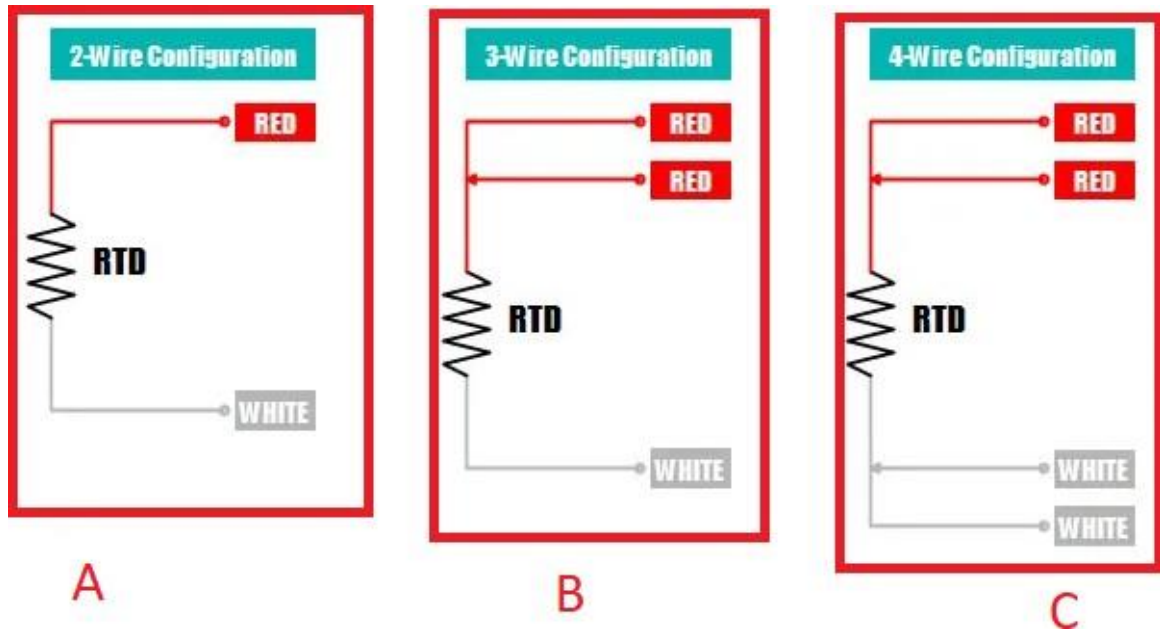


FIGURE 1.2: PT100 connection mode [26]

1.5 Display

In the majority of industrial environments, it is essential to effectively present information for visualizing our processes. This display enables human operators to monitor the status of a controlled process. This is achieved through the utilization of a Human-Machine Interface (HMI), which allows human operators to monitor and control the status of various processes and manually intervene in automatic control operations in case of emergencies. There are numerous types of displays available [8] and three of them are described below:

1.5.1 LCD (liquid Crystal Display)

LCD is a flat panel display technology that utilizes liquid crystals as its primary operational medium. LEDs (Light Emitting Diodes) have an extensive and diverse range of applications for both consumers and businesses, being commonly used in smartphones, televisions, computer monitors, and instrument panels. In general, LCDs can be connected using either parallel or serial interfaces. [9]

1.5.2 RGB Display

The RGB (Red, Green, and Blue) display technology finds widespread application in a diverse range of consumer and business contexts. It is commonly employed in devices such as smartphones, televisions, and computer monitors. The RGB color model represents the primary colors used in digital display screens. By combining red, green, and blue in varying proportions, it becomes possible to achieve a vast array of colors within the visible spectrum. In the RGB model, each color channel (red, green, and blue) utilizes 8 bits, allowing for a total of 256 possible intensity levels (ranging from 0 to 255) for each color channel. This precise control over color intensity enables the faithful reproduction of a wide gamut of colors, enhancing the visual experience and ensuring accurate color representation in various applications. [10]

1.5.3 MIPI-DSI Display

The MIPI DSI (Mobile Industry Processor Interface Display Serial Interface) is a high-speed interface specifically designed for applications involving smartphones, tablets, smartwatches, and other embedded display systems. Developed by the Mobile Industry Processor Interface Alliance, the MIPI DSI is a serial communication protocol that offers several advantages over traditional display interfaces like RGB and parallel.

Compared to RGB and parallel interfaces, which require a higher number of pins to support high resolutions and refresh rates, the MIPI DSI interface achieves the same level of performance with fewer pin connections. This reduction in pin count contributes to space-saving benefits, simplifies board designs, and allows for slimmer device form factors.

The MIPI DSI interface is optimized for high-speed data transmission, ensuring efficient and reliable communication between the display controller and the display panel. By employing a serial communication protocol, it enables faster data transfer rates while minimizing power consumption.

With its widespread adoption in the mobile industry and beyond, the MIPI DSI interface has become a standard choice for achieving high-performance display connectivity in various embedded systems. Its efficient pin utilization, high-speed data transmission, and compatibility with a range of display applications make it an essential component in modern display technologies. [11]

1.6 conclusion

In conclusion, after an extensive review of the available research, it is evident that platinum RTDs are widely adopted in the industry. Furthermore, careful analysis has determined that the STM32 platform excels as the optimal choice due to its exceptional reliability, competitive pricing, and robust community support. RTD (Resistance Temperature Detector) and display technologies hold significant importance as integral components across various industries. RTDs offer precise temperature sensing for efficient process monitoring and control, ensuring enhanced efficiency and safety. Displays serve as essential visual interfaces, empowering operators to monitor processes and make well-informed decisions. The continuous advancements in these technologies drive progress and innovation, thereby facilitating improved control, productivity, and safety measures in industrial operations.

2.1 Introduction

In the majority of industrial installations To be able to measure and display the temperature from a PT100 probe, a set of components is associated with this sensor. For this, a detailed study of the measurement chain is necessary in order to be able to set up a device capable of meeting the requirements. we are therefore going to propose and develop an acquisition system, which will allow us to acquire and display the temperatures from the eight pt100 sensors. We will also proceed to the choice of the different circuits used for the implementation of the measurement chain and the display.

2.2 HARDWARE OF THE DISPLAY CARD

in our project we used two PCB, we going to go through it one by one. The first PCB is responsible about displaying, the second one it's the responsible about receiving DATA from the RTD.

2.2.1 specification

The implementation of the display card requires very precise specifications to be followed For the HARDWARE part, our goal is to build a display card that has the following characteristics :

- An RJ45 connector.
- A 24V operating voltage that meets the needs of industry.
- An SPI port to have connected an API or external sensor.
- A micro-controller with a RAM of at least 300 KB which takes the display card.
- A small size PCB to reduce costs with a design that respects electromagnetic compatibility.
- A 24V/3.3V Buck stage to operate all equipment components.
- Adjustable and fixed voltage regulators 3.3V/1.2V .
- A Parallel Port to MIPI-DSI .
- A touch screen controller .
- A Back-light LED drivers for controlling the brightness of the LCD back- light.
- A pram (Serial Pseudo-SRAM with SPI and QPI) .

2.2.2 power injector

It is a device that combines energy and data, then sends it through an rj45 connector RJ45 is a type of connector used in Ethernet cables, commonly used in computer networks. It has eight pins, which can be used to transmit power, data, or both. It is an ideal choice for power injector applications, as it is reliable, inexpensive,

and easy to install. Power injectors are devices that are used to provide power to other devices via an Ethernet cable. They are often used in applications where the power supply is not close to the device that needs power SPI, or Serial Peripheral Interface, is a type of serial communication protocol used for short-distance communication. It is commonly used to connect microcontrollers to external devices such as sensors, memory in our case we used to connect with our API, and other integrated circuits. It is a full-duplex communication protocol, which means that it can send and receive data simultaneously RJ45 and SPI can be used together to create a powerful, reliable communication system. The RJ45 can be used to provide power to the SPI devices, while the SPI can be used to transmit data between them. This combination is often used in industrial automation applications, as it is fast, reliable, and low-power. Using RJ45 and SPI together provides many benefits. It is fast, reliable, and low-power, making it ideal for industrial automation applications. It is also easy to install and maintain, and provides a secure connection for data transmission. The components we need to have made this are: A simple rj45 connector.

a. DC/DC Buck converter : The XL1509 is a 150 KHz fixed frequency PWM buck (step-down) DC/DC converter, capable of driving a 2A load with high efficiency the table 2.1 shows the characteristics of the Buck XL1509 circuit.

Product attribute	Attribute value
Maker :	XLSEMI
Product Category :	Switching voltage regulators
Mounting style :	smd/smt
Package :	SOP8
Topology :	Buck
Max input voltage :	40V
Min input voltage :	4.5V
Output voltage :	1.23V to 37V
Switching frequency :	150KHz

Table 2.1: Buck XL1509 Features [12]

b. VOLTAGE REGULATOR : The AMS1117 series of adjustable and fixed voltage regulators are designed to provide 800mA output current and to operate down to 1V input-to-output differential as show in the table 2.2. [13]

Product attribute	Attribute value
Maker :	Advanced Monolithic Systems
series :	AMS1117
Product Category :	VOLTAGE REGULATOR
Mounting style :	smd/smt
Package :	SOT-223
Max input voltage :	15V
Min input voltage :	3V
Output voltage :	1.25V to 11.75V
Operating Junction Temperature Range :	0 to 125C

TABLE 2.2: AMS1117 REGULATOR Features [13]

Circuit used on software: For those who have never used such programs before, we will first explain the methods of connecting wires between components. Figure 2.1 shows two different ways of diagramming the connections of an electrical circuit.

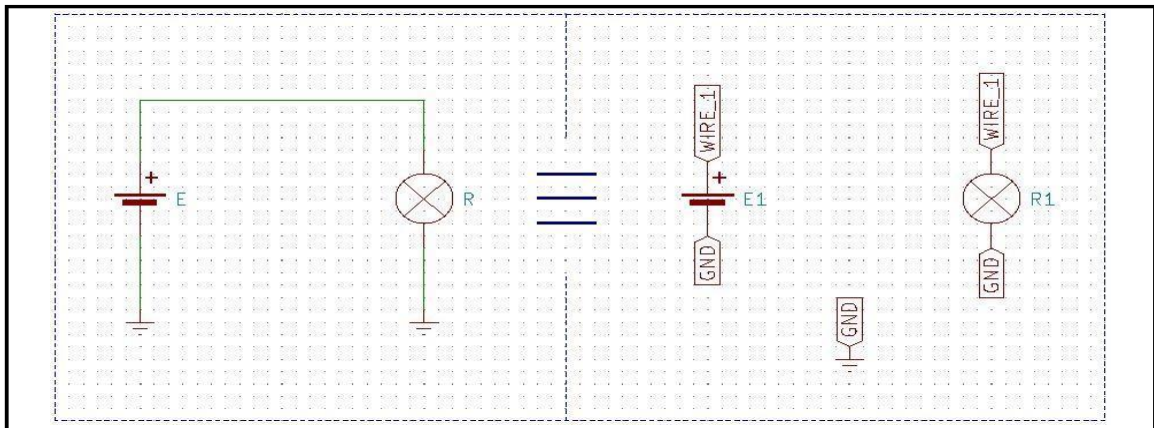


Figure2.1: Different component connection diagrams.

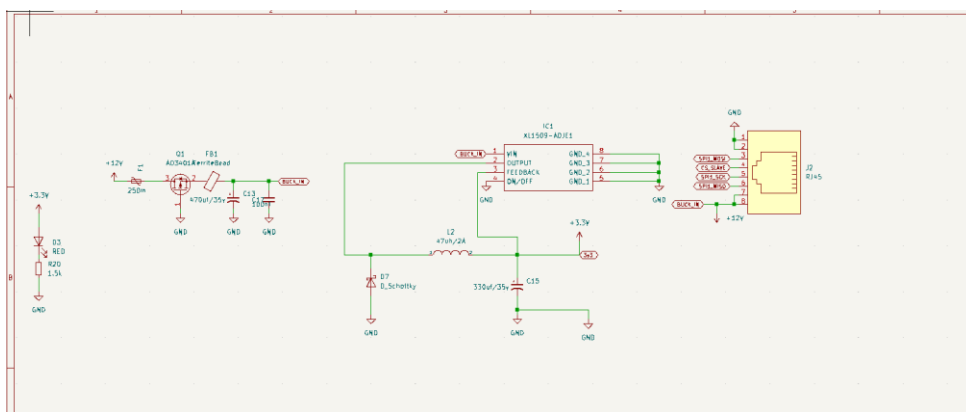


Figure 2.2: Electrical circuit used for the power injector.

2.3 I/O Devices

2.3.1 Definition

An IO-Device, also known as an Input/output Device is a hardware component that enables communication between the PLC and the outside world. These devices are responsible for sending and receiving data from the computer. They are essential for interacting with the computer system, IO-Devices can be broadly classified into two categories: input devices and output devices.

2.3.2 Choice and characteristics of the main components

The choice of components depends mainly on the specifications and the synoptic diagram in figure We have chosen the following components because of their compatibility, availability, prices and sizes.

a. MCU: STM32H7B0VBT6: In the software of ST Microelectronics (STM32CubeMX), we can choose the microcontroller according to the features it contains, Figure 2.3 shows how we chose the MCU. We first chose the tft lcd controller (LTDC) graphics display controller, a list of microcontrollers appears in ascending order in terms of specifications. Then we chose the RAM required in the specifications. The choice of case (package) is then defined, it must be the smallest. Finally, the correct microcontroller is listed. finally we choose STM32H7B0VBT6 due to its availability and the current semiconductor manufacturing crisis and their price STM32H7B0VBT6 is a32-bit microcontroller based on ARM

architecture, Table 2.3 shows its characteristics .

The screenshot shows the STM32CubeMX software interface. On the left, the 'FEATURES' sidebar has 'LCD TFT Controller' selected. The main window displays the 'STM32H7 Series' product overview for 'STM32H7B0VBT6'. Below this, a table lists various MCU variants. A red box highlights the 'LCD TFT Controller' selection. Another red box highlights the 'STM32H7B0VBT6' variant in the table. A third red box highlights the 'LQFP 100 14x14x1.4 mm' package type. A fourth red box highlights the '1184 kBytes' RAM value. Red arrows point from these boxes to the corresponding data in the table below.

Commercial Part Number	Part No.	Reference	Marketing St.	Unit Price for 10k (US\$)	Board	Package	Flash	RAM	IO	Freq.
STM32H7A3VIT6Q	STM32H7A3VIT6Q	STM32H7A3VIT6Q	Active	8.0316		LQFP 100 14x14x1.4 mm	2048 kB	1184 kBytes	70	280 MHz
STM32H7A3ZGT6	STM32H7A3ZGT6	STM32H7A3ZGT6	Active	8.1004		LQFP 144 20x20x1.4 mm	1024 kB	1184 kBytes	114	280 MHz
STM32H7A3ZIT6Q	STM32H7A3ZIT6Q	STM32H7A3ZIT6Q	Proposal	NA		LQFP 144 20x20x1.4 mm	1024 kB	1184 kBytes	99	280 MHz
STM32H7A3ZIT6	STM32H7A3ZIT6	STM32H7A3ZIT6	Active	8.7753		LQFP 144 20x20x1.4 mm	2048 kB	1184 kBytes	114	280 MHz
STM32H7A3ZIT6Q	STM32H7A3ZIT6Q	STM32H7A3ZIT6Q	Active	8.7753		LQFP 144 20x20x1.4 mm	2048 kB	1184 kBytes	99	280 MHz
STM32H7B0AB6Q	STM32H7B0AB6Q	STM32H7B0AB6Q	Active	5.7737		UFPGA 169 7x7x0.6 P 0.5 mm	28 kB	1184 kBytes	25	280 MHz
STM32H7B0BK6Q	STM32H7B0BK6Q	STM32H7B0BK6Q	Active	6.0851		UFPGA 176+25 10x10x0.6 P...	28 kB	1184 kBytes	32	280 MHz
STM32H7B0BT6	STM32H7B0BT6	STM32H7B0BT6	Active	7.0674		LQFP 176 24x24x1.4 mm	28 kB	1184 kBytes	40	280 MHz
STM32H7B0BT6	STM32H7B0BT6	STM32H7B0BT6	Active	4.48		LQFP 64 10x10x1.4 mm	28 kB	1184 kBytes	9	280 MHz
STM32H7B0BT6R	STM32H7B0BT6R	STM32H7B0BT6R	Active	8.1508		LQFP 100 14x14x1.4 mm	28 kB	1184 kBytes	9	280 MHz
STM32H7B0VBT6	STM32H7B0VBT6	STM32H7B0VBT6	Active	5.1508		LQFP 100 14x14x1.4 mm	28 kB	1184 kBytes	32	280 MHz
STM32H7B0ZBT6	STM32H7B0ZBT6	STM32H7B0ZBT6	Active	6.1809		LQFP 144 20x20x1.4 mm	28 kB	1184 kBytes	114	280 MHz
STM32H7B3AI6Q	STM32H7B3AI6Q	STM32H7B3AI6Q	Active	6.084		UFPGA 169 7x7x0.6 P 0.5 mm	168 kB	1184 kBytes	25	280 MHz
STM32H7B3AI6Q	STM32H7B3AI6Q	STM32H7B3AI6Q	Active	6.084		UFPGA 176+25 10x10x0.6 P...	168 kB	1184 kBytes	32	280 MHz

FIGURE 2.3 : MCU selection steps

Product attribute	Attribute value
Maker :	STMicroelectronics
Product Category :	ARM Microcontrollers - MCUs
Series :	STM32H7B0VB
Mounting style :	smd/smt
Package :	LQFP 100
core :	Arm Cortex M7
Flash memory :	128 Kbytes

RAM :	1.4 Mbytes
Data bus width :	32-bit
CAN resolution :	16-bit
Max clock frequency :	280 MHz
Number of I/O :	80 I/O
Operating supply voltage :	1.62 V to 3.6 V
Minimum operating temperature :	-40 C
Maximum operating temperature :	85 C
Type of program memory :	Flash
Data Ram Type :	SRAM

TABLE 2.3: Features of the stm32h7b0vbt6 [14]

b. Parallel Port to MIPI-DSI: Toshiba TC358778XBG

The Toshiba TC358778XBG is a parallel port to MIPI DSI (RGB to DSI) converter that allows for seamless communication between different devices. This device is particularly useful in situations where legacy displays need to be connected to modern devices with MIPI DSI interfaces. All internal registers can access through I2C or SPI. the Table 2.4 shows the specifications of the TC358778XBG. [15]

Product attribute	Attribute value
Maker :	Toshiba
Product Category :	RGB to DSI Bridge
Series :	TC358778
Mounting style :	smd/smt
Package :	VFBGA-80
Data rate :	1GB/s
Type d'interface :	I2C/SPI
Operating supply voltage :	1.1 V to 3.6 V
Minimum operating temperature :	-30 C
Maximum operating temperature :	+85 C

TABLE 2.4: Features of the TC358778XBG [15]

c. Touch screen controller NS2009

The NS2009 is a 4-wire resistive touch screen controller with I2C Interface, includes 12-bit resolution A / D converter. The NS2009 through the implementation of the two A / D conversion has been identified by the location of the screen, in addition to measurable increase in pressure on the touch screen. 2.7V typical work in the state, the closure of the reference voltage, power consumption can be less than 0.75mW. the Table 2.5 shows the specifications of the NS2009. [16]

Product attribute	Attribute value
Maker :	Shenzhen Nsiway Tech
Product Category :	Touch Screen Controllers
Mounting style :	smd/smt
Package :	MSOP-10
Type d'interface :	I2C
Operating supply voltage :	2V to 5V
Minimum operating temperature :	-40 C
Maximum operating temperature :	+85 C

TABLE 2.5 : Features of the NS2009 [16]

d. BOOST converter MT9284

The MT9284 is a step-up converter designed for driving up to 7 series white LEDs from a single cell Lithium Ion battery. The MT9284 uses current mode, fixed frequency architecture to regulate an LED current, which is measured through an external current sense resistor. the Table 2.6 shows the specifications of the MT9284. [19]

Product attribute	Attribute value
Maker :	XI'AN Aerosemi Tech
Product Category :	Boost White LED Driver
Mounting style :	smd/smt
Package :	SOT-23-6
Switching Frequency :	1.2 MHz
Operating supply voltage :	2.5V to 5.5V
Max Output voltage :	30V

Minimum operating temperature :	-40 C
Maximum operating temperature :	+85 C
LED current OUTPUT :	0mA to 20mA

TABLE2.6: Features of theMT9284 [19]

e. Pseudo-SRAM APS6404L-3SQR-SN

This Pseudo-SRAM device features a high speed, low pin count interface. It has 4 SDR I/O pins and operates in SPI (serial peripheral interface) or QPI (quad peripheral interface) mode with frequencies up to 133 MHz. The data input (A/DQ) to the memory relies on clock (CLK) to latch all instructions, addresses and data. It is most suitable for low-power and low cost portable applications. It incorporates a seamless self-managed refresh mechanism. Hence it does not require the support of DRAM refresh from system host. The self-refresh feature is a special design to maximize performance of memory read operation. [17]

Product attribute	Attribute value
Maker :	AP Memory Technology
Product Category :	Psram
Mounting style :	smd/smt
Package :	SOP-8
Switching Frequency :	133 MHz
interface Type :	: SPI/QSPI
Ram size :	64mb
Operating supply voltage :	2.7V to 3.6V
Minimum operating temperature :	-40 C
Maximum operating temperature :	+85 C
Page size :	1024 bytes

TABLE 2.7: Features of the APS6404L-3SQR-SN [17]

2.3.3 hardware Configuration

The hardware configuration is linked to the datasheet, here we will show how to configure each component from its datasheet.

a. The STM32H7B0VBT6 microcontroller

Power circuit : Figure 2.4 shows the stm32h7b0vbt6 power supply circuit. The 4.7F ceramic capacitor should be connected to one of the VDD pins Each power supply pair (VDD/VSS, VDDA/VSSA ...) must be decoupled with filtering ceramic capacitors as shown above. These capacitors must be placed as close as possible to, or below, the appropriate pins on the underside of the PCB to ensure good operation of the device. It is not recommended to remove filtering capacitors to reduce PCB size or cost. This might cause incorrect operation of the device.

Check Appendix B for power supply schematics of the MCU.

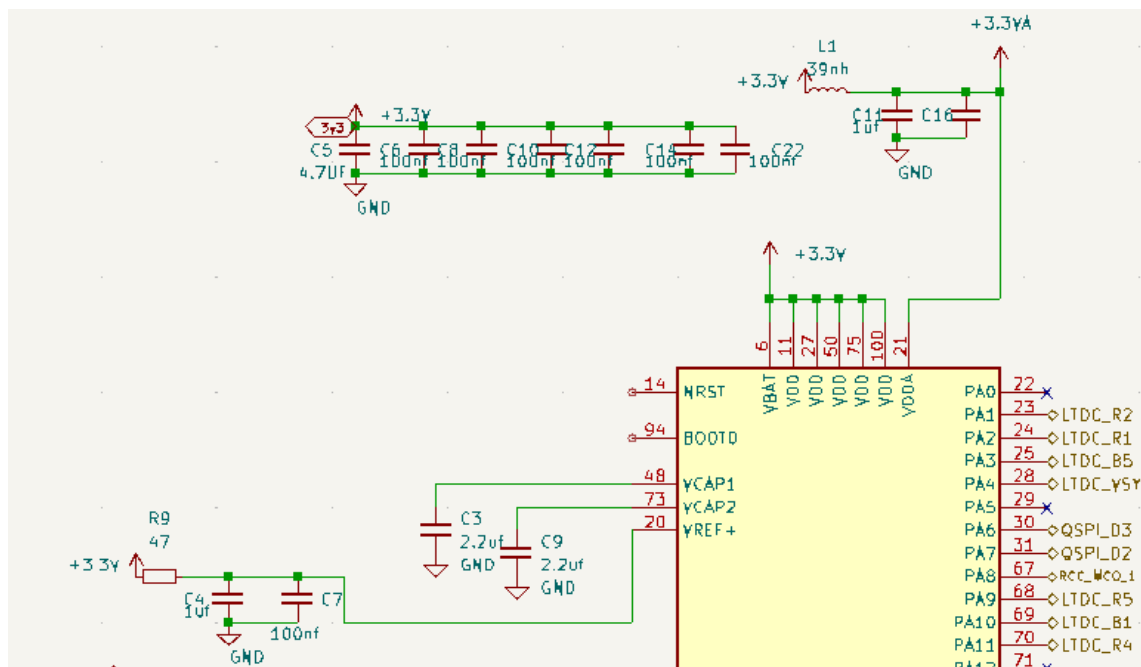


FIGURE 2.4: Power supply diagram on software

Clock management:

The devices embed four internal oscillators, two oscillators with external crystal or resonator, two internal oscillators with fast startup time and three PLLs. The high-speed external (HSE) clock can be supplied with a 4 to 50 MHz crystal/ceramic resonator oscillator. All the information given in this paragraph are based on characterization results obtained with typical external components. In the application, the resonator and the load capacitors have to be placed as close as possible to the oscillator pins in order to minimize output distortion and startup stabilization time for CL1 and CL2, it is recommended to use high-quality external ceramic capacitors in the 5 pF to 25 pF range (typical), designed for high-frequency applications, and selected to match the requirements of the crystal or resonator (see the figure 2.5. Typical application with an 8 MHz crystal). CL1 and CL2 are usually the same size. The crystal

manufacturer typically specifies a load capacitance (CL) which is the series combination of CL1 and CL2. The PCB and MCU pin capacitance must be included (6pF can be used as a rough estimate of the combined pin and board capacitance) when sizing CL1 and CL2. The following equation gives the expression of CL :

$$CL = 2 * (Cr - cs)$$

Cr :load capacitance of the crystal(12pf see on data sheet of it)

cs=the straight capacitance of the pcb (it's 6pf)

so CL1=CL2=12pf

Check Appendix B for typical application with an 8 MHz crystal.

the figure 2.5 show configuration of the HSE crystal.

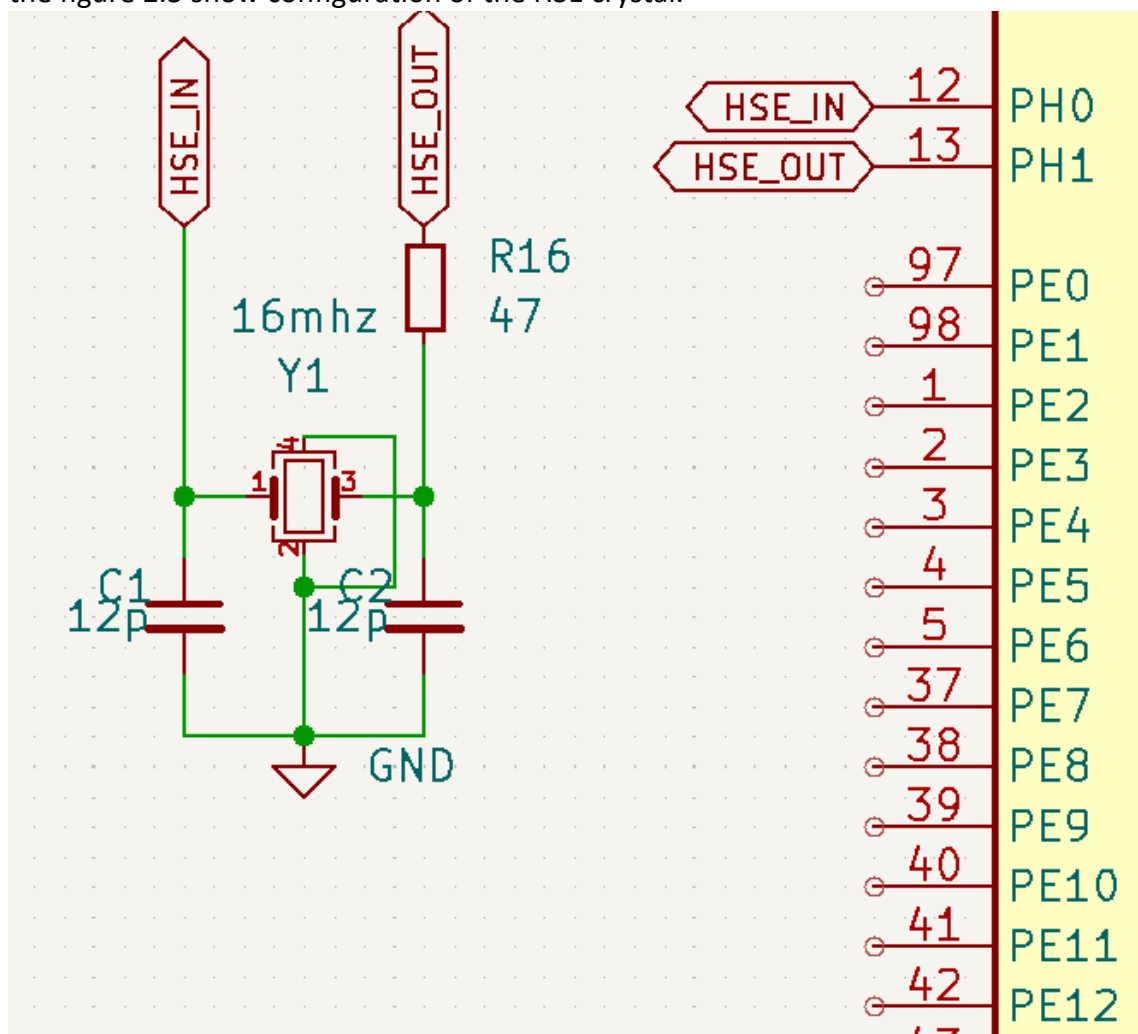


FIGURE 2.5: HSE crystal configuration

Serial wire debug (SWD):

Code transfer and debugging is done on five pins, two pins of SWD, reset and power pins as shown in Figure 2.6 And to program the microcontroller we need ST-LINK/V2 In

Circuit Debugger/Programmer for STM8 and STM32.

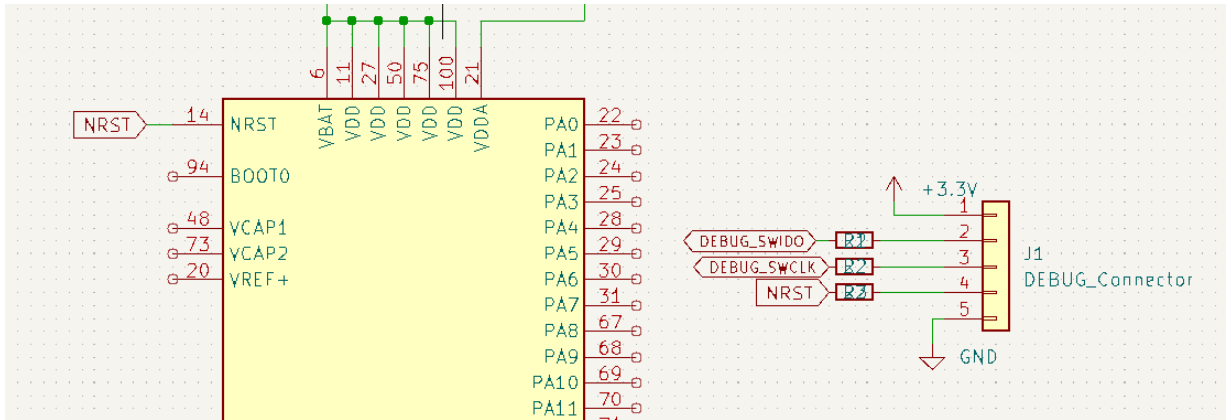


FIGURE 2.6: Serial wire debug (SWD)



FIGURE 2.7: ST-LINK/V2 In-Circuit Debugger/Programmer [18]

Figure 2.8 illustrates the connection of the five pins of the stm32 with the ST-LINK/V2.

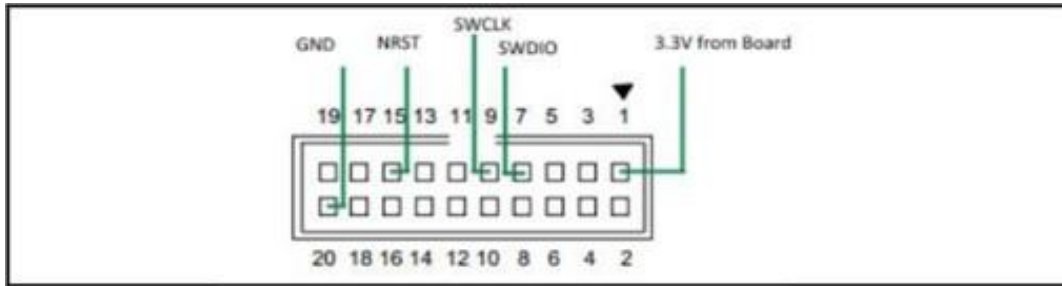


FIGURE 2.8: Connecting the MCU with ST-LINK/V2

Communication io-device/I2C:

Communication between input/output (IO) devices and microcontrollers is often facilitated through the I2C (Inter-Integrated Circuit) protocol, which utilizes a two-wire interface consisting of a serial data line (SDA) and a serial clock line (SCL). The SDA line serves as the communication channel for transmitting and receiving data between devices, while the SCL line provides the clock signal that synchronizes the data transfer. The I2C protocol operates in a master-slave configuration, where the master device initiates communication by generating start and stop signals on the bus. Slave devices connected to the bus respond accordingly by transmitting or receiving data as directed by the master. This synchronous, bidirectional communication protocol allows for efficient and reliable exchange of data, commands, and control signals, enabling seamless integration of various IO devices, such as sensors, displays, memory modules, and actuators, with microcontroller-based systems. The figure 2.9 shows connections of three basic I2C devices to an I2C bus. [20]

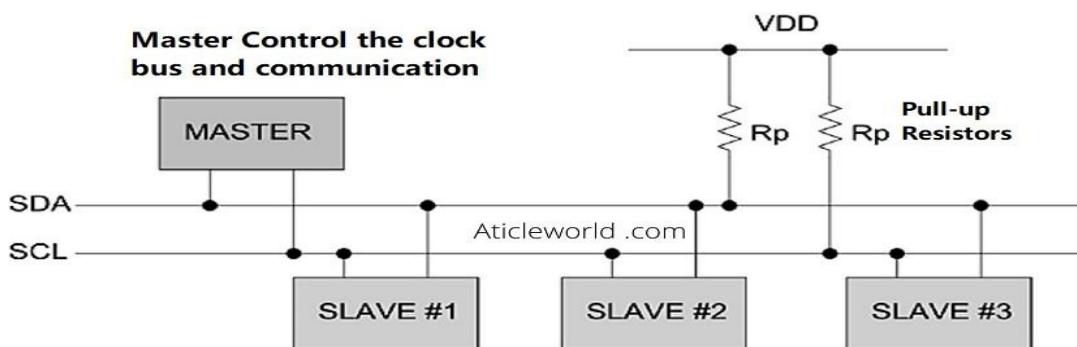


FIGURE 2.9: three basic I2C devices to an I2C bus

LCD connection:

LCD (Liquid Crystal Display) connection involves establishing a physical and electrical connection between the LCD module and a microcontroller or development board. The specific connection method depends on the type of LCD module and the interface it uses. In general, LCDs can be connected using either parallel or serial interfaces. For

parallel connection, multiple data lines are used to send commands and data to the LCD, along with control lines for synchronization and control signals, the connection process entails correctly mapping the pins of the LCD module to the corresponding pins of the microcontroller, ensuring proper voltage levels, and configuring the microcontroller to communicate with the LCD using the appropriate interface. It is crucial to consult the datasheet and documentation of both the LCD module and the microcontroller to ensure accurate pin assignments and to follow any specific guidelines or requirements provided by the manufacturer. the figure 2.12 show the Interface pin description

Check appendix A Table 1 for Interface Pin Description.

the figure 2.10 show the LCD connection in software.

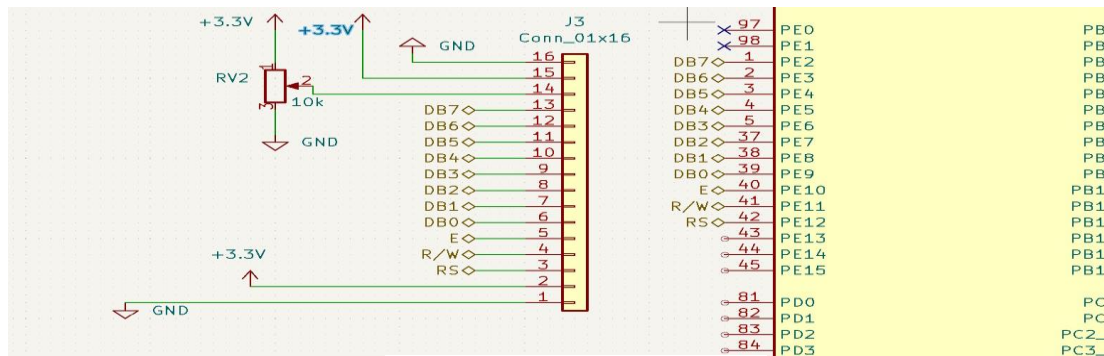


FIGURE 2.10: LCD connection

LTDC connection :

The LTDC (LCD-TFT Display Controller) connection on STM32 microcontrollers provides a robust and versatile interface for driving LCD and TFT display panels. Integrated within the STM32 microcontroller, the LTDC module simplifies the process of connecting and controlling displays. This connection supports parallel interfaces, enabling high-speed data transfer between the microcontroller and the display panel. Configuring the LTDC connection on STM32 involves specifying parameters such as display resolution, timing, and color format. STMicroelectronics provides the STM32Cube software package, which includes drivers and libraries specifically designed for the LTDC connection. These software components abstract low-level details and offer high-level APIs, facilitating the development of graphical user interfaces (GUIs) with ease. By utilizing the LTDC connection on STM32 microcontrollers, developers can create captivating GUIs for a wide range of applications. With the processing power and rich peripheral set of STM32 microcontrollers, the LTDC connection ensures smooth rendering of graphics, images, and text on LCD and TFT displays. From industrial automation to medical devices and consumer electronics, the LTDC connection on STM32 microcontrollers delivers a reliable and efficient solution for driving high-quality displays. [21]

Check Appendix A Table 2 for LTDC interface output signals

the figure 2.11 show the LTDC connection in software.

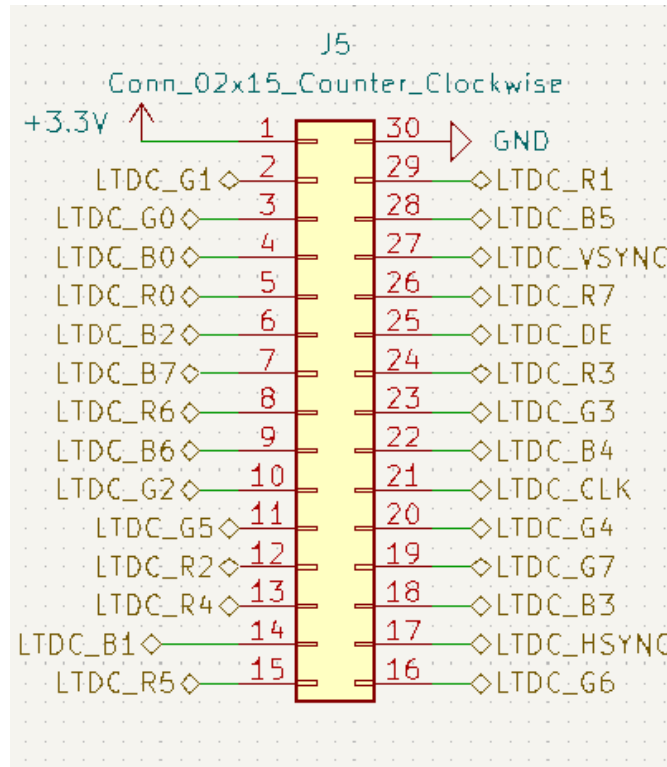


FIGURE 2.11: LTDC connection

b. DC/DC Buck converter XL1509

Before proceeding to configure the XL1509, we must first follow the IC datasheet, Figure 2.16 illustrates the recommended and maximum operating conditions of the circuit. On the other hand, Figure 2.17 illustrates the efficiency as a function of the current when Vout is equal to 3.3V.

Check Appendix C table 1,2 for Working conditions and Typical performance characteristics of XL1509.

Typical Application Circuits:

We have configured the XL1509 circuit, a typical application circuit when VOUT is 3.3V and VIN is +12V. The role of the 4th pin EN (enable), Drive ON/OFF pin low to turn on the device, drive it high to turn it off. Floating is default low.

Check Appendix B figure 3 for Typical application diagram of 3.3V output of XL1509.

the figure 2.12 show the Diagram used in the software.

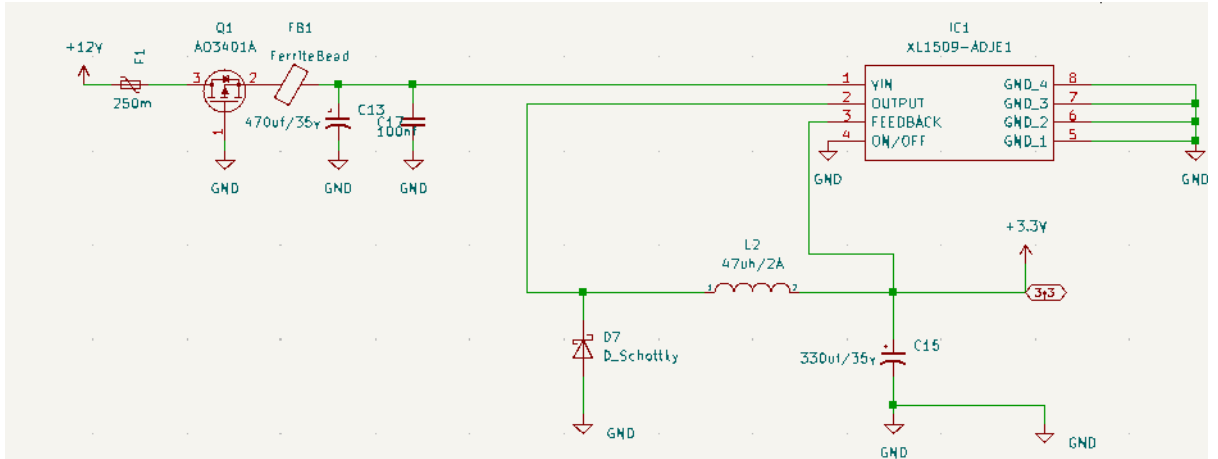
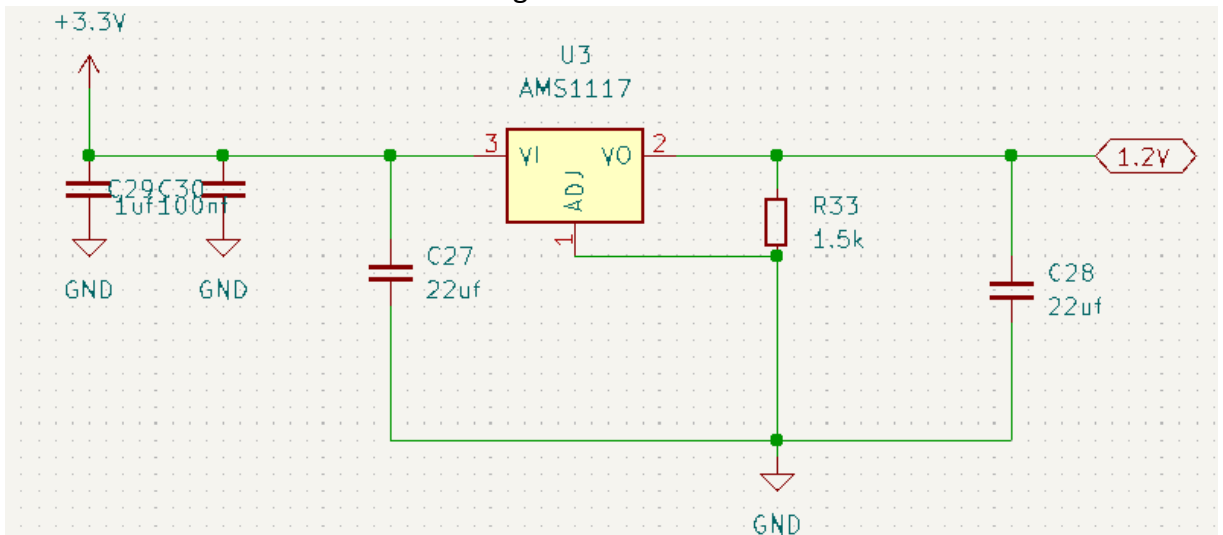


FIGURE 2.12: Wiring diagram of the power management unit

c. VOLTAGE REGULATOR AMS117

The AMS1117 series of adjustable and fixed voltage regulators are designed to provide 800mA output current and to operate down to 1V input-to-output differential as show in the table we used to drive from 3.3v to 1.2v, the figure 2.13 show the Diagram used in the software.

FIGURE 2.13: Diagram used in the software



d. RGB to DSI Converter TC358778XBG

System diagram :

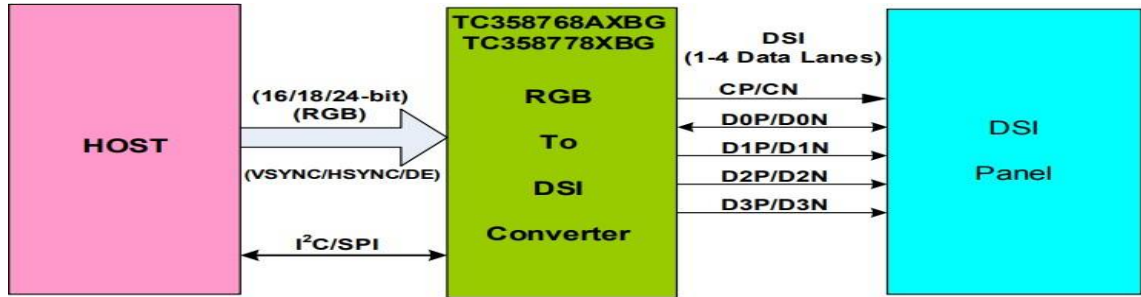


FIGURE 2.14: System Overview

Check Appendix A Table 3 for pinout description of TC358778XBG.

The figure 2.15 show the Diagram used in the software.

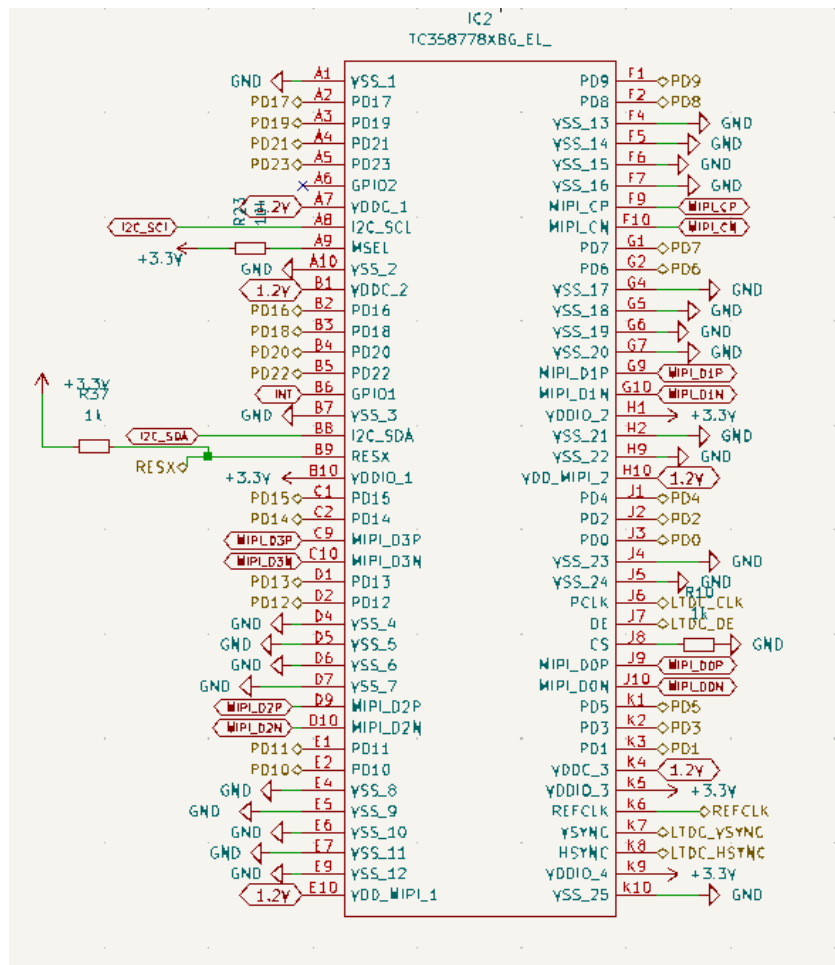


FIGURE 2.15: typical application diagram of TC358778XBG in software

Mipi-DSI connection :

Mipi-DSI (Mobile Industry Processor Interface Display Serial Interface) is a widely adopted interface standard for establishing a seamless connection between display panels and mobile devices such as smartphones and tablets. With its high-speed and efficient communication capabilities, MIPI DSI plays a pivotal role in ensuring vibrant and immersive visual experiences. The connection process involves the integration of two key components: the DSI host, typically embedded within the system-on-chip (SoC) of the mobile device, and the DSI device, integrated into the display panel itself. These components are linked through a flexible printed circuit (FPC) cable, facilitating the transmission of data, commands, and control signals. By leveraging MIPI DSI, device manufacturers can unlock the full potential of their display panels, delivering stunning visuals and enabling advanced features such as touch input and display configuration. the figure 2.16 show the Mipi-DSI connection on software.

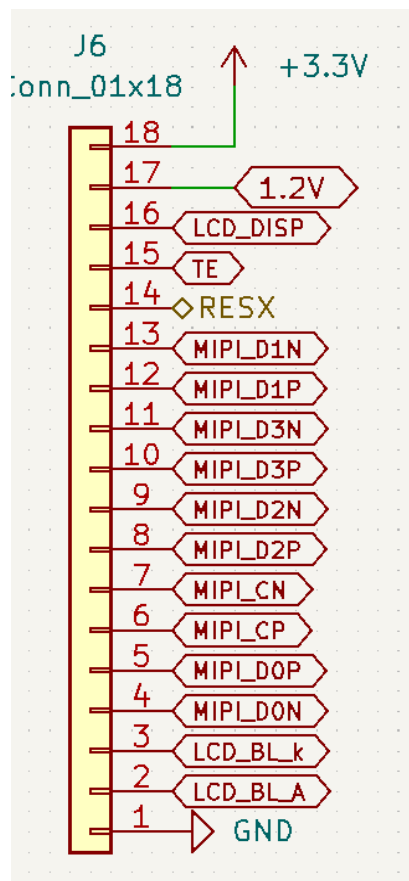


FIGURE 2.16: Mipi-DSI connection

e. Touch Screen Controller NS2009

Before proceeding to configure the NS2009, we must first follow the datasheet of the integrated circuit.

Check Appendix C table 3 for Working conditions of NS2009.

Check Appendix A table 4 for pin description of NS2009.

Typical Application Circuit:

The figure 2.17 show Typical Application Circuit in software the figure 2.18 show the touch penal output.

Check Appendix B figure 4 for Typical Application Circuit of NS2009.

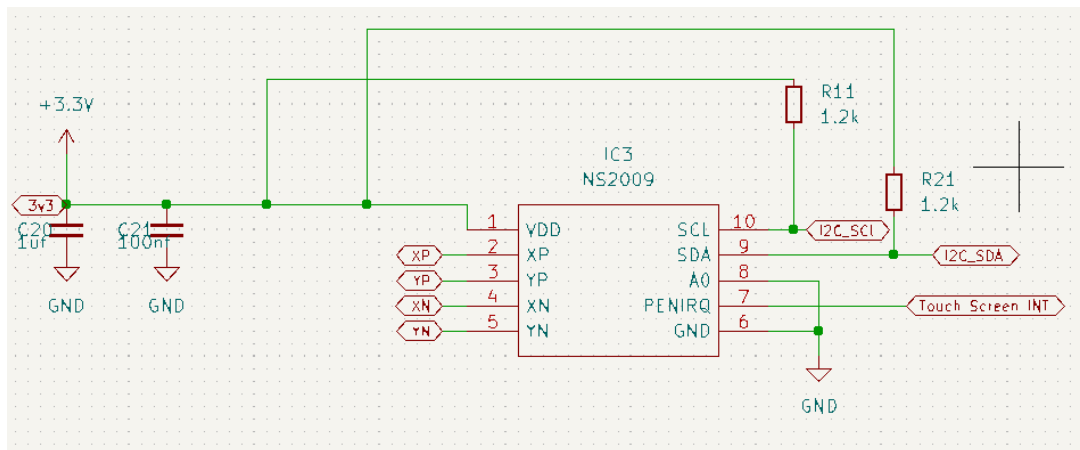


FIGURE 2.17: Typical Application Circuit in software

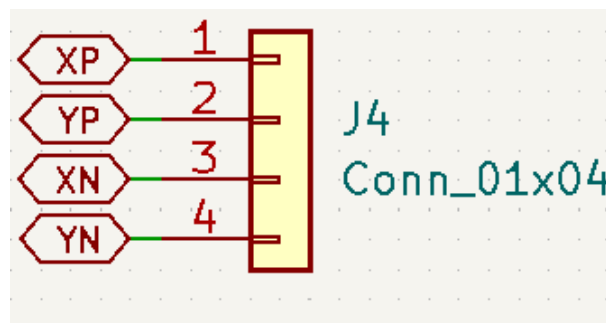


FIGURE 2.18: touch penal output

f. BOOST Converter MT9284

Before proceeding to configure the MT9284, we must first follow the datasheet of the integrated circuit.

Check Appendix C figure 1 for Working conditions of MT9284

Check Appendix A table 5 for MT9284 pin description

Typical Application Circuit:

The figure 2.19 show Typical Application Circuit in software.

Check Appendix B figure 5 for Typical Application Circuit of MT9284.

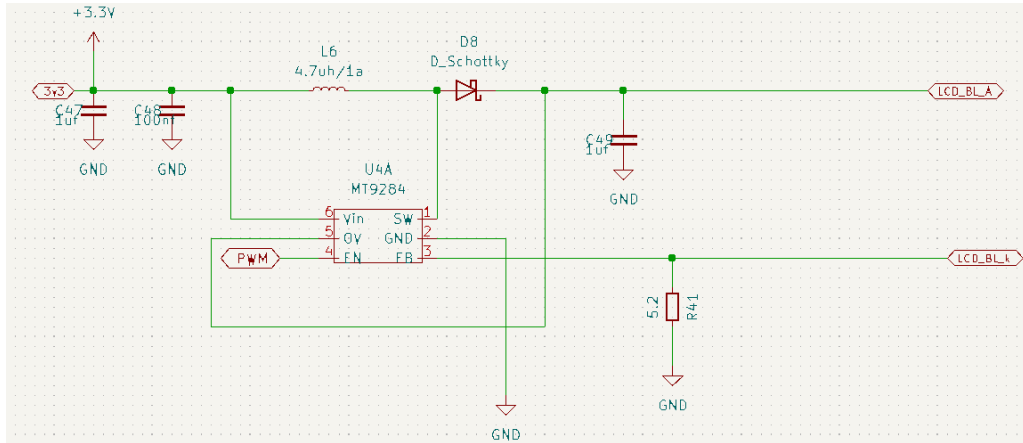


FIGURE 2.19: Typical Application Circuit in software

g. Pseudo-SRAM APS6404L-3SQR-SN

The figure 2.20 show the circuit used on software.

Check Appendix A table 6 for pin description of APS6404L-3SQR-SN

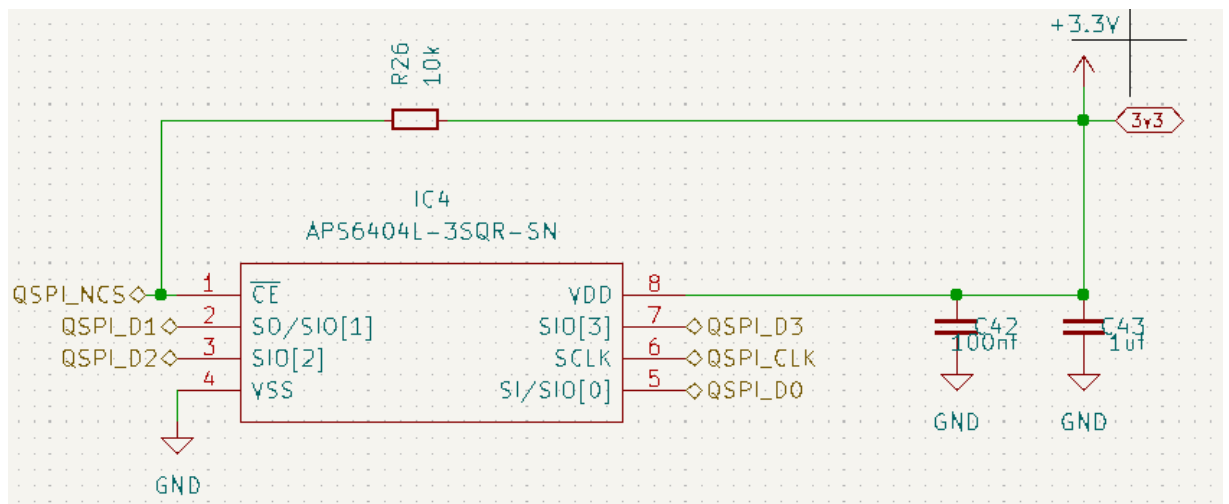


FIGURE 2.20: circuit used on software.

This was all about our first PCB (Data Display Card), now we are going to move to the second PCB (Data Charges Model).

2.4 HARDWARE OF DATA CHARGES MODEL

The figure 2.21 shows the overall view of the HARDWARE of our project.

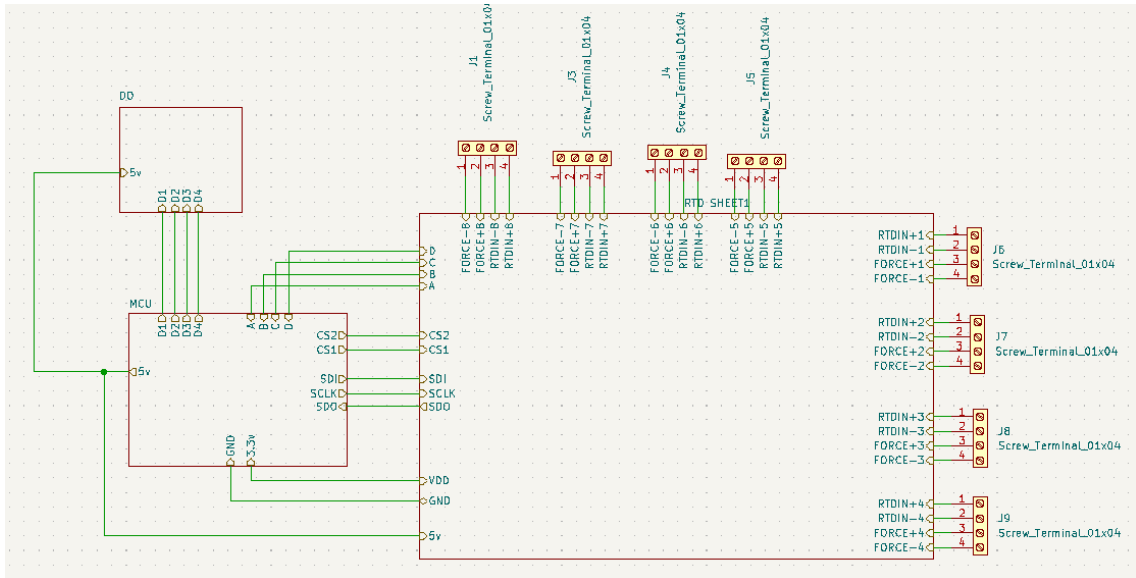


FIGURE 2.21: Overall block diagram

2.4.1 specification

The implementation of the data acquisition card requires very precise specifications to be followed for the HARDWARE part, our goal is to build a data acquisition card that has the following characteristics:

- Two SPI port to connect with the API and sensors (Master, Slave) and receiving power.
- The capacity of receiving data of eight RTD.
- A small size PCB to reduce costs with a design that respects electromagnetic compatibility.
- A 5V / 3.3V Voltage Regulator to operate all equipment components.
- About four terminal blocks for the DO.
- The ability to read all kind of RTD (2wire , 3wire , 4wire).
- A micro-controller with at least 2 SPI port and enough RAM to do the work

2.4.2 power supply

So our board is connected with an API using an SPI port, since the API has his own power, he also going to be charged of supplying our board with 5V through the SPI port. The figure 2.22 will explain the pins of the SPI.

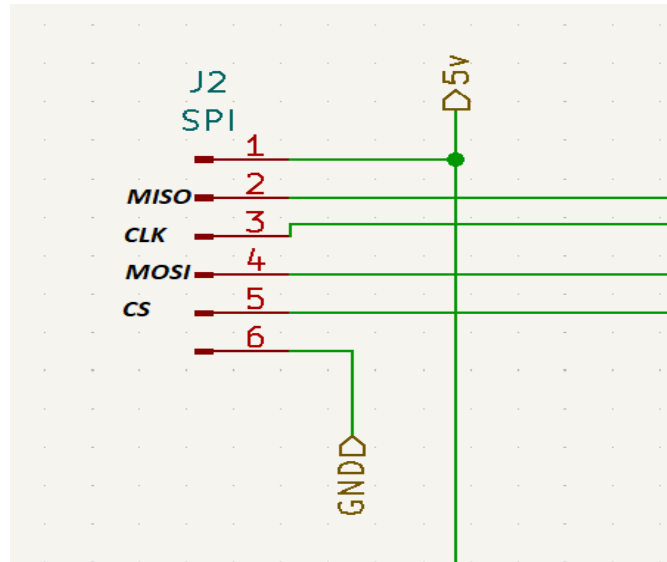


FIGURE 2.22: SPI pins

We also need a 3.3V to supply some component in our board, for that we used a voltage regulator on the 5v. figure 2.23 will show you the regulator we used.

VOUT	Package	Order No.	Package Marking	Supplied As	Status
3.3V	SOT-223	LM1117S-3.3V	1117C 3.3	Reel	Active
	SOT-223	LM1117GS-3.3V	1117GC 3.3	Reel	Contact us
	TO-252	LM1117RS-3.3V	LM1117C 3.3	Reel	Active
	TO-252	LM1117GRS-3.3V	LM1117GC 3.3	Reel	Contact us
	SOT-89	LM1117F-3.3V	1117C 3.3	Reel	Active
	SOT-89	LM1117GF-3.3V	1117GC 3.3	Reel	Active
5.0V	SOT-223	LM1117S-5.0V	1117C 5.0	Reel	Active
	SOT-223	LM1117GS-5.0V	1117GC 5.0	Reel	Contact us
	TO-252	LM1117RS-5.0V	LM1117C 5.0	Reel	Active
	TO-252	LM1117GRS-5.0V	LM1117GC 5.0	Reel	Contact us
	SOT-89	LM1117F-5.0V	1117C 5.0	Reel	Active
	SOT-89	LM1117GF-5.0V	1117GC 5.0	Reel	Active

FIGURE 2.23: different type of regulator [27]

a. Voltage regulator LM1117S-3.3

The LM1117S-3.3 is a popular voltage regulator integrated circuit (IC) widely used in electronic circuits and power supply applications. Manufactured by various semiconductor companies, it is designed to provide a fixed output voltage of 3.3 volts with a maximum output current of 800 mA. This low-dropout (LDO) regulator offers efficient voltage regulation, even when the input voltage is only slightly higher than the desired output voltage. With its compact size, thermal shutdown protection, and excellent load and line regulation characteristics, the LM1117S-3.3 is highly regarded for its reliability and ease of use in a variety of electronic devices and systems. [27]

Check Appendix C table 4 for Electrical Characteristics of LM1117s

Check Appendix A table 7 for LM1117s pin description

the figure 2.24 show the application in software.

Check Appendix B figure 6 for Typical Application Circuit of LM1117s

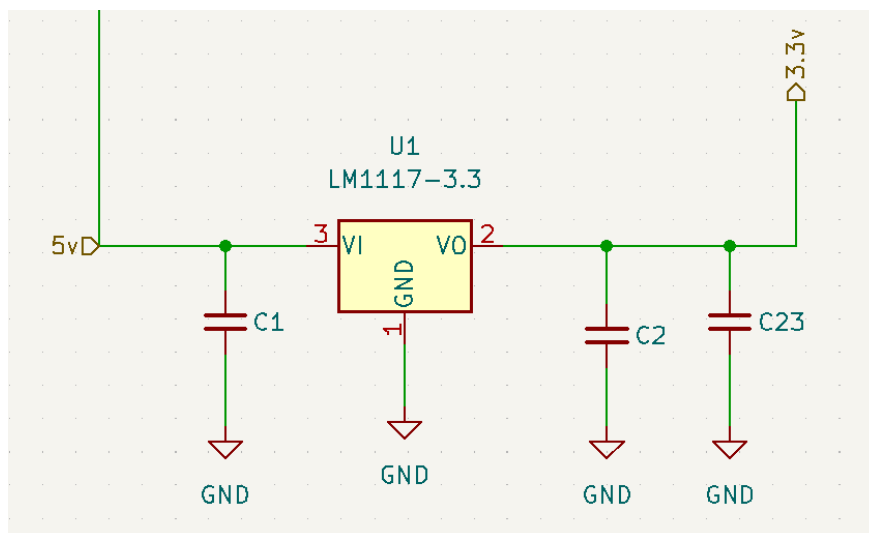


FIGURE 2.24: application in software

2.4.3 data acquisition

The sensor used in our project is the Pt100, in order to have the abilities to receive eight sensors we used multiplexer to switch between the sensors. The multiplexer used here is CD4052B, an analogue multiplexer.

a. Multiplexer CD4052B

The CD4052B is a widely used integrated circuit (IC) that belongs to the CMOS family. It is specifically designed as a multiplexer/demultiplexer, allowing for efficient signal routing and switching in electronic circuits. The IC features two independent 4-channel analog multiplexers, which can be controlled through binary signals to select one of the input channels and route it to the output. The CD4052B operates over a wide voltage range and is known for its low power consumption, making it suitable for various applications in digital and analog systems, such as data acquisition, audio/video signal routing, and communication systems. Its compact size, ease of use, and reliable performance have made it a popular choice among electronic enthusiasts and professionals alike. [28]

Check Appendix A table 8 for the truth table of CD4052B

after that the signal is leaded to a resistance to digital converter Max31865.

b. Resistance to Digital Converter MAX31865

Description :

The MAX31865 is an easy-to-use resistance-to-digital converter optimized for platinum resistance temperature detectors (RTDs). An external resistor sets the sensitivity for the RTD being used and a precision delta-sigma ADC converts the ratio of the RTD resistance to the reference resistance into digital form. The MAX31865's inputs are protected against overvoltage faults as large as Q45V. Programmable detection of RTD and cable open and short conditions is included.[29]

Benefits and Features:

- Integration Lowers System Cost, Simplifies Design Efforts, and Reduces Design Cycle Time
 - Simple Conversion of Platinum RTD Resistance to Digital Value
 - Handles 100Ω to 1kΩ (at 0°C) Platinum RTDs (PT100 to PT1000)
 - Compatible with 2-, 3-, and 4-Wire Sensor Connections
 - SPI-Compatible Interface
 - 20-Pin TQFN and SSOP Packages
- High Accuracy Facilitates Meeting Error Budgets
 - 15-Bit ADC Resolution; Nominal Temperature Resolution 0.03125NC (Varies Due to RTD Nonlinearity)
 - Total Accuracy Over All Operating Conditions: 0.5NC (0.05% of Full Scale) max
 - Fully Differential VREF Inputs

- 21ms (max) Conversion Time
- Integrated Fault Detection Increases System Reliability
 - $\pm 45V$ Input Protection
 - Fault Detection (Open RTD Element, RTD Shorted to Out-of-Range Voltage, or Short Across RTD Element)

Applications :

- Industrial Equipment
- Medical Equipment
- Instrumentation

Check Appendix A table 9 for pin configuration of MAX31865.

Check Appendix B figure 7,8,9 for Typical Application Circuits for 2, 3 or 4 wire

The data is led to the MCU for data processing. the MCU used here is STM32F103CBT6.

c. Microcontroller **STM32F103CBT6**

Description :

The STM32F103CBT6 is a microcontroller from the STM32F1 series developed by STMicroelectronics. It is built on the ARM Cortex-M3 core, offering a balance between performance, power efficiency, and cost-effectiveness. The STM32F103CBT6 provides a wide range of features and peripherals, including GPIO ports, timers, UART, SPI, I2C, and ADC, making it suitable for a variety of applications. It has 128 KB of Flash memory and 20 KB of RAM, providing ample space for program storage and data manipulation. The microcontroller operates at a maximum frequency of 72 MHz, enabling fast execution of tasks. With its robust architecture and comprehensive set of capabilities, the STM32F103CBT6 serves as a reliable and versatile choice for embedded system development.[30]

Features :

- ARM 32-bit Cortex™-M3 CPU Core
 - 72 MHz maximum frequency, 1.25 DMIPS/MHz (Dhrystone 2.1) performance at 0 wait state memory access
 - Single-cycle multiplication and hardware division
- Memories
 - 64 or 128 Kbytes of Flash memory
 - 20 Kbytes of SRAM
- Clock, reset and supply management

- 2.0 to 3.6 V application supply and I/Os
- POR, PDR, and programmable voltage detector (PVD)
- 4-to-16 MHz crystal oscillator
- Internal 8 MHz factory-trimmed RC
- Internal 40 kHz RC
- PLL for CPU clock
- 32 kHz oscillator for RTC with calibration
- Low power
 - Sleep, Stop and Standby modes
 - VBAT supply for RTC and backup registers
- 2 x 12-bit, 1 μ s A/D converters (up to 16 channels)
 - Conversion range: 0 to 3.6 V
 - Dual-sample and hold capability
 - Temperature sensor
- DMA
 - 7-channel DMA controller
 - Peripherals supported: timers, ADC, SPIs, I²Cs and USARTs
- Up to 80 fast I/O ports
 - 26/37/51/80 I/Os, all mappable on 16 external interrupt vectors and almost all 5 V-tolerant
- Debug mode
 - Serial wire debug (SWD) & JTAG interfaces
- 7 timers
 - Three 16-bit timers, each with up to 4 IC/OC/PWM or pulse counter and quadrature (incremental) encoder input
 - 16-bit, motor control PWM timer with deadtime generation and emergency stop
 - 2 watchdog timers (Independent and Window)
 - SysTick timer 24-bit downcounter
- Up to 9 communication interfaces
 - Up to 2 x I²C interfaces (SMBus/PMBus)
 - Up to 3 USARTs (ISO 7816 interface, LIN, IrDA capability, modem control)
 - Up to 2 SPIs (18 Mbit/s)
 - CAN interface (2.0B Active)
 - USB 2.0 full-speed interface
- CRC calculation unit, 96-bit unique ID
- Packages are ECOPACK [30]

2.5 Software implementation

in figure 2.25 show the global view of the software side used in our project

In our project, we have three essential steps that need to be executed. Firstly, we acquire temperature values using an RTD card, specifically the MAX31865, which communicates via SPI full duplex master mode. With a total of eight RTDs available, we select the desired one by setting the appropriate select bit. Once the data, representing the temperature, is read, we wait for a request from the SPI sent by our API, Safir.

In Safir, an extensive processing takes place. It initiates a request to the RTD card, retrieving the temperature data. Subsequently, Safir sends the acquired temperature value to the display card for visualization. Alongside this, Safir performs various other tasks, including sending output data to the RTD card to manipulate the output based on temperature conditions or other relevant factors.

Moreover, the display card also facilitates two-way communication with Safir. It can transmit data to Safir, enabling manual control over the output. This allows for direct intervention and adjustment of the output based on specific requirements or conditions.

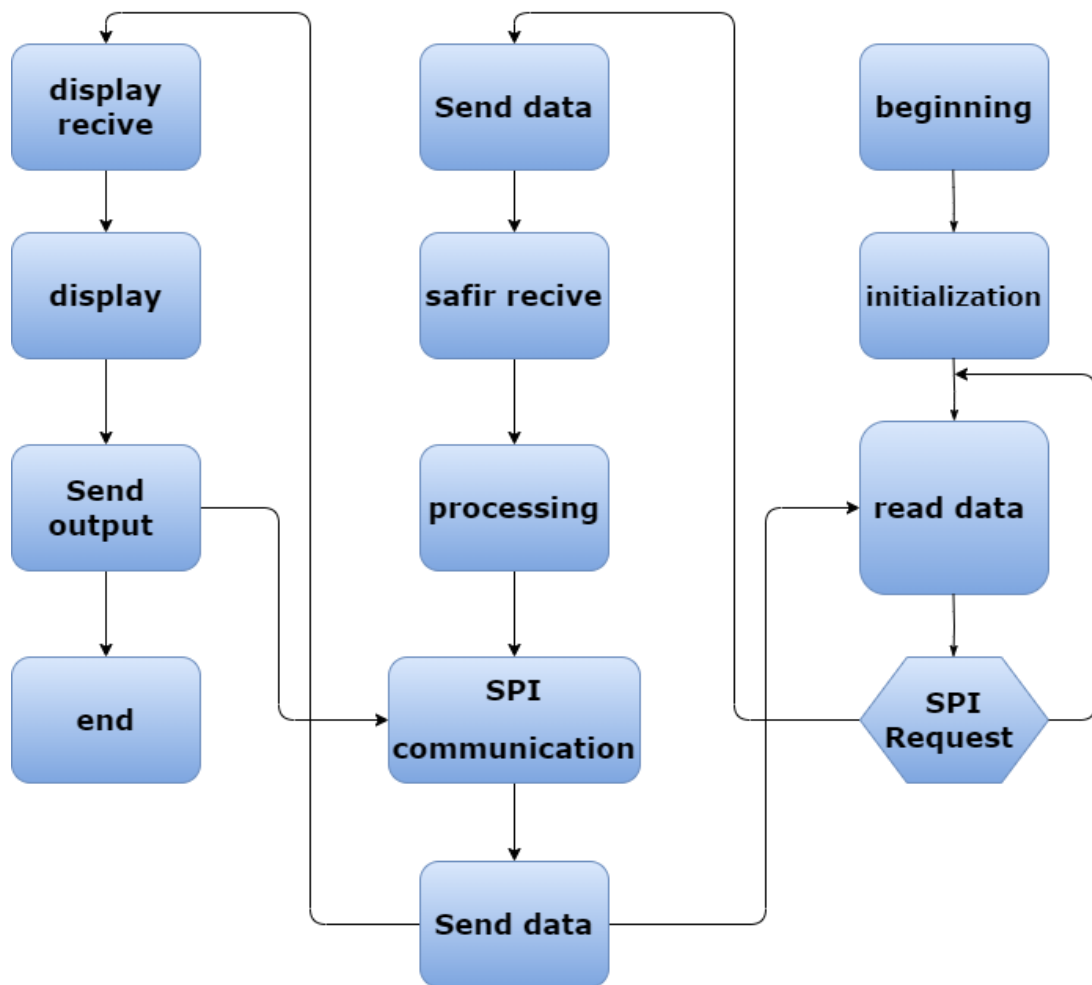


FIGURE 2.25: Overview of the program

2.6 Software implementation of display cart

in figure 2.26 show the global view of the software side of the display cart The software side we made is a program that runs on the STM32H7B0VBT6 microcontroller

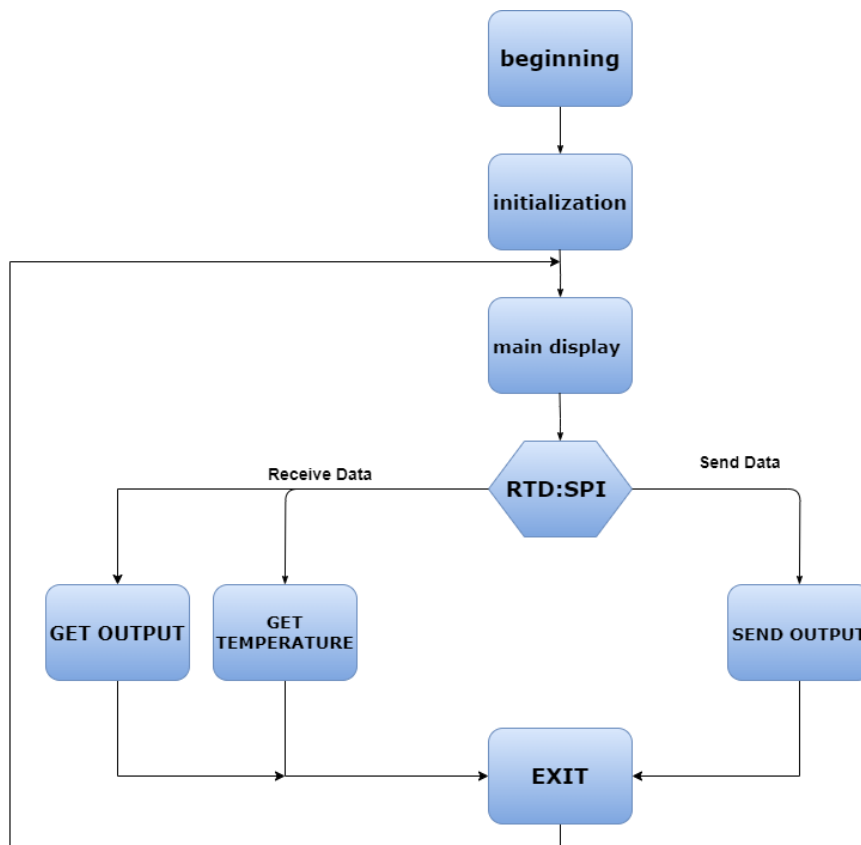


FIGURE 2.26: Overview of the display program

The software used in the display cart serves the purpose of presenting data received from Safir. It features a user interface with four distinct menus. The main menu acts as the principal menu, allowing users to navigate to different menus by scrolling up or down. To access a specific menu, users simply need to click the "OK" button. The first menu is dedicated to displaying temperature information obtained from the RTD (Resistance Temperature Detector). The second menu, labeled "Get Output," provides visibility into the state of the output from the RTD or Safir cart. Lastly, the "Set Output" menu allows users to configure four different outputs. Scrolling up or down enables selection of the desired output, and clicking "OK" triggers a change in the output state, either setting it to 1 or 0. In all other menus, a common button labeled "Exit" serves as a means to return to the main display.

2.6.1 Configuring the STM32H7B0VBT6

To configure the initialization code of the stm32H7B0VT6, we use the STM32CubeIDE and STM32CubeMX software from STMicroelectronics.

a. RCC

To configure the RCC you must:

- Enable HSE by selecting Crystal/Ceramic Resonator.
- Enable Master Clock Output to use as the MIPI DSI-bridge(TOSHIBA TC358778XBG) clock.

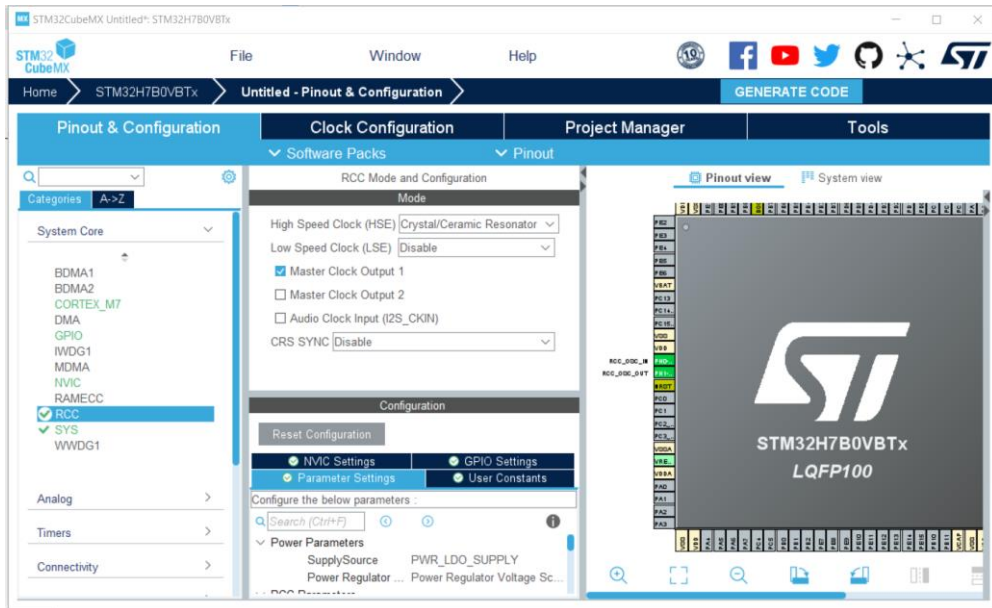


FIGURE 2.27: RCC Configuration

b. The Clock

- Configure the input frequency to 16 Mhz from HSE.
- Select PLL clock source from HSE.
- Select 280Mhz system clock from PLLCLK.

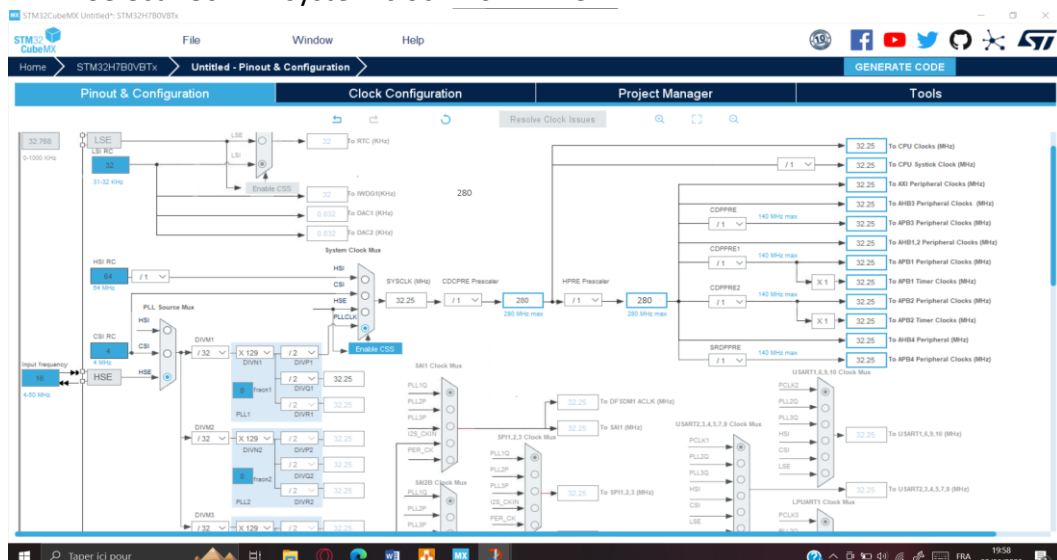


FIGURE 2.28: Clock configuration

c. SYS (Debug)

To configure the SYSTEM, you must select the debug mode on Serial Wire.

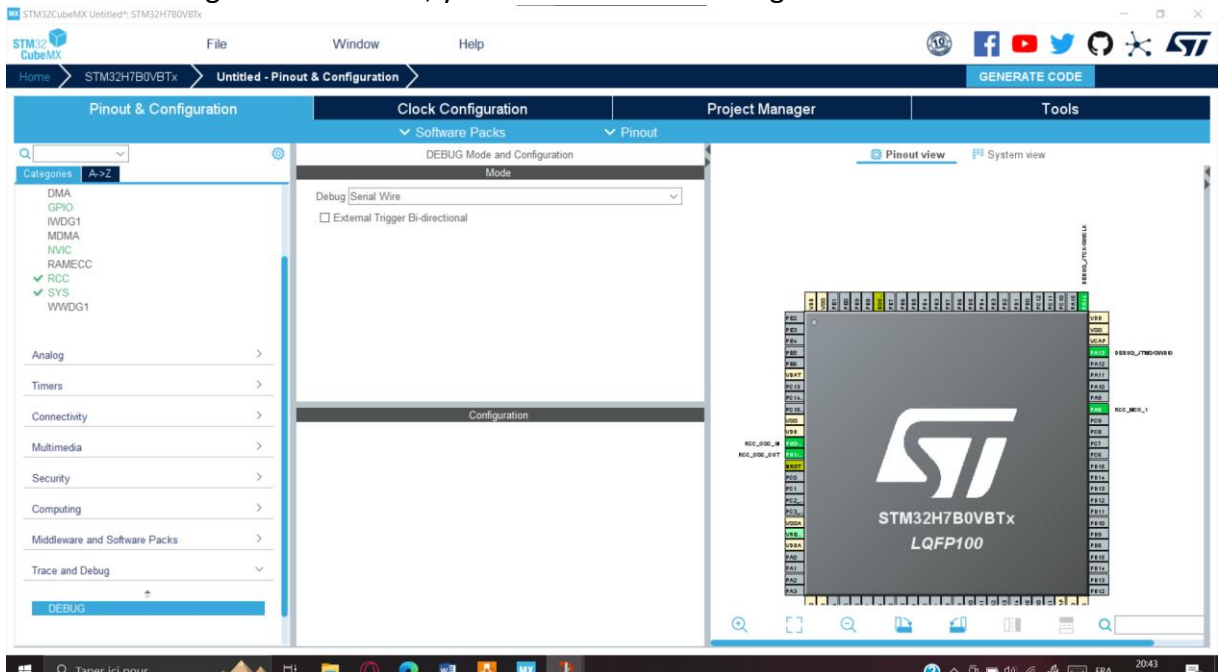


FIGURE 2.29: configuring SYS (debug mode)

d. SPI

To configure the SPI, we should set it to full-duplex slave mode.

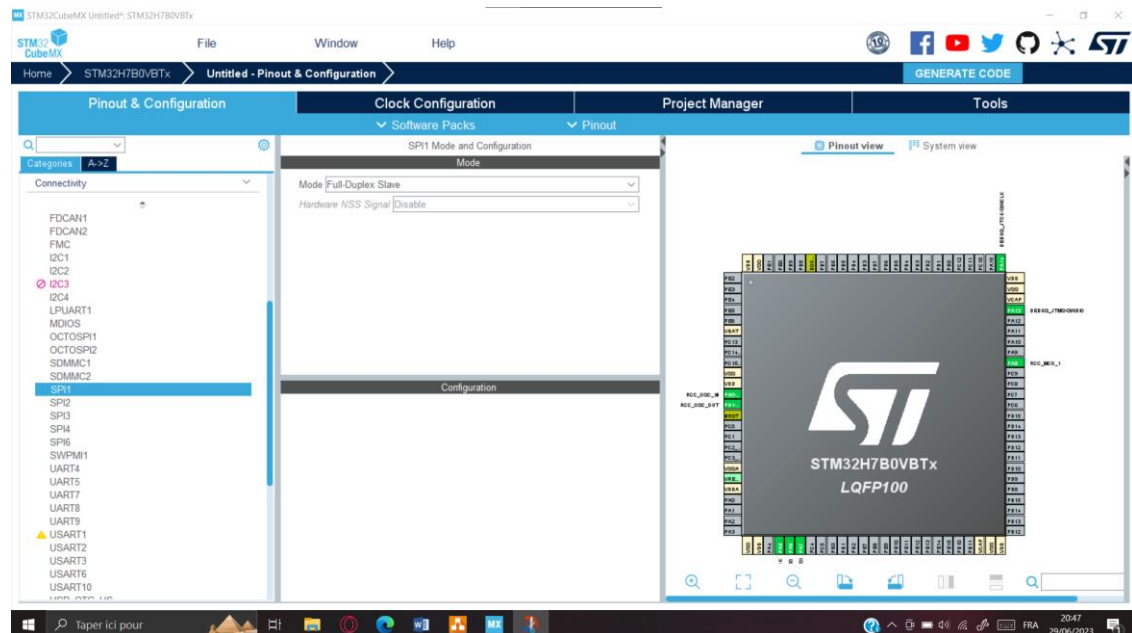


FIGURE 2.30: SPI configuration

e. LTDC

To configure the LTDC you must Choose the display type: 24-bit, 18-bit, or 16-bit. In our case, we select 24-bit to ensure compatibility with all types of displays.

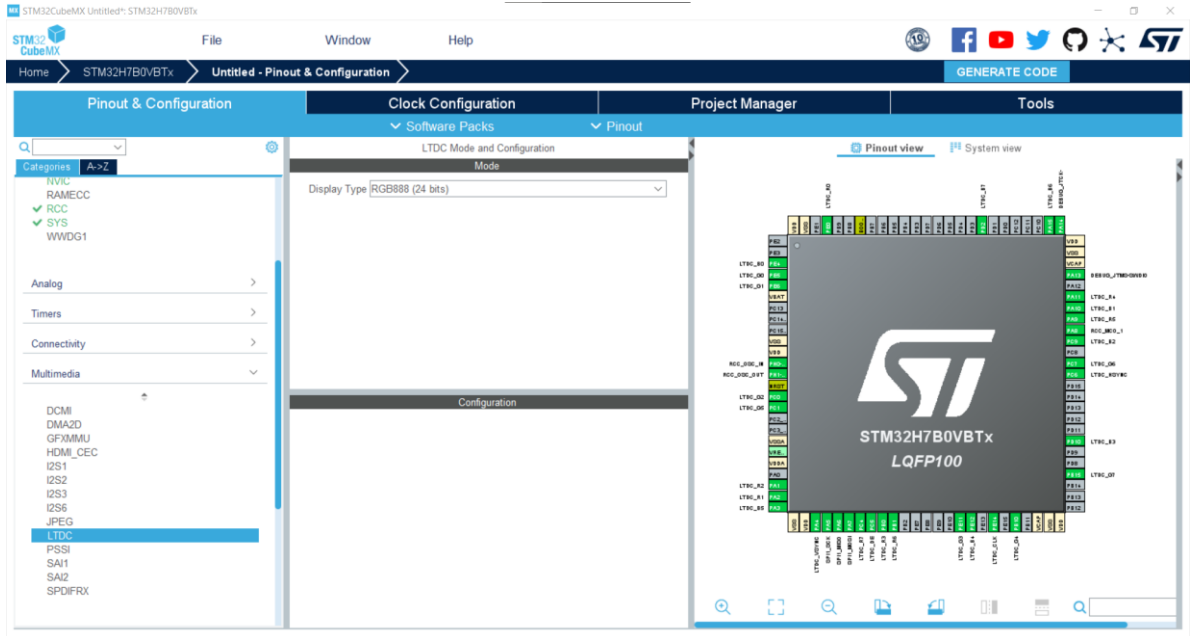


FIGURE 2.31: LTDC Configuration

2.6.2 Realization of the program

a. ST7920

ST7920 LCD controller/driver IC can display alphabets, numbers, Chinese fonts and self-defined characters. It supports 3 kinds of bus interface, namely 8-bit, 4-bit and serial. All functions, including display RAM, Character Generation ROM, LCD display drivers and control circuits are all in a one-chip solution. With a minimum system configuration, a Chinese character display system can be easily achieved.

To begin, we analyze the datasheet of the ST7920 to understand its functionality and register structure. The initialization process involves sending commands using the appropriate register functions. Subsequently, data can be sent to the display. After initializing the display, we can start presenting data on it. If we intend to draw graphics, such as a logo, we need to initialize the graphic mode separately, as stated in the datasheet. [22]

in the figure 2.32, show how the send commands work.

```

void ST7920_SendCmd (uint8_t cmd)
{
    HAL_GPIO_WritePin(CS_PORT, CS_PIN, GPIO_PIN_SET); // PULL the CS high

    SendByteSPI(0xf8+(0<<1)); // send the SYNC + RS(0)
    SendByteSPI(cmd&0xf0); // send the higher nibble first
    SendByteSPI((cmd<<4)&0xf0); // send the lower nibble
    delay_us(50);

    HAL_GPIO_WritePin(CS_PORT, CS_PIN, GPIO_PIN_RESET); // PULL the CS LOW
}

```

FIGURE 2.32: send command configuration

after that we have to send data, in the figure 2.33 we see how it's work

```

void ST7920_SendData (uint8_t data)
{
    HAL_GPIO_WritePin(CS_PORT, CS_PIN, GPIO_PIN_SET); // PULL the CS high

    SendByteSPI(0xf8+(1<<1)); // send the SYNC + RS(1)
    SendByteSPI(data&0xf0); // send the higher nibble first
    SendByteSPI((data<<4)&0xf0); // send the lower nibble
    delay_us(50);
    HAL_GPIO_WritePin(CS_PORT, CS_PIN, GPIO_PIN_RESET); // PULL the CS LOW
}

```

FIGURE 2.33: Send data command configuration

After completing the aforementioned steps, we proceed to send a command to enable writing on our display. This involves sending a string of characters to the display module, in the figure 2.34 show how it's work

```

void ST7920_SendString(int row, int col, char* string)
{
    switch (row)
    {
        case 0:
            col |= 0x80;
            break;
        case 1:
            col |= 0x90;
            break;
        case 2:
            col |= 0x88;
            break;
        case 3:
            col |= 0x98;
            break;
        default:
            col |= 0x80;
            break;
    }

    ST7920_SendCmd(col);

    while (*string)
    {
        ST7920_SendData(*string++);    }
}

```

FIGURE 2.34: Send string command configuration

After completing all the previous steps, we proceed to initialize the graphic mode in order to display the desired graphics as shown in Figure 2.35

```

void ST7920_GraphicMode (int enable) // 1-enable, 0-disable
{
    if (enable == 1)
    {
        ST7920_SendCmd(0x30); // 8 bit mode
        HAL_Delay (1);
        ST7920_SendCmd(0x34); // switch to Extended instructions
        HAL_Delay (1);
        ST7920_SendCmd(0x36); // enable graphics
        HAL_Delay (1);
        Graphic_Check = 1; // update the variable
    }

    else if (enable == 0)
    {
        ST7920_SendCmd(0x30); // 8 bit mode
        HAL_Delay (1);
        Graphic_Check = 0; // update the variable
    }
}

```

FIGURE 2.35: graphic mode configuration

Finally, we need to clear the display before writing or displaying new content. Figure 2.36 illustrates the process of clearing the display, as described in the datasheet. By following the instructions provided, we ensure that the display is empty and ready to showcase new information or graphics.

```
void ST7920_Clear()
{
    if (Graphic_Check == 1) // if the graphic mode is set
    {
        uint8_t x, y;
        for(y = 0; y < 64; y++)
        { if(y < 32)
          { ST7920_SendCmd(0x80 | y);
            ST7920_SendCmd(0x80);
          }
          else
          {
              ST7920_SendCmd(0x80 | (y-32));
              ST7920_SendCmd(0x88);
          }
          for(x = 0; x < 8; x++)
          {
              ST7920_SendData(0);
              ST7920_SendData(0);}
        }
    }
    else
    {
        ST7920_SendCmd(0x01); // clear the display using command
        HAL_Delay(2); // delay >1.6 ms
    }
}
```

FIGURE 2.36: clear display configuration

Once all the display register commands are properly initialized, we proceed to our program. Firstly, we initialize the SPI communication to facilitate data transmission and reception from the Safir api module. We work with SPI interrupts, which enable us to receive and send data every time a button is pressed.

Moving to the display operations, we decide whether we are receiving or sending data. Initially, the display will showcase the company logo. Next, we navigate through the main menu display, which offers three options: "Get Temperature," "Get Output," and "Set Output." We use different buttons to scroll through the options, such as the up and down buttons. To confirm a selection, we utilize the OK button.

Within the "Get Temperature" and "Get Output" options, we can view the respective states without making any changes. However, within the "Set Output" option, we can modify the output based on our preference, choosing between 1 and 0. Additionally, an exit button is available to return to the main display.

2.7 Software implementation of Data charges card

in figure 2.37 show the global view of the software side of the data charges card The software side we made is a program that runs on the STM32F103CBT6 microcontroller

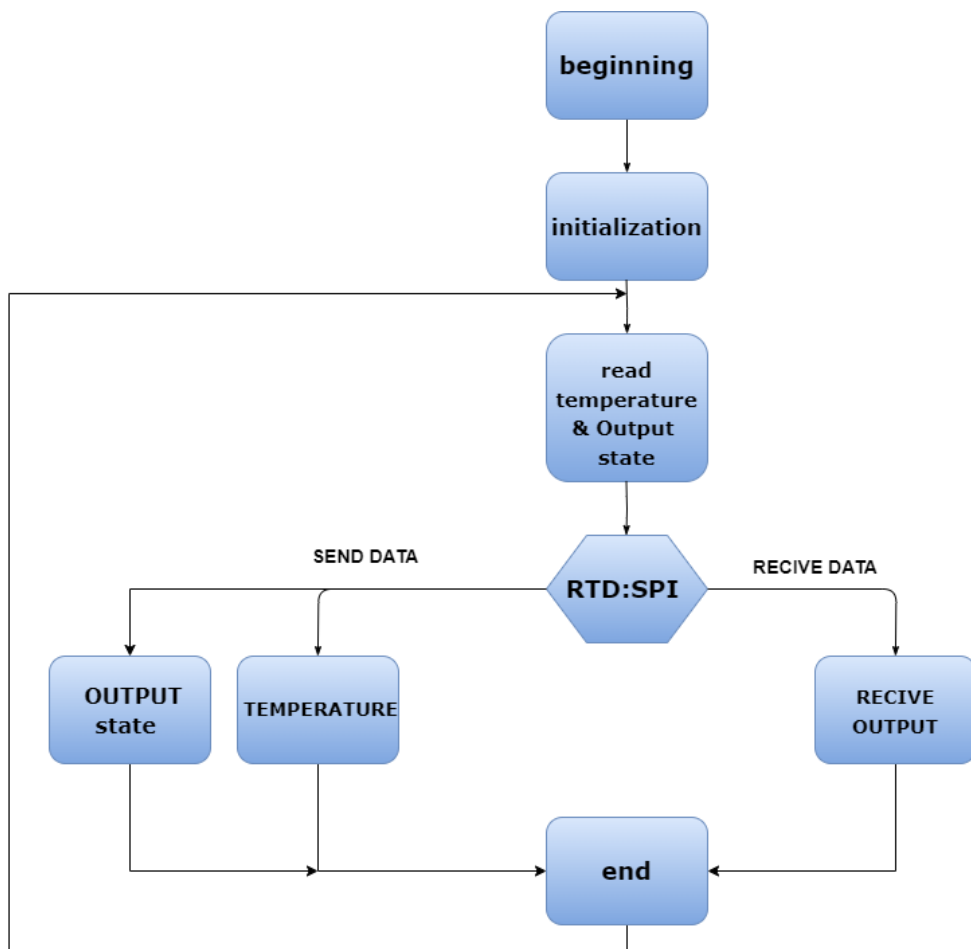


FIGURE 2.37: Overview of the Data charges program

In the RTD section, the initial step involves configuring the MAX31865 and its associated registers to establish communication with our RTDs. Following that, we set up the SPI as a master since we are interfacing with two MAX31865 devices. We utilize the select bit (CS) of the SPI to choose the specific device we wish to communicate with, thereby establishing communication between the MCU (STM32F103) and the selected MAX31865.

Moving to the main program, we are presented with eight RTDs to read from, along with a multiplexer. To facilitate this, we create a 4-bit selection mechanism to choose the desired RTD for reading. Additionally, we have four output pins that can be set to either 1 or 0 based on the program logic. For example, if the temperature exceeds a certain threshold, we set the output pin to 1.

To manage the acquired information effectively, we employ a buffer. The data from the RTDs, along with the output pins, is stored in this buffer. Once the buffer is populated, we establish another SPI full duplex master to communicate with the display module. Here, we wait for a SPI request from the display module to send the buffer data, enabling the display of the collected information.

2.7.1 Configuration of the STM32F103CBT6

To configure the initialization code of the stm32H7B0VT6, we use the STM32CubeIDE and STM32CubeMX software from STMicroelectronics, some of this configuration was the same as the STM32H7B0VT6 that don't need to be explain again

a. Clock configuration

- Configure the input frequency to 16 Mhz from HSE
- Select PLL clock source from HSE
- Select 72Mhz system clock from PLLCLK

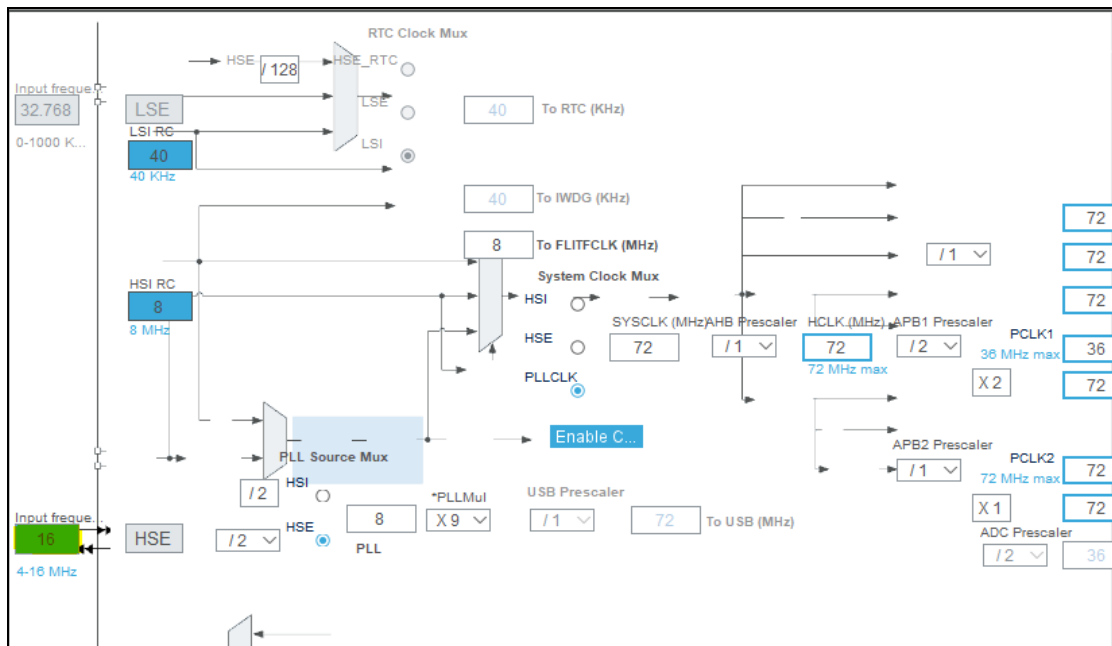


FIGURE 2.38: clock configuration


```

28
29 enum REG{
30     REG_READ_CONFIGURATION = 0x00,
31     REG_READ_RTD_MSB,
32     REG_READ_RTD_LSB,
33     REG_READ_HIGH_FAULT_TH_MSB,
34     REG_READ_HIGH_FAULT_TH_LSB,
35     REG_READ_LOW_FAULT_TH_MSB,
36     REG_READ_LOW_FAULT_TH_LSB,
37     REG_READ_FAULT_STATUS,
38     REG_WRITE_CONFIGURATION = 0x80,
39     REG_WRITE_HIGH_FAULT_TH_MSB = 0x83,
40     REG_WRITE_HIGH_FAULT_TH_LSB,
41     REG_WRITE_LOW_FAULT_TH_MSB,
42     REG_WRITE_LOW_FAULT_TH_LSB
43 };
44

```

FIGURE 2.40: register configuration program

The figure 2.41 show the program that apply the register configuration

```

45 enum {
46     D0 = 0x01,
47     D1 = 0x02,
48     D2 = 0x04,
49     D3 = 0x08,
50     D4 = 0x10,
51     D5 = 0x20,
52     D6 = 0x40,
53     D7 = 0x80
54 };
55

```

FIGURE 2.41: register configuration

2.8 Conclusion

In this chapter, we have comprehensively examined the software and hardware implementation, meticulously selecting each component and meticulously designing the electronic circuitry that comprises the display and RTD card. The primary objective of this design is to establish seamless communication with a Programmable Logic Controller (PLC), ensuring a cohesive and efficient integration within the overall system.

3.1 Introduction

Every modern device has electronic components, and these components are found on a printed circuit board (PCB) called the motherboard. In this chapter, we explain the design of the printed circuit and the realization of the PCB while adhering to industry standards. The importance of adhering to these standards is to ensure that the PCB is reliable, durable, and cost-effective for its intended use.

3.2 PCB design

During the PCB design phase, we meticulously incorporated the recommendations provided by renowned engineer Rick Hartley, an expert in the domains of signal integrity and EMI (electromagnetic interference). Mr. Hartley places significant emphasis on the criticality of meticulous printed circuit board and card design to effectively mitigate and prevent the occurrence of electromagnetic interference. By adhering to his insights, we aimed to ensure optimal performance and functionality of the PCB, while concurrently minimizing any potential disruptions stemming from electromagnetic interference.

3.2.1 electromagnetic interference

Electromagnetic Interference (EMI) is abbreviated as EMI. EMI refers to the unintended disruption caused by an external source that affects the electrical circuit through electromagnetic induction, electrostatic coupling, or conduction. It is a particular problem with sensitive equipment where transmission signals can be corrupted or distorted. Data transmission can also result in increased error rates or complete loss of data. To avoid EMI, it is important to understand that electrical energy is not solely determined by voltage or current, but rather by electric and magnetic fields. Therefore, the transportation of energy does not solely occur within the copper, but also within the space between tracks and planes. [23] [24]

a. transmission line The transmission line is any pair of transmission lines or waveguides, both of which are pairs of conductors used to move energy from point A to point B. There is a voltage across the copper of the transmission line and current flowing through it. The energy, on the other hand, resides in the fields traveling through the dielectric...

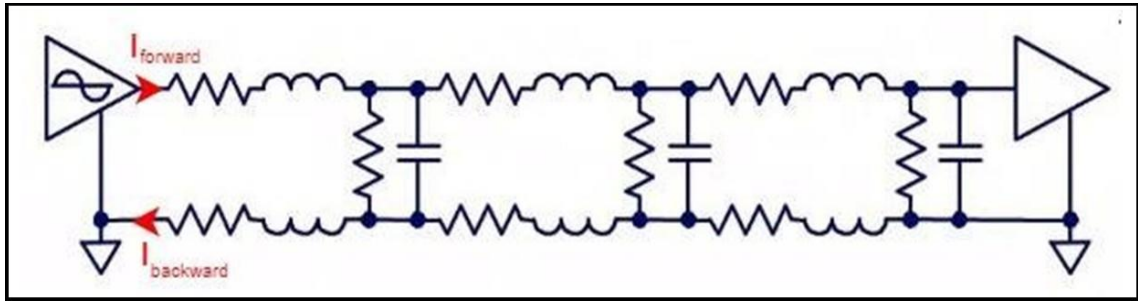


FIGURE 3.1: Formation of current in the circuit

In Figure 3.1, the energy launched into the circuit is in the form of a wave consisting of fields. The fields create a voltage between the two copper elements, while also generating a forward current and a return current simultaneously in both copper element. As a result, the return current forms exactly at the same time as the forward current in the transmission line. It is not a round trip, but a simultaneous event. [23] [24]

This line is a center-trace transmission line, as shown in Figure 3.2

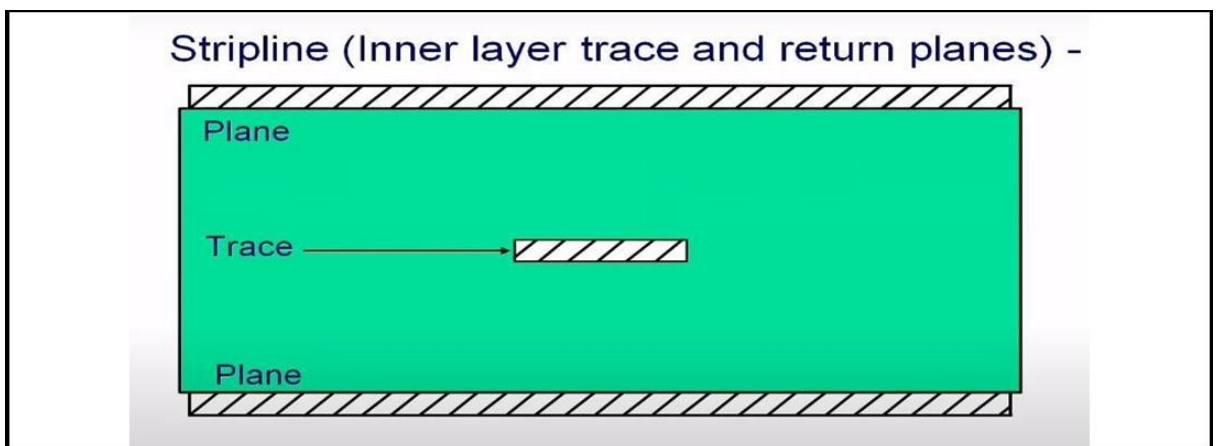


FIGURE 3.2: Inner layer trace and return planes

For this transmission line centered between the pair of planes, which can be ground planes or power and ground planes, when we launch energy into this transmission line, the first thing that appears is the electric field, as shown in Figure 3.3.

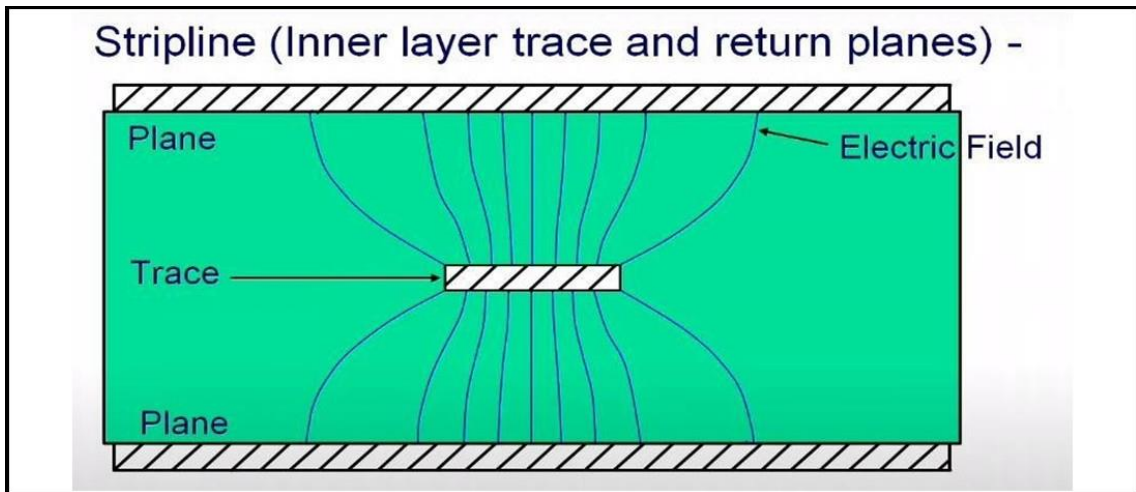


FIGURE 3.3: Electric field in the PCB

This energy excites the electrons, resulting in a current flow in the copper of the planes and in the copper of the trace, as shown in Figure 3.4.

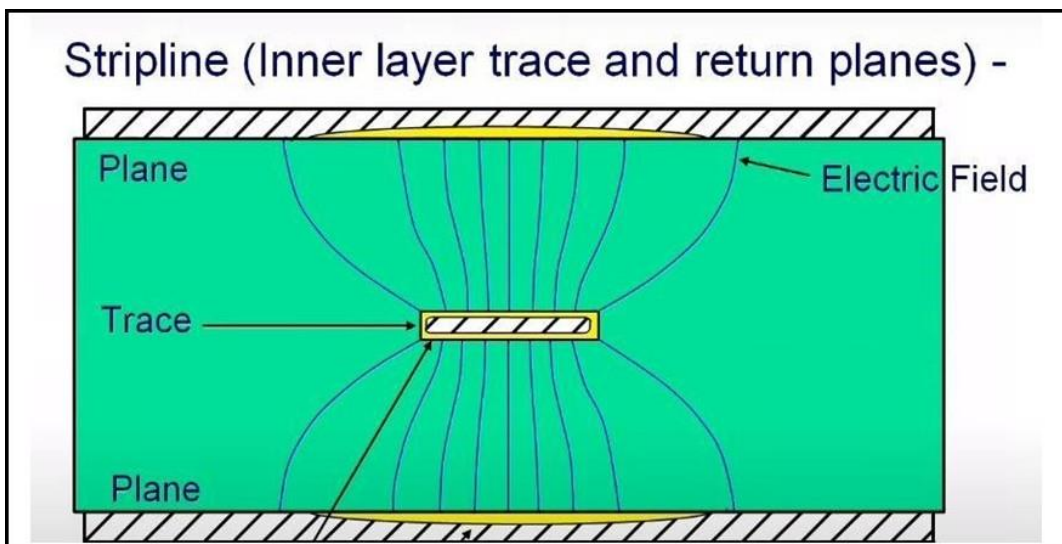


FIGURE 3.4: Currents induced through an electric field

The response to this is the formation of a magnetic field that surrounds the trace, as shown in **Figure 3.5**

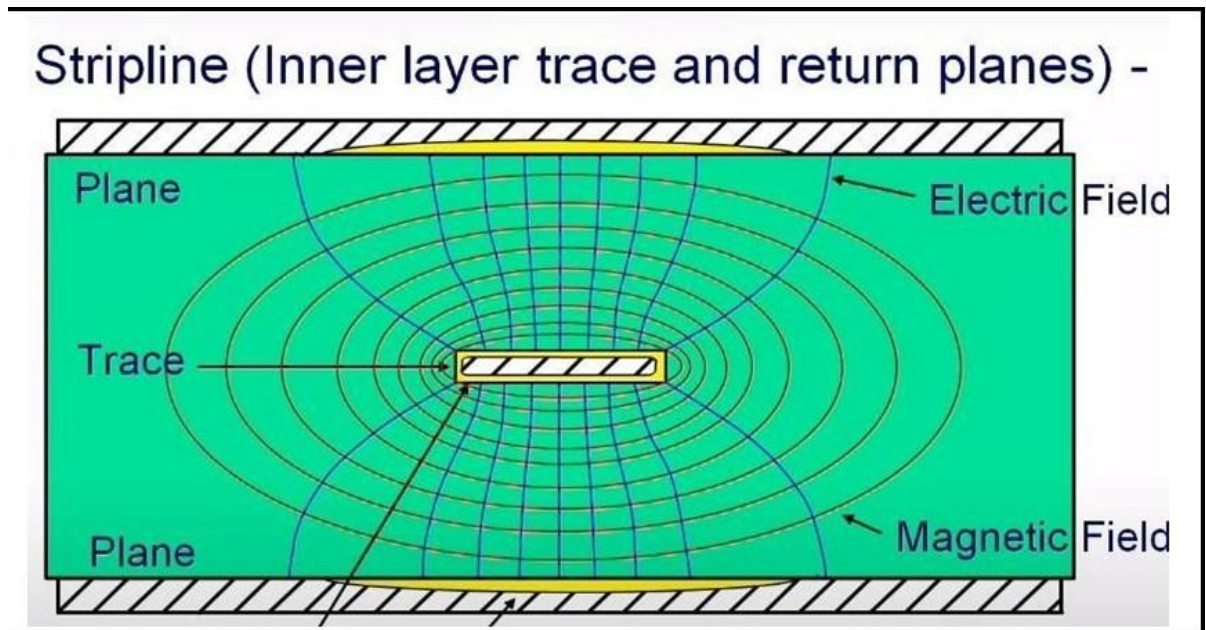


FIGURE 3.5: Electric and magnetic fields in the PCB.

Noticing that all the energy is in this space between the trace and the planes, there is energy diffusion, and this diffusion causes crosstalk as well as other forms of interference. In Figure 3.6, the fields of an outer layer transmission trace are visualized.

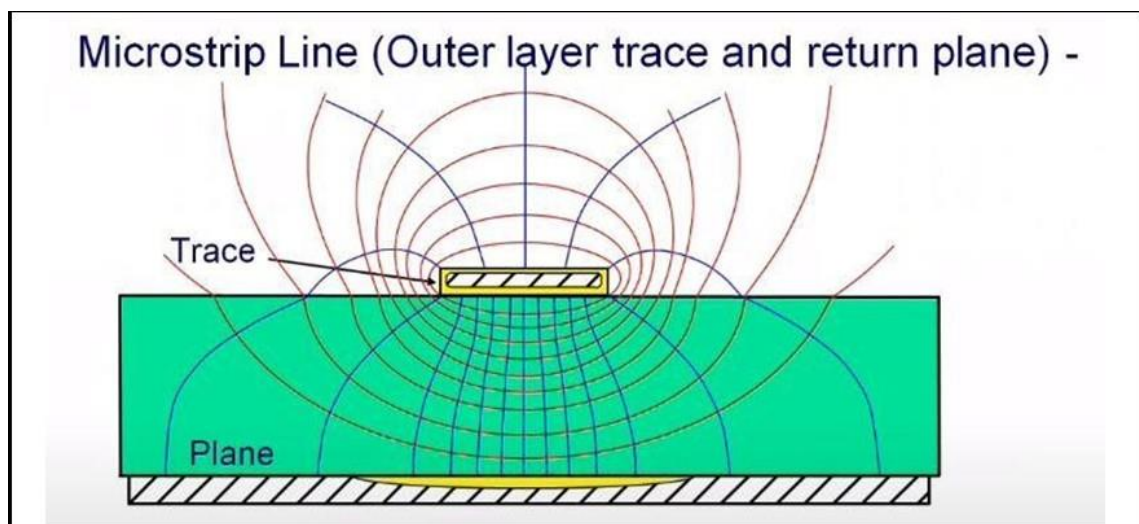


FIGURE 3.6: Electric and magnetic fields in the PCB.

For a trace routed above a ground plane and as the second layer of a board, the fields extend further than the fields in an inner layer, and this expansion of fields causes certain radiations from the outer surface of the board, which can be problematic in some cases. [23] [24]

b. Effect of ground The ground plays a significant role in the design of printed circuit boards. An experiment conducted by Professor Wu from National Taiwan University helps determine which of the following four printed circuit boards has the least electromagnetic interference (EMI).

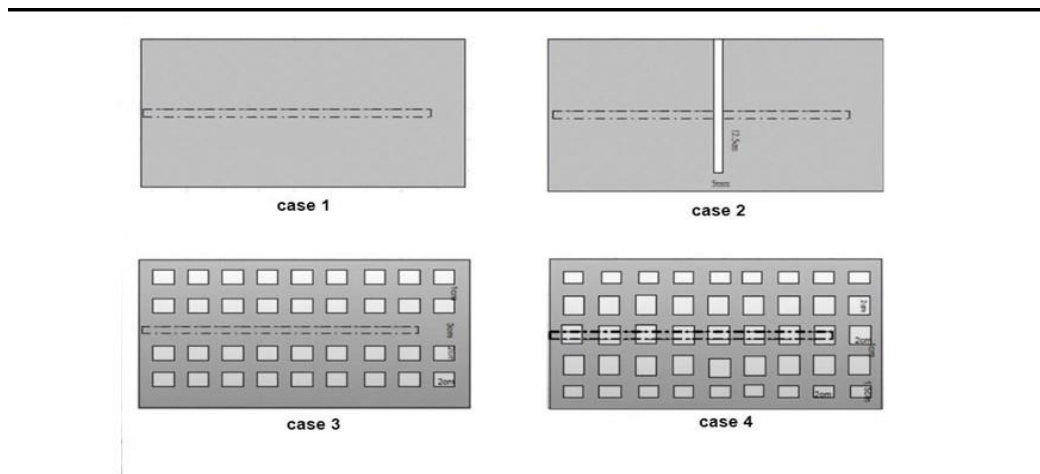


FIGURE 3.7: Circuit boards with different grounds

Figure 3.7 shows four printed circuit boards. The large gray area represents a ground plane on the second layer of the board, and the dashed line represents a transmission trace. At higher frequencies above audio, the return current takes the path directly beneath the trace.

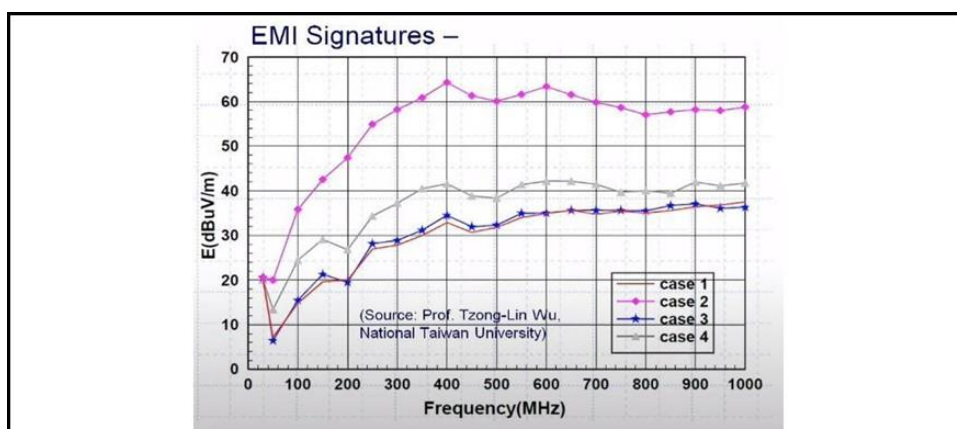


FIGURE 3.8: EMI measured in all four PCBs

Figure 3.8 illustrates the EMI output measured by an antenna in the horizontal and vertical directions. In terms of frequency, Case 2 shows a range of 20 to 30 dB, which is higher than Case 1 and Case 3.

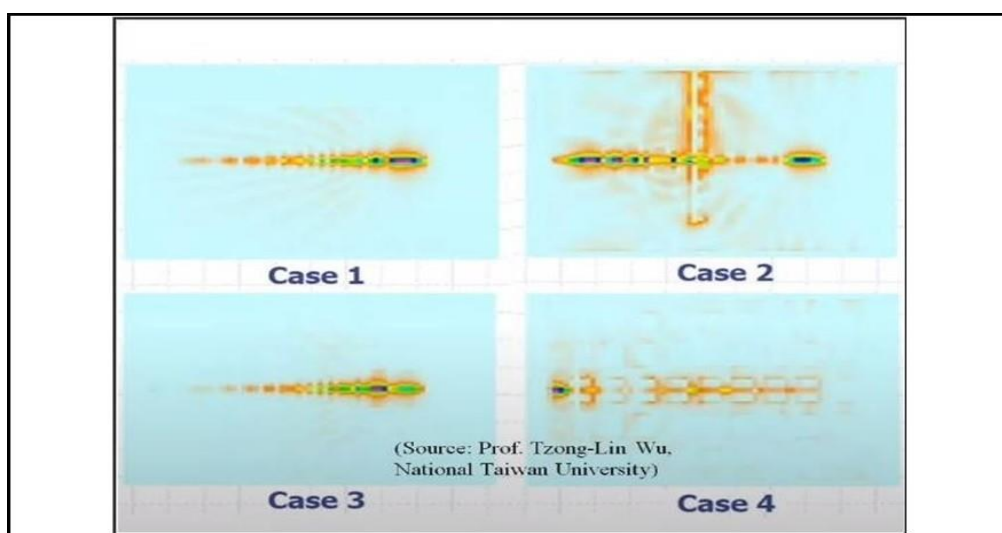


FIGURE 3.9: Energy dissipation in each circuit

Figure 3.9 illustrates the current patterns developed within the circuit planes. Case 2 represents the worst situation, leading the author to deduce a rule: "Never cross splits in ground planes". [23] [24]

c. Ground via The proper way to transition from one layer to another is by using a ground via, which provides a coupling between the layers that is relatively close to the signal via. Dr. Howard Johnson conducted a study on this topic and determined that there are many advantages from an EMI perspective. This is illustrated in Figure 3.10. [23] [24]

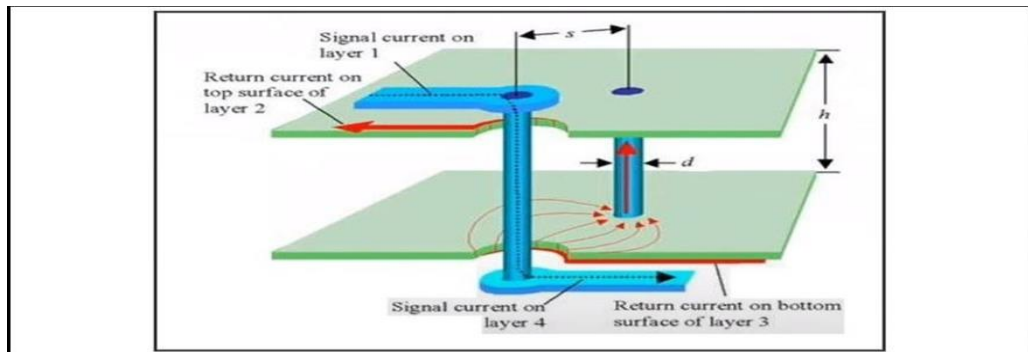


FIGURE 3.10: Ground via

3.2.2 The design of the Display card

We have chosen to design our Display card with a four-layer printed circuit board (PCB) for several reasons, including :

- To reduce EMI and ensure proper functionality.
- To facilitate routing.

Based on the advice from engineer Rick Hartley regarding four-layer PCBs, the recommended layer order is as follows :

- Layer 1 : GROUND
- Layer 2 : SIGNAL/POWER
- Layer 3 : SIGNAL/POWER
- Layer 4 : GROUND

According to Rick Hartley, this combination is the best for reducing EMI, and it also prevents reverse engineering, making imitation nearly impossible. Figure 3.11 illustrates the layer order in the software.

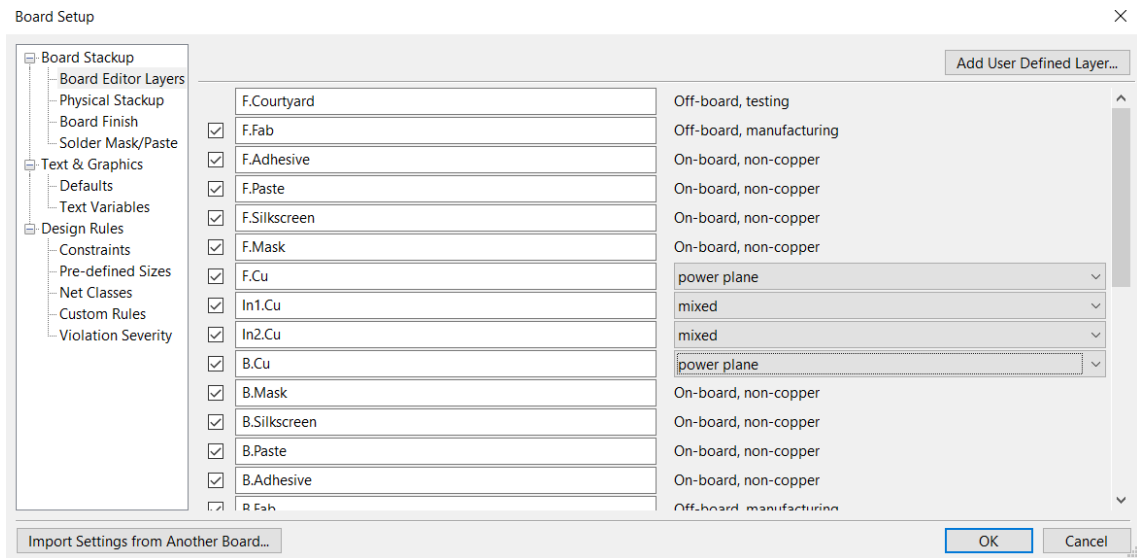


FIGURE 3.11: Layer order combination.

Prior to commencing the PCB design process, it is crucial to have a thorough understanding of the manufacturer’s capabilities and production options. Our circuit manufacturing is entrusted to JLCPCB, a reputable company in the industry

a. Copper layers The construction of our Display card entails the utilization of a four-layer printed circuit board (PCB).

- The F.Cu layer Figure 3.12 provides an illustrative depiction of the top copper layer (1st layer : ground plane), offering insight into its composition and distinctive attributes.

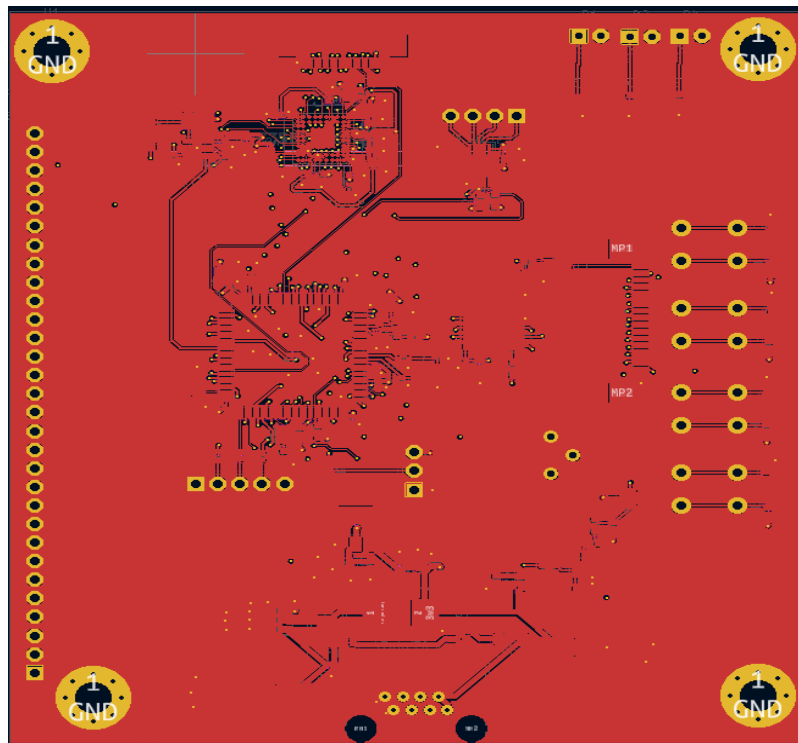


FIGURE 3.12: Top Copper layer.

- Layer In1.Cu Figure 3.13 visually represents the first internal copper layer (2nd layer : signal/3.3V) in detail.

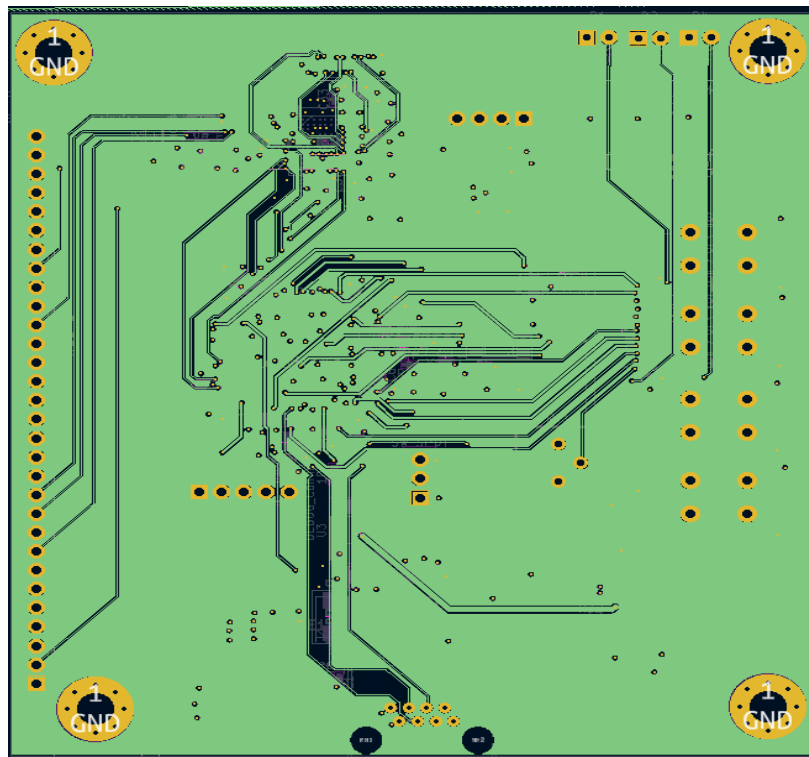


FIGURE 3.13 : First internal layer.

- Layer In2.Cu Figure 3.14 provides a visual representation of the second internal copper layer (3rd layer : signal/3.3V), highlighting its characteristics and composition.

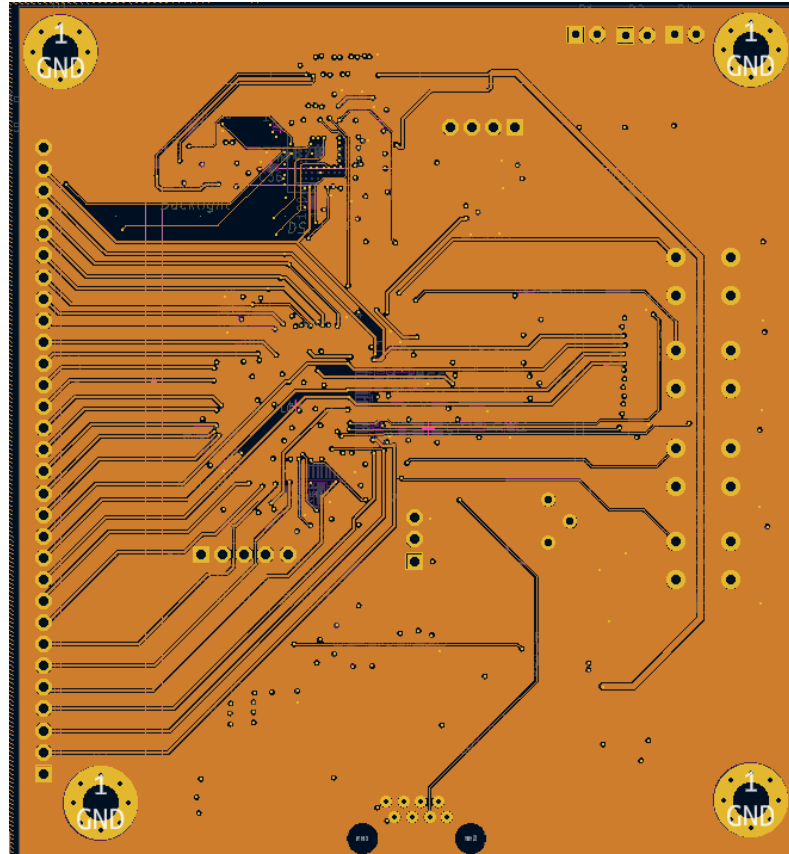


FIGURE 3.14 : Second internal layer.

- Layer B.Cu Figure 3.15 visually depicts the copper layer beneath (4th layer : ground plane), offering a comprehensive representation of this specific layer.

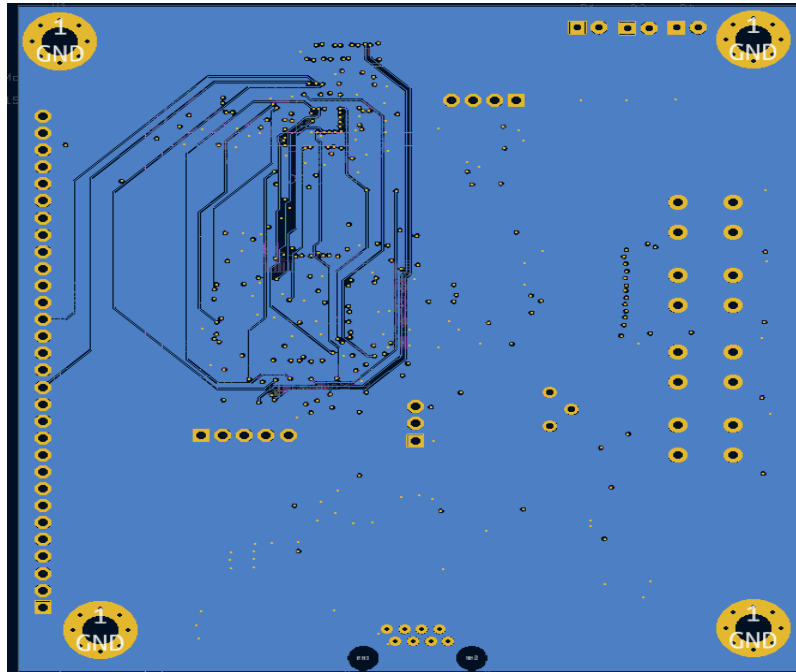


FIGURE 3.15: The fourth copper layer

b. Routing method: We have followed the rule of “never crossing splits in ground planes” during routing. Figure 3.16 illustrates the routing of the first internal layer beneath the ground plane.

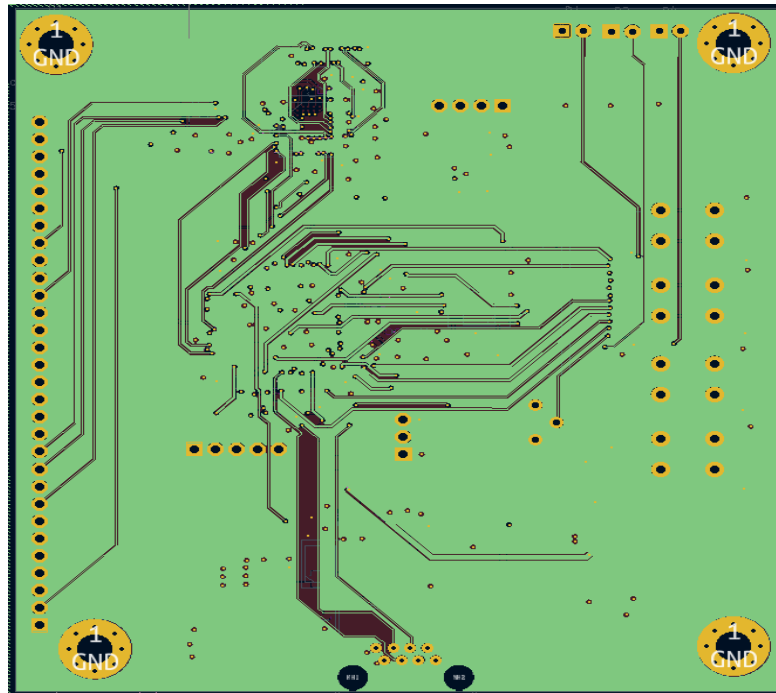


FIGURE 3.16: First internal layer below the ground plane.

Figure 3.17 illustrates the routing of the second internal layer above the ground plane.

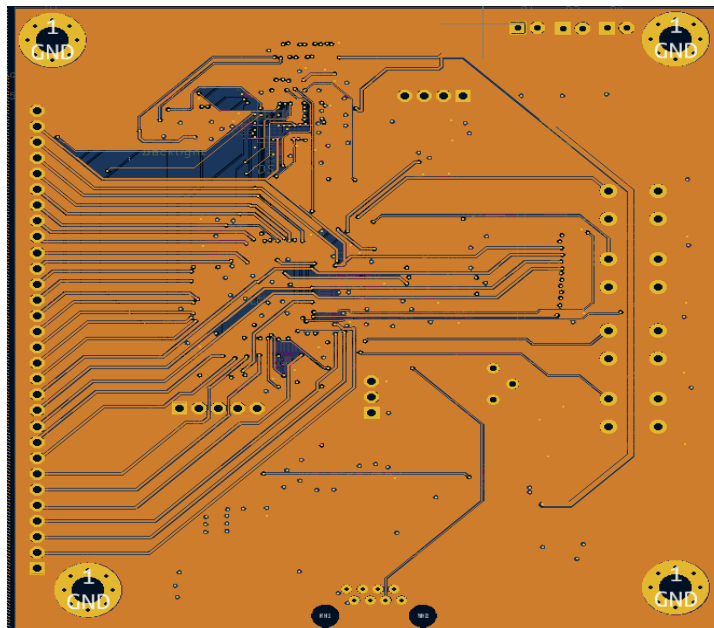


FIGURE 3.17: Second internal layer above the ground plane.

c. **3D models:** The 3D model of our Display Card was designed using the Ki Cad soft-ware. Figures 3.18 and 3.19 showcase the 3D model of our Display Card.

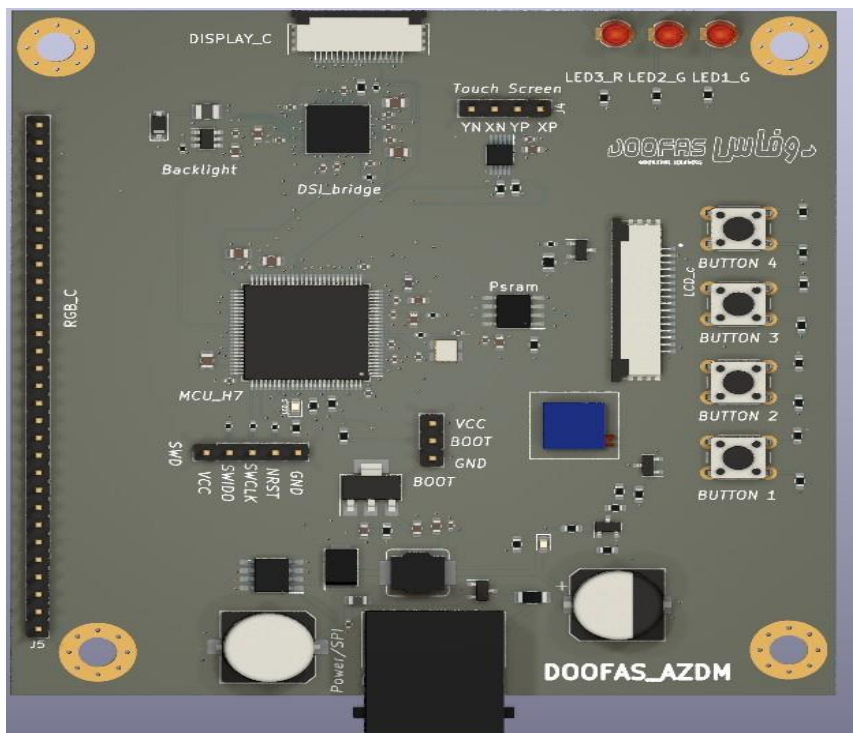


FIGURE 3.18: Top view of the 3D model of our I/O Device in KiCad

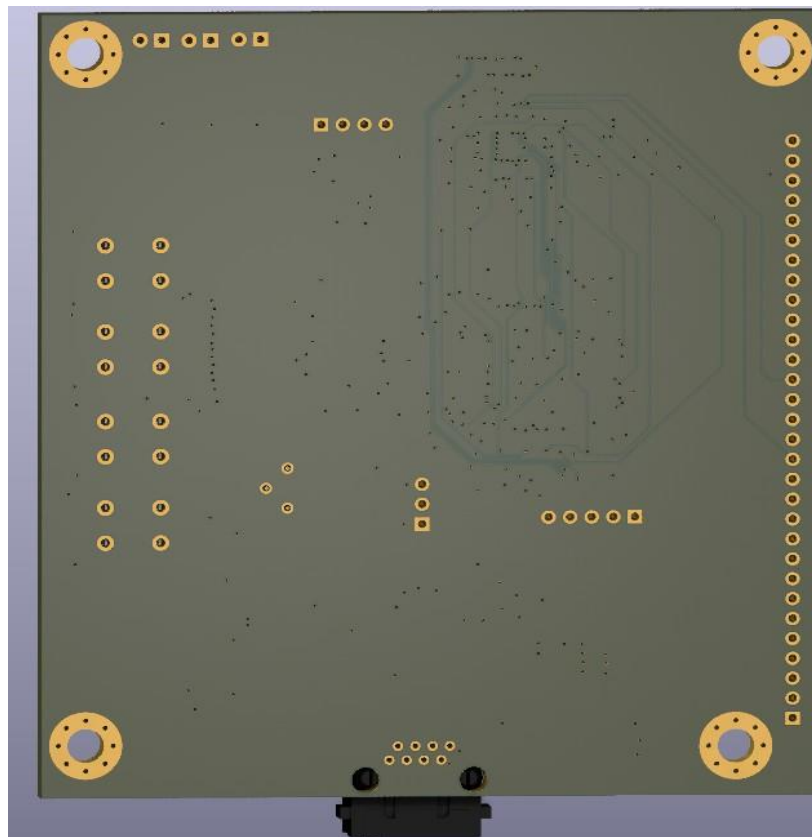


FIGURE 3.19: Bottom view of the 3D model of our I/O Device in KiCad

d. Hardware description Figure 3.22 illustrates the hardware description.

- 1 : Button 1
- 2 : Button 2
- 3 : Button 3
- 4 : Button 4
- 5 : LCD interface(Fpc/Fcc connector)
- 6 : potentiometer
- 7 : Voltage regulator ams117
- 8 : CI Buck XL1059
- 9 : the microcontroller stm32H7B0VBT6
- 10 : Backlight controller module
- 11 : MIPI-DSI BRIDGE
- 12 : Touch Screen Controller
- 13 : Touch Screen connector
- 14 : PSRAM
- 15 : MIPI-DSI interface (Fpc/Fcc connector)
- 16 : SWD interface

- 17 : LTDC (RGB) interface
- 18 : RJ45 port
- 19 : crystal 16Mhz
- 20 : LED RED
- 21 : LED 1 GREEN
- 22 : LED 2 GREEN
- 23 : BOOT interface
- 24 : Power indicator LED
- 25 : The PCB motherboard

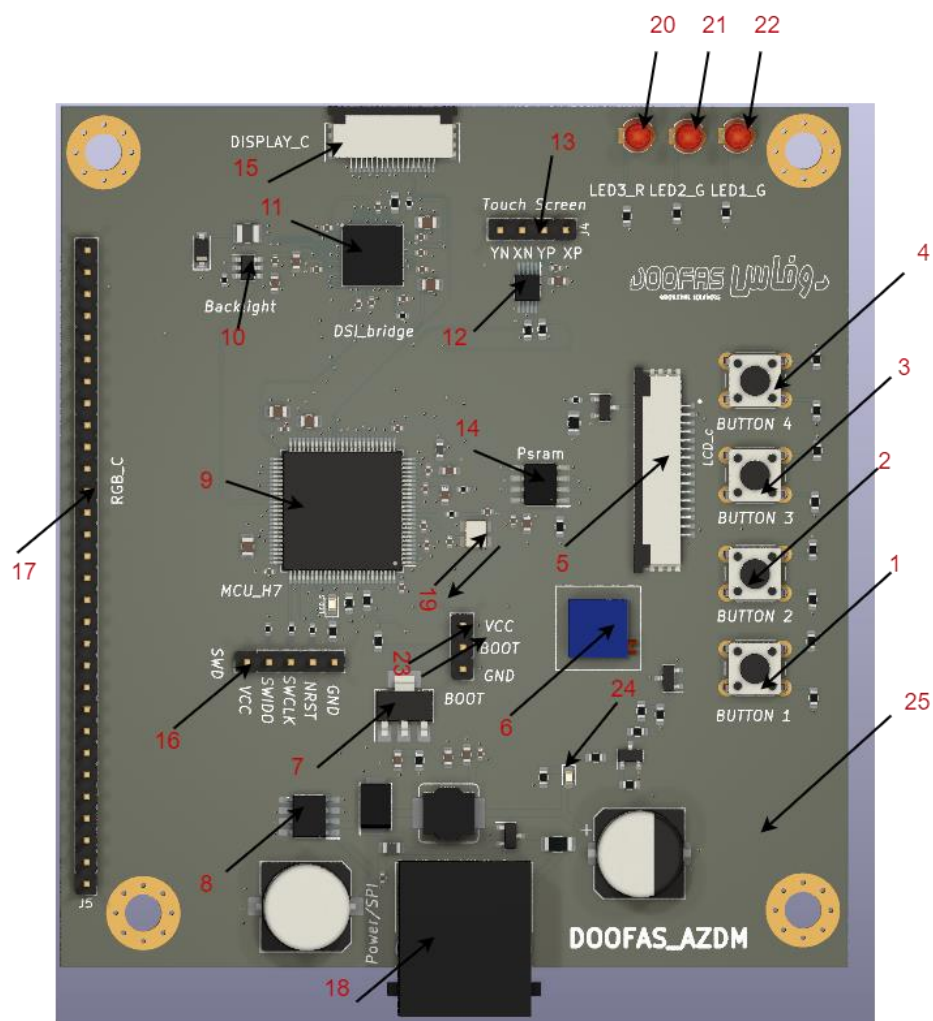


FIGURE 3.20: Hardware description

3.2.3 The design of the data acquisition card

Our second card was designed in the same way as the display card, same layers with the same parameters, the figures from 3.21 to figure 3.24 will show the four layers as shown.

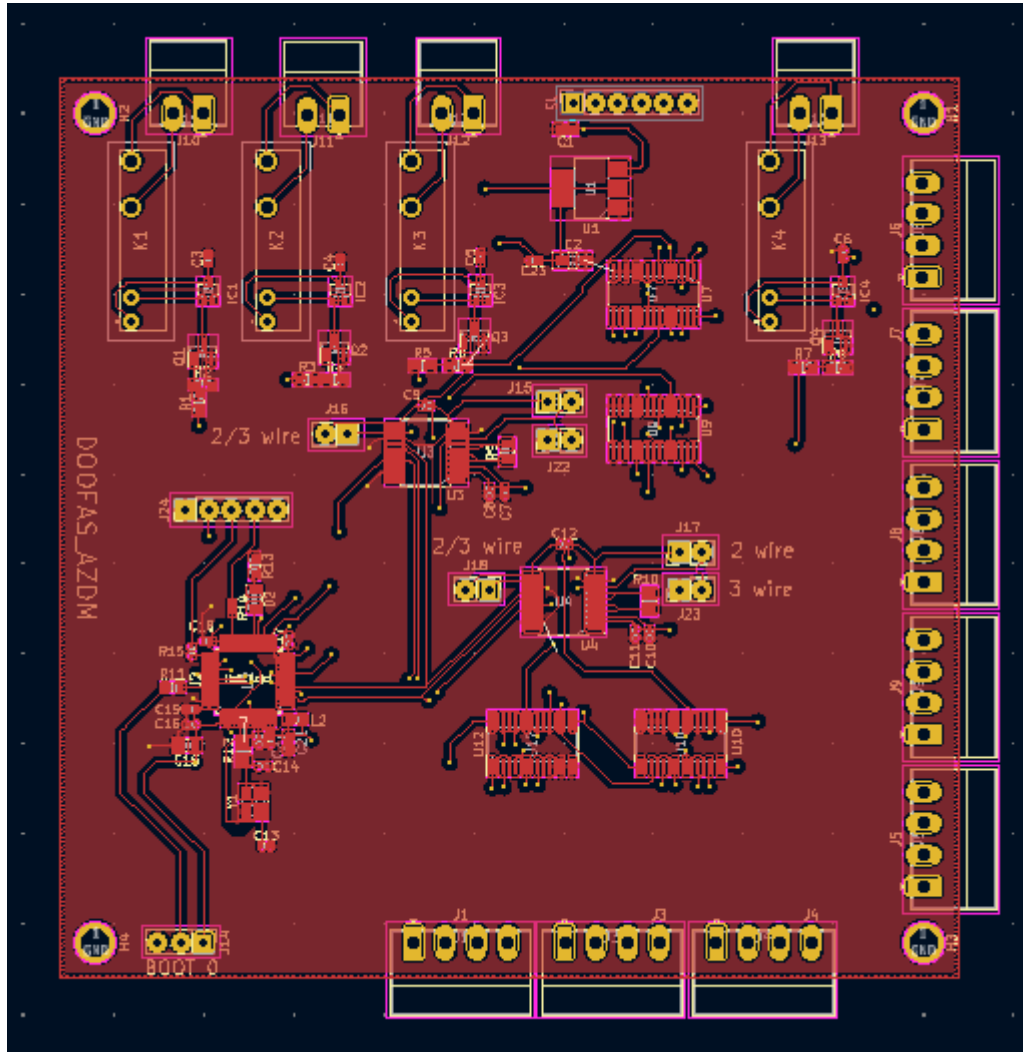


FIGURE 3.21: Top copper layer.

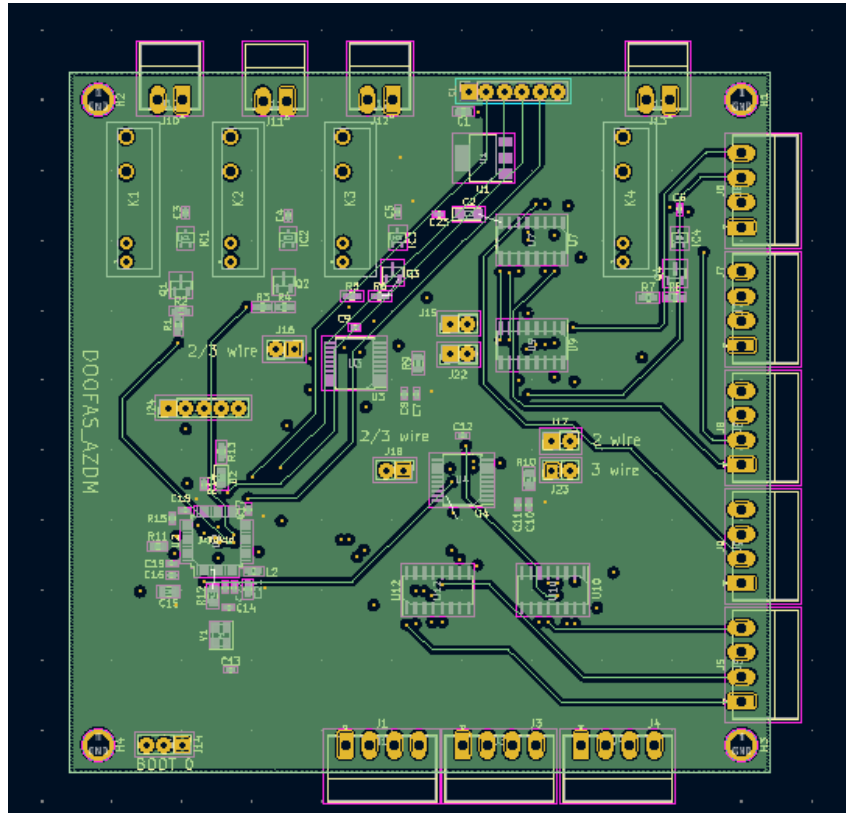


FIGURE 3.22: First internal layer.

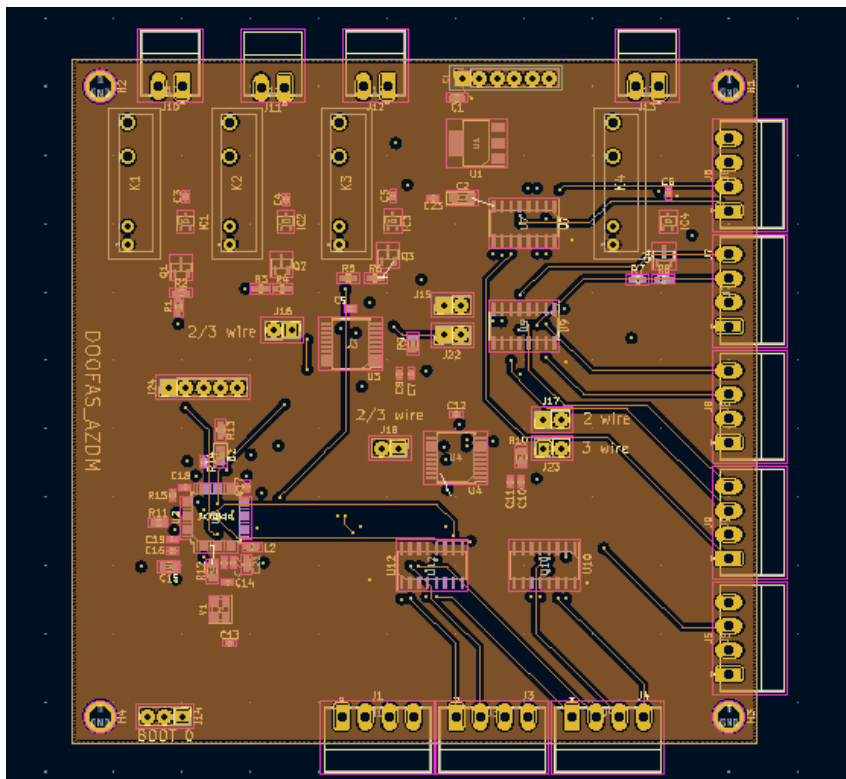


FIGURE 3.23: second internal layer.

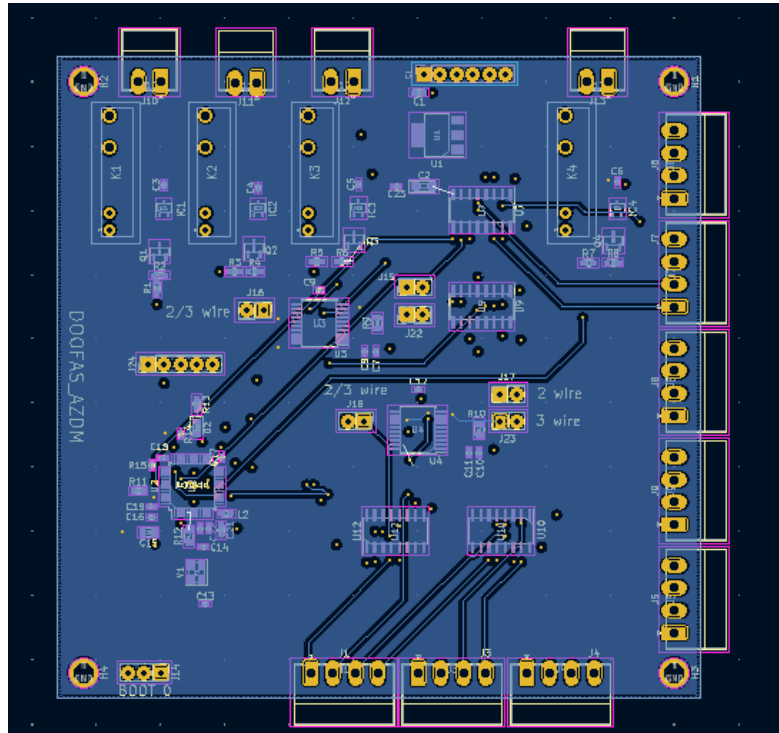


FIGURE 3.24: The fourth copper layer

a. **3D models:** The 3D model of our Display Card was designed using the Ki Cad soft-ware as well. Figures 3.25 and 3.26 showcase the 3D model of our Display Card.

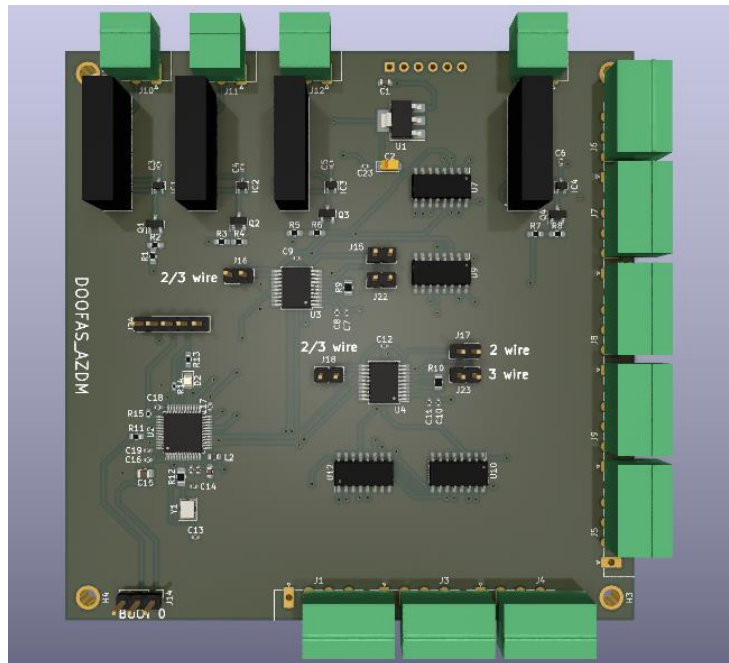


FIGURE 3.25: Top view of the 3D model of our data acquisition in KiCad

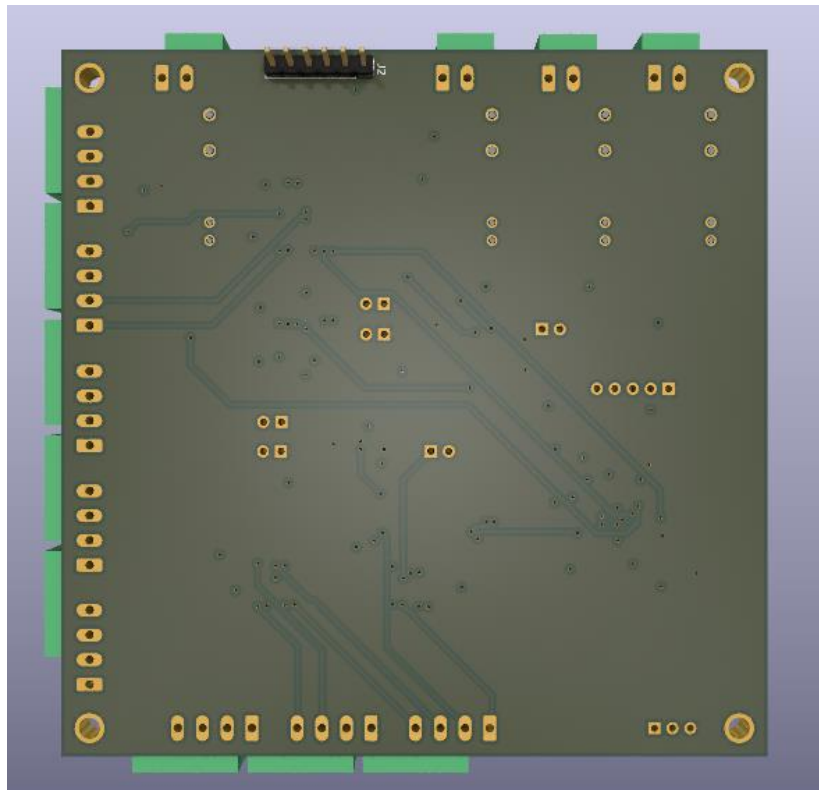


FIGURE 3.26: Bottom view of the 3D model of our data acquisition in KiCad

b. Hardware description Figure 3.27 illustrates the hardware description.

- 1 : the microcontroller STM32f103CBT6
- 2 : multiplexer CD4052B
- 3 : Max31865
- 4 : voltage regulator LM1117S-3.3
- 5 : debug PINS
- 6 : HSE crystal oscillator
- 7 : relay APAN3105
- 8 : RTD input
- 9 : 5v outputs
- 10 : boot0 pins
- 11 : SPI pins
- 12 : configuration pins

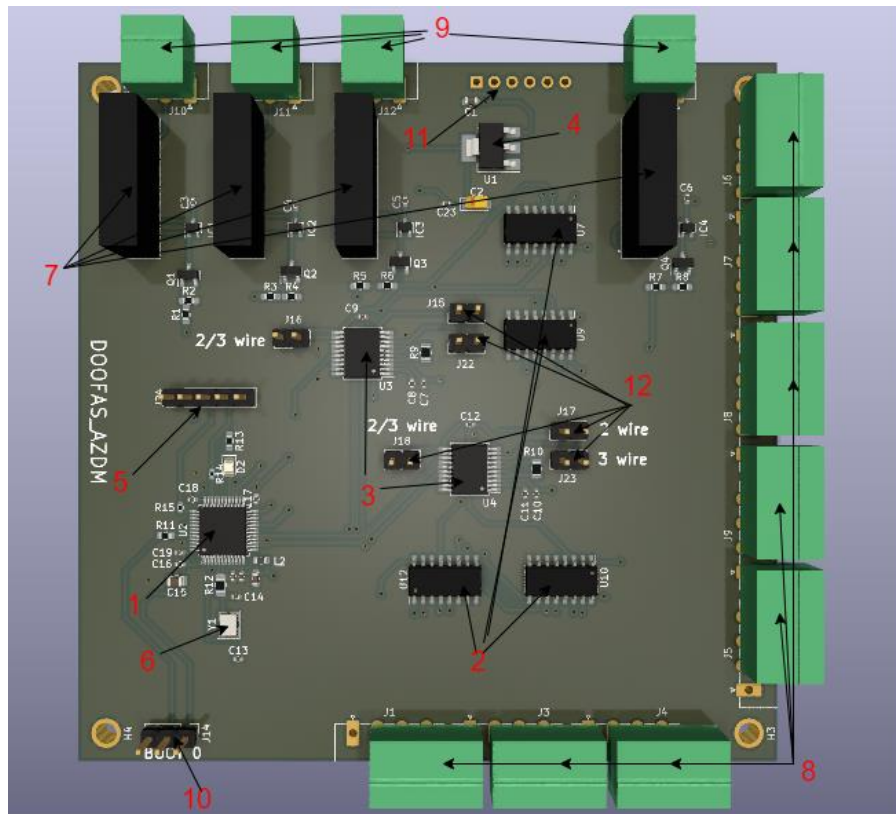


FIGURE 3.27: Hardware description

3.3 Implementation of the Display Card

The implementation of our Display Card was executed by JLCPCB, a renowned company with expertise in this domain. The implementation process was systematically divided into two distinct phases to ensure an efficient and successful outcome

3.3.1 PCB (printed circuit board)

To initiate the manufacturing process, the generation of the Gerber file in the KiCad software is the initial step. Once completed, the file is subsequently uploaded to the JLCPCB website for further processing. The detailed procedure for downloading the Gerber file from JLCPCB is depicted in Figure 3.21.

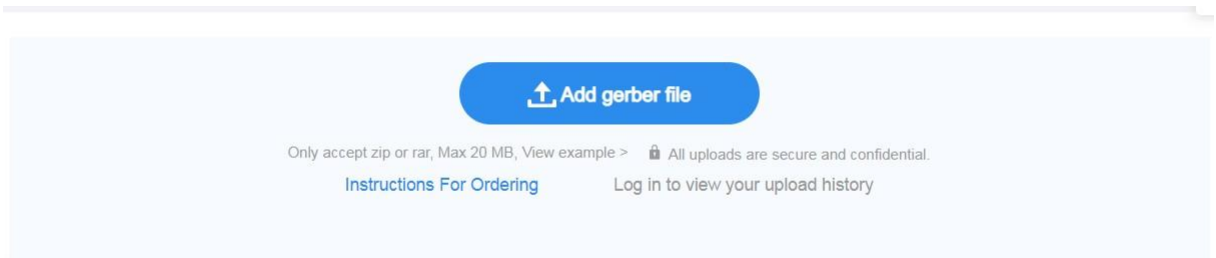


FIGURE 3.28: How to download the Gerber file

Upon successful download of the Gerber file from JLCPCB, the website accurately identifies the PCB, as depicted in Figure 3.22.

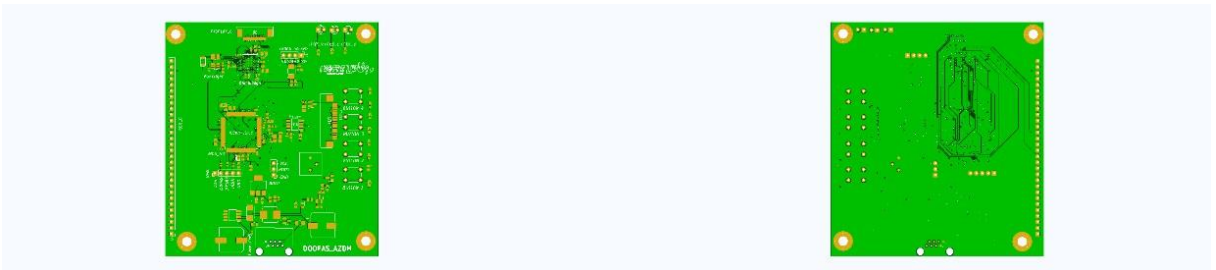


FIGURE 3.29: How to download the Gerber file

Subsequently, it is necessary to input project specifics, including layer sequencing, PCB color, and other relevant parameters.

3.3.2 PCBA (PCB Assembly)

This is the assembly of components on the PCB (PCB Assembly).



FIGURE 3.30: PCBA and the assembly side

Figure 3.23 demonstrates the process of enabling the PCBA option in JLCPCB and selecting the assembly side. Following the previous steps, it is necessary to proceed with the upload of the BOM file, which is commonly referred to as a Bill of Materials. The BOM file serves as a comprehensive document that enumerates all the components essential for the PCB assembly process, providing detailed information about each component. In addition, the POS file, known as a Pick and Place file, should also be uploaded to JLCPCB. The POS file plays a crucial role in the PCB manufacturing process by furnishing precise data regarding the exact locations and orientations of the components during the assembly phase. For a visual representation of this upload procedure, Figure 3.24.

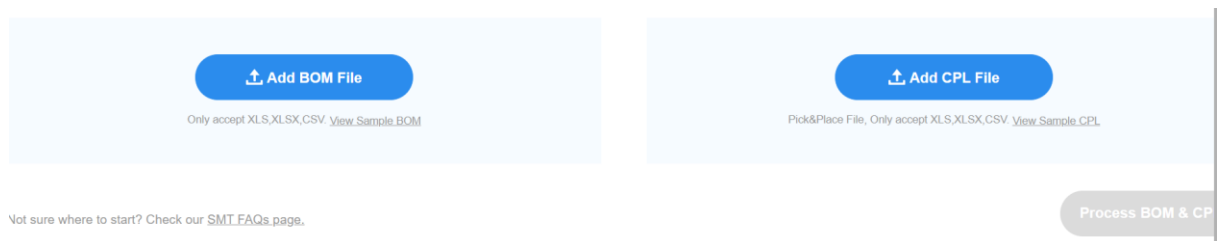


FIGURE 3.31: How to download bom and pos file

Finally, you should carefully review the final component placements on your PCB to identify any errors or discrepancies. It is crucial to ensure the correct positioning of components before placing an order. By thoroughly inspecting and verifying the component placements, you can identify and rectify any issues to guarantee the accuracy of your order. Figure 3.25.

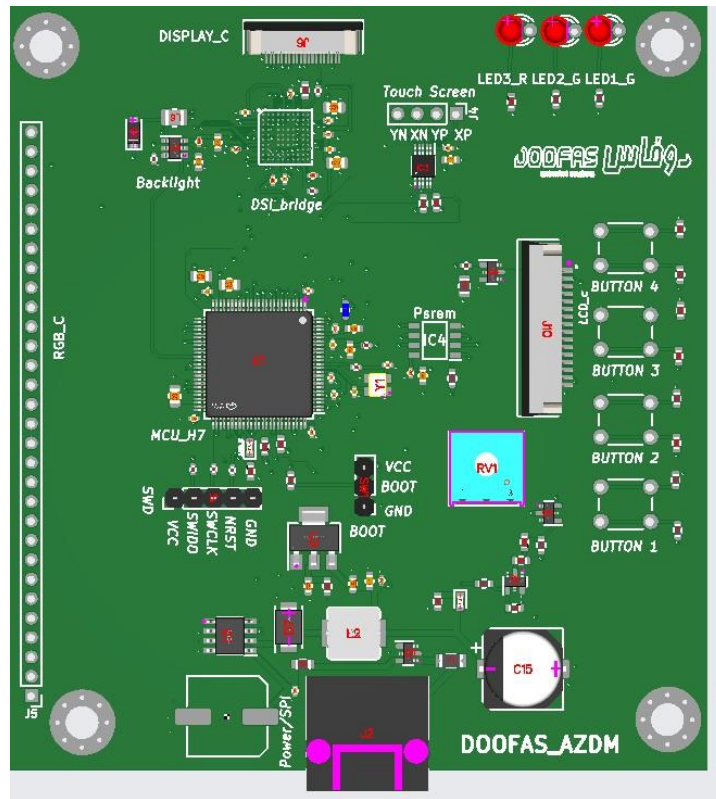


FIGURE 3.32: Final process

3.4 Implementation of the Data Acquisition Card

The implementation of our Data Acquisition Card was executed the same way as the Display Card, same steps are followed, the figure 3.33 show the bill of materials.

Top Side Total 34 parts detected | 29 Parts confirmed | 5 parts not selected [Upload BOM/CPL](#)

Uploaded BOM Data			Review Matched Parts					
Top Designator	Comment	Footprint	Matched Part Detail	Qty	Source	Lib Type	Total Cost	Select
R1,R3,R5,R7	100R	Resistor_SMD...	RC0603FR-07100RL C105588 100mW Thick Film Resistors ±1% 100Ω 0603 ...	25	JLPCPB	Extended	\$0.0250	<input checked="" type="checkbox"/>
U1	LM1117-3.3	Package_TO...	LM1117S-3.3 C126027 75dB@(120Hz) 1A Fixed 3.3V~3.3V Positive 1...	5	JLPCPB	Extended	\$0.7015	<input checked="" type="checkbox"/>
C2	22uF	Capacitor_Tant...	CA45-A-10V-22uF-K C129272 22uF 10V 10Q@100kHz ±10% CASE-A-3216 T...	6	JLPCPB	Extended	\$0.3588	<input checked="" type="checkbox"/>
Y1	16MHZ	Crystal_Crystal...	X322516MLB4SI C13738 16MHz 9pF ±10ppm ±30ppm SMD3225-4P Cry...	5	JLPCPB	Basic	\$0.3675	<input checked="" type="checkbox"/>
C7,C8,C10,C11	0.1uF	Capacitor_SM...	CT41G-0402-2X1-16V-0.1uF-K(N)C141382 16V 100nF 2X1 ±10% 0402 Multilayer Ceramic...	30	JLPCPB	Extended	\$0.0930	<input checked="" type="checkbox"/>
C23	0.1uF	Capacitor_SM...	CT41G-0402-2X1-16V-0.1uF-K(N)C141382 16V 100nF 2X1 ±10% 0402 Multilayer Ceramic...	30	JLPCPB	Extended	\$0.0930	<input checked="" type="checkbox"/>
R11	10k	Resistor_SMD...	0603WAJ0103T5E C15401 100mW Thick Film Resistors ±5% 10kΩ 0603 ...	20	JLPCPB	Extended	\$0.0220	<input checked="" type="checkbox"/>
C13,C14	12p	Capacitor_SM...	0402CG120J500NT C1547 50V 12pF C0G ±5% 0402 Multilayer Ceramic C...	10	JLPCPB	Basic	\$0.0100	<input checked="" type="checkbox"/>
C9,C12	100nf	Capacitor_SM...	CL05B104KA5NNNC C155422 25V 100nF X7R ±10% 0402 Multilayer Ceramic...	20	JLPCPB	Extended	\$0.0420	<input checked="" type="checkbox"/>
C21	1u	Capacitor_SM...	CL10A105KB8NNNC C15849 50V 1uF X5R ±10% 0603 Multilayer Ceramic C...	5	JLPCPB	Basic	\$0.0245	<input checked="" type="checkbox"/>
C15	4.7u	Capacitor_SM...	CL21A475KA0NNNE C1779 25V 4.7uF X5R ±10% 0805 Multilayer Ceramic ...	5	JLPCPB	Basic	\$0.0555	<input checked="" type="checkbox"/>
C1	10uF	Capacitor_SM...	LMK107BJ106MALTD C18800 10V 10uF X5R ±20% 0603 Multilayer Ceramic ...	20	JLPCPB	Extended	\$0.2860	<input checked="" type="checkbox"/>
D2	LED_Small	LED_SMD.LED...	KT-0603R C2286 Red 615~630nm 1.9~2.2V 0603 Light Emitting ...	5	JLPCPB	Basic	\$0.0270	<input checked="" type="checkbox"/>
U7,U9,U10,U12	CD4052B	Package_SO_S...	CD4052BM/TR C253890 SOP-16 Analog Switches / Multiplexers ROHS ...	20	JLPCPB	Extended	\$2.1440	<input checked="" type="checkbox"/>

FIGURE 3.33: the bill of materials.

The figure 3.34 show the final process of our second card.

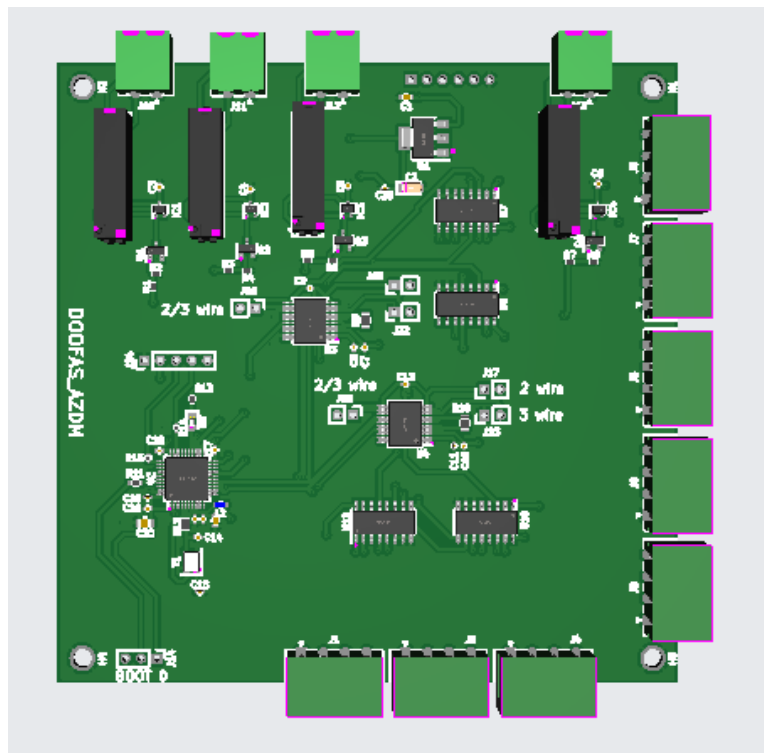


FIGURE 3.34: final process

3.5 Conclusion

A thorough understanding of Electromagnetic Interference (EMI) and its avoidance techniques is crucial in the field of PCB design to ensure seamless operation of the designed device and maintain the integrity of surrounding equipment. Successful PCB design entails implementing effective strategies to mitigate EMI, thereby optimizing performance and ensuring compatibility with electromagnetic environments.

4.1 Introduction

After finalizing the design and manufacturing stages of the device, we proceeded with comprehensive software and hardware testing. To evaluate the functionality of our program meticulously, we employed STM32CubeIDE, emphasizing the reliability of our project. As for the hardware testing, we used a Multimeter to assess voltage levels and ensure proper connectivity of the components.

4.2 TEST

For the test we have two cards, the RTD card and the Display Card manufactured according to our design, the figure 4.1 show our two cards.

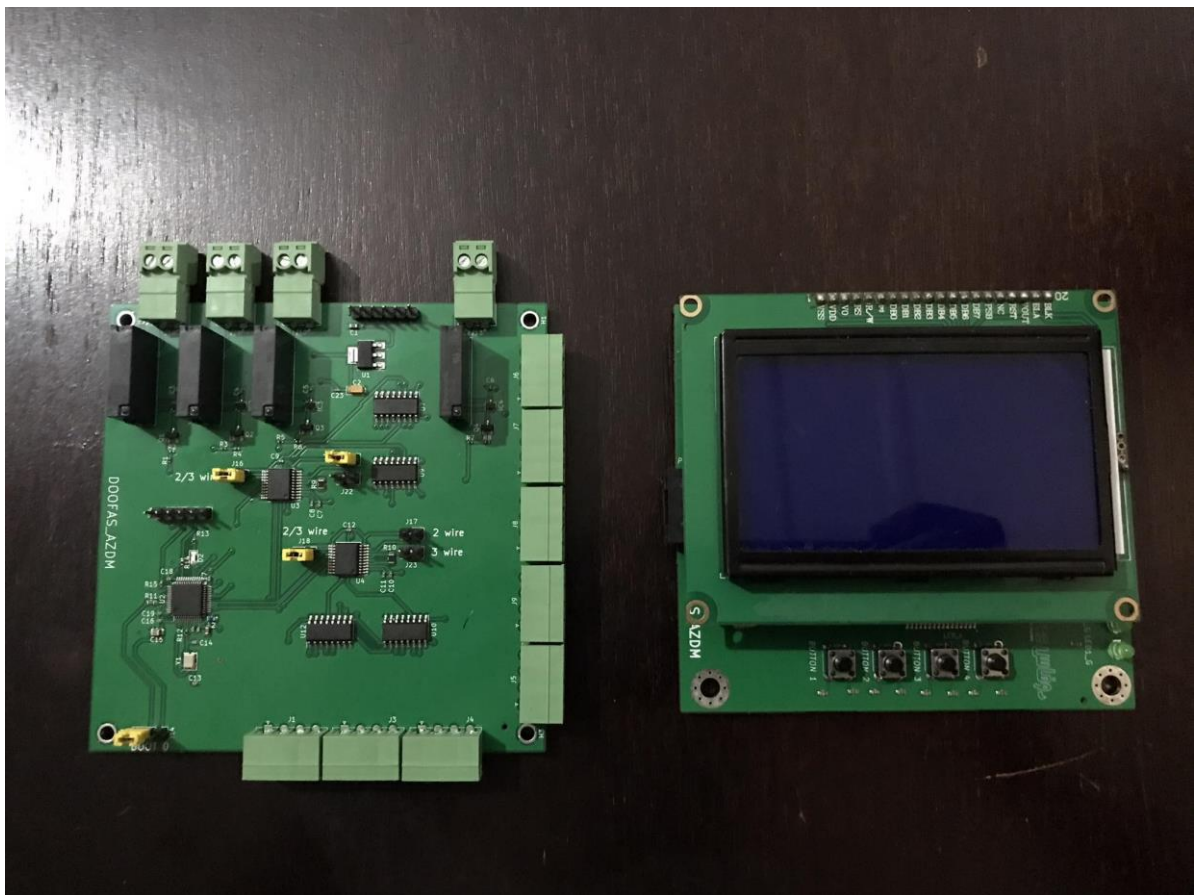


FIGURE 4.1: RTD and Display Card

4.2.1 Testing the on voltage

Prior to deploying our cards, we diligently verify that the voltage aligns precisely with the designated voltage we have designed them for, the voltage desire is 3.3V.

The figure 4.2 will show the result of testing with the Multimeter .

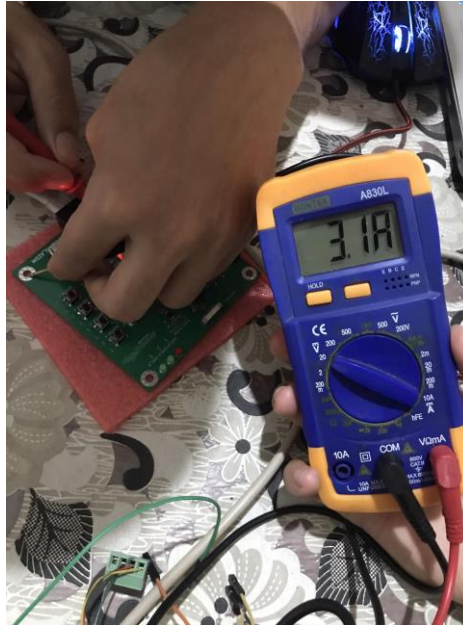


FIGURE 4.2: Display card power test

The figure 4.3 will show the result taken from the RTD card.



FIGURE 4.3: RTD card power test

4.2.2 program Compilation

the compilation of the code figure 4.5 is done on the software STM32CubeIDE figure 4.4 to check if there are no errors in the program.

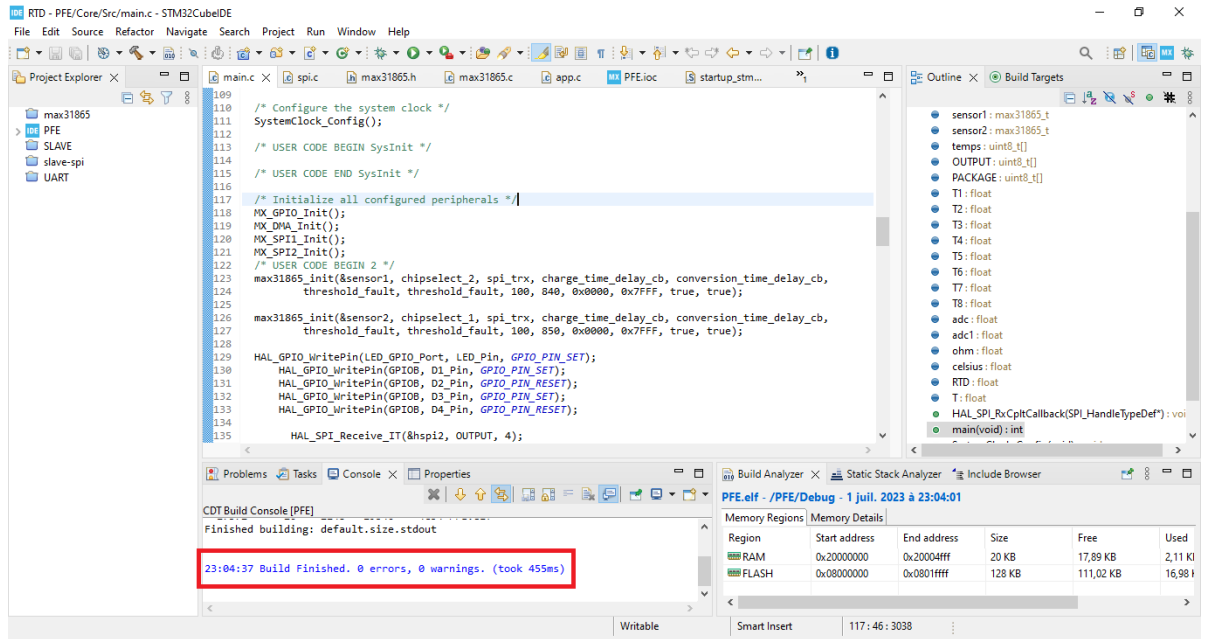


FIGURE 4.4: STM32CubeIDE Interface

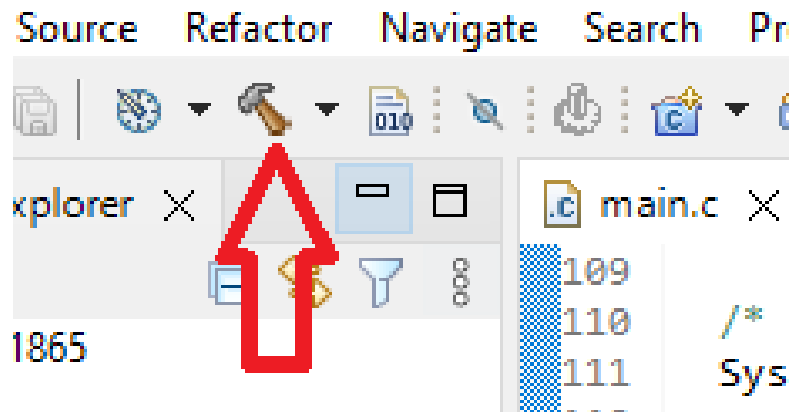


FIGURE 4.5: code compilation

After the code compilation we notice that the program uses 10.55% from RAM memory and 13.27% from flash memory which is fine and safe to use, the figure 4.6 will show the memory usage.

Region	Start address	End address	Size	Free	Used	Usage (%)
RAM	0x20000000	0x20004fff	20 KB	17,89 KB	2,11 KB	10,55%
FLASH	0x08000000	0x0801ffff	128 KB	111,02 KB	16,98 KB	13,27%

FIGURE 4.6: memory usage

4.2.3 Debugging

to debug and inject the program on the STM, you must connect the ST-LINK/ V2 programmer to the SWD port, power on the two cards and connect the programmer via USB to the computer.

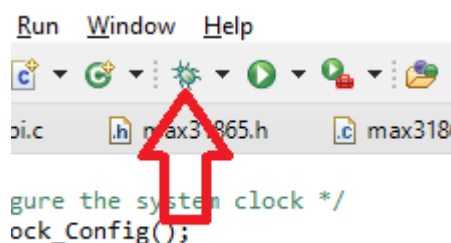


FIGURE 4.7: debug launching



FIGURE 4.8: debug wiring

4.3 Results

Once the debugging process is completed and the data charges card is successfully connected with two RTD sensors, the results can be conveniently observed on the Display card. Additionally, the output status can also be monitored for further analysis.

The figures 4.9, 4.10, 4.11 show the display as seen by order



FIGURE 4.9: Start LOGO



FIGURE 4.10: Initialization interface



FIGURE 4.11: menu interface

As you can see in the menu interface we have a cursor that allow us to navigate through this menu, the figure 4.12 will show us the inside of **GET TEMPERATURE**.

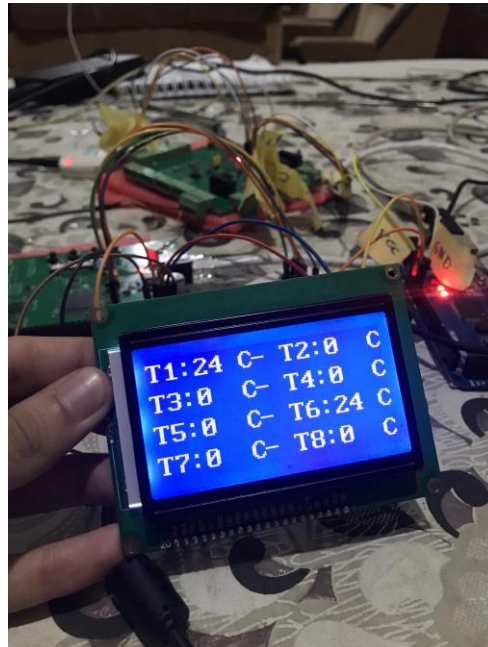


FIGURE 4.12: Get Temperature

Next we move to the inside of GET OUTPUT menu figure 4.14, the figure 4.13 show you the movement of the cursor inside the menu.



FIGURE 4.13: cursor second position

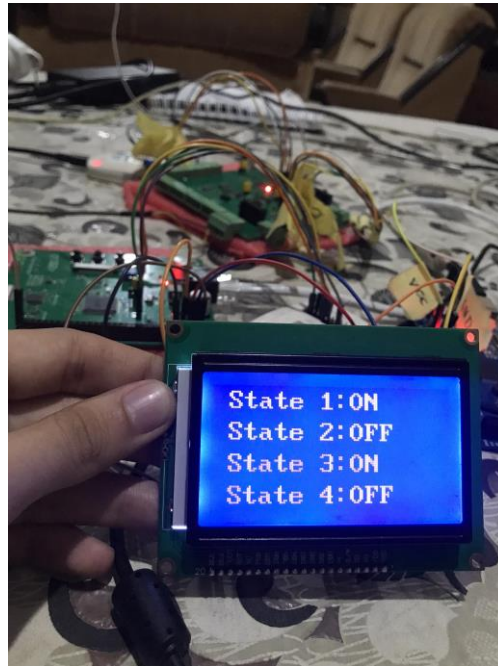


FIGURE 4.14: OUTPUTs states

Finally, we move to our last menu, SET OUTPUT which allow us to change the OUTPUT state, inside this menu we also have a cursor that allow us to choose which output to change his state



FIGURE 4.15: cursor third position



FIGURE 4.16: OUTPUTs state before change

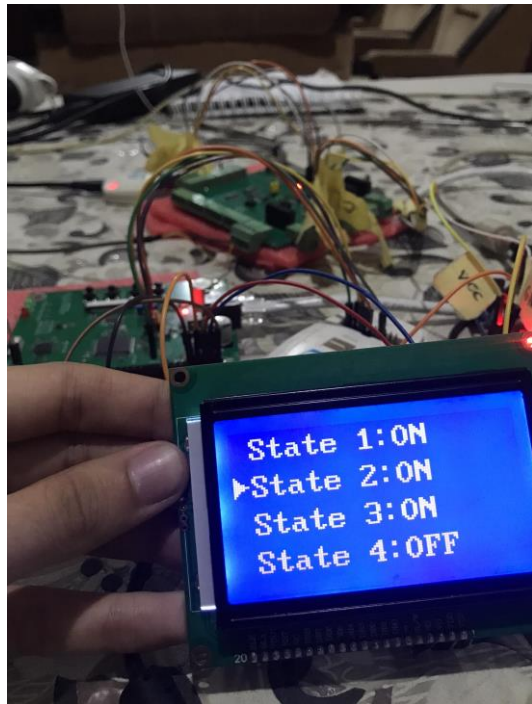


FIGURE 4.17: OUTPUTs state after change

4.4 Conclusion

Throughout this chapter, we have presented a comprehensive account of the hardware and software testing procedures that will be meticulously designed and executed. Each step has been meticulously explained to ensure the utmost precision and reliability in the testing process. These tests are poised to play a critical role in validating the functionality and performance of our system, thereby ensuring its seamless integration and successful implementation in real-world applications.

GENERAL CONCLUSION

In summary, the focus of this project was to design and implement a multi-channel temperature sensing system using RTD PT100 sensors for real-time data acquisition. The system architecture consisted of two main components: the RTD card and the display card.

The RTD card was developed to support up to eight channels of RTD sensors, accommodating various wire configurations such as 4-wire, 3-wire, and 2-wire connections. It also featured four output channels, allowing for simultaneous monitoring of multiple temperature readings.

The display card was designed to provide visual representation of the acquired temperature data. It offered compatibility with three different display types: MIPI DSI, LCD, and RGB. This flexibility allowed for the selection of the most suitable display technology based on specific application requirements. Any display supporting the MIPI DSI or RGB interface can be used with our card.

Throughout the project, the STM32 platform was utilized for its reliability and advanced features, ensuring precise data acquisition, processing, and control. The STM32 platform played a crucial role in achieving high system performance and seamless integration of the RTD and display cards.

By successfully implementing this multi-channel temperature sensing system, we have achieved real-time data acquisition and visualization capabilities. This system has potential applications in various industries where accurate and simultaneous temperature monitoring is critical.

Overall, this project demonstrates the effective integration of RTD PT100 sensors, the STM32 platform, and display technologies to develop a robust and versatile temperature sensing system. The successful implementation opens doors for broader applications, promoting enhanced process control, efficiency, and safety in diverse industrial environments.

Annex A : Pin Description

LCD-TFT signal	Description
LCD_CLK	The LCD_CLK acts as the data valid signal for the LCD-TFT. The data is considered by the display only on the LCD_CLK rising or falling edge.
LCD_HSYNC	The line synchronization signal (LCD_HSYNC) manages horizontal line scanning and acts as line display strobe.
LCD_VSYNC	The frame synchronization signal (LCD_VSYNC) manages vertical scanning and acts as a frame update strobe.
LCD_DE	The DE signal, indicates to the LCD-TFT that the data in the RGB bus is valid and must be latched to be drawn.
Pixel RGB data	The LTDC interface can be configured to output more than one color depth. It can use up to 24 data lines (RGB888) as display interface bus.

TABLE 1: LTDC interface output signals [21]

Pin no.	Symbol	External connection	Function
1	V _{SS}	Power supply	Signal ground for LCM (GND)
2	V _{DD}		Power supply for logic (+3.3V) for LCM
3	V ₀		Contrast adjust
4	RS	MPU	Register select signal
5	R/W	MPU	Read/write select signal
6	E	MPU	Operation (data read/write) enable signal
7~10	DB0~DB3	MPU	Four low order bi-directional three-state data bus lines. Used for data transfer between the MPU and the LCM. These four are not used during 4-bit operation.
11~14	DB4~DB7	MPU	Four high order bi-directional three-state data bus lines. Used for data transfer between the MPU
15	LED+(A)	LED BKL power Supply	Power supply for BKL (+3.3V)
16	LED-(K)		Power supply for BKL (GND)

TABLE 2: Interface Pin Description LCD [25]

Group	Pin Name	I/O	Type	Function	Note
System: Reset & Clock (4)	RESX	I	Sch	System reset input, active low	-
	REFCLK	I	N	Reference clock input (6MHz - 40MHz)	-
	MSEL	I	N	Mode Select 1'b0: Test mode 1'b1: Normal mode	-
	CS	I	N	Configuration Select - When CS = L, enable I ² C interface - When CS = H, enable SPI interface	-
MIPI-DSI (10)	MIPI_CP	-	PHY	MIPI-DSI clock positive	-
	MIPI_CN	-	PHY	MIPI-DSI clock negative	-
	MIPI_D0P	-	PHY	MIPI-DSI Data 0 positive	-
	MIPI_D0N	-	PHY	MIPI-DSI Data 0 negative	-
	MIPI_D1P	-	PHY	MIPI-DSI Data 1 positive	-
	MIPI_D1N	-	PHY	MIPI-DSI Data 1 negative	-
	MIPI_D2P	-	PHY	MIPI-DSI Data 2 positive	-
	MIPI_D2N	-	PHY	MIPI-DSI Data 2 negative	-
	MIPI_D3P	-	PHY	MIPI-DSI Data 3 positive	-
MIPI_D3N	-	PHY	MIPI-DSI Data 3 negative	-	
I ² C IF (2)	I2C_SCL	OD	Sch	I ² C serial clock or SPI_SCLK	4 mA
	I2C_SDA	OD	Sch	I ² C serial data or SPI_MOSI	4 mA
Parallel Port IF (28)	PD[23:0]	I	N	Parallel Port Input Data Note: PD[23:16] can be configure to be GPIO[10:3]	-
	VSYNC	I	N	Parallel port VSYNC signal	-
	HSYNC	I	N	Parallel port HSYNC signal	-
	DE	I	N	Parallel Port DE signal	-
	PCLK	I	N	Parallel Port Clock signal	-
GPIO (2)	GPIO[2:1]	I/O	N	GPIO[2:1] signals - (GPIO[1] option to become SPI_SS or INT signal) - (GPIO[2] option to become SPI_MISO signal)	4 mA
POWER (9)	VDDC (1.2V)	NA	-	VDD for Internal Core (3)	-
	VDDIO (1.8V - 3.3V)	NA	-	VDDIO is for IO power supply (4)	-
	VDD_MIPI (1.2V)	NA	-	VDD for the MIPI (2)	-
GROUND (25)	VSS	NA	-	Ground	-

TABLE 3: pinout description of TC358778XBG [15]

PIN#		NAME	DISCRIPTION
QFN(3×3)-16L	MSOP-10		
1	--	A1	I2C Address Input1
2	8	A0	I2C Address Input0
3	6	GND	Ground
4	--	AUX	Auxiliary Input
5	1	VDD	Power Supply
6	2	XP	XP Position Input
7	3	YP	YP Position Input
8	4	XN	XN Position Input
9	5	YN	YN Postion Input
10	--	GND	Ground
11	--	BAT	Battery Monitor Input
12	--	NC	
13	--	VREF	Reference Voltage Input/Output
14	7	PENIRQ	Pen Interrupt Pin
15	9	SDA	I2C Data Interface
16	10	SCL	I2C Clock Interface

TABLE 4: Pin Description of NS2009 [16]

Pin Name	Pin Number	Description
SW	1	Inductor Connection. Connect to the switched side of the external inductor as well as the anode of the external diode. SW is high impedance during shutdown.
GND	2	Ground Pin.
FB	3	Current-Sense Feedback Input. Connect a resistor from FB to GND to set the LED current.
EN	4	Enable and LED Brightness Control Input. Pull high to turn on IC. Drive EN with a 20kHz to 1MHz unfiltered PWM dimming signal for DC LED current that is proportional to the signal's duty cycle.
OV	5	Over Voltage Input. The MT9284 turn off the N-channel MOSFET when V_{OUT} exceeds 28V .Connect OV to the output at the top of the LED string.
VIN	6	Power Supply Input. Must be closely decoupled to GND with a 1 μ F or greater ceramic capacitor.

TABLE 5: pin description of MT9284 [19]

Symbol	Type	SPI Mode Function		QPI Mode Function	Comments
VDD	Power	Core supply			
VSS	Ground	Core supply ground			
CE#	Input	Chip select, active low. When CE#=1, chip is in standby state			
CLK	Input	Clock Signal			
SI/SIO[0]	IO	Serial Input	IO[0]*	IO[0]	
SO/SIO[1]	IO	Serial Output	IO[1]*	IO[1]	
SIO[2]	IO	--	IO[2]*	IO[2]	
SIO[3]	IO	--	IO[3]*	IO[3]	

TABLE 6: pin description of APS6404L-3SQR-SN [17]

PIN DESCRIPTION

Pin No.	SOT-223 / TO-252 / SOT-89	
	Name	Function
1	ADJ/GND	Adjustable / Ground
2	V _{OUT}	Output Voltage
3	V _{IN}	Input Voltage

TABLE 7: pin description of LM1117s [28]

INPUTS			OUTPUTS
INH	B	A	"ON" CHANNEL(S)
0	0	0	X0、Y0
0	0	1	X1、Y1
0	1	0	X2、Y2
0	1	1	X3、Y3
1	×	×	None

TABLE 8: truth table of CD4052B [28]

PIN		NAME	FUNCTION
TQFN	SSOP		
1	4	BIAS	Bias Voltage Output (V_{BIAS})
2	5	REFIN+	Positive Reference Voltage Input. Connect to BIAS. Connect the reference resistor between REFIN+ and REFIN-.
3	6	REFIN-	Negative Reference Voltage Input. Connect the reference resistor between REFIN+ and REFIN-.
4	7	ISENSOR	Low Side of R_{REF} . Connect to REFIN-.
5	8	FORCE+	High-Side RTD Drive. Connect to FORCE2 when using the 3-wire connection configuration. Protected to $\pm 45V$.
6	9	FORCE2	Positive Input Used in 3-Wire Only. When in the 3-wire connection configuration, connect to FORCE+. When in the 2-wire or 4-wire connection configuration, connect to ground. Protected to $\pm 45V$.
7	10	RTDIN+	Positive RTD Input. Protected to $\pm 45V$.
8	11	RTDIN-	Negative RTD Input. Protected to $\pm 45V$.
9	12	FORCE-	Low-Side RTD Return. Protected to $\pm 45V$.
10	13	GND2	Analog Ground. Connect to GND1.
11	14	SDI	Serial-Data Input
12	15	SCLK	Serial-Data Clock Input
13	16	\overline{CS}	Active-Low Chip Select. Set \overline{CS} low to enable the serial interface.
14	17	SDO	Serial-Data Output
15	18	DGND	Digital Ground
16	19	GND1	Analog Ground. Connect to GND2.
17	20	N.C.	Do Not Connect
18	1	\overline{DRDY}	Active-Low, Push-Pull, Data-Ready Output. \overline{DRDY} goes low when a new conversion result is available in the data register. When a read operation of an RTD resistance data register occurs, \overline{DRDY} returns high.
19	2	DVDD	Digital Supply Voltage Input. Connect to a 3.3V power supply. Bypass to DGND with a 0.1 μ F bypass capacitor.
20	3	V_{DD}	Analog Supply Voltage Input. Connect to a 3.3V power supply. Bypass to GND1 with a 0.1 μ F bypass capacitor.
—	—	EP	Exposed Pad (Bottom Side of Package). Connect to GND1. Applies to TQFN package only.

TABLE 9: Pin configuration of MAX31865 [29]

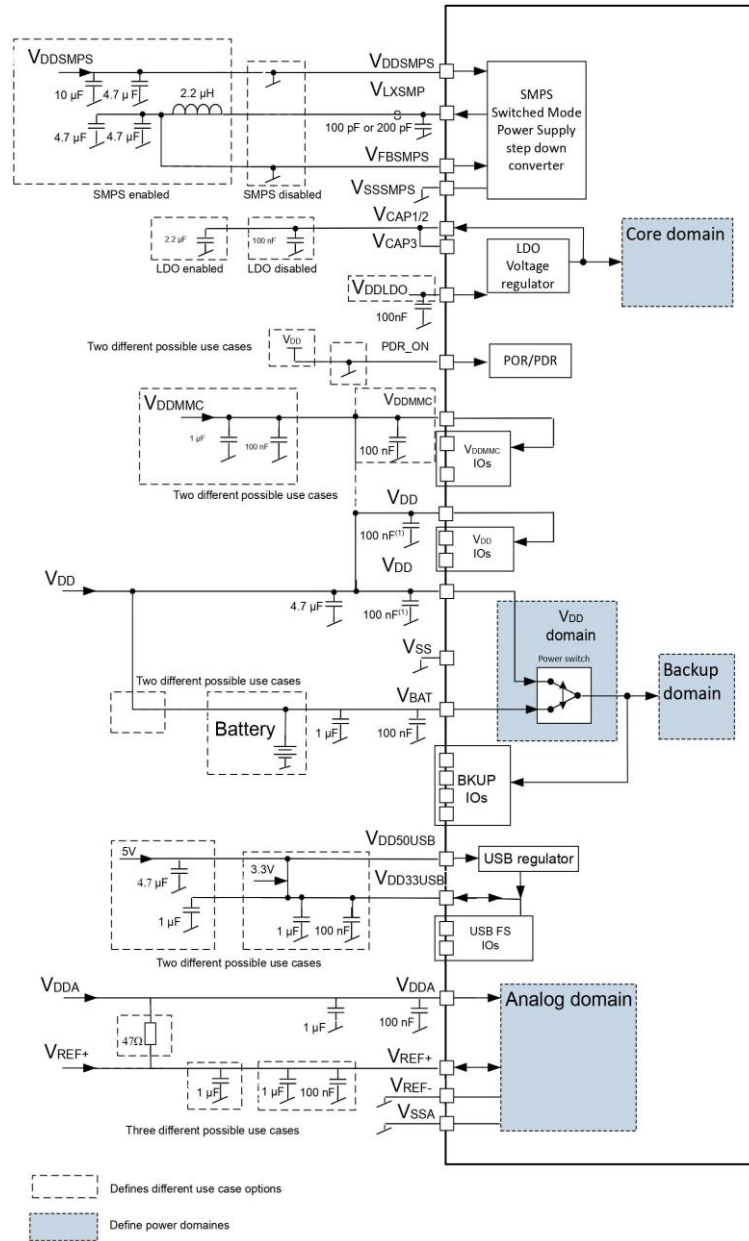


FIGURE 1: power supply schematics of MCU [14]

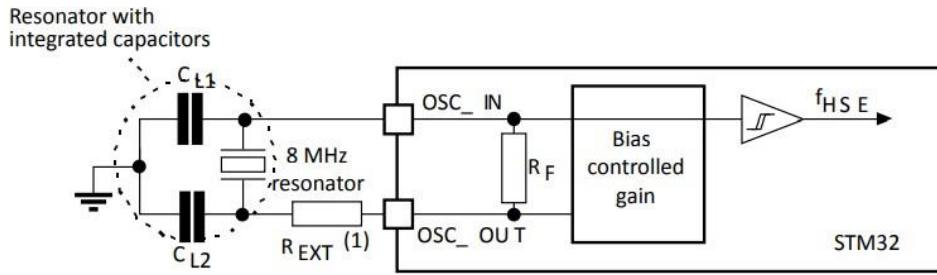


FIGURE 2: typical application with an 8 MHz crystal [14]

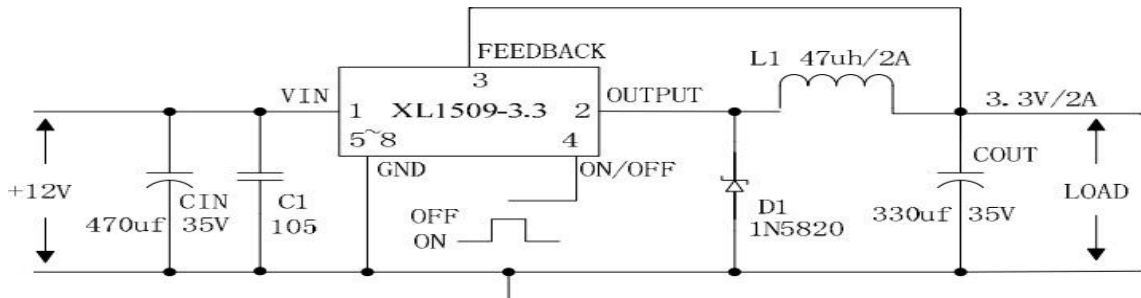


FIGURE 3: Typical application diagram of 3.3V output for XL1509 [12]

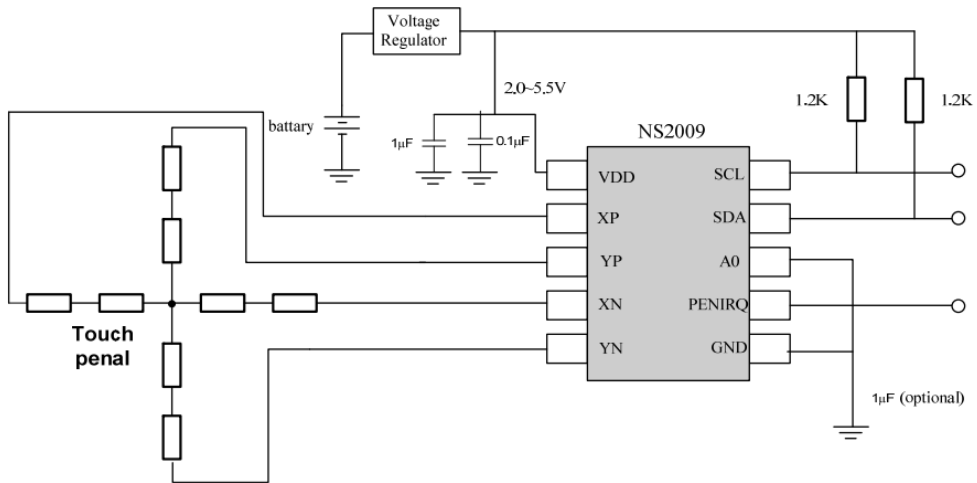


FIGURE 4: Typical Application Circuit of NS2009 [16]

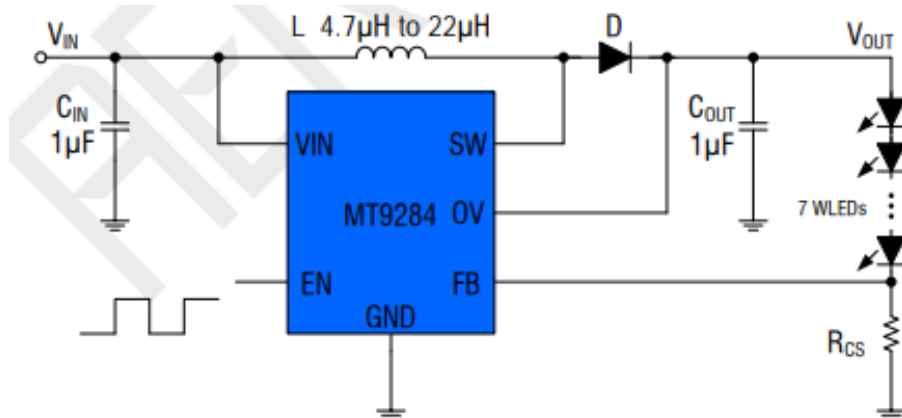


FIGURE 5: Typical Application Circuit of MT9284 [19]

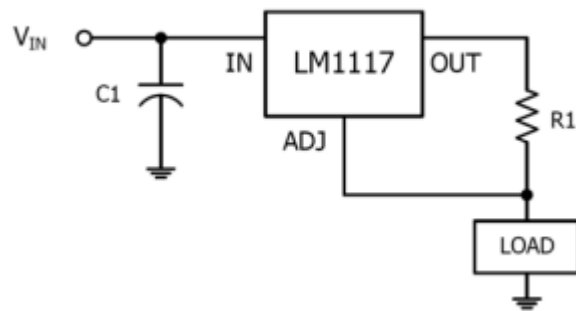


FIGURE 6: Typical Application Circuit of LM1117s [27]

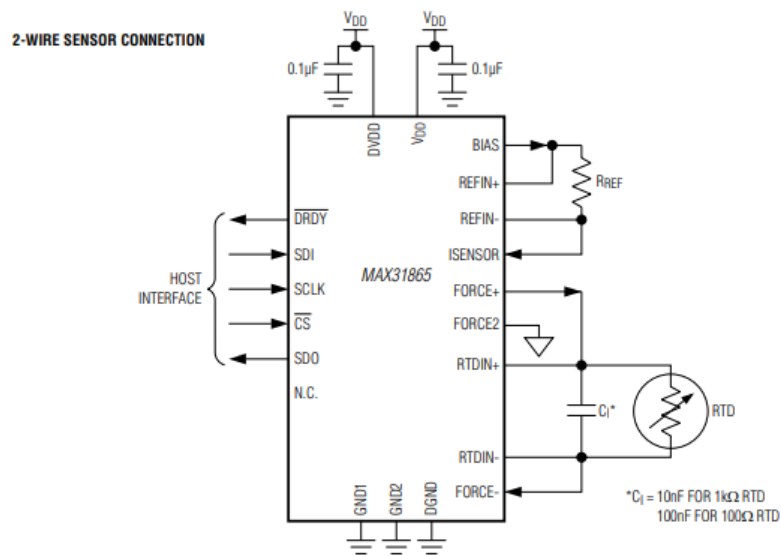


FIGURE 7: Typical Application Circuits for 2 wire [29]

3-WIRE SENSOR CONNECTION

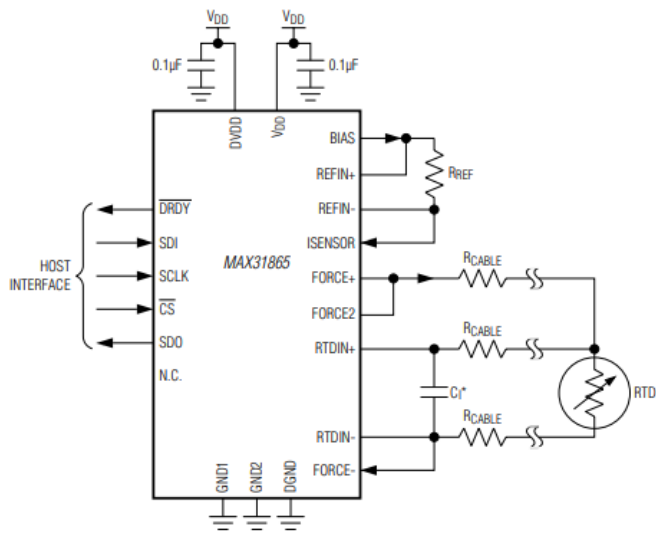


FIGURE 8: Typical Application Circuits for 3 wire [29]

4-WIRE SENSOR CONNECTION

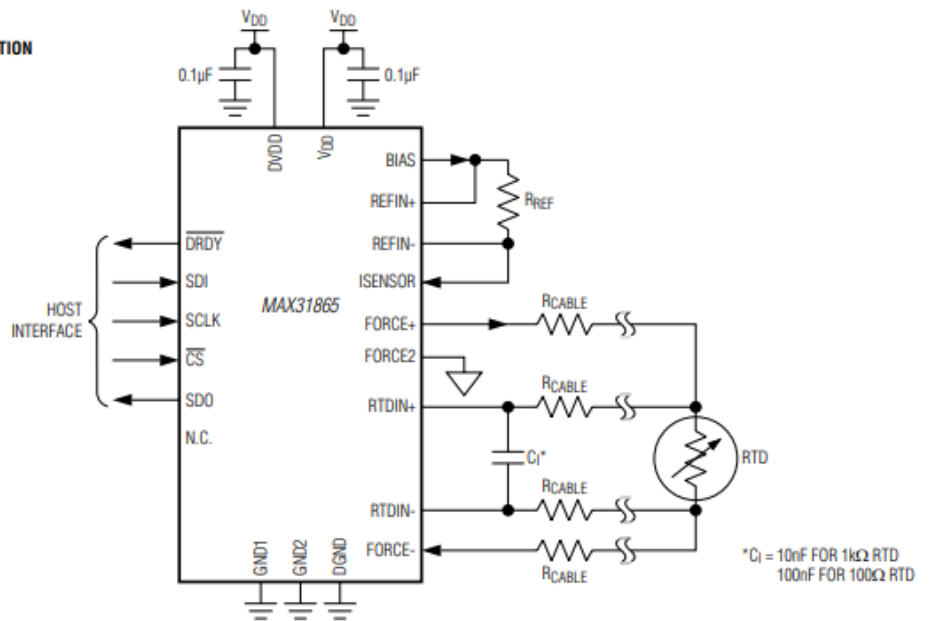


FIGURE 9: Typical Application Circuits for 4 wire [29]

Absolute Maximum Ratings (Note1)

Parameter	Symbol	Value	Unit
Input Voltage	V _{in}	-0.3 to 45	V
Feedback Pin Voltage	V _{FB}	-0.3 to V _{in}	V
ON/OFF Pin Voltage	V _{ON/OFF}	-0.3 to V _{in}	V
Output Switch Pin Voltage	V _{Output}	-0.3 to V _{in}	V
Power Dissipation	P _D	Internally limited	mW
Thermal Resistance (SOIC8) (Junction to Ambient, No Heatsink, Free Air)	R _{JA}	100	°C/W
Operating Junction Temperature	T _J	-40 to 125	°C
Storage Temperature	T _{STG}	-65 to 150	°C
Lead Temperature (Soldering, 10 sec)	T _{LEAD}	260	°C
ESD (HBM)		2000	V

TABLE 1: Working conditions of XL1509 [12]**XL1509-3.3 Electrical Characteristics**T_a = 25°C; unless otherwise specified.

Symbol	Parameter	Test Condition	Min.	Typ.	Max.	Unit
<i>System parameters test circuit figure5</i>						
V _{OUT}	Output Voltage	V _{in} = 4.75V to 40V I _{load} =0.2A to 2A	3.168	3.3	3.432	V
Efficiency	η	V _{in} =12V , V _{out} =3.3V I _{out} =2A	-	75	-	%

TABLE 2: Typical performance characteristics of XL1509 [12]

Name	Parameter
VDD Voltage	-0.3V To +5.5V
Analog Input Voltage	-0.3V To +VDD+0.3V
Digital Input Voltage	-0.3V To+VDD+0.3V
Consumption	1W
Maximum Junction Temperature	+150°C
Operating Temperature	-40°C~+85°C
Storage Temperature	-65°C~+150°C
Welding Temperature (less than 10 seconds)	+260°C
ESD	+/- 8000V (HMD)
Latch Up	+/- 100mA

TABLE 3: Working conditions of NS2009 [19]

ABSOLUTE MAXIMUM RATINGS (Note 1)

Input Supply Voltage.....	-0.3V to 6V	Junction Temperature(Note2).....	160°C
EN,FB Voltages.....	-0.3V to 6V	Operating Temperature Range.....	-40°C to 85°C
SW Voltage.....	-0.3V to 30V	Lead Temperature(Soldering,10s).....	300°C
Power Dissipation.....	0.6W	Storage Temperature Range.....	-65°C to 150°C
Thermal Resistance θ_{JC}	130°C/W	ESD HBM(Human Body Mode).....	2kV
Thermal Resistance θ_{JA}	250°C/W	ESD MM(Machine Mode).....	200V

FIGURE 1: Working conditions of MT9284 [19]

For 3.3V Output Voltage ($T_A=25^\circ\text{C}$, $C_O = 10\mu\text{F}$ unless otherwise specified)

Symbol	Parameters	Condition	Min.	Typ.	Max.	Unit
V_O	Output Voltage	$V_{IN} = 4.8\text{V}$, $I_O = 10\text{mA}$	3.267	3.3	3.333	V
V_O	Output Voltage	$V_{IN} = 4.8\text{V}$ to 12V , $I_O = 0\text{mA}$ to 1A ($T_J = 0 \sim 125^\circ\text{C}$)	3.234		3.366	V
ΔV_{LINE}	Line Regulation	$I_O = 0\text{mA}$, $V_{IN} = 4.8\text{V}$ to 12V		0.1	0.2	%
ΔV_{LOAD}	Load Regulation	$I_O = 0\text{mA}$ to 1A , $V_{IN} = 5.3\text{V}$		0.2	0.4	%
V_{IN}	Operating Input Voltage	$I_O = 100\text{mA}$			12	V
I_D	Quiescent Current	$V_{IN} - V_O = 5\text{V}$		5	10	mA
I_O	Current Limit	$V_{IN} - V_O = 5\text{V}$	1000	1250	1600	mA
eN	Output Noise(% V_O)	$B = 10\text{Hz}$ to 10kHz , $T_J = 25^\circ\text{C}$		100		μV
SVR	Supply Voltage Rejection	$I_O = 1\text{A}$, $f = 120\text{Hz}$, $V_{IN} - V_O = 3\text{V}$, $V_{RIPPLE} = 1\text{V}_{PP}$	60	75		dB

TABLE 4: ELECTRICAL CHARACTERISTICS of LM1117s [27]

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