Design and Development of

Egy_Univer_Sat (EUS)

Graduation Project

The Communication Subsystem Board in a Cube Satellite

Detailed Design Book

Supervisors:

Shubra faculty of Engineering

- **Prof. Dr. Adly Tag El-Dien**
- **Dr. Sawsan Abdellatif**

Egyptian Space Agency

- **Ass. Prof. Dr. Hesham Abd Elhady**
- **Eng. Mohamed Abd Elfatah**

Project Team

- Mahmoud Mohamed Saeed
- Mohamed Farag Fadly
- Taher Magdy Ashour
- Mohamed Adel Zohery
- Heba allah Abdelaaziz
- Ghada Osama Mohamed
- Passant Essam Ibrahem
- Norhan Hussien ELsayed

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- Eng. Mohamed Abd Elfatah

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Acronyms

COTS: Commercial of the Shelf components

LEO: low Earth orbit

EPS: Electrical Power Subsystem

OBC: On Board Computer

ADCS: Attitude Determination and Control Subsystem

CS: Communication Subsystem

POL: Point-of-Load

PCM: Pulse code modulation

COM: Communications system

XIPS: Xenon Electrostatic ion thruster system

VHF: Very High Frequency

UHF: Ultra High Frequency

IOT: Internet of things

UART: Universal Asynchronous Receiver/Transmitter.

USART: Universal Synchronous Asynchronous Receiver/Transmitter

USB: Universal Serial Bus

I2C: Inter Integrated Circuit

SPI: Serial Peripheral Interface

CAN: Controller Area Network

RS: Recommended Standard

MCU: Micro Control Unit

CPU: Control Processing Unit

Tx: Transmitter

Rx: Receiver

SYNC: Synchronization

PID: Packet Identification

ADDR: Designation Address

CRC: Cyclic Redundancy Check

EOP: End of Packet

ACK: Acknowledgment for packet received

NAK: NON-Acknowledgment data miss

LCD: liquid-crystal display

SDA: Serial Data

SCL: Serial Clock

MOSI: Master Out Slave In (data output from master)

MISO: Master in Slave Out (data output from slave)

SS: Slave Select (often active low, output from master)

SCLK: Serial Clock (output from master)

DTH: Direct To Home

GPS: Global Positioning System

GMSK: Gaussian Minimum Shift Keying

AX.25: (Amateur X.25) is a data link layer protocol

MMCX: Micro-miniature coaxial

SSP: Simple Serial Protocol

JTAG: Joint Test Action Group

RF: Radio Frequency

HPA: High Power Amplifier

LPF: Low Pass Filter

LNA: Low Noise Amplifier

BPF: Band Pass Filter

GFSK: Gaussian Frequency Shift Keying

GPIO: General Purpose Input Output

ISM: Industrial, Scientific and Medical

SRD: Short Range Device

FIFO: Frist In Frist Out

DUT: Devices under test

SPDT: Single Pole Double Throw

SNR: Signal-to-Noise Ratio

CPE: Customer-premises equipment

WLAN: Wireless Local Area Network

RFID: Radio-frequency identification

WSN: Wireless Sensor Network

SMATV: Satellite Master Antenna TV

VLSI: Very large-scale integration

ADC: Analog to digital converter

DAC: digital to analog converter

FPU: Floating Point Unit

ART: Adaptive real-time

DMIPS: Dhrystone Microprocessor without Interlocked Pipelined Stages

DSP: Digital signal processor

RAM: Random-Access Memory

SRAM: Static Random-Access Memory

PSRAM: Pseudo Static Random-Access Memory

CCM: Core coupled memory

POR: Power-On Reset

PDR: Power-Down Reset

PVD: programmable voltage detector

BOR: Brownout Reset

RTC: Real Time Clock

DMA: Direct Memory Access

LIN: Local Interconnect Network

IrDA: Infrared Data Association

SDIO: Secure Digital Input Output

OTG: On-The-Go

PHY: Physical Layer

MAC: Media Access Control

MII/RMII: Media-Independent Interface/ Reduced Media-Independent Interface

SWD: Serial Wire Debug

SWJ-DP: Serial Wire / JTAG Debug Port

JNTRST: JTAG test Reset

JTDI: JTAG test data input

JTMS/SWDIO: JTAG test mode selection

JTCK/SWCLK: JTAG test clock

JTDO: JTAG test data output

CMR: Common-Mode Range

RTD: Resistance Temperature Detector

NTC: Negative Temperature Coefficient

MOSFET: Metal–Oxide–Semiconductor Field-Effect Transistor

Pt: Power Transmit

EIRP: Effective Isotropic Radiated Power

L bo: Backoff loss

Lb: Branching Loss

Lf: Feeding Loss

Eb/N0: Energy of Bit-to-Noise density Ratio

VSS: Visual System Simulator

BER: Bit error rate

TP: Test Point

PCB: Print circuit board

LED: Light emitting diode

PTH: Plated Through Hole

GND: Ground

FR: Flame retardant

CEM: Composite epoxy materials

HASL*:* Hot air solders leveling

Purpose of Document

The purpose of this document is to present the work done in our graduation project. The current document presents block diagram of communication subsystem, link budget and simulation by using AWR, detailed steps for PCB Board design (show how to draw schematic and footprint for each component, collecting the total integrated library, draw schematic diagram for the circuit, Routing stage and testing stage).

Applicability

The present design is used at the following stages:

• Next phase design and operation documentation development for

(Communication Subsystem Hardware) and on-board equipment control and test equipment.

• Subsystem manufacturing, off-line and integration tests.

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Abstract

The essential mission requirement of a satellite is the ability to provide a link to transmit information to and from the ground station that is why we need communication subsystem.

We will be discussed CubeSat structure, how it works, advantages, disadvantage, application, cost and weight. We also discussed communication protocols needed in our project.

And how to make a communication subsystems start from how we design and make the block diagram, the simulation how we choose the component and how we will design using Altium program and how we test the PCB board.

Chapter 1: CubeSat Introduction

1.1 Introduction

1.1.1 What Is a Satellite?

A satellite is an object that moves around a larger object. Earth is a satellite because it moves around the sun. The moon is a satellite because it moves around Earth. Earth and the moon are called "natural" satellites.

But usually when someone says "satellite", they are talking about a "man-made" satellite. Man-made satellites are machines made by people. These machines are launched into space and orbit Earth or another body in space.

There are thousands of man-made satellites. Some take pictures of our planet. Some take pictures of other planets, the sun and other objects. These pictures help scientists learn about Earth, the solar system and the universe. Other satellites send TV signals and phone calls around the world.

Figure 1.1: Satellite

1.1.2 Why Are Satellites Important?

Satellites fly high in the sky, so they can see large areas of Earth at one time. Satellites also have a clear view of space. That's because they fly above Earth's clouds and air.

Before satellites, TV signals didn't go very far. TV signals only travel in straight lines. So, they would go off into space instead of following Earth's curve. Sometimes they would be blocked by mountains or tall buildings Phone calls to faraway places were also a problem. It costs a lot, and it is hard to set up telephone wires over long distances or underwater.

With satellites, TV signals and phone calls can be sent up to a satellite. The satellite can then send them back down to different spots on Earth.

1.2 CubeSat

CubeSat range in size from 1U to 3U. They're always 10×10 cm in length and width, but their height can vary from 11.35 to 34.05 cm.

CubeSat have a mass of no more than 1.33 kilograms per unit and often use commercial off-the-shelf (COTS) components for their electronics and structure. They float in low Earth orbit (LEO), which has an altitude between 160 km to 2,000 km and orbit the Earth roughly every 90 minutes.

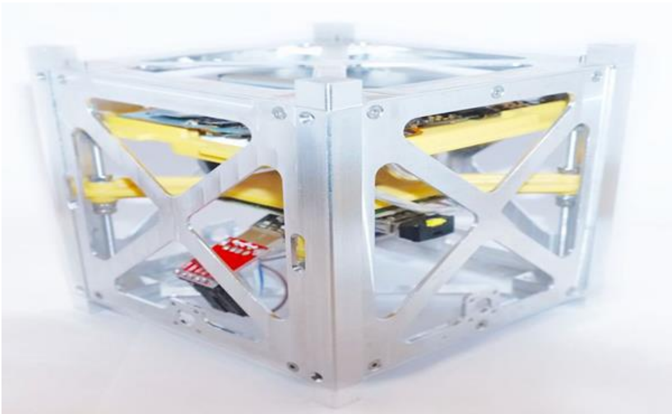


Figure 1.2: A CubeSat

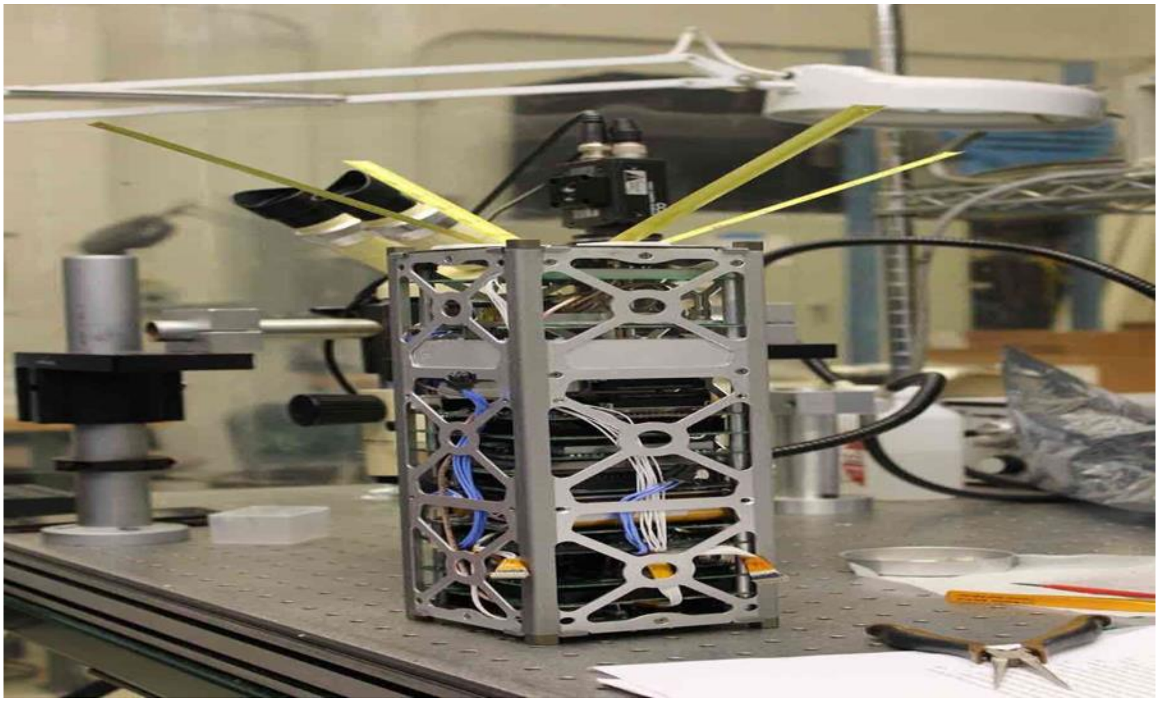


Figure 1.3: An example of CubeSat construction

1.2.1 CubeSat Vs Conventional Satellites

With the Sputnik models from the Soviet Union, humanity successfully launched the first artificial satellites into Earth's orbit in 1957. Since then, and until the twentieth century's end, Hundreds of satellites were launched by the world's superpowers, headed by their governments, in a quest to explore space in a series of highly ambitious and complex ventures.

the world's most developed countries' space agencies or big companies having access to it.

The first Sputnik weighed 83.6 kilograms, while the second weighed more than 500 kilograms. The International Space Station currently weighs 420,000 kilograms.

Until now, space technology tends to become increasingly broad and complex, with only.

Because of falling costs and miniaturization of electronic components, New Space is based on a theory of manufacturing less costly satellites in shorter periods of time. Benefits that was previously only available to large corporations or space agencies with enormous financial resources have been democratized with nanosatellites and are now available to businesses of all types and sizes.

1.2.2 How Long Does It Take to Develop a New CubeSat (Nanosatellite)

Aside from their size and expense, a nanosatellite's biggest benefit is the short time it takes to build each model. Under normal conditions, it takes between 3 years and more than 10 years for an average-sized or large satellite to detect the need and position it in the proper orbit.

This mean in terms of ramifications: The requirements may have changed between the start and end of operations, meaning that the original intended uses are no longer marketable. Telecommunications innovations, on the other hand, are advancing rapidly.

As a result, conventional satellites will potentially be operating on 15-year-old technology. Large satellites can't be updated on a regular basis, so they can't be changed even if a commercial or technological opportunity occurs.

Nanosatellites, on the other hand, can detect a need and be launched into space in less than eight months.

1.2.3 How much does a CubeSat (Nanosatellite) cost

The development of small satellites in compliance with CubeSat requirements helps to minimize research and development costs. This helps to break down the barrier to entry into space, which has resulted in a surge in CubeSat popularity since their launch. A nanosatellite can be designed and launched into orbit for $50,000, depending on the requirements.

The cost of a single traditional satellite launch will range from around $50 million to around $400 million. A space shuttle flight would easily cost $500 million to launch, despite the fact that one mission can take several satellites into orbit. The advent of micro-launchers around the world, which are dedicated solely to sending small satellites into orbit and have decreased launch costs, is especially noteworthy.

Launching a nanosatellite as part of a constellation allows the risk associated with any space mission to be broken up into smaller parts, in addition to the actual construction of each satellite. As a consequence, if a nanosatellite is lost or one of the units fails, it can be quickly and inexpensively replaced. The failure of a large-scale satellite, on the other hand, could jeopardize the entire project.

Nanosatellites' lower cost does not imply that they are less efficient. The success of a mission can be assured using the right methodologies during both the satellite design and testing phases, leaving only those variables that cannot be managed to chance launch failures, solar storms, or the effects of a meteorite or piece of space junk.

1.2.4 Key Facts about CubeSat

1. Polar orbit

Satellites orbit the Earth in circular or elliptical orbits because the gravitational and escape pulls are balanced during launch. Since there is no air, there is no friction to change the equation, and they can stay in orbit forever. When a nanosatellite's operating life is over, it re-enters the atmosphere and disintegrates.

2. Low Altitude

Nanosatellites are usually launched into low circular or elliptical orbits (altitudes of 400 to 650 km) and fly at a speed of about 8 km per second. It takes those about 90 minutes to orbit the Earth at this altitude and height, and they complete between 14 and 16 orbits every day. Nanosatellites thrive in these conditions. They are better shielded from solar and cosmic rays by orbiting near to the Earth. This ensures ideal conditions for land observation or communications.

1.3 CubeSat Subsystems

1.3.1 Structure Subsystem
1.3.2 Electrical Power Subsystem (EPS)
1.3.3 On Board Computer (OBC)
1.3.4 Thermal Control Subsystem
1.3.5 Attitude Determination and Control Subsystem (ADCS)
1.3.6 CubeSat Payload
1.3.7 Communication Subsystem (CS)

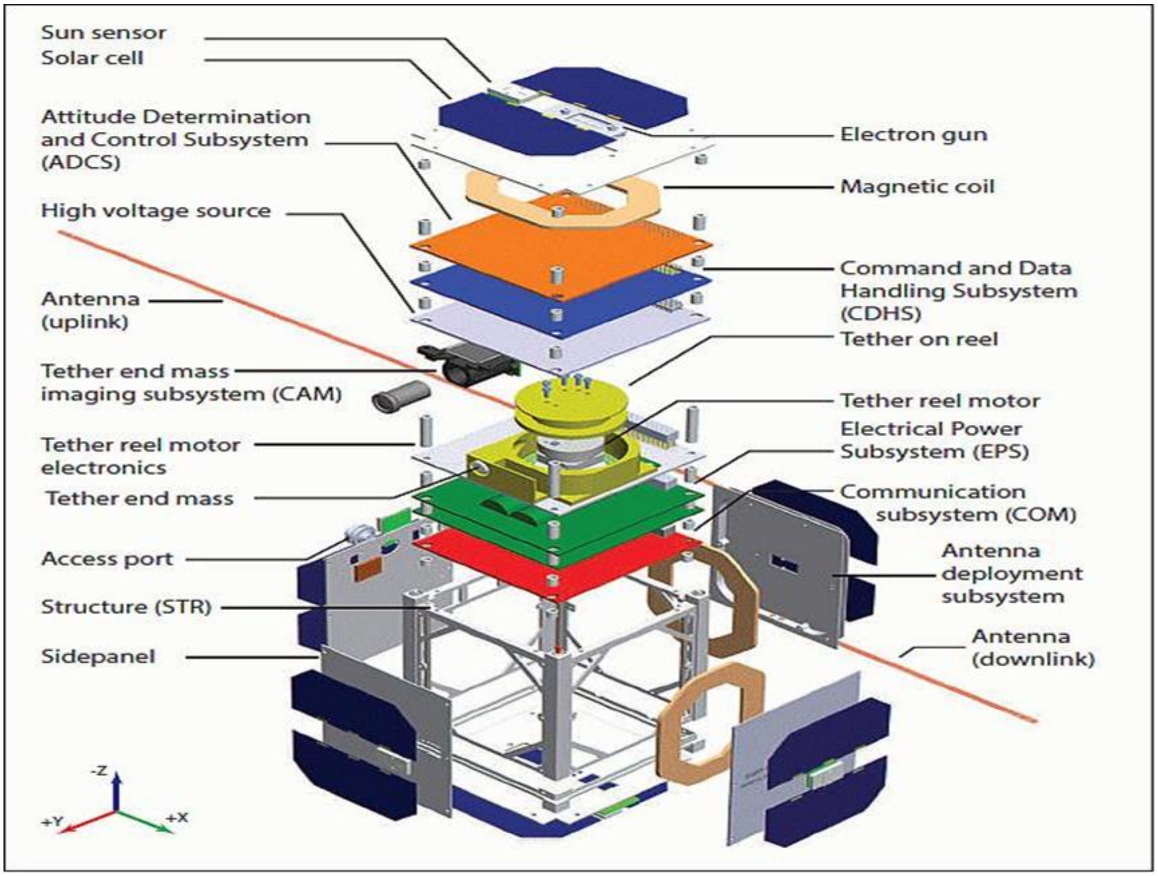


Figure 1.4: Cube satellite subsystems

1.3.1. Structure subsystem

Small satellite structures and mechanisms primarily and mechanically assist all other satellite subsystems, mount the satellite to the launch vehicle, and fulfil all functional requirements on orbit. Throughout its life, satellite would be exposed to harsh environmental conditions.

Figure 1.5: 1U structure

Figure 1.6: 2U structure

Figure 1.7: 3U structure

Satellite structure function:

1. Maintain a satellite's main components in desirable positions during mission operation and in their stowed configuration within the payload envelope of the launch vehicle.

2. The satellite's components must be protected from the complex conditions experienced during ground operations, launch, deployment, and mission operations.

3. Deploy antennas and sensors during the mission and have enough stiffness to maintain them stable while remaining light enough for the launch vehicle of choice.

4. Prevent vibrations from interfering with the control systems of the launch vehicle or the spacecraft's own on-orbit control system.

5. All other subsystems are kept together by the Satellite Structure.

1.3.2 Electrical Power Subsystem (EPS)

The CubeSat uses highly integrated Electrical Power System (EPS) electronics designed to optimize for power. For the CubeSat to become used for real world missions, the EPS must not only be efficient but flexible too. The ideal EPS design is one that meets the power requirements of a specific mission and can then be used multiple times in different mission scenarios, without having to be redesigned for each mission. Distributive architectures are flexible. They have enabled modular designs that result in greater design reuse, while still meeting system requirements of varying satellite payloads and spacecraft configurations.

In addition to standard DC-Converters, the charge pump will also be considered as the distributed Point-of-Load (POL) converter.

The point-of-load converter is one where the convertor is located near the load that it sources power to. The load can be a card, or it can be a component or sub circuit element on a card. The charge pump is typically only used in low-power applications. The CubeSat is exactly a low power application.

1.3.3 On Board Computer (OBC)

The OBC (on-board computer) is one of the most important subsystems of the CubeSat, it is the subsystem that considered as the brain of the whole satellite; as any operation happens in the satellite or outside the satellite to connect to the earth station takes permission first from the on-board computer subsystem, thus we can say that it is the subsystem that controls the whole system.

It can also be considered as a bridge that connects all the subsystems of the CubeSat together as manages many tasks done by several subsystems to ensure existing of harmony between these tasks.

The OBC is a nanosatellite. And Nanosatellites have some important properties; they have a mass between 1 and 10 kg. Actually, as the CubeSat is a common Nano-satellite, it is known that its mass is no more than 1.33 kilograms.

But what is the OBC exactly?!... The OBC is just a microprocessor; it has memory banks and also has an interfacing chip to make it connected to the other subsystems all the time.

1.3.4 Thermal Control Subsystem

The thermal control system serves the main function of maintaining the internal components within their operational temperatures throughout the proposed mission life. The Satellite system is composed of multiple heat generating subsystems, each with their own components, as follows: Optical, attitude determination and control, communication and computing.

In this thermal control system, the PCM is component dependent, meaning that each component requires its own thermal control system. A CubeSat system containing many heat generating internal components would not benefit from such a system due to the strict payload and space parameters. A design containing a centralized PCM thermal control system would have the greatest advantage for a CubeSat system because it will centralize the heat and transfer it equally throughout the system.

1.3.5 Attitude Determination and Control Subsystem (ADCS)

It is obvious from the name of this Subsystem, that it is responsible for determining and controlling the attitude of the CubeSat, which means that it is responsible for the CubeSat position in the space, as the space external effects (like radiations or any another space crafts or even natural phenomena) will affect the required position of the satellite, making it getting out of the orbit it is supposed to be follow its path, which is leading at the end to the failure of the mission that the CubeSat is launched for accomplishing.

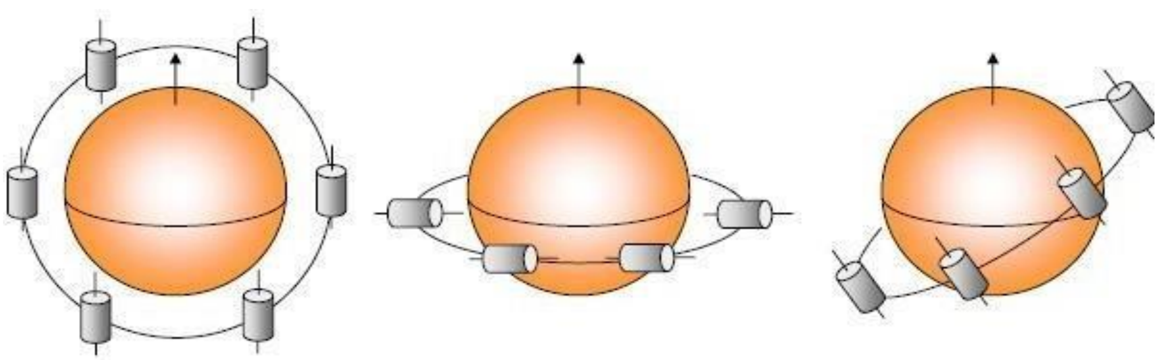


Figure 1.8: Satellite remains initially fixed in space.

1.3.6 CubeSat Payload

What is a payload? The payload is what the satellite is about, since it is the payload that performs the functions that the satellite is designed to perform. The payload is made up of communications antennas, receivers, and transmitters in a nutshell.

Depending on the type of mission needed, the payload, or function of the CubeSat, differs drastically. These may include cameras for taking pictures or video, such as Planet Labs', as well as space testing of electronic components, flight control system testing, and even biological experiments.

What are the different types of CubeSat payloads? While the majority of CubeSat payloads can be divided into four groups, there are several practical applications for small satellites.

1. Earth observation (camera)
2. Communications (Transponder)
3. Navigation
4. Science and technology
5. Sensor (multi-function)

Can multiple payloads be carried on a single small satellite?

Yes, of course. It can be a significant benefit in some projects because it allows you to integrate multiple missions into a single CubeSat, distribute costs, and conduct simultaneous observations. This knowledge could be exchanged, for example, by a small satellite that can analyze the position of ships while also detecting the existence of spills in the oceans.

Is it possible to change a CubeSat's payload while it's in orbit?

Although the payload cannot be physically changed, it is possible to reconfigure the payload in space (orbit).

1.3.7 Communication Subsystem (CS)

One of the major subsystems of the satellite system is the communications subsystem, which is responsible for creating a connection between the satellite and the ground station for information transmission.

This connection is the only way to learn about the satellite's status and health during its launch, as well as all pertinent information about the satellite's payload.

The communication subsystem's primary goal is to provide a connection for relaying data findings and sending commands to and from the CubeSat.

The ground station and the CubeSat will be in constant touch thanks to telemetry and command subsystems.

The communications system (COM) is severely limited by the amount of power available, which is usually around 2W. Compared to Boeing’s Spacecraft, which uses a Xenon Electrostatic ion thruster system (XIPS), operates in the low- to mid-power range of satellites, and has three to eight kilowatts of power, CubeSat’ power is exponentially les.

CubeSat use radio-communication systems in VHF, UHF, F-, S-, C- and X-band. The satellite uses an antenna, usually deployed once in orbit to help with communication. Antennas range from commercial measuring tape to more complicated inflatable dish antennas.

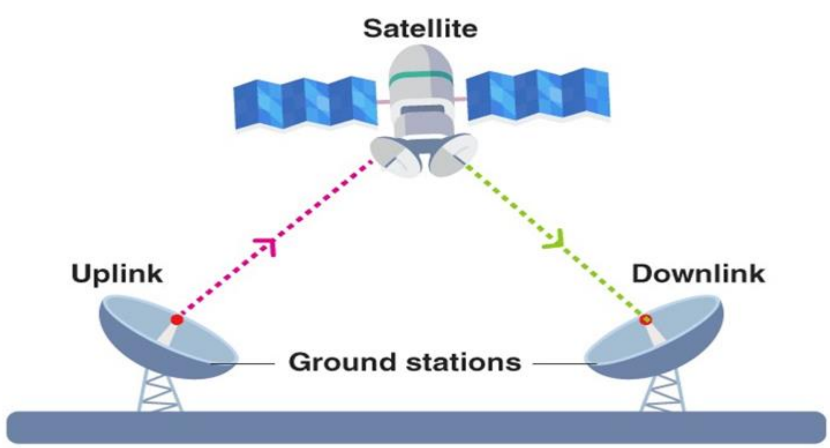


Figure 1.9: Satellite Communication

1.4 Advantage and disadvantage and applications of CubeSat

1.4.1 Advantages of CubeSat

1. More accessible to companies of all types and sizes.
2. More affordable prices.
3. Shorter development times.
4. More up-to-date technology.
5. Smaller size and weight.
6. Risk distribution.
7. More flexible services.
8. Greater independence and control over the project.
9. Greater data security.
10. Standing out from the competition.

1.4.2 Disadvantage of CubeSat

1. Very resource limited (power, mass, telemetry).
2. Shorter operational lifetime.
3. Often limited to a single instrument.
4. Low budget = harder to develop new hardware.
5. Secondary payload means less control over orbit, schedule.

1.4.3 Applications of CubeSat

1. Earth and Space Observation
2. Capturing images of the Earth
3. Earth mapping
4. IOT and Communications
5. IOT and M2M communications
6. Remote management
7. Asset Tracking
8. Science and Environment
9. Security, Defence and National Space Programmers

Chapter 2: Communication Protocols

2.1 Introduction to Communication Protocols:

In the technology world there are vast numbers of users who communicate in different languages with different devices. This also includes many ways in which data is transmitted along with the various software that they implement. Therefore, it will not be possible to communicate worldwide if there are no fixed 'standards' governing the way users communicate for data as well as the way our devices treat data, so We'll discuss the types of communication protocols.

A communication protocol is a system of rules allowing two or more communications system entities to transmit information through any type of variation of a physical quantity. The protocol defines the rules, syntax, semantics and communication synchronization, as well as possible methods for recovering errors. Hardware, software or a combination of both may implement protocols.

Communication protocols are used both for software and hardware and are implemented in analog and digital communications.

There are two important types of communication protocols methods:

1. **Network communication protocols**
2. **Electronic communication protocols**

We will talk about Electronic communication protocols that it is important for our project.

2.2 Electronics communication protocols

Protocol: The protocol is considered a set of rules and regulations.

Communication: Communication is called the exchange of information through a medium from one system to another.

Communication Protocol: A collection of rules and regulations authorizing two electronic devices to link to each other to share the data.

Communication protocols are formal descriptions of digital message formats and rules. They are required to exchange messages in or between computing systems. Communication protocols are important in telecommunications systems and other systems because they create consistency and universality for the sending and receiving of messages.

Communications protocols can cover authentication, error detection and correction, and signaling. They can also describe the syntax, semantics, and synchronization of analog and digital communications.

Communications protocols are implemented in hardware and software. There are thousands of communications protocols that are used everywhere in analog and digital communications. Computer networks cannot exist without them.

Types of Electronic Communication Protocols

There are two types of communication protocols listed under it:

2.2.1 Inter System Protocol

2.2.2 Intra System Protocol

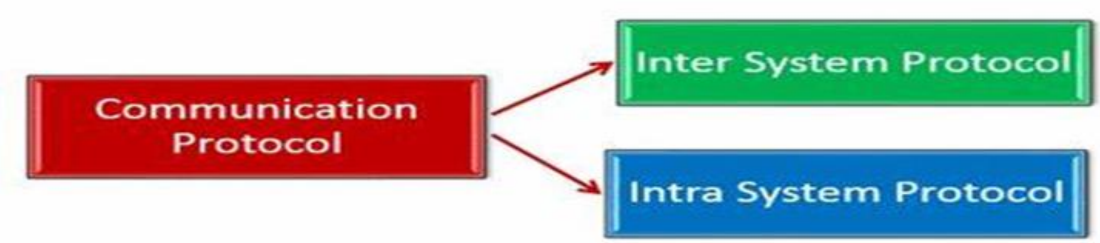


Figure 2.1: Communication Protocol

2.2.1 Inter System Protocol:

An inter-system protocol used to connect the two different devices. Such as the connection between a computer and a set of microcontrollers. Communication is done through an inter-bus system.

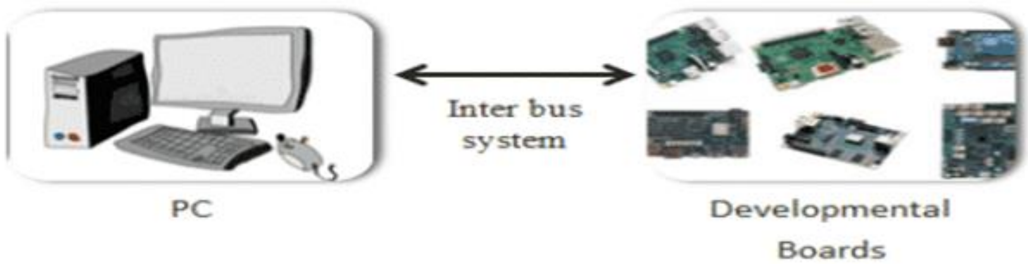


Figure 2.2: Inter System Protocol

<u>Different categories of Inter system protocol:</u>

1. UART Protocol
2. USART Protocol
3. USB Protocol

2.2.2 Intra System Protocol:

The Intra system protocol is used inside the circuit board to connect the two devices. By using these intra-system protocols, we can extend the microcontroller's peripherals without going through intra system protocols. By using intra system protocol the circuit complexity and power consumption will be increased. Using intra-system protocols circuit complexity and power consumption, the cost is reduced and access to the data is very reliable.

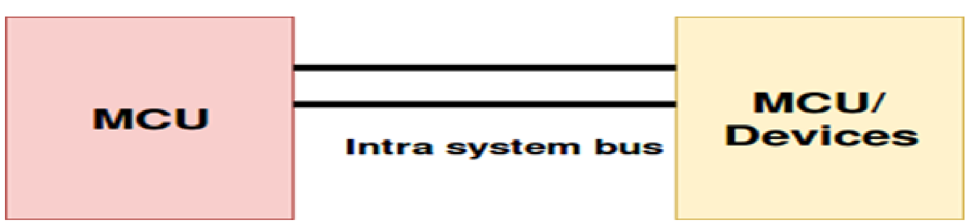


Figure 2.3: Intra System Protocol

<u>**Different categories of Intra system protocol**</u>

1. I2C Protocol
2. SPI Protocol
3. CAN Protocol

2.3 The basics of the most common protocols:

1. Universal Asynchronous Receiver/Transmitter.	(UART)
2. Universal Synchronous Asynchronous Receiver/Transmitter.	(USART)
3. Universal Serial Bus	(USB)
4. Inter Integrated Circuit	(I2C)
5. Serial Peripheral Interface	(SPI)
6. Controller Area Network	(CAN)
7. Recommended Standard	(RS8485, RS422, RS232)

2.3.1 UART Protocol:

In UART communication, two UARTs communicate directly with each other. The transmitting UART converts parallel data from a controlling device like a CPU into serial form, transmits it in serial to the receiving UART, which then converts the serial data back into parallel data for the receiving device. Only two wires are needed to transmit data between two UARTs. Data flows from the Tx pin of the transmitting UART to the Rx pin of the receiving UART.

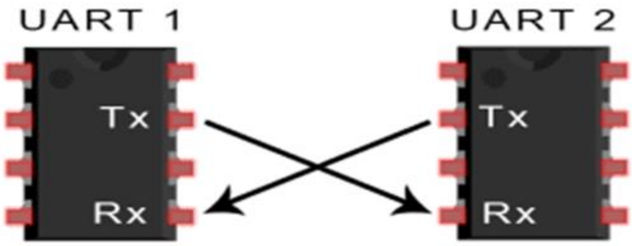


Figure 2.4: UART Basic Connection Diagram

UARTs transmit data asynchronously, which means there is no clock signal to synchronize the output of bits from the transmitting UART to the sampling of bits by the receiving UART. Instead of a clock signal, the transmitting UART adds start and stop bits to the data packet being transferred. These bits define the beginning and end of the data packet so the receiving UART knows when to start reading the bits.

When the receiving UART detects a start bit, it starts to read the incoming bits at a specific frequency known as the *baud rate*. Baud rate is a measure of the speed of data transfer, expressed in bits per second. Both UARTs must operate at about the same baud rate. The baud rate between the transmitting and receiving UARTs can only differ by about 10% before the timing of bits gets too far off.

<u>How UART Works:</u>

The UART that is going to transmit data receives the data from a data bus. The data bus is used to send data to the UART by another device like a CPU, memory, or microcontroller. Data is transferred from the data bus to the transmitting UART in parallel form. After the transmitting UART gets the parallel data from the data bus, it adds a start bit, a parity bit, and a stop bit, creating the data packet. Next, the data packet is output serially, bit by bit at the Tx pin. The receiving UART reads the data packet bit by bit at its Rx pin. The receiving UART then converts the data back into parallel form and removes the start bit, parity bit, and stop bits. Finally, the receiving UART transfers the data packet in parallel to the data bus on the receiving end:

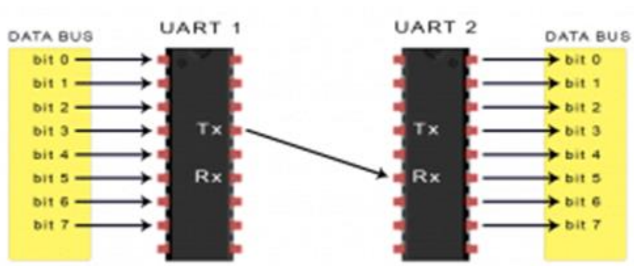


Figure 2.5: UART Data Transmission Diagram

UART transmitted data is organized into *packets*. Each packet contains 1 start bit, 5 to 9 data bits (depending on the UART), an optional parity bit, and 1 or 2 stop bits:

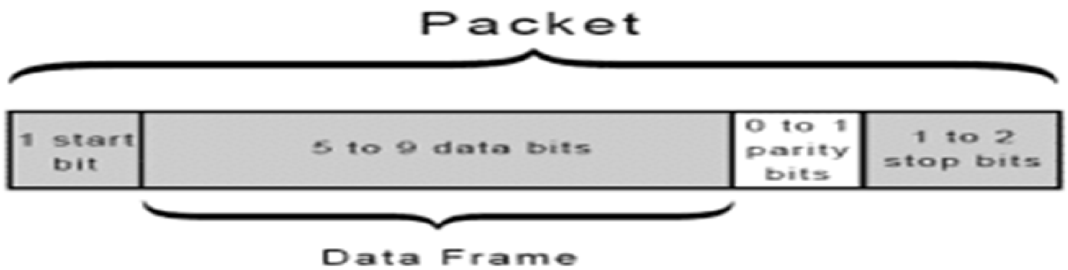


Figure 2.6: UART Format

A) START BIT

The UART data transmission line is normally held at a high voltage level when it's not transmitting data. To start the transfer of data, the transmitting UART pulls the transmission line from high to low for one clock cycle. When the receiving UART detects the high to low voltage transition, it begins reading the bits in the data frame at the frequency of the baud rate.

B) DATA FRAME

The data frame contains the actual data being transferred. It can be 5 bits up to 8 bits long if a parity bit is used. If no parity bit is used, the data frame can be 9 bits long. In most cases, the data is sent with the least significant bit first.

C) PARITY BIT

Parity describes the evenness or oddness of a number. The parity bit is a way for the receiving UART to tell if any data has changed during transmission. Bits can be changed by electromagnetic radiation, mismatched baud rates, or long-distance data transfers. After the receiving UART reads the data frame, it counts the number of bits with a value of 1 and checks if the total is an even or odd number. If the parity bit is a 0 (even parity), the 1 bit in the data frame should total to an even number. If the parity bit is a 1 (odd parity), the 1 bit in the data frame should total to an odd number. When the parity bit matches the data, the UART knows that the transmission was free of errors. But if the parity bit is a 0, and the total is odd; or the parity bit is a 1, and the total is even, the UART knows that bits in the data frame have changed.

D) STOP BITS

To signal the end of the data packet, the sending UART drives the data transmission line from a low voltage to a high voltage for at least two-bit durations.

STEPS OF UART TRANSMISSION

1. The transmitting UART receives data in parallel from the data bus:

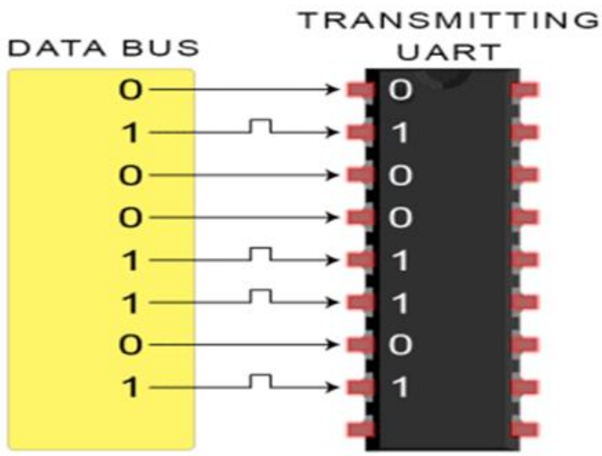


Figure 2.7: UART Transmission step 1

2. The transmitting UART adds the start bit, parity bit, and the stop bit(s) to the data frame:

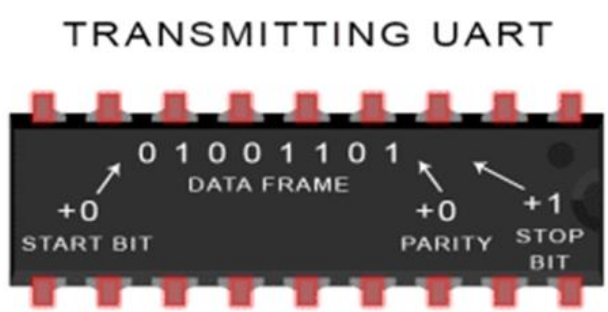


Figure 2.8: UART Transmission step 2

3. The entire packet is sent serially from the transmitting UART to the receiving UART. The receiving UART samples the data line at the pre-configured baud rate:

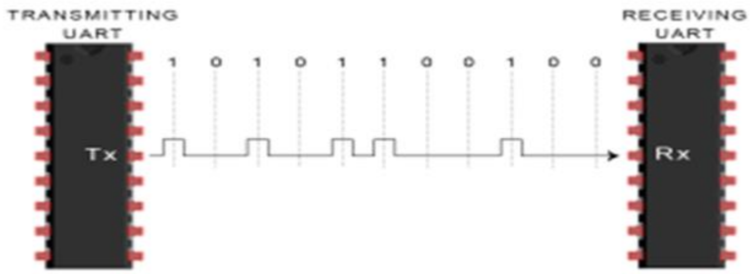


Figure 2.9: UART Transmission step 3

4. The receiving UART discards the start bit, parity bit, and stop bit from the data frame:

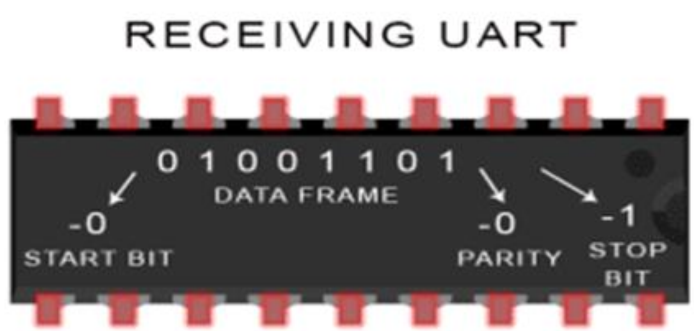


Figure 2.10: UART Transmission step 4

5. The receiving UART converts the serial data back into parallel and transfers it to the data bus on the receiving end:

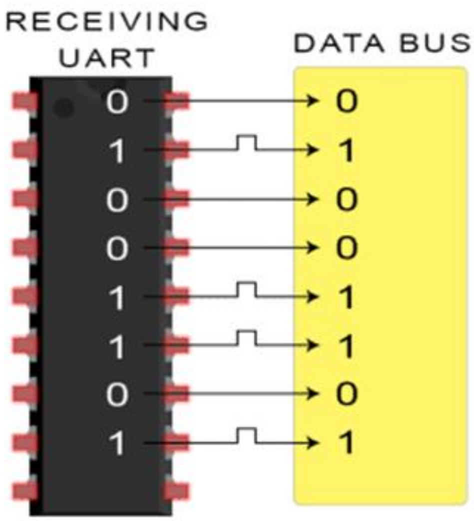


Figure 2.11: UART Transmission step 5

Advantages:

1. Only uses two wires.
2. No clock signal is necessary.
3. Has a parity bit to allow for error checking.
4. The structure of the data packet can be changed as long as both sides are set up for it.
5. Well documented and widely used method.

Disadvantages:

1. The size of the data frame is limited to a maximum of 9 bits.
2. Doesn't support multiple slave or multiple master systems.
3. The baud rates of each UART must be within 10% of each other.

2.3.2 USART Protocol:

USART stands for universal synchronous asynchronous receiver/transmitter. It is a serial two wire protocol communication. The signal lines of the data cable shall be identified as Rx and TX.

<u>How USART works:</u>

This protocol is used along with the clock pulses to transmit and receive the data byte by byte. It is a full-duplex protocol that means data being transmitted and received at different board rates simultaneously. Different devices communicate with microcontroller to this protocol.

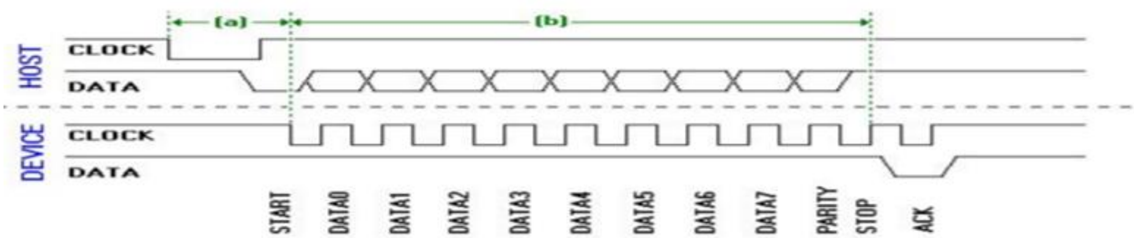


Figure 2.12: USART Protocol Data Flow

A USART provides the computer with the interface necessary for communication with modems and other serial devices. However, unlike a UART, a USART offers the option of synchronous mode. In program-to-program communication, the synchronous mode requires that each end of an exchange respond in turn without initiating a new communication. Asynchronous operation means that a process operates independently of other processes.

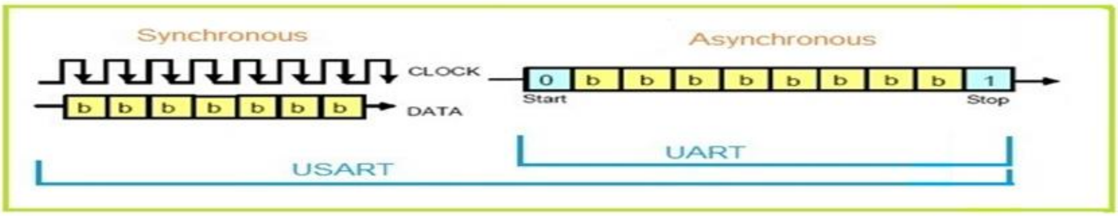


Figure 2.13: USART Data Transmission

Advantages:

1. Support high energy consumption.
2. Have high data rate.
3. Share a clock between transmitter and receiver.

Disadvantages:

1. More complex.

2.3.3 USB Protocol:

Figure 2.14: USB Protocol Communications

The USB Protocol, also known as Universal Serial Bus, was first created and introduced in 1996 as a way to institutionalize a more widespread, uniform cable and connector that could be used across a multitude of different devices. With the increase in technological devices during this time, having a universal cable would help reduce the confusion and inconvenience of having a collection of cables needed for each individual device.

The USB architecture was conceptualized at the juncture of companies including Compaq, Digital Equipment, IBM, Intel, Microsoft, and Northern Telecom, and is currently maintained and regulated by the USB Implementers Forum, or USB-IF. USB-IF enforces the standards and specifications that USB device manufactures must comply with in order to be verified as a trusted USB source. Devices that are compliant with both the USB standard’s physical layer (mechanical and electrical) and software layer are approved to use the USB logo, informing consumers and other USB adopters that their cables or devices are safe to use.

How USB works:

There are a variety of mechanisms that must be adhered to, including how various USB devices should interact with each other upon enumeration and communication.

USB hosts are also known as master devices, and they initiate all the communication that occurs over the USB bus. Typically, a computer or other controller is considered to be the master, only responding to other devices if requesting certain information. The peripheral device, or the slave device, is connected to the host device, and is programmed to provide the host device with the information it needs to operate. Typically, peripheral devices include USB flash drives, computer mice and keyboards, cameras, and other such devices.

It is important for host and peripheral devices to be able to effectively communicate with each other. If either one isn't able to perform its job function, the communication between two devices would falter. For instance, if a user plugs in a flash device on their host computer and nothing happens, this would likely indicate a problem with the communication over the bus. This leads to how communication takes place over the USB bus. How is USB data transmitted and received? This can be better understood by getting to know the theory of operation on how USB data is sent over the bus, the different USB data packet fields and packet types, and the types of USB data transfers.

USB Data Packets:

These fields are used to form data packets, which define the various transactions. There are four USB packet types including:

A) Token Packet, which is initiated by the host and determines if the host will send or receive data.

	SYNC	PID	ADDR	ENDR	CRC	EOP
NOUMBER OF BITS	8 bits(low/full) /32 bits (high)	8	7	4	5	n/o

Figure 2.15: USB Token Packets

B) Data Packet, where the Data is sent by the transmitter and a device can return a NAK or Stall packet to indicate if they are not able to respond.

	SYNC	PID	FRAMENUMBER	CRC	EOP
NOUMBER OF BITS	8 bits(low/full) /32 bits (high)	8	11	5	n/o

Figure 2.16: USB Data Packet

C) Handshake Packet, used for acknowledging data or reporting errors.

	SYNC	PID	EOP
NOUMBER OF BITS	8 bits(low/full) /32 bits (high)	8	n/o

Figure 2.17: USB Handshake **Packet**

D) Start-of-Frame Packet splits the USB bus into time segments and schedules the data transfers.

These packets are formed into frames and sent through a USB transaction. The length and frequency of the transaction depends upon the transfer type being used for an endpoint.

	SYNC	PID	DATA	CRC	EOP
NOUMBER OF BITS	8 bits(low/full) /32 bits (high)	8	Up to 8 bytes (low)/1023 bytes(full)/1024 bytes (high)	16	n/o

Figure 2.18: USB Start-of-Frame Packet

Types of USB Data Transfers

All communication between a USB host and a USB device is addressed to a specific endpoint on the device. Each device endpoint is a unidirectional receiver or transmitter of data; either specified as a sender or receiver of data from the host.

Each endpoint is different, specified through their bandwidth requirements and the way they transfer data. The four types of USB data transfers include: Control, Isochronous, Interrupt, and Bulk transfers.

A) **Control:** Non-periodic transfers. Typically, used for device configuration, commands, and status operation.

B) **Interrupt**: This is a transaction that is guaranteed to occur within a certain time interval. The device will specify the time interval at which the host should check the device to see if there is new data. This is used by input devices such as mice and keyboards.

C) **Isochronous**: Periodic and continuous transfer for time-sensitive data. There is no error checking or retransmission of the data sent in these packets. This is used for devices that need to reserve bandwidth and have a high tolerance to errors. Examples include multimedia devices for audio and video.

D) **Bulk**: General transfer scheme for large amounts of data. This is for contexts where it is more important that the data is transmitted without errors than for the data to arrive in a timely manner. Bulk transfers have the lowest priority. If the bus is busy with other transfers, this transaction may be delayed. The data is guaranteed to arrive without error. If an error is detected in the CRCs, the data will be retransmitted. Examples of this type of transfer are files from a mass storage device or the output from a scanner.

Advantages:

1. Fast and simple.
2. It is of low cost.
3. Plug and Play hardware

Disadvantages:

1. Needs powerful master device.
2. Specific drivers are required.

EgSA
وكالة الفضاء المصرية
Egyptian Space Agency
ESP
Educational Satellite Program
BENHA UNIVERSITY
كلية الهندسة بشبرا

Comparison Between Inter System Protocols:

UART	USART	USB
UART stands for universal Asynchronous data transmitter and receiver	USART stands for universal synchronous and Asynchronous data transmitter and receiver	USB stands for serial bus
It is two wire protocol RX and TX	It is two wire protocol RX and TX	It is two wire protocol D+ and D-
It is transmitting and receiving pockets of The data byte by byte without classes pulses	It is sent and receives a block of data along with classes pulses	Send and receives a data along with clock pulses
It is a half-duplex communication	It is a full duplex communication	It is also full duplex communication
It is slow compare with USART	It is slow compare with USB	It is fast compare with USART and USB

Table 2.1: Comparison Between Inter System Protocols

2.3.4 I2C Protocol:

<u>What Is I2C Protocol</u>

I2C combines the best features of SPI and UARTs. With I2C, you can connect multiple slaves to a single master (like SPI), and you can have multiple masters controlling single, or multiple slaves.

This is really useful when you want to have more than one microcontroller logging data to a single memory card or displaying text to a single LCD.

Like UART communication, I2C only uses two wires to transmit data between devices:

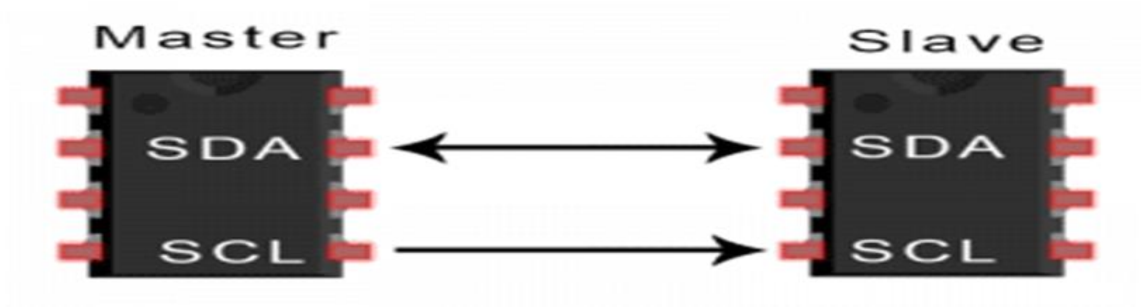


Figure 2.19: I2C-Communication-Working

SDA (Serial Data) – The line for the master and slave to send and receive data.

SCL (Serial Clock) – The line that carries the clock signal.

I2C is a serial communication protocol, so data is transferred bit by bit along a single wire (the SDA line).

Like SPI, I2C is synchronous, so the output of bits is synchronized to the sampling of bits by a clock signal shared between the master and the slave. The clock signal is always controlled by the master.

<u>How I2C Works:</u>

With I2C, data is transferred in messages. The messages are broken up into frames of data. Each message has an address frame that contains the binary address of the slave, and one or more data frames that contain the data being transmitted. The message also includes start and stop conditions, read/write bits, and ACK/NACK bits between each data frame:

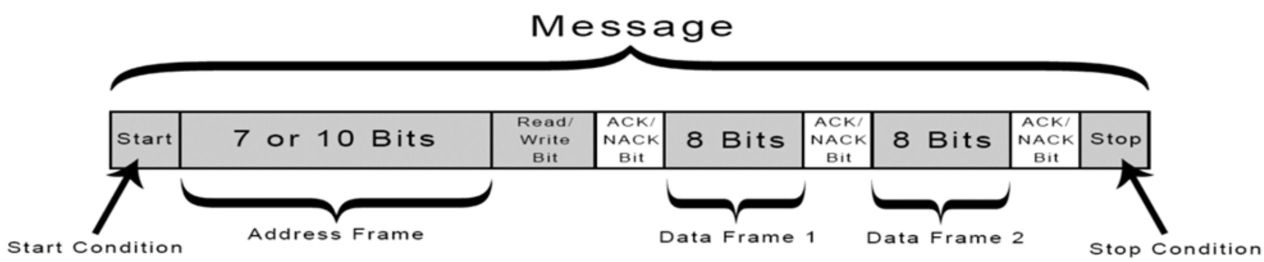


Figure 2.20: I2C Message Frame and Bit

A) Start Condition:
The SDA line switches from a high voltage level to a low voltage level before the SCL line switches from high to low.

B) Stop Condition:
The SDA line switches from a low voltage level to a high voltage level after the SCL line switches from low to high.

C) Address Frame:
A 7 or 10-bit sequence unique to each slave identifies the slave when the master wants to talk to it.

D) Read/Write Bit:
A single bit specifying whether the master is sending data to the slave (low voltage level) or requesting data from it (high voltage level).

E) ACK/NACK Bit:
Each frame in a message is followed by an acknowledge/no-acknowledge bit. If an address frame or data frame was successfully received, an ACK bit is returned to the sender from the receiving device.

STEPS OF I2C DATA TRANSMISSION:

1. The master sends the start condition to every connected slave by switching the SDA line from a high voltage level to a low voltage level before switching the SCL line from high to low:

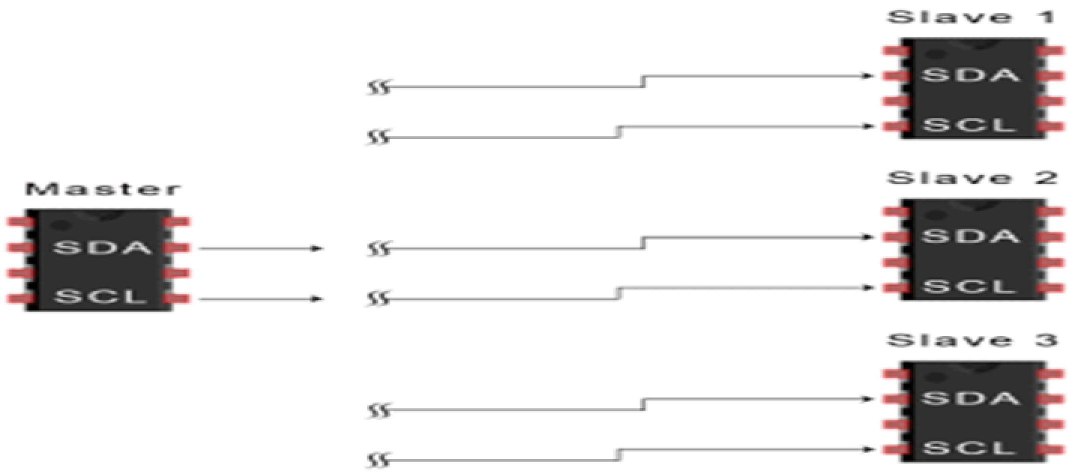


Figure 2.21: 2C Transmission step 1

2. The master sends each slave the 7- or 10-bit address of the slave it wants to communicate with, along with the read/write bit:

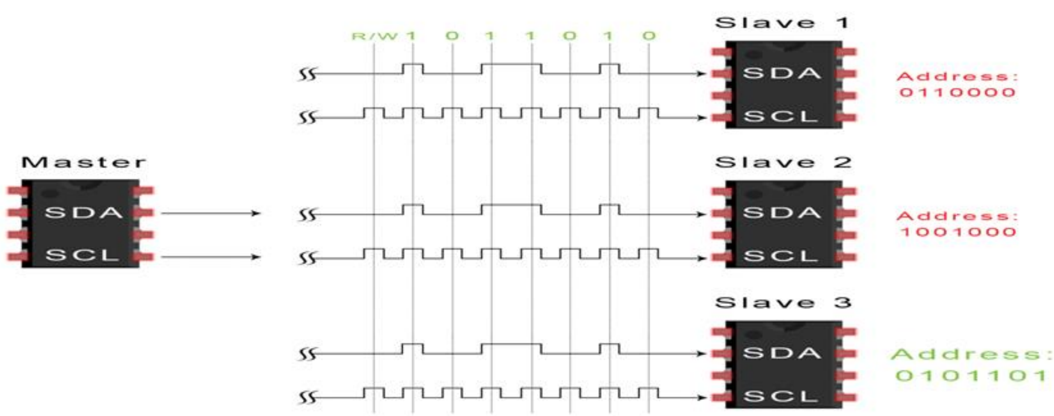


Figure 2.22: I2C Transmission step 2

3. Each slave compares the address sent from the master to its own address. If the address matches, the slave returns an ACK bit by pulling the SDA line low for one bit. If the address from the master does not match the slave's own address, the slave leaves the SDA line high.

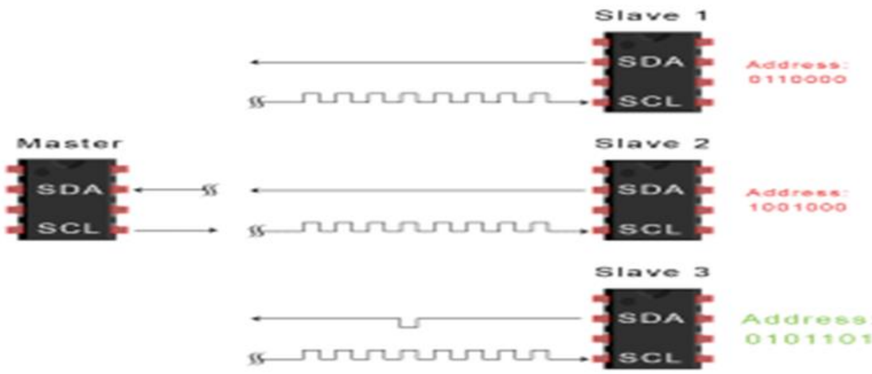


Figure 2.23: I2C Transmission step 3

4. The master sends or receives the data frame:

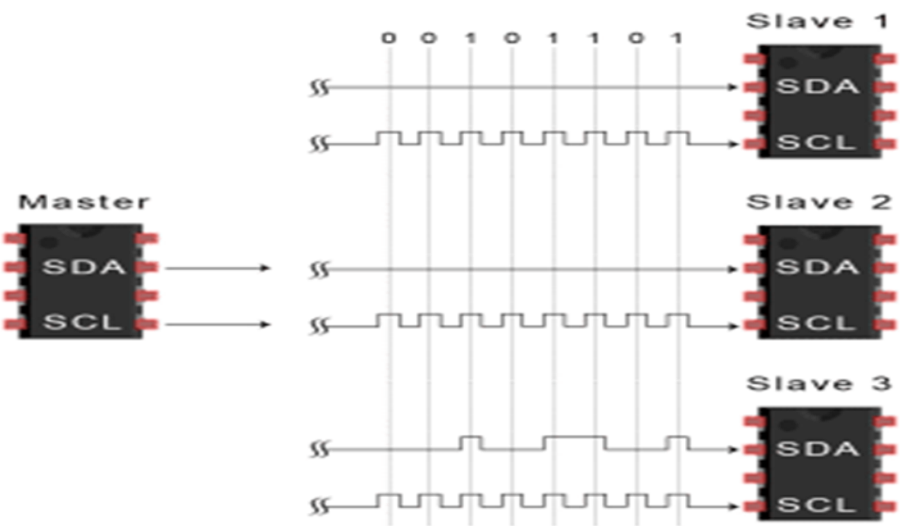


Figure 2.24: I2C Transmission step 4

5. After each data frame has been transferred, the receiving device returns another ACK bit to the sender to acknowledge successful receipt of the frame:

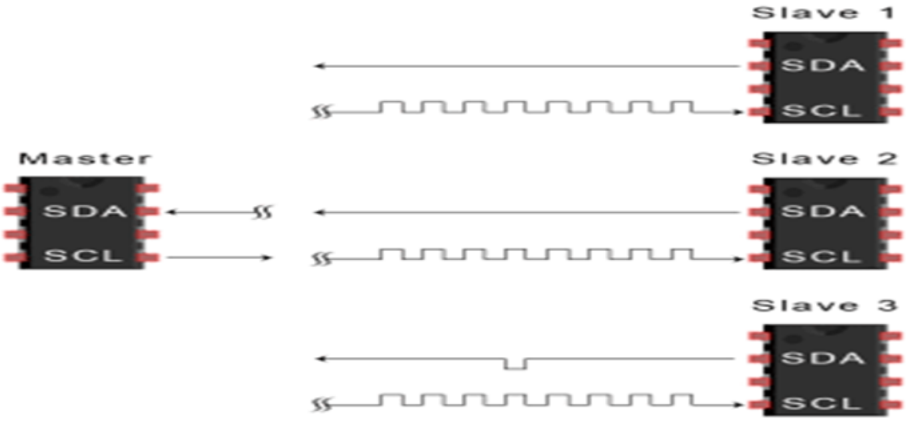


Figure 2.25: I2C Transmission step 5

6. To stop the data transmission, the master sends a stop condition to the slave by switching SCL high before switching SDA high:

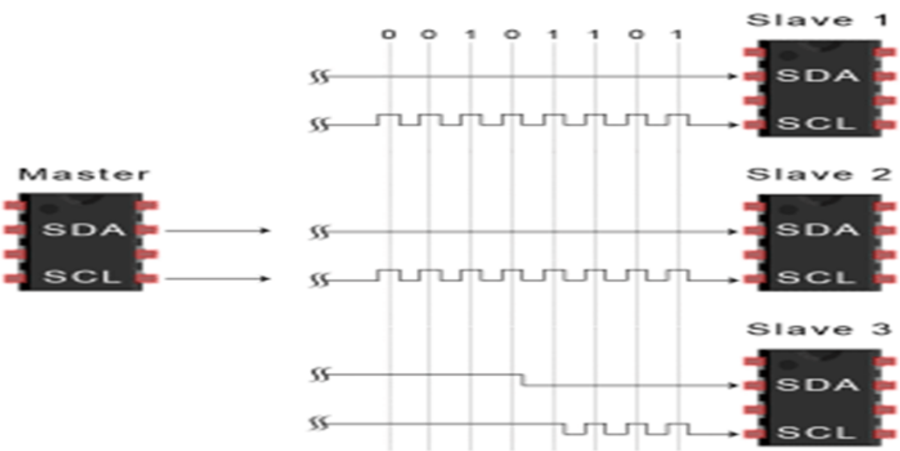


Figure 2.26: I2C Transmission step 6

Types of I2C:

1. SINGLE MASTER WITH MULTIPLE SLAVES

To connect multiple slaves to a single master, wire them like this, with 4.7K Ohm pull-up resistors connecting the SDA and SCL lines to VCC this way of connection is called open drain:

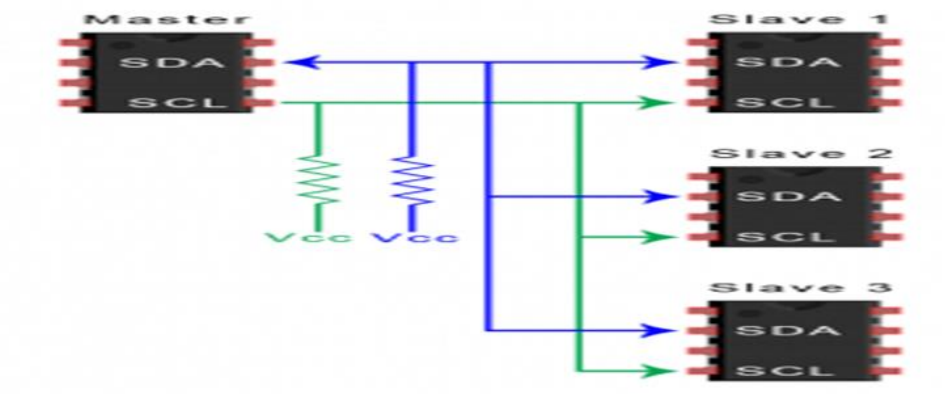


Figure 2.27: I2C Single Master with Multiple Slaves

I2C Pull-up Resistors:

Why given the pull-up resistors in I2C SCL and SDA line.

1. Both SDA and SCL lines are open-drain drivers.
2. It can drive output low cannot driver it high.
3. For the lines to be able to go high you must provide pull-up resistors

2. MULTIPLE MASTERS WITH MULTIPLE SLAVES

Multiple masters can be connected to a single slave or multiple slaves. The problem with multiple masters in the same system comes when two masters try to send or receive data at the same time over the SDA line.

To solve this problem, each master needs to detect if the SDA line is low or high before transmitting a message. If the SDA line is low, this means that another master has control of the bus, and the master should wait to send the message.
If the SDA line is high, then it's safe to transmit the message.

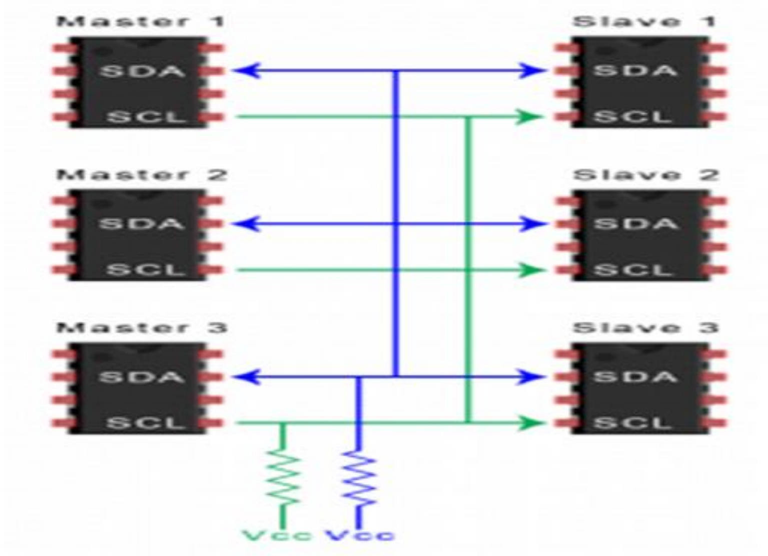


Figure 2.28: I2C Multiple Master with Multiple Slaves

Advantage:

1. Only uses two wires.
2. Supports multiple masters and multiple slaves.
3. ACK/NACK bit gives confirmation that each frame is transferred successfully (error handling).
4. Hardware is less complicated than with UARTs.
5. Well known and widely used protocol.

Disadvantage:

1. Slower data transfer rate than SPI.
2. The size of the data frame is limited to 8 bits.
3. More complicated hardware needed to implement than SPI.

2.3.5 SPI Protocol:

<u>what is SPI protocol</u>

SPI stands for the peripheral serial interface. It is one of the Motorola-developed serial communication protocols. SPI protocol is also often called a 4-wire protocol. The MOSI, MISO, SS, and SCLK.SPI protocol used to contact the master and slave devices requires four wires. First the master uses a frequency to configure the clock.

The master then pulls the chip select button to pick the specific slave device to connect with. This particular system is chosen, and the correspondence between the master and that particular slave begins. The master only chooses one slave at a time. It is a protocol for full duplex communication. For bit conversion, not restricted to 8-bit words.

Figure 2.29: A standard SPI bus signal

<u>HOW IT WORKS:</u>

1. Master and slave contain shift register.
2. SPI is also a master to slave communication protocol. In SPI, the master device first configures the clock at a particular frequency.

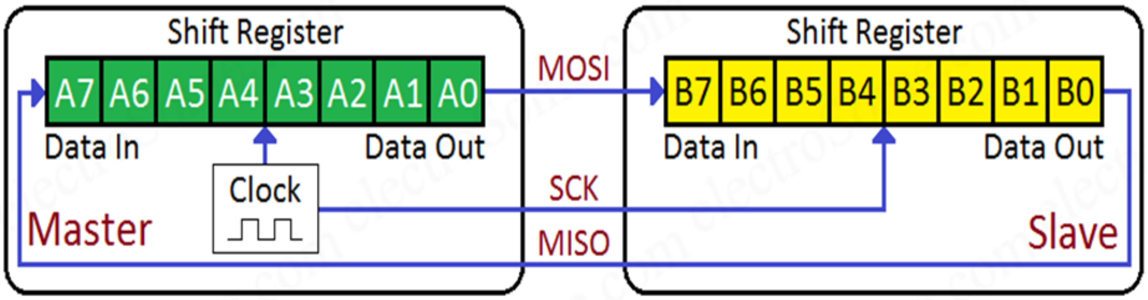


Figure 2.30: SPI Data Transmission

Advantage:

1. Faster than asynchronous serial communication protocol.
2. Support multiple slaves connectivity.
3. Universally accepted protocol and low cost.

Disadvantages:

1. Requires more wires than other communication protocols.
2. Numerous slave devices lead to circuit complexity.
3. Master device should control all slaves communication.
4. Slave-slave communication impossible.

2.3.6 CAN Protocol:

<u>What is CAN protocol:</u>

It is a communication protocol between the various control units in the vehicle where control units (computers) can exchange information directly (without a link between them). It is a protocol to serial communication.

CAN is a 2-wire protocol:

CAN-High (H+)

CAN-Low (H -)

And at the end of each wire there is a resistance to prevent the signal from backing up.

CAN protocol is based on a message oriented communication protocol.

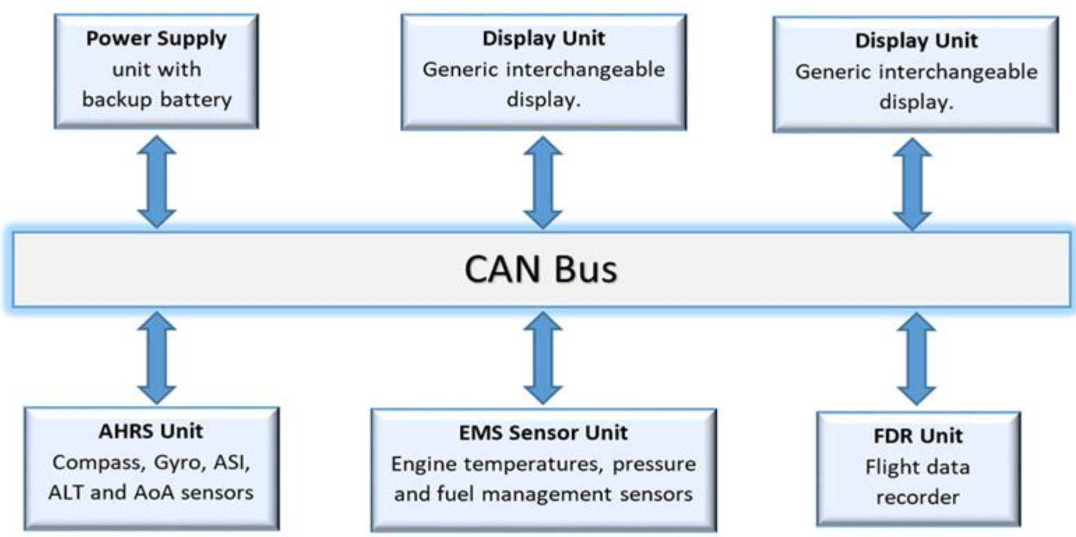


Figure 2.31: A standard CAN bus

How it works:

It is a messaging protocol each message has its own electronic structure consisting of:

Message ID / message start / body message / end message

CAN messages contain neither the sender nor the addressee However, the message content itself contains an additional identifier for the information transmitted: RPM / Temperature / ..., Where the control unit looks at it, if this information is important to its work, it will be processed If not, it will be ignored.

The message identifier contains an electronic mark that identifies (message priority) the message that has priority is transmitted first on the network and the second message is postponed in the unit that sends for a period of time, where it becomes priority and is sent.

This system was developed by the two companies Bosch and Intel to be used specifically in cars to solve the problem of sizes, costs and weights of the wires group that multiplied with the large number of computers / controllers.

Advantages:

1. Low cost and reliable.
2. Shows robust performance.
3. Secured and fast protocol.

Disadvantages:

1. Automotive oriented.
2. Bit complex protocol.

Comparison Between Inter System Protocols:

Parameter	I2C	SPI
Originator	Philips (1982)	Motorola (1979)
Plug & Play	Yes	No
Interface type	Serial (2 wires)	Serial (3+N wires) *
Distance	Short (in box communication)	Short (in box communication)
Application	Multi-master register-access	Transfer of data-streams
Protocol Complexity	Low	Lower
Design Cost	Low	Lower
Transfer rate	Limited (100 & 400 KHz and 3.4 MHz)	Free (n x MHz to 10n x MHz)
Power consumption	Low (2 pull up resistors)	Lower
Transfer type	Half Duplex	Full Duplex
Time constraint	Synchronous	Synchronous
Multi Master	Yes	No
Multi Slave +	Yes	Yes
I/O Constraints	Open-drain-wit Pull-up resistor	No constrain
Addressing +	Software (7/10 bits)	Hardware (chip select)
Flow control +	Yes	No
Clock stretching +	Yes	No

Table 2.2: Comparison between I2C and SPI Protocols

Note:

Bit rate of CAN protocol is up to 1Mbps.

***:** N is the number of devices connected to a single master on the bus.

+: Feature inducing substantial area overhead**.**

I2C	SPI	CAN
I2C stands for inter integrated circuit.	SPI stands for serial peripheral interface.	CAN stands for controller Area network.
It is developed by the Philips.	It is developed by the Motorola	It is developed by the Robert Bosch
Synchronization	Synchronization	Synchronization
It is tow wire protocol SCL and SDL	It is a four wire protocol SCL and MISO/MOSI, SS	It is a tow wire protocol CAN H+ and CAN H -
It is multi master protocol	It is single master protocol	It is multi master protocol
Within the circuit board	Within the circuit board	Within two circuit board

Table 2.3: Comparison Between Inter System Protocols

2.3.7 Recommended Standard protocols

<u>Now we will talk about three protocols which are very important:</u>

1. **RS485**
2. **RS422**
3. **RS232**

Figure 2.32: Recommended Standard protocols

Let's define every single one. Bear in mind that all three, as opposed to IEEE-488 which is PARALLEL, are considered SERI.

1. **<u>RS232 protocol</u>**

Definitely the most common interface, one of the first being too. For obvious reasons though, things may change soon.

Any PC purchased will have one (and sometimes more) RS232 port. Often they are simply referred to as SERIAL PORTS, but this may cause confusion as other Serial interfaces are available.

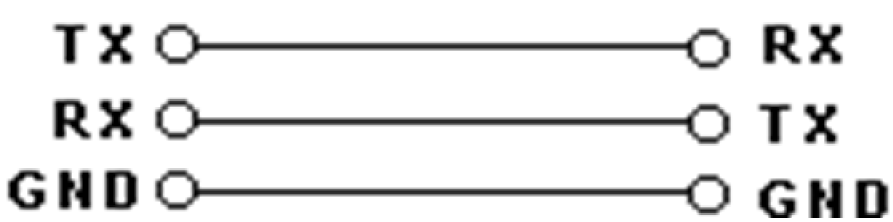


Figure 2.33: Typical RS -232 Wiring

RS232 is commonly used, since it's available so readily. However, it does have some disadvantages. Here are a few:

1) Limited Distance - Cable lengths are limited to 50 Ft. or less. Many will claim to go further, but this is not recommended, and is not part of the RS232 specification.

2) Susceptible to Noise - RS232 is single-ended, which means that transmit and receive lines are referenced to a common ground.

3) Not Multi-drop - You can only connect one RS232 protocol device per port. There are some devices designed to echo a command to a second unit of the same family of products, but this is very rare. This means that if you have 3 meters to connect to a PC, you will need 3 ports, or at least, an RS232 multiplexor.

2. **RS422 protocol**

RS422 is similar to RS232 protocol and can be configured in the same way but provides some advantage and disadvantages. One issue is that you need to buy an RS422 port or at least an RS422 to RS232 converter, since this device doesn't come standard with PC's. You may also find there are fewer RS422-supporting units. Such benefits include:

Long Distance Runs - Up to 500 feet is generally supported, and with repeaters, even further distances can be achieved.

Multi-Drop-Normally it is possible to connect up to 32 devices per port, and even more so when using repeaters. Devices are identified by unique addresses each device is assigned to. If you have five devices connected to a port, for example, they will be addressed as units 1 to 5. You give a command to Unit 1 if you want to communicate. All units HEAR the command, but it will only respond to the addressed device. This refers to RS485 too. Depending on the device's design the addresses can be set through switches or software.

Noise Resistant - Since it uses a separate floating transmit and receive pair (four wires), it offers better noise immunity than RS232.

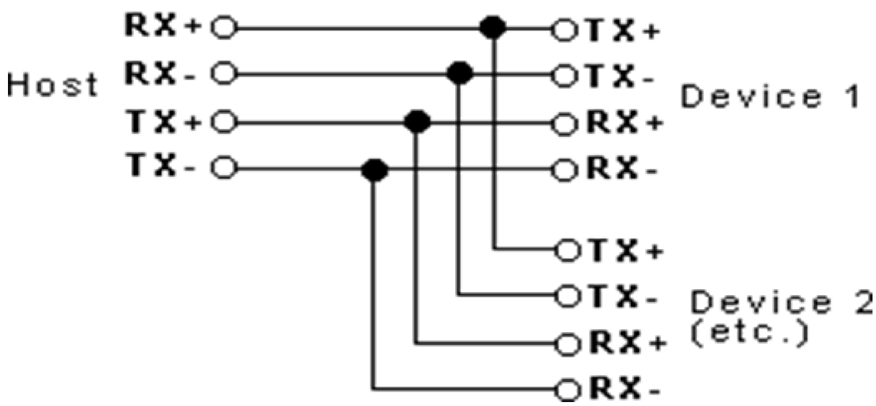


Figure 2.34: Typical RS -422 Wiring

3.RS485 protocol

RS485 is quite similar to RS422. So much so that confusion is sometimes induced by this. Both of these are multi-drop and can communicate over very long distances, so why pick one over the other? First of all, RS485 is usually a 2-wire device, but some manufacturers can define RS485 4-wire, which is much less common and somewhat similar to RS422 protocol. It is critical that when evaluating an instrument, you recognize which one is being employed. Here are some main differences between the RS485 and RS422 2-wire systems:

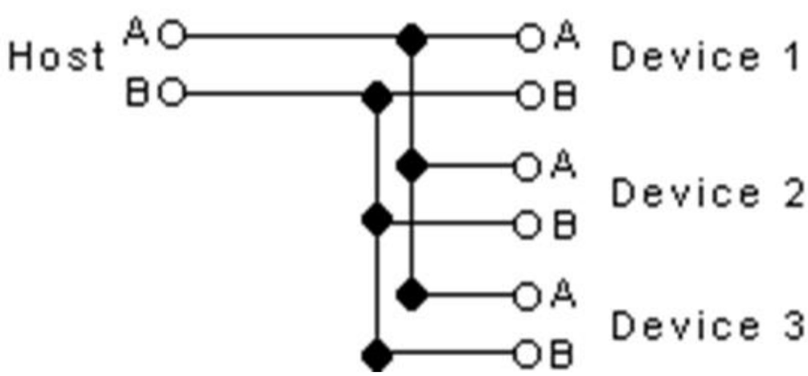


Figure 2.35: Typical RS -485 Wiring

RS485 may have multiple Listening Devices and Commanding Devices. RS422 only has one Commander and several Listeners. You can attach one PC (the Commanding Device) to ten temperature controllers (listeners) for example.

The PC can tell any controller to change the set point or send a temperature read, but none of the controllers can control any of the other controllers. With RS485, multiple PCs and multiple controllers can be mounted on one bus, so one PC can send a command to modify a set point, and another PC can send a command to send back data etc.

Note that the unit address of all devices on the bus must be unique, so that only the addressed unit can respond. (As in RS422).RS485 pinout cabling is simpler since you only handle 2 wires instead of 4 wires.

RS485 programming is much more difficult, since you are sending and receiving on the same wires, you need to enable and disable the transmitter at the correct time in order for it to make proper communications. Imagine sending a 2-order sent from the transmitter. If the transmitter is not turned off in time, the data sent by another device will be lost. If the transmitter turns off too quickly, there is a possibility that part of the USD S2END command will be truncated before it has a chance to finish sending the character bits.

When programming RS485 patch card, you can read STATUS REGISTER to determine if it is time to switch or not. Some cards, like the OMG- ULTRA-485 have an automatic mode where it's smart enough to do it automatically, making it transparent to the programmer.

Comparison between RS 232, RS 422, RS 485:

Parameter	RS 232	RS 422	RS 485
Cabling	ingle Ended	Differential	Differential
Number of Devices	1 Transmit and 1 Receiver	5 Transmit and 10 Receiver	32 Transmit and 32 Receiver
Communication Mode	Full Duplex	Full Duplex/Half Duplex	Half Duplex
Signaling Mode	Unbalanced	Balanced	Balanced
Output Power Capability	500mA	150mA	250mA
Maximum Distance	50 feet at 19.2 Kbps	4000 feet at 100 Kbps	4000 feet at 100 Kbps

Table 2.4: Comparison between RS 232, RS 422, RS 485

2.4 The protocols which used in our project

Micro controller works with three types of protocols **SPI, RS485, UART.**

1. SPI

Microcontroller	Transceiver
PA4	Slave select
PA5	SCLK
PA6	MISO
PA7	MOSI

Table 2.5: SPI connection with Microcontroller

2. RS485

Microcontroller	RS Converter
PC11	RO
PC10	DI
PD2	50
PD12	52

Table 2.6: RS485 connection with Microcontroller

Chapter 3: Communication Subsystem

3.1 Introduction

We know that **Communication** refers to the exchange (sharing) of information between two or more entities, through any medium or channel. In other words, it is nothing but sending, receiving and processing of information.

If the communication takes place between any two earth stations through a satellite, then it is called as satellite communication. In this communication, electromagnetic waves are used as carrier signals. These signals carry the information such as voice, audio, video or any other data between ground and space and vice-versa.

Soviet Union had launched the world's first artificial satellite named, Sputnik 1 in 1957. Nearly after 18 years, India also launched the artificial satellite named, Aryabhata in 1975.

3.1.1 Need of Satellite Communication

The following two kinds of propagation are used earlier for communication up to some distance.

1. Ground wave propagation − Ground wave propagation is suitable for frequencies up to 30MHz. This method of communication makes use of the troposphere conditions of the earth.
2. Sky wave propagation − the suitable bandwidth for this type of communication is broadly between 30–40 MHz and it makes use of the ionosphere properties of the earth.

The maximum hop or the station distance is limited to 1500KM only in both ground wave propagation and sky wave propagation. Satellite communication overcomes this limitation. In this method, satellites provide communication for long distances, which is well beyond the line of sight.

Since the satellites locate at certain height above earth, the communication takes place between any two earth stations easily via satellite. So, it overcomes the limitation of communication between two earth stations due to earth’s curvature.

3.1.2 How a Satellite

A satellite is a body that moves around another body in a particular path. A communication satellite is nothing but a microwave repeater station in space. It is helpful in telecommunications, radio and television along with internet applications.

A repeater is a circuit, which increases the strength of the received signal and then transmits it. But this repeater works as a transponder. That means, it changes the frequency band of the transmitted signal from the received one.

The frequency with which, the signal is sent into the space is called as Uplink frequency. Similarly, the frequency with which, the signal is sent by the transponder is called as Downlink frequency. The following figure illustrates this concept clearly.

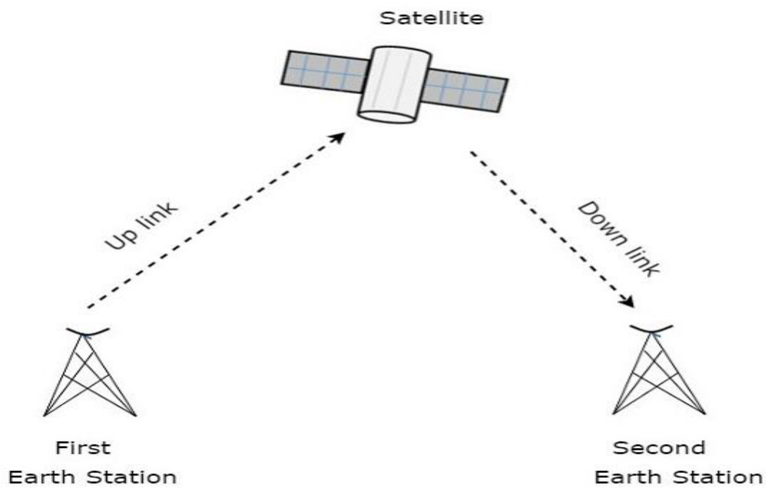


Figure 3.1: communication system in satellite

The transmission of signal from first earth station to satellite through a channel is called as uplink. Similarly, the transmission of signal from satellite to second earth station through a channel is called as downlink.

Uplink frequency is the frequency at which, the first earth station is communicating with satellite. The satellite transponder converts this signal into another frequency and sends it down to the second earth station. This frequency is called as Downlink frequency. In similar way, second earth station can also communicate with the first one.

The process of satellite communication begins at an earth station. Here, an installation is designed to transmit and receive signals from a satellite in an orbit around the earth. Earth stations send the information to satellites in the form of high powered, high frequency (GHz range) signals.

The satellites receive and retransmit the signals back to earth where they are received by other earth stations in the coverage area of the satellite. Satellite's footprint is the area which receives a signal of useful strength from the satellite.

3.1.3 Pros and Cons of Satellite Communication

Following are the advantages of using satellite communication:

1. Area of coverage is more than that of terrestrial systems.
2. Each and every corner of the earth can be covered.
3. Transmission cost is independent of coverage area.
4. More bandwidth and broadcasting possibilities

Following are the disadvantages of using satellite communication −

1. Launching of satellites into orbits is a costly process.
2. Propagation delay of satellite systems is more than that of conventional terrestrial systems.
3. Difficult to provide repairing activities if any problem occurs in a satellite system.
4. Free space loss is more.
5. There can be congestion of frequencies.

3.1.4 Applications of Satellite Communication

Satellite communication plays a vital role in our daily life. Following are the applications of satellite communication.

1. Radio broadcasting and voice communications
2. TV broadcasting such as Direct to Home (DTH)
3. Internet applications such as providing Internet connection for data transfer, GPS applications, Internet surfing, etc.
4. Military applications and navigations
5. Remote sensing applications
6. Weather condition monitoring & Forecasting

3.2 Specifications at Communication Subsystem

State	Parameter	Value
UHF Transmitter	Frequency range,MHZ	437-440(Synthesizable)
	Trnsmit power, mW	500
	Modulation	GMSK
	Data rate, bits/s	9600
	Data Protocol	AX.25
UHF Receiver	Frequency range,MHZ	437-440(Synthesizable)
	Trnsmit power,mW	500
	Modulation	GMSK
	Data rate , bits/s	1200
	Data Protocol	AX.25
Operating tempreture range		-40 to 60
Power supply,V		3.3
Mass, g		<=100
Dimension, mm		96*90*15
Max.power consumption, mW		500 with receiver only 3000 with transmitter ON
RF input interface		MMCX, 50ohm
RF output interface		MMCX, 50ohm
Control interface		RS485 UART Backup
Control protocol with OBC		SSP

Table 3.1: specification of communication subsystem

3.3 Block Diagram of Communication Subsystem

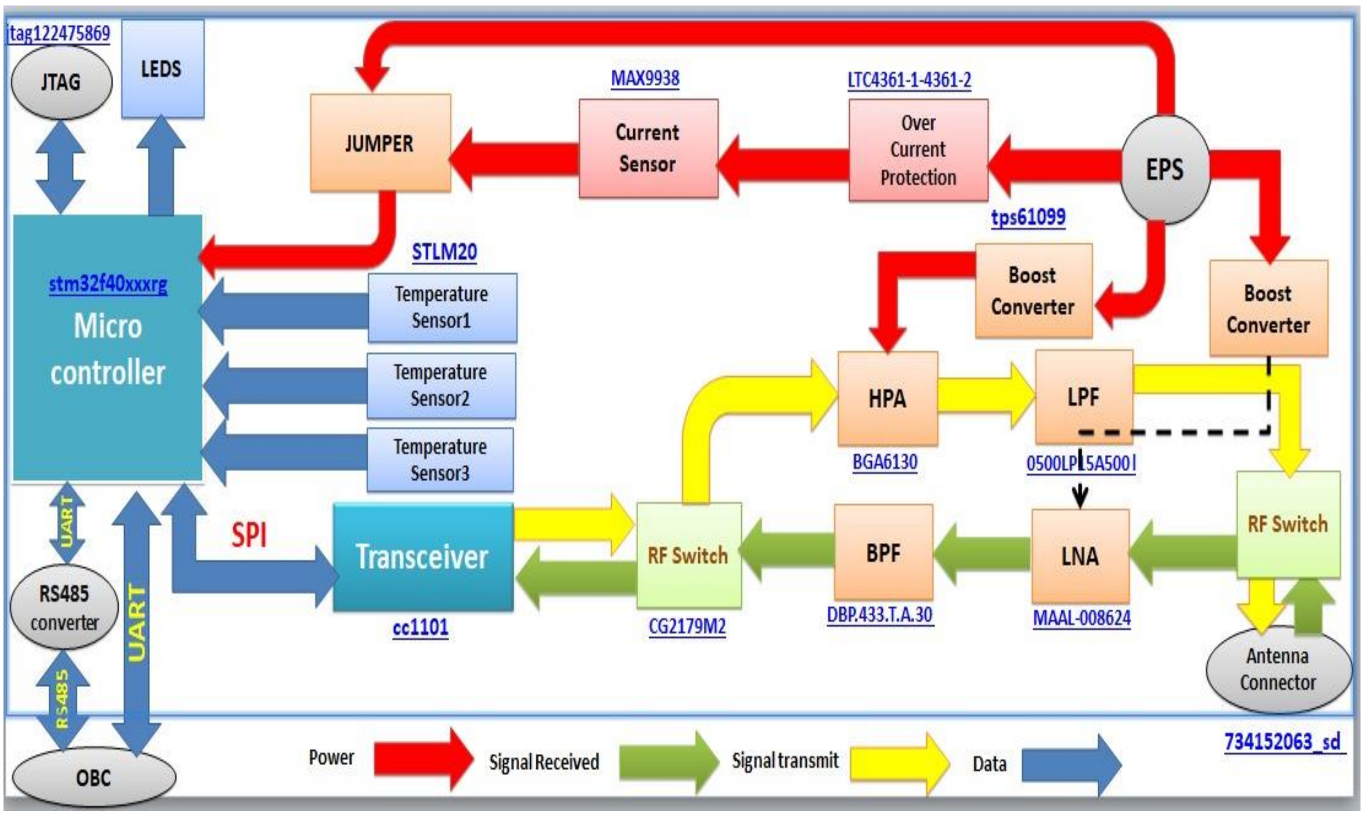


Figure 3.2: block diagram of Communication subsystem

1. Block Diagram of Communication Subsystem describes how the component of the system connected

2. The main component is microcontroller that is the brain of the circuit and connected to all parameters

3. It connected with OBC by UART protocol , and RS485 converter convert RS485 protocol to UART protocol because microcontroller can deal with this protocol

4. On other way microcontroller is connected with JTAG to can connect between hardware and software by this connection

5. Microcontroller is also connected with current sensor by using the analog pins in microcontroller, Current sensor is connected with over current protection to protect the current sensor and the circuit from any high current by connected it with power board

6. Other connection to microcontroller is connected it with temperature sensor by using analog pins except the one used with current sensor

7. The circuit has two ways , one way for transmitting and another for receiving, for send and receive from antenna the microcontroller is connected with transceiver by more than one connection with different types from SPI protocols

8. The transceiver is connected with RF switch, which is work at transmit and receive, at transmitter way the RF switch is switch on HPA to amplify the power come from transceiver and send the signal to LPF to make it in suitable frequency range and send to RF switch which connected with the satellite antenna

9. At receiver way the RF switch which connected with antenna receive the signal from antenna and send it to LNA to amplify the original signal and reject any noise and send it for BPF to reject any frequency out of wanted range (430-440) MHZ and then send it to RF switch which connected with transceiver

10. The booster converter is used to increase the voltage for LNA from 3.3volt to 5volt because the used LNA work at input voltage 5volt and output is 3.3 volt and the circuit work at 3.3volt and increase the voltage for HPA to 3.6 V because the used HPA works at input voltage 3.6V

3.4 RF Component of Communication Subsystem

3.4.1 Transceiver (CC1101)

A transceiver is a combination transmitter/receiver in a single package. The term applies to wireless communications devices such as cellular telephones, cordless telephone sets, handheld two-way radios, and mobile two-way radios. Occasionally the term is used in reference to transmitter/receiver devices in cable or optical fiber systems.

In a radio transceiver, the receiver is silenced while transmitting. An electronic switch allows the transmitter and receiver to be connected to the same antenna and prevents the transmitter output from damaging the receiver. With a transceiver of this kind, it is impossible to receive signals while transmitting. This mode is called half duplex. Transmission and reception often, but not always, are done on the same frequency.

Some transceivers are designed to allow reception of signals during transmission periods. This mode is known as full duplex and requires that the transmitter and receiver operate on substantially different frequencies, so the transmitted signal does not interfere with reception. Cellular and cordless telephone sets use this mode. Satellite communications networks often employ full-duplex transceivers at the surface-based subscriber points. The transmitted signal (transceiver-to- satellite) is called the uplink, and the received signal (satellite-to-transceiver) is called the downlink.

Why we use CC1101?

The CC1101 Support frequency range is 437-440 MHZ which is required at parameter list:

1. The data rate for CC1101 is more than CC1000.
2. High output power
3. Bigger voltage range
4. Small size

Description

CC1101 is a low-cost sub-1 GHz transceiver designed for very low-power wireless applications. The circuit is mainly intended for the ISM (Industrial, Scientific and Medical) and SRD (Short Range Device) frequency bands at 315, 433, 868, and 915 MHz, but can easily be programmed for operation at other frequencies in the 300-348 MHz, 387-464 MHz and 779-928 MHz bands. The RF transceiver is integrated with a highly configurable baseband modem. The modem supports various modulation formats and has a configurable data rate up to 600 kbps. CC1101 provides extensive hardware support for packet handling, data buffering, burst transmissions, clear channel assessment, link quality indication, and wake-on-radio. The main operating parameters and the 64byte transmit/receive FIFOs of CC1101 can be controlled via an SPI interface. In a typical system, the CC1101 will be used together with a microcontroller and a few additional passive components.

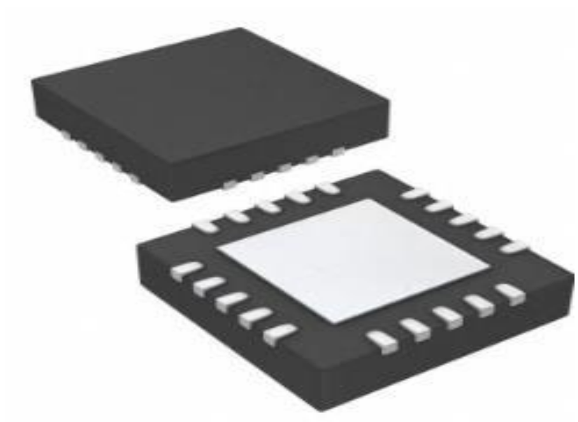


Figure 3.3: Transceiver

Features

1. Few external components Completely on chip frequency synthesizer, no external filters or RF switch needed.
2. Green package: RoHS compliant and no antimony or bromine
3. Small size (QLP 4x4 mm package, 20 pins)
4. Suited for systems targeting compliance with EN 300 220 (Europe) and FCC CFR Part 15 (US)
5. Suited for systems targeting compliance with the Wireless MBUS standard EN 13757-4:2005.
6. Support for asynchronous and synchronous serial receive/transmit mode for backwards compatibility with existing radio communication protocols.

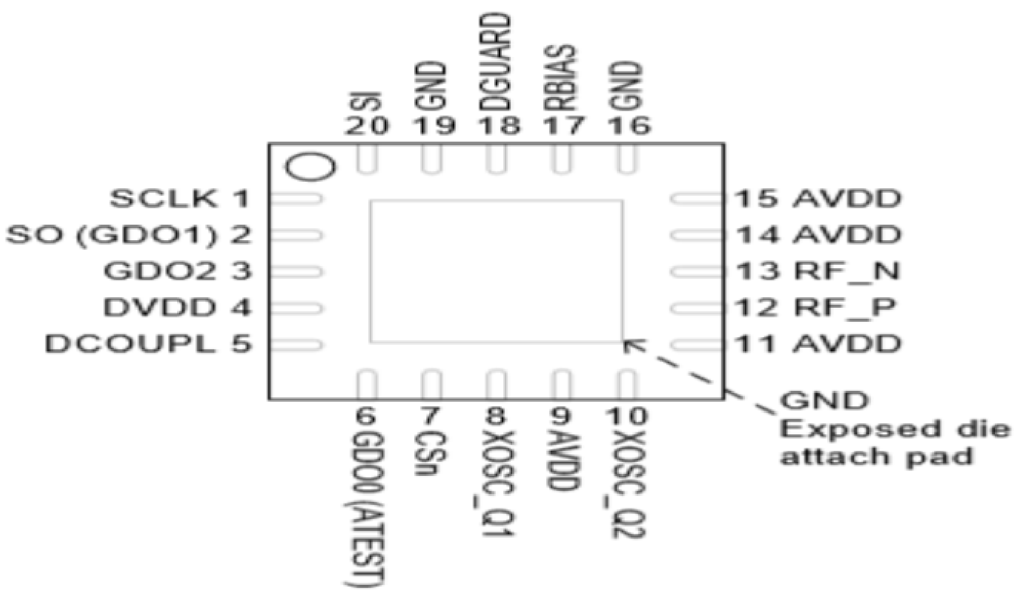


Figure 3.4: Pin Configuration of transceiver

Applications

1. Ultra-low-power wireless applications operating in the 315/433/868/915 MHz ISM/SRD bands
2. Wireless alarm and security systems
3. Industrial monitoring and control
4. Wireless sensor networks
5. AMR – Automatic Meter Reading
6. Home and building automation.
7. Wireless MBUS

Evaluation Circuit

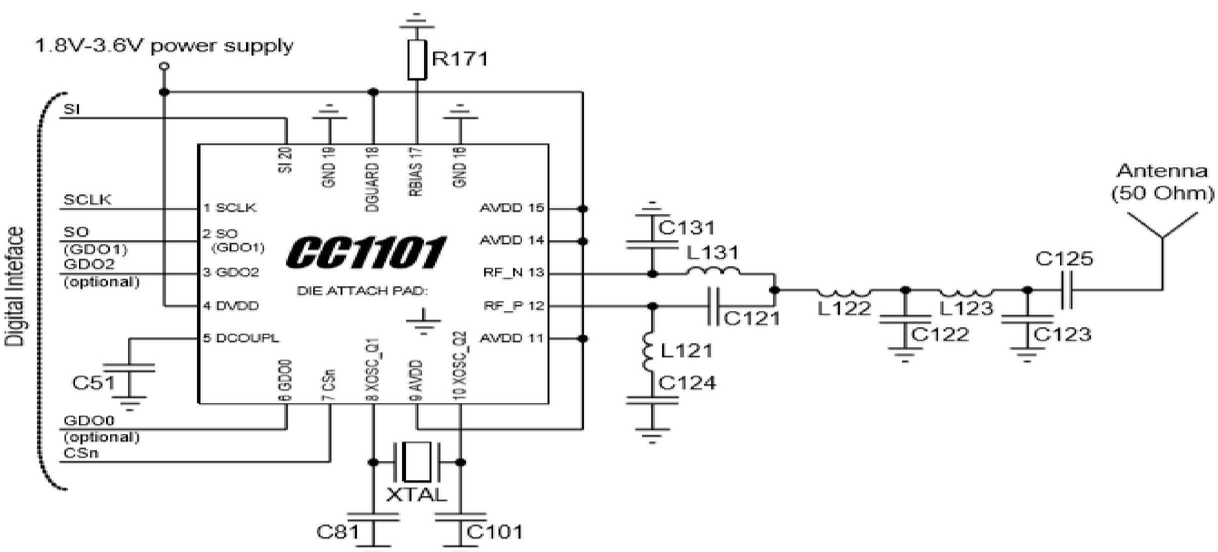


Figure 3.5: Evaluation Circuit 315/433 MHz (excluding supply decoupling capacitor

Transceiver Pin Connections:

altium		Pin Assignment			
Pin Name	Designator	Designator	Pin Name	Description	Type
SCLK	1	1	SCLK	Serial configuration interface, clock input	Input
SO(GDO1)	2	2	SO(GDO1)	Serial configuration interface, data output	Output
GDO2	3	3	GDO2	Digital output pin for general use:	Output
DVDD	4	4	DVDD	3.6 V digital power supply for digital I/O's	Power
DCOUPL	5	5	DCOUPL	2.0 V digital power supply output for decoupling	Power
GDO0(ATEST)	6	6	GDO0(ATEST)	Digital output pin for general use:	I/O
CSN	7	7	CSN	Serial configuration interface, chip select	Input
XOSC_Q1	8	8	XOSC_Q1	Crystal oscillator pin 1, or external clock input	I/O
AVDD_2	9	9	AVDD_2	3.6 V analog power supply connection	Power
XOSC_Q2	10	10	XOSC_Q2	Crystal oscillator pin 2	I/O
AVDD_3	11	11	AVDD_3	6 V analog power supply connection	Power
RF_P	12	12	RF_P	Positive RF input signal to LNA in receive mode	I/O
RF_N	13	13	RF_N	Negative RF input signal to LNA in receive mode	I/O
AVDD_4	14	14	AVDD_4	3.6 V analog power supply connection	Power
AVDD	15	15	AVDD	3.6 V analog power supply connection	Power
GND_2	16	16	GND_2	Analog ground connection	Power
RBIAS	17	17	RBIAS	External bias resistor for reference current	I/O
DGUARD	18	18	DGUARD	Power supply connection for digital noise isolation	Power
GND	19	19	GND	Ground connection for digital noise isolation	Power
SI	20	20	SI	Serial configuration interface, data input	Input
EP	21	21	EP	GND	Power

Figure 3.6: Transceiver pins

3.4.2 RF Switch (CG2179M2)

An RF switch or microwave switch is a device to route high frequency signals through transmission paths. RF (radio frequency) and microwave switches are used extensively in microwave test systems for signal routing between instruments and devices under test (DUT).

Incorporating a switch into a switch matrix system enables you to route signals from multiple instruments to single or multiple DUTs. This allows multiple tests to be performed with the same setup, eliminating the need for frequent connects and disconnects.

The entire testing process can be automated, increasing the throughput in high- volume production environments.

The two main kinds of RF and microwave switches have different capabilities: Electromechanical switches are based on the simple theory of electromagnetic induction.

A solid state switch is an electronic switching device based on semiconductor technology (MOSFET, PIN diode). It functions similarly to an electromechanical switch except that it has no moving parts.

Comparison between RF Switches:

We compare these RF Switches in the table below so we should define:

Isolation:

Isolation is a measure of how effectively a switch is turned off. It's the attenuation between the input and output ports of the circuit.

Insertion losses:

Whenever a signal travels through a component or a system, there is always some loss of power due to a number of reasons. This loss that occurs while a signal is traveling through a component or system is called as Insertion Loss. It is measured in decibels (dB).

There are three main causes of insertion loss:

1. Reflected Losses: Losses caused by the VSWR.
2. Dielectric Losses: Losses caused by the power dissipated in the dielectric materials Copper.
3. Losses: Losses caused by the power dissipated due to the conducting surfaces

NOTE Insertion loss is the most critical parameter to a designer because it may add directly to the system's noise figure.

Type	frequency	temp	VL	VH	Isolation	Insertion losses
HMC347A	0.1GHZ~20GHZ	-55~ 85	-0.2~0V	-5~-3V	40dB	2dB
SW/228– PIN	0HZ~0.5GHZ	-65~ 125	-0.2-0V	-5~-8V	52dB	0.7dB
CG2179M2	0.05GHZ~0.5GHZ	-45~ 85	0V	3V	39dB	0.3dB
ADRF5027	9KHZ~44GHZ	-40~ 105	0~0.8	1.2~3.3	53dB	1.1dB

Table 3.2: Comparison of RF switches

As the table shown above this is a comparison between different types of RF Switches, we choose CG2179M2 type which is more suitable for our project.

CG2179M2:

Figure 3.7: RF switch

Work at the circuit

At the circuit there are two RF switches one after transceiver and one before antenna the two RF switch are used to change the way of the signal from transmit to receive or from receive to transmit by change the volt between VC1 and VC2 according to the truth table

Description

The CG2179M2 is a PHEMT GaAs SPDT (Single Pole Double Throw) switch. This device can operate from 0.05 GHz to 3.0GHz, having low insertion loss and high isolation.

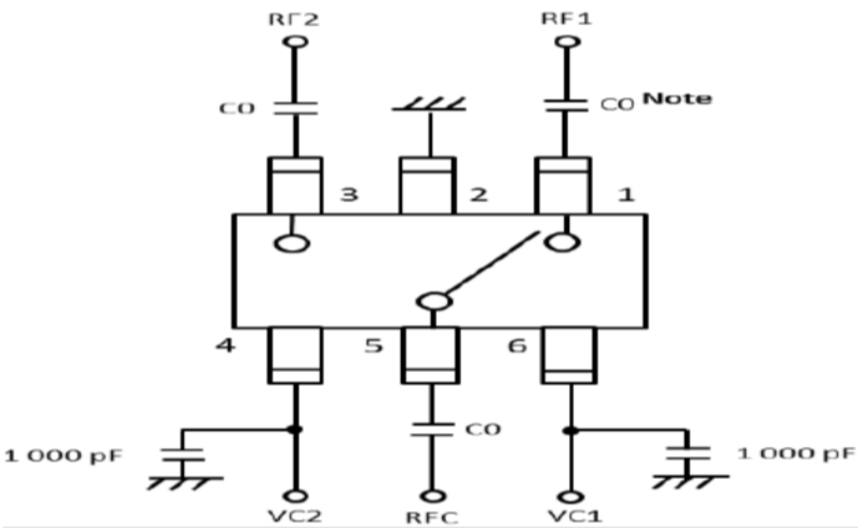


Figure 3.8: Typical circuit of RF switch

Features

Control voltage:

1. VC (H) = 1.8 to 5.3 V (3.0 V TYP.)
2. VC (L) = -0.2 to 0.2 V (0 V TYP.)

Low insertion loss:

1. Lins1 = 0.30 dB TYP. @ f = 0.05 to 0.5 GHz
2. Lins2 = 0.30 dB TYP. @ f = 0.5 to 1.0 GHz
3. Lins3 = 0.40 dB TYP. @ f = 1.0 to 2.0 GHz
4. Lins4 = 0.45 dB TYP. @ f = 2.0 to 2.5 GHz
5. Lins5 = 0.45 dB TYP. @ f = 2.5 to 3.0 GHz

High isolation:

1. ISL1 = 39 dB TYP. @ f = 0.05 to 0.5 GHz
2. ISL2 = 33 dB TYP. @ f = 0.5 to 1.0 GHz
3. ISL3 = 27 dB TYP. @ f = 1.0 to 2.0 GHz
4. ISL4 = 26 dB TYP. @ f = 2.0 to 2.5 GHz
5. ISL5 = 23 dB TYP. @ f = 2.5 to 3.0 GHz

Power handling

1. Pin(0.5dB) = +32 dBm TYP. @ f = 3.0 GHz,
2. VC(H) = 3.0 V, VC(L) = 0 V

Applications

1. Wireless LAN (IEEE 802.11 b/g/n/ac)

VC1	VC2	RFC-RF1	RFC-RF2
low	High	ON	OFF
High	Low	OFF	ON

Table 3.3: Truth table

3.4.3 Low Noise Amplifier (MAAL-008624)

A low-noise amplifier (LNA) is an electronic amplifier that amplifies a very low-power signal without significantly degrading its signal-to-noise ratio. An amplifier will increase the power of both the signal and the noise present at its input, but the amplifier will also introduce some additional noise. LNAs are designed to minimize that additional noise. Designers can minimize additional noise by choosing low-noise components, operating points, and circuit topologies.

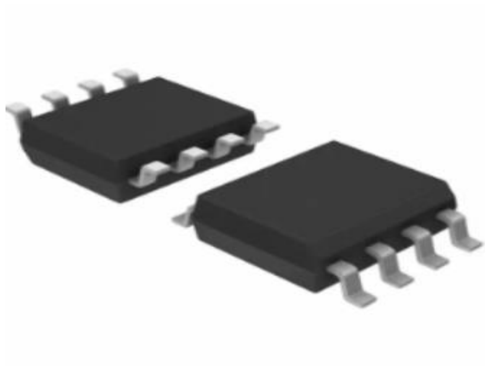


Figure 3.9: LNA

Comparison of LNA:

TYPE	Gain	Power supply	Frequency	Noise figure	P1dB
MAAL-008624	21dB	3-8V	400-500MHZ	0.9dB	16.5dBm
MAX-2611	18dB	3.8V	01100MHZ	3.5dB	2.9dBm
TQP3M9036	19.8dB	5V	50-2000MHZ	0.45dB	20dBm
HILNA-V1	20dB	12V	50M-1GHZ	0.8dB	17dB
hmc356	17dB	5V	350-550MHZ	1dB	21dBm

Table 3.4: Comparison of LNA

Noise figure:

Noise figure (NF) and noise factor (F) are measures of degradation of the signal-to-noise ratio (SNR), caused by components in a signal chain. It is a number by which the performance of an amplifier or a radio receiver can be specified, with lower values indicating better performance.

P1dB:

The **1 dB compression point (P1dB)** is the output power level at which the gain decreases 1 dB from its constant value. Once an amplifier reaches its P1dB it goes into compression and becomes a non-linear device, producing distortion, harmonics and intermodulation products. Amplifiers should always be operated below the compression point**.**

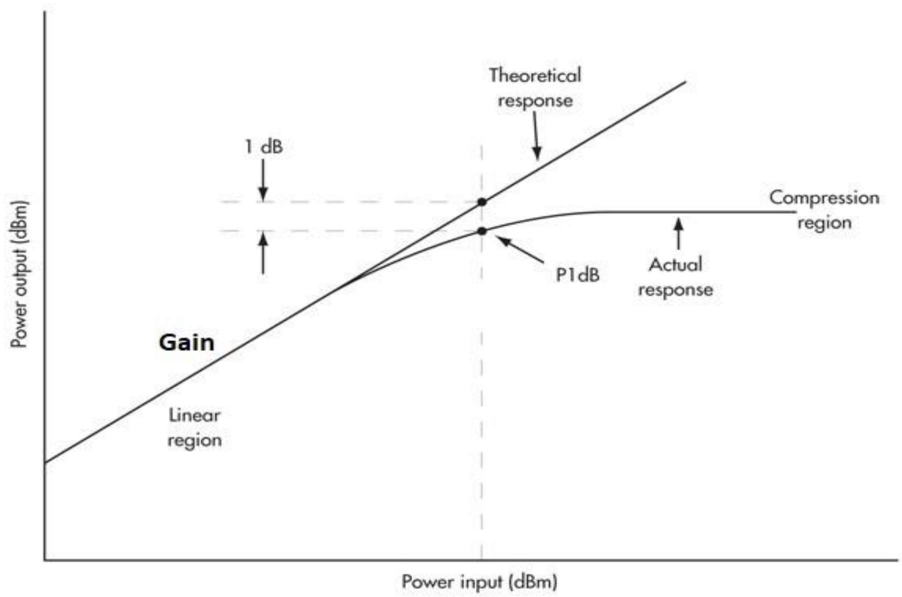


Figure3.10: Graph description of LNA

From the table shown above we choose MAAL-008624 which is more suitable for our project

MAAL-008624:

Description

M/A-COM's MAAL-008624 is a high dynamic range, low noise GaAs MMIC amplifier in a low cost, surface mount package. It employs external input matching to obtain optimum noise figure performance and operating frequency flexibility.

The MAAL-008624 also features flexible biasing to control the current consumption vs. dynamic range trade-off. The MAAL-008624 can operate from any supply voltage in the 3 V to 8 V range. Its current can be controlled over a range of 20 mA to 80 mA with an external resistor.

The MAAL-008624 is ideally suited for use where low noise figure, high gain, high dynamic range, and low power consumption are required. Typical applications include receiver front ends in CDMA450 base stations. It is also useful as a gain block, buffer, driver, and IF amplifier in both fixed and portable cellular and 450 MHz ISM systems.

The MAAL-008624 is fabricated using a low-cost 0.5-micron gate length GaAs process. The process features full passivation for increased performance reliability.

Features

1. Low Noise Figure: 0.9 dB
2. High OIP3: +28 dBm at 5 V, 60 mA bias
3. High Gain: 21 dB
4. Single Supply: +3 to +8 VDC
5. Lead-Free SOIC-8 Package
6. 100% Matte Tin Plating over Copper
7. Halogen-Free “Green” Mold Compound
8. 260°C Reflow Compatible
9. RoHS* Compliant Version of MAALSS0025
10. Adjustable current: 20 to 80 mA with external resistor

Applications

1. radio communications systems
2. medical instruments
3. electronic test equipment

Entire Equivalent Circuit

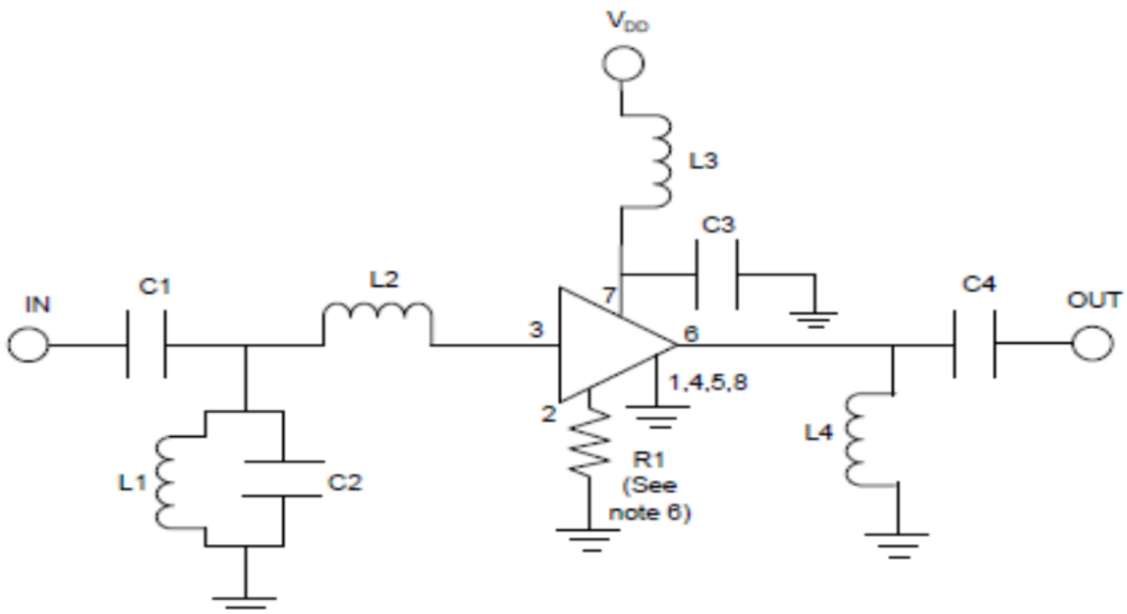


Figure 3.11: Typical circuit of LNA

3.4.4 Low Pass Filter (0500LP15A500)

A low-pass filter (LPF) is a filter that passes signals with a frequency lower than a selected cutoff frequency and attenuates signals with frequencies higher than the cutoff frequency. The exact frequency response of the filter depends on the filter design. The filter is sometimes called a high-cut filter or treble-cut filter in audio applications.

Work at the circuit

It is used to pass any it’s frequency is lower than 500 MHZ from HPA and antenna and the range of frequencies that the circuit is working on is from430 to 440 so this LPF can be used at this circuit.

Typical circuit

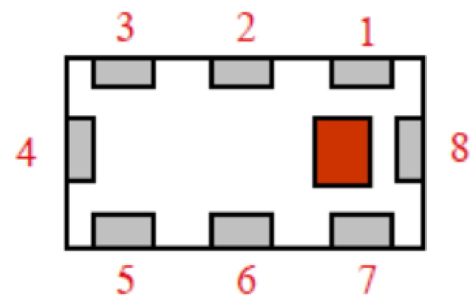


Figure 3.12: Typical circuit for LPF

Figure 3.13: LPF

3.4.5 Band Pass Filter (DBP.433. T.A.30)

A bandpass filter is an electronic device or circuit that allows signals between two specific frequencies to pass, but that discriminates against signals at other frequencies.

Work at the circuit

It placed at receiving way on the circuit after LNA to filter the signal from any frequency not in using range (430-440) MHZ.

Description

Dielectric Band Pass Filter for 433MHZ Bandwidth 2MHz.

Features

1. Center Frequency 433.92MHz
2. Supports ISM 433.05MHz to 434.79MHz use.
3. Low Insertion Loss
4. Low Pass-Band Ripple
5. High Ultimate Attenuation

3.4.6 High Power Amplifier (BGA6130)

At high-power, the transistor is operating as a large signal device.

Compare between BGA6130 and BGA615L

Parameter	BGA6130	BGA615L
Frequency	400MHZ~2.7GHZ	1.575GHZ
Gain	14dB~17dB	18dB
Voltage	3.6V	2.4V~3.2V

Table 3.5: Comparison of HPA

Why we use BGA6130?

1. The frequency range include the wanted frequency.
2. The voltage range include the wanted voltage 3.3volt where the BGA615L is less than it.

Work at the circuit

It used to increase the power that come from transceiver by 20dB to send it to antenna and transmit it.

Description

The MMIC is a one-stage amplifier, offered in a low-cost leadless surface-mount package. At 3.6 V it delivers 29.5 dBm output powers at 3 dB gain compression with efficiency higher than 55 %. Its power saving features includes simple quiescent current adjustment, which allows class-AB operation and logic-level shutdown control to reduce the supply current to 4 µA.

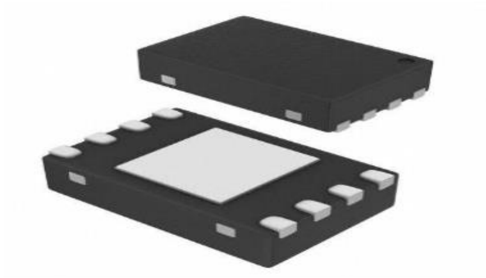


Figure 3.14: HPA

Features

1. 400 MHz to 2700 MHz frequency operating range
2. Integrated active biasing.
3. External matching allows broad application optimization of the electrical performance.
4. Efficiencies higher than 55 %
5. 3.6 V single supply operation
6. Power-down
7. Excellent robustness:
8. All pins ESD protected (HBM 6 kV: CDM 2 kV)
9. Withstands mismatch of VSWR 50: 1 through all phases.
10. Withstands electrical over-stress peaks of 4.5 V on the supply voltage.

Applications

1. Broadband CPE / MO CA
2. WLAN / ISM / RFID
3. Wireless Sensor Network (WSN)
4. Industrial applications
5. Satellite Master Antenna TV (SMATV)

Entire Equivalent Circuit

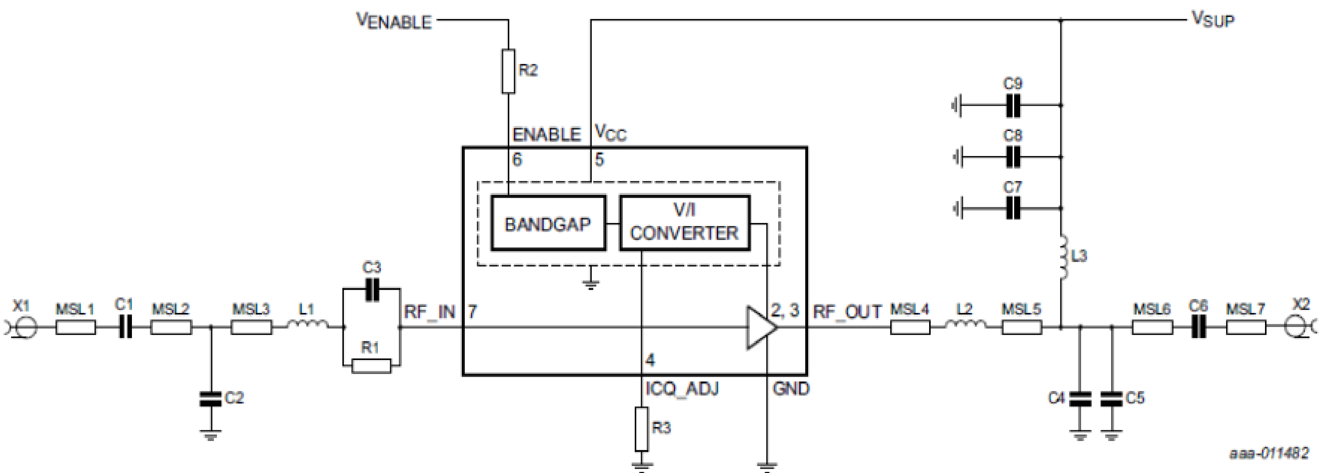


Figure 3.15: Typical circuit of HPA

High Power Amplifier Pin Connection:

altium		Pin Assignment			
Pin Name	Designator	Designator	Pin Name	Description	Type
N.C	1	1	N.C	not connected	Passive
RF_OUT	2	2	RF_OUT	RF output and supply to the amplifier	Output
RF_OUT	3	3	RF_OUT	RF output and supply to the amplifier	Passive
N.C	4	4	N.C	not connected	Passive
Vcc	5	5	Vcc	bias supply voltage	Passive
ENABLE	6	6	ENABLE	enable	Passive
RF_IN	7	7	RF_IN	RF input	Passive
ICQ_ADJ	8	8	ICQ_ADJ	quiescent collector current adjustment by an external resistor	Passive
EP	9	9	EP	exposed die pad ground	Power

Figure 3.16: HPA Pin Connection

3.5 Microcontroller and connectors

3.5.1 Microcontroller (STM32F40)

A microcontroller (μC or uC) is a solitary chip microcomputer fabricated from VLSI fabrication. A micro controller is also known as embedded controller. Today various types of microcontrollers are available in market with different word lengths such as 4bit, 8bit, 64bit and 128bit microcontrollers. Microcontroller is a compressed microcomputer manufactured to control vehicles, and a number of other gadgets. A microcontroller comprises components like – memory, peripherals and most importantly a processor. Microcontrollers are basically employed in devices that need a degree of control to be applied by the user of the device.

Figure 3.17: microcontroller

Microcontroller Basics

Any electric appliance that stores, measures, displays information or calculates comprise of a microcontroller chip inside it.

The basic structure of a microcontroller comprises of:

1. CPU – Microcontrollers brain is named as CPU. CPU is the device, which is employed to fetch data, decode it and at the end complete the assigned task successfully. With the help of CPU all the components of microcontroller are connected into a single system. Instruction fetched by the programmable memory is decoded by the CPU.

2. Memory – In a microcontroller memory chip works same as microprocessor. Memory chip stores all programs & data. Microcontrollers are built with certain amount of ROM or RAM (EPROM, EEPROM, etc.) or flash memory for the storage of program source codes.

3. Input/output ports – I/O ports are basically employed to interface or drive.

4. Serial Ports – These ports give serial interfaces amid microcontroller & various other peripherals such as parallel port.

5. Timers – A microcontroller may be in-built with one or more timer or counters. The timers & counters control all counting & timing operations within a microcontroller. Timers are employed to count external pulses. The main operations performed by timer's are- pulse generations, clock functions, frequency measuring, modulations, making oscillations, etc.

6. ADC (Analog to digital converter) – ADC is employed to convert analog signals to digital ones. The input signals need to be analog for ADC. The digital signal production can be employed for different digital applications (such as- measurement gadgets).

7. DAC (digital to analog converter) – this converter executes opposite functions that ADC perform. This device is generally employed to supervise analog appliances like- DC motors, etc.

8. Interpret Control- This controller is employed for giving delayed control for a working program. The interpret can be internal or external.

9. Special Functioning Block – Some special microcontrollers manufactured for special appliances. Like- space systems, robots, etc., comprise of this special function block. This special block has additional ports so as to carry out some special operations.

- **In satellite communication hardware board, we used STM32F407VG with package LQFP100.**

Features

1. Core: ARM® 32-bit Cortex®-M4 CPU with FPU, Adaptive real-time accelerator (ART Accelerator™) allowing 0-wait state execution from Flash memory, frequency up to 168 MHz, memory protection unit, 210 DMIPS/ 1.25 DMIPS/MHz (Dhrystone 2.1), and DSP instructions

2. Memories

3. Up to 1 Mbyte of Flash memory

4. Up to 192+4 Kbytes of SRAM including 64Kbyte of CCM (core coupled memory) data RAM.

5. Flexible static memory controller supporting Compact Flash, SRAM, PSRAM, NOR and NAND memories

6. LCD parallel interface, 8080/6800 modes

7. Clock, reset and supply management.

    - 1.8 V to 3.6 V application supply and I/O
    - POR, PDR, PVD and BOR
    - 4-to-26 MHz crystal oscillator
    - Internal 16 MHz factory-trimmed RC (1% accuracy)
    - 32 kHz oscillator for RTC with calibration
    - Internal 32 kHz RC with calibration

8. Low-power operation
    - Sleep, Stop and Standby modes

9. 3×12-bit, 2.4 MSPS A/D converters: up to 24 channels and 7.2 MSPS in triple interleaved mode

10. 2×12-bit D/A converters

11. General-purpose DMA: 16-stream DMA controller with FIFOs and burst support.

12. Up to 17 timers: up to twelve 16-bit and two 32bit timers up to 168 MHz, each with up to 4 IC/OC/PWM or pulse counter and quadrature (incremental) encoder input
13. Debug mode
    - Serial wire debug (SWD) & JTAG interfaces
    - Cortex-M4 Embedded Trace Macrocell™

14. Up to 140 I/O ports with interrupt capability
    - Up to 136 fast I/Os up to 84 MHz
    - Up to 138 5 V-tolerant I/Os

15. Up to 15 communication interfaces
    - Up to 3 × I2C interfaces (SMBus/PMBus)
    - Up to 4 USARTs/2 UARTs (10.5 Mbit/s, ISO 7816 interface, LIN, IrDA, modem control)
    - Up to 3 SPIs (42 Mbits/s), 2 with muxed full-duplex I2S to achieve audio class accuracy via internal audio PLL or external clock.
    - 2 × CAN interfaces (2.0B Active)
    - SDIO interface

16. Advanced connectivity
    - USB 2.0 full-speed device/host/OTG controller with on-chip PHY
    - USB 2.0 high-speed/full-speed device/host/OTG controller with dedicated DMA, on-chip full-speed PHY and ULPI
    - 10/100 Ethernet MAC with dedicated DMA: supports IEEE 1588v2 hardware, MII/RMII.

17. 8- to 14-bit parallel camera interface up to 54 Mbytes/s

18. True random number generator

19. CRC calculation unit

20. 96-bit unique ID

21. RTC: sub second accuracy, hardware calendar

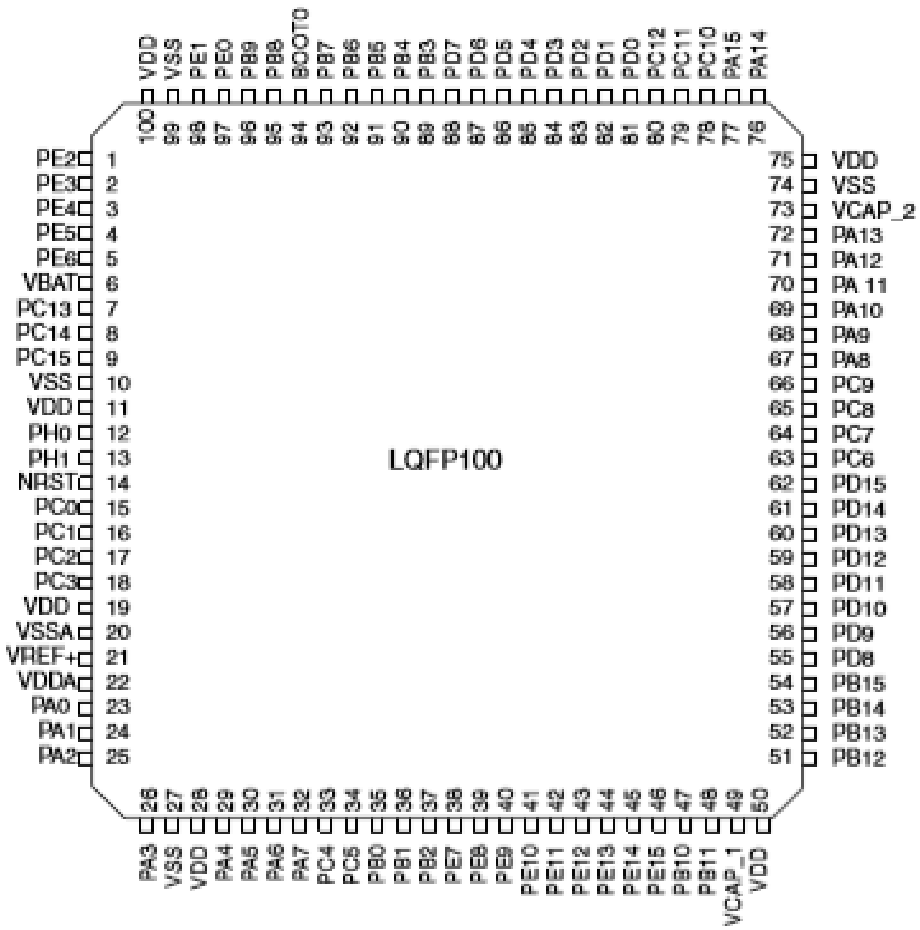


Figure 3.18: STM32F40xxx LQFP100 pinout

Microcontroller Pin Connection:

Pin Assignment				
Designator	**Pin Name**	**Net**	**Description**	**Type**
1	PE2	RF1C	GPIO pin used for RF Swich	Output
2	PE3	RF2C	GPIO pin used for RF Swich	Output
3	PE4	NetU1_3	Not connected	Passive
4	PE5	NetU1_4	Not connected	Passive
5	PE6	NetU1_5	Not connected	Passive
6	VBAT	NetC19_1	For backup voltage	Power
7	PC13	NetU1_7	Not connected	Passive
8	PC14(RCC_OSC32_IN)	RCC_OSC32_in	Input LSE oslilator pin	Passive
9	PC15(RCC_OSC32_OUT)	RCC_OSC32_out	Output LSE oslilator pin	Passive
10	VSS1	GND	Main input voltage 3v3	Power
11	VDD1	VCC 3V3	GND	Power
12	PH0(RCC_OSC_IN)	RCC_OSC_in	Input HSE oslilator pin	Passive
13	PH1(RCC_OSC_OUT)	RCC_OSC_out	Output HSE oslilator pin	Passive
14	NRST	NRST	Reset the microcontroller code active low	Input
15	PC0	NetU1_15	Not connected	Passive
16	PC1	NetU1_16	Not connected	Passive
17	PC2(ADC_IN12)	TEMP1_in	Analog input for the temperature sensor	Input
18	PC3	NetU1_18	Not connected	Passive
19	VDD2	VCC 3V3	Main input voltage 3v3	Power
20	VSSA	GND	GND	Power
21	VREF+	NetC7_1	Analog voltage ref 3v3	Power
22	VDDA	NetC11_1	Analog voltage ref 3v3	Power
23	PA0	PA0		Power
24	PA1(ADC_IN1)	TEMP2_in	Analog input for the temperature sensor	Input
25	PA2(ADC_IN2)	TEMP3_in	Analog input for the temperature sensor	Input
26	PA3(ADC_IN3)	Current_in	Analog input for the current sensor	Input
27	VSS2	GND	GND	Power
28	VDD3	VCC 3V3	Main input voltage 3v3	Power
29	PA4(spi_nss)	SPI1_NSS_out	This pin is a GPIO pin and have alternative function as slave select to SPI1	Output
30	PA5(spi_sck)	SPI1_SCK_out	This pin is a GPIO pin and have alternative function as a clock to SPI1	Output
31	PA6(spi_miso)	SPI1_MISO_out	This pin is a GPIO pin and have alternative function as a MISO to SPI1	Input
32	PA7(spi_mosi)	SPI1_MOSI_out	This pin is a GPIO pin and have alternative function as a MOSI to SPI1	Output
33	PC4	NetU1_33	Not connected	Passive
34	PC5	NetU1_34	Not connected	Passive
35	PB0	NetU1_35	Not connected	Passive
36	PB1	NetU1_36	Not connected	Passive
37	PB2(BOOT1)	BOOT1	Can be used as I/O Pin and used to Boot1	Passive

38	PE7	HPA_EN_out	GPIO Pin used to HPA enable	Output
39	PE8	NetU1_39	Not connected	Passive
40	PE9	NetU1_40	Not connected	Passive
41	PE10	NetU1_41	Not connected	Passive
42	PE11	NetU1_42	Not connected	Passive
43	PE12	NetU1_43	Not connected	Passive
44	PE13	NetU1_44	Not connected	Passive
45	PE14	NetU1_45	Not connected	Passive
46	PE15	NetU1_46	Not connected	Passive
47	PB10	NetU1_47	Not connected	Passive
48	PB11	NetU1_48	Not connected	Passive
49	VCAP1	Net_C10_1	Connect to capacitor and to GND	Power
50	VDD4	VCC 3V3	Main input voltage 3v3	Power
51	PB12	NetU1_51	Not connected	Passive
52	PB13	NetU1_52	Not connected	Passive
53	PB14	NetU1_53	Not connected	Passive
54	PB15	NetU1_54	Not connected	Passive
55	PD8	NetU1_55	Not connected	Passive
56	PD9	NetU1_56	Not connected	Passive
57	PD10	NetU1_57	Not connected	Passive
58	PD11	NetU1_58	Not connected	Passive
59	PD12	Net_R6_1	GPIO pin used for Green LED	Output
60	PD13	Net_R8_1	GPIO pin used for Orange LED	Output
61	PD14	Net_R11_1	GPIO pin used for Orange LED	Output
62	PD15	Net_R13_1	GPIO pin used for Orange LED	Output
63	PC6	NetU1_63	Not connected	Passive
64	PC7	NetU1_64	Not connected	Passive
65	PC8	NetU1_65	Not connected	Passive
66	PC9	NetU1_66	Not connected	Passive
67	PA8	NetU1_67	Not connected	Passive
68	PA9	NetU1_68	Not connected	Passive
69	PA10	NetU1_69	Not connected	Passive
70	PA11	NetU1_70	Not connected	Passive
71	PA12	NetU1_71	Not connected	Passive
72	PA13(SWDIO)	SWDIO	This pin is a GPIO pin and have alternative function as JTAG I/O	I/O
73	VCAP2	Net_C9_1	Connect to capacitor and to GND	Power
74	VSS3	GND	GND	Power
75	VDD5	VCC 3V3	Main input voltage 3v3	Power
76	PA14(SWCLK)	SWCLK	This pin is a GPIO pin and have alternative function as JTAG clock	Input
77	PA15(JTDI)	JTDI	is a GPIO pin ,have alternative function as JTAG input line in 4/5 line mood	Input
78	PC10(uart4-tx)	NetU1_78	is a GPIO pin , have alternative function as a UART4_TX for the RS Converter	Output
79	PC11(uart4_rx)	NetU1_79	is a GPIO pin ,have alternative function as a UART4_RX for the RS Converter	Input
80	PC12(uart5-tx)	UART5_TX	is a GPIO pin and have alternative function as a UART4_TX for the OBC	Output
81	PD0	NetU1_81	Not connected	Passive
82	PD1	NetU1_82	Not connected	Passive
83	PD2(uart5_rx)	UART5_RX	is a GPIO pin and have alternative function as a UART4_RX for the OBC	Input
84	PD3	NetU1_84	Not connected	Passive
85	PD4	NetU1_85	Not connected	Passive
86	PD5	NetU1_86	Not connected	Passive
87	PD6	NetU1_87	Not connected	Passive
88	PD7	NetU1_88	Not connected	Passive
89	PB3(JTDO)	JTDO	is a GPIO pin , have alternative function as JTAG output line in 4/5 line mood	Output
90	PB4(JTRST)	JTRST	is a GPIO pin and have alternative function as JTAG reset in 5 line mood	Input
91	PB5	NetU1_91	Not connected	Passive
92	PB6	NetU1_92	Not connected	Passive
93	PB7	NetU1_93	Not connected	Passive
94	BOOT0	BOOT0	Active high pin can't be floated	Passive
95	PB8	NetU1_95	Not connected	Passive
96	PB9	NetU1_96	Not connected	Passive
97	PE0	NetU1_97	Not connected	Passive
98	PE1	NetU1_98	Not connected	Passive
99	PDR_ON	P/G	GND	Power
100	VDD6	VCC 3V3	Main input voltage 3v3	Power

Figure 3.19: Microcontroller Pin Connection

3.5.2 JTAG (75869-104LF)

The STM32F4xxxx core integrates the serial wire / JTAG debug port (SWJ-DP). It is an Arm® standard Core Sight™ debug port that combines a JTAG-DP (5-pin) interface and a SW-DP (2-pin) interface.

1. The JTAG debug port (JTAG-DP) provides a 5-pin standard JTAG interface to the AHPAP port.
2. The serial wire debug port (SW-DP) provides a 2-pin (clock + data) interface to the AHP-AP port
3. In the SWJ-DP, the two JTAG pins of the SW-DP are multiplexed with some of the five JTAG pins of the JTAG-DP.

Internal pull-up and pull-down resistors on JTAG pins:

The JTAG input pins must not be floating since they are directly connected to flip-flops to control the debug mode features. Special care must be taken with the SWCLK/TCK pin that is directly connected to the clock of some of these flip-flops.

To avoid any uncontrolled, I/O levels, the STM32F4xxxx embeds internal pull-up and pulldown resistors on JTAG input pins:

1. JNTRST: Internal pull-up
2. JTDI: Internal pull-up
3. JTMS/SWDIO: Internal pull-up
4. TCK/SWCLK: Internal pull-down

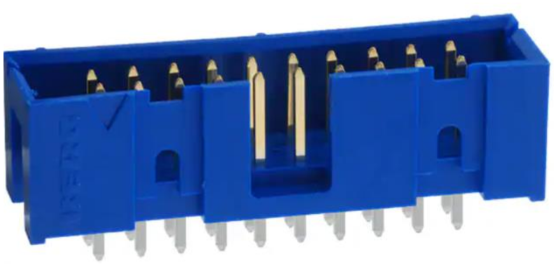


Figure 3.20: JTAG

Once a JTAG I/O is released by the user software, the GPIO controller takes control again. The reset states of the GPIO control registers put the I/Os in the equivalent state:

1. JNTRST: Input pull-up
2. JTDI: Input pull-up
3. JTMS/SWDIO: Input pull-up
4. JTCK/SWCLK: Input pull-down
5. JTDO: Input floating

Entire Equivalent Circuit

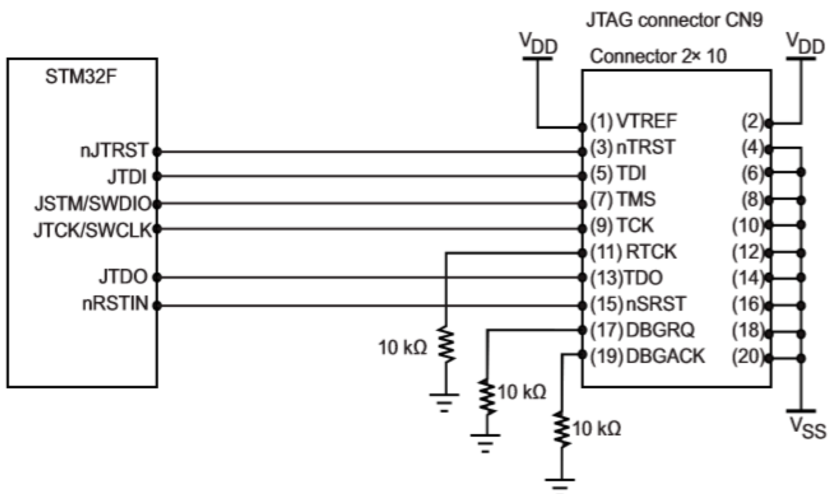


Figure 3.21: JTAG connector implementation

3.5.3 PC104 (ESQ-126-49-G-D)

This is male female header that used to connect between all hardware boards in the satellite subsystem It consists of 52 pins each subsystem in satellite has known pins and ground common for all systems.

Figure 3.22: PC104pins

Connect and work at the circuit.

It connected with the circuit with 4 pins (A-CS, B-CS, Y-CS, Z-CS) with RS converter that used to connect with microcontroller by UART protocol and connect directly with microcontroller with two pins (UART1, UART2) as testing. And connect the circuit with EPS power board and with other satellite boards.

PC104 Pin Connection:

altium		Pin Assignment		
Pin Name	**Designator**	**Designator**	**Pin Name**	**Type**
A-EPS	1	1	A-EPS	Passive
B-EPS	2	2	B-EPS	Passive
Y-EPS	3	3	Y-EPS	Passive
Z-EPS	4	4	Z-EPS	Passive
A-CS	5	5	A-CS	Output
B-CS	6	6	B-CS	Output
07	7	7	07	Passive
5 V	8	8	5 V	Passive
09	9	9	09	Passive
3.3 V	10	10	3.3 V	Passive
GND	11	11	GND	Passive
GND	12	12	GND	Passive
Y-CS	13	13	Y-CS	Input
Z-CS	14	14	Z-CS	Input
15	15	15	15	Passive
GND	16	16	GND	Passive
V bat	17	17	V bat	Passive
OBC (3.3V)	18	18	OBC (3.3V)	Passive
GND	19	19	GND	Passive
ADCS-MT(3.3V)	20	20	ADCS-MT(3.3V)	Passive
21	21	21	21	Passive
ADCS(5V	22	22	ADCS(5V	Passive
23	23	23	23	Passive
CS(3.3V)	24	24	CS(3.3V)	Passive
A-CAM	25	25	A-CAM	Passive
Exp(5 V)	26	26	Exp(5 V)	Passive
B-CAM	27	27	B-CAM	Passive
CAMERA(5V)	28	28	CAMERA(5V)	Passive
GND	29	29	GND	Passive
GND	30	30	GND	Passive
GND(ANALOG)	31	31	GND(ANALOG)	Passive
GND	32	32	GND	Passive
33	33	33	33	Passive
34	34	34	34	Passive
35	35	35	35	Passive
36	36	36	36	Passive
37	37	37	37	Passive
38	38	38	38	Passive
A-ADCS	39	39	A-ADCS	Passive
B-ADCS	40	40	B-ADCS	Passive
41	41	41	41	Passive
Y-ADCS	42	42	Y-ADCS	Passive
43	43	43	43	Passive
Z-ADCS	44	44	Z-ADCS	Passive
GND	45	45	GND	Passive
GND	46	46	GND	Passive
47	47	47	47	Passive
48	48	48	48	Passive
49	49	49	49	Passive
UART_2	50	50	UART_2	Output
HRes_CS	51	51	HRes_CS	Passive
UART_2	52	52	UART_2	Passive

Figure 3.23: PC104 Pin Connection

3.5.4 RS Converter (ISL83488)

This is RS-485/RS-422 Transceivers that meet both RS-485and RS-422 standers for balanced communication between microcontroller and OBC board.

Figure 3.24: RS converter

Features

1. Operate from a single +3.3V supply (10% tolerance)
2. Interoperable with 5V logic
3. High data rates up to 10Mbps
4. Single unit load allows up to 32 devices on the bus.
5. Slew rate limited versions for error free data transmission (ISL83483, ISL83488)
6. up to 250kbps
7. Low current Shutdown mode (ISL83483, ISL83485, ISL83491) 15nA
8. -7V to +12V common-mode input voltage range
9. Three-state Rx and Tx outputs (except ISL83488, ISL83490)
10. 10ns propagation delay, 1ns skew (ISL83485, ISL83490, ISL83491)
11. Full duplex and half duplex pinouts
12. Current limiting and thermal shutdown for driver overload protection
13. Pb-free (RoHS compliant)

Work at the circuit

It works as converter to change from RS485 coming from PC52 to UART that connect with microcontroller.

Applications

1. Factory automation
2. Security networks
3. Building environmental control systems
4. Industrial/process control networks
5. Level translators (for example, RS-232 to RS-422)
6. 6.RS-232 “Extension Cords”

Application Information

RS-485 and RS-422 are differential (balanced) data transmission standards for use in long haul or noisy environments. RS-422 is a subset of RS-485, so RS-485 transceivers are also RS-422 compliant. RS-422 is a point-to-multipoint (multidrop) standard, which allows only one driver and up to 10 (assuming one-unit load devices) receivers on each bus. RS-485 is a true multipoint standard, which allows up to 32 one-unit load devices (any combination of drivers and receivers) on each bus. To allow for multipoint operation, the RS-485 specification requires that drivers must handle bus contention without sustaining any damage. Another important advantage of RS-485 is the extended Common-Mode Range (CMR), which specifies that the driver outputs and receiver inputs withstand signals that range from +12V to -7V. RS-422 and RS-485 are intended for runs as long as 4000’, so the wide CMR is necessary to handle ground potential differences, as well as voltages induced in the cable by external fields.

Pin out

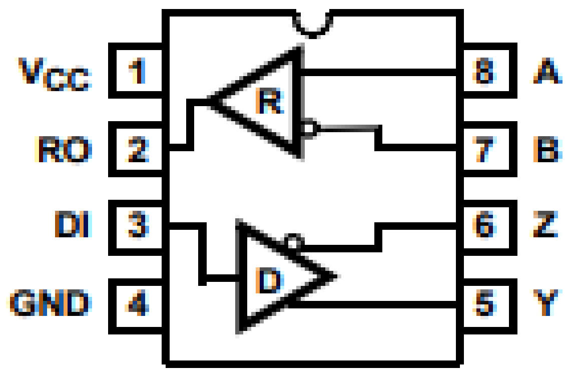


Figure 3.25: Pin out of RS converter

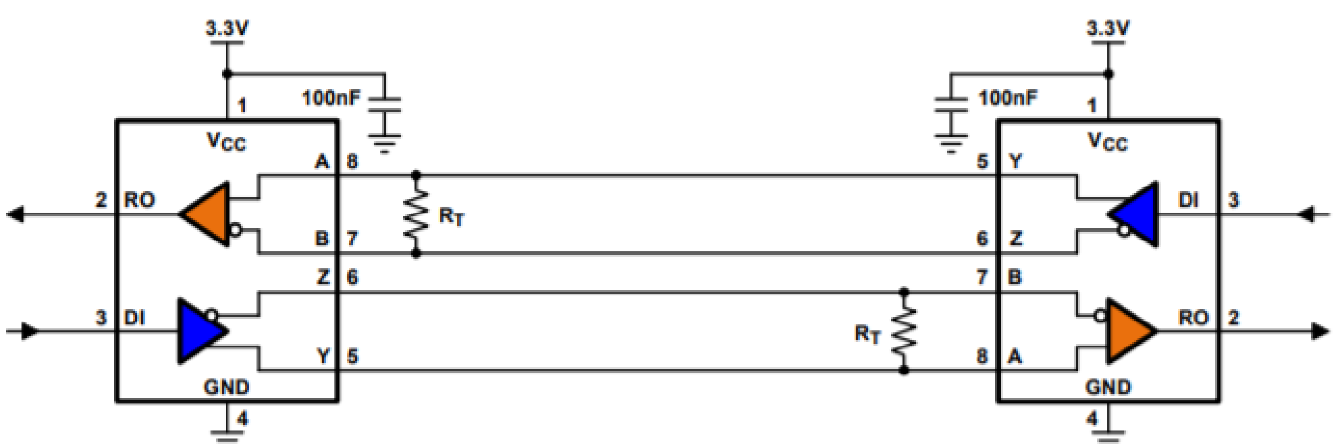


Figure 3.26: ISL83488, ISL83490 RS converter

3.6 Power subsystems and sensors

3.6.1 Temperature Sensor (STLM20)

A temperature sensor is a device, usually an RTD (resistance temperature detector) or a thermocouple, that collects the data about temperature from a particular source and converts the data into understandable form for a device or an observer.

Main Temperature Sensor Types:

1. Negative Temperature Coefficient (NTC) thermistor

A thermistor is a thermally sensitive resistor that exhibits a continuous, small, incremental change in resistance correlated to variations in temperature. An NTC thermistor provides higher resistance at low temperatures. As temperature increases, the resistance drops incrementally, according to its R-T table. Small changes reflect accurately due to large changes in resistance per °C. The output of an NTC thermistor is non-linear due to its exponential nature; however, it can be linearized based on its application. The effective operating range is -50 to 250 °C for glass encapsulated thermistors or 150°C for standard thermistors.

2. Resistance Temperature Detector (RTD)

A resistance temperature detector, or RTD, changes the resistance of the RTD element with temperature. An RTD consists of a film or, for greater accuracy, a wire wrapped around a ceramic or glass core. Platinum makes up the most accurate RTDs while nickel and copper make RTDs that are lower cost; however, nickel and copper are not as stable or repeatable as platinum. Platinum RTDs offer a highly accurate linear output across -200 to 600 °C but are much more expensive than copper or nickel.

3. Thermocouples

A thermocouple consists of two wires of different metals electrically bonded at two points. The varying voltage created between these two dissimilar metals reflects proportional changes in temperature. Thermocouples are nonlinear and require a conversion with a table when used for temperature control and compensation, typically accomplished using a lookup table. Accuracy is low, from 0.5 °C to 5 °C but thermocouples operate across the widest temperature range, from -200 °C to 1750 °C.

4. Semiconductor-based temperature sensors

A semiconductor-based temperature sensor is usually incorporated into integrated circuits (ICs). These sensors utilize two identical diodes with temperature-sensitive voltage vs current characteristics that are used to monitor changes in temperature. They offer a linear response but have the lowest accuracy of the basic sensor types. These temperature sensors also have the slowest responsiveness across the narrowest temperature range (-70 °C to 150 °C).

Comparison between temperature sensors:

Parameter	STLM75DS2F	STLM20DD9F
Temperature range	–55°C to +125°C	–40 °C to 85 °C
operating voltage range	2.7 V to 5.5 V	2.4 V to 5.5 V
Sensor type	Local digital	Local analog
accuracy	±0.5°C (typical)	(±0.5 °C typical)
Operating current	125 µA (typical)	4.8 µA (typical)

Table 3.6: Comparison between temperature sensors

As the table shown above we choose STLM20DD9F because this sensor is more suitable for specifications in our project

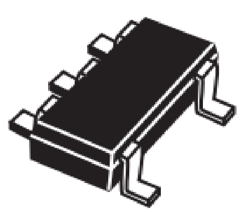


Figure 3.27: Temperature Sensor

Features

1. Precision analog voltage output temperature sensor
2. ±1.5°C temperature accuracy at 25°C
3. Ultra-low quiescent supply current: 8.0µA (max)
4. Operating voltage range: 2.4V to 5.5V Figure 3.8 temperature sensor
5. Operating temperature range:
6. –55°C to 130°C (grade - 7)
7. –40°C to 85°C (grade – 9
8. SOT323-5 (SC70-5) 5-lead package
9. UDFN 4-lead package

Work at the circuit

The most of component of the circuit can bear temperature between (-40to+ 60°C) so temperature sensor is used to protect the circuit at very high and very low temperature.

Applications

1. Third generation (3G) cell phones
2. Multimedia PDA devices
3. GPS devices
4. Portable medical instruments
5. Voltage-controlled crystal oscillator temperature monitors
6. RF Power transistor monitor

Description

1. The STLM20 is a precision analog output temperature sensor for low current.

2. Applications where maximizing battery life is important. It operates over a –55 °C to

3. 130 °C (grade 7) or –40 °C to 85 °C (grade 9) temperature range. The power supply Operating range is 2.4 V to 5.5 V. The maximum temperature accuracy of the STLM20 is ± 1.5 °C (±0.5 °C typ) at an ambient temperature of 25 °C and VCC of 2.7 V. The temperature error increases linearly and reaches a maximum of ±2.5 °C at the temperature range extremes. The temperature range is affected by the power supply voltage. For the temperature grade 7 device, a power supply voltage of 2.7 V to 5.5 V, the temperature range extremes are +130 °C and –55 °C (decreasing the power supply voltage from 2.7 V to 2.4 V changes the low end of the operating temperature range from –55 °C to –30 °C, while the positive remains at +130 °C

Operating Circuit

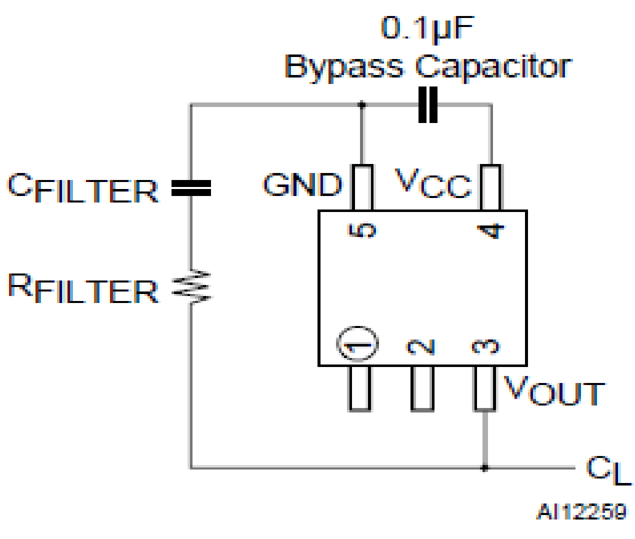


Figure 3.28: Typical Operating Circuits

3.6.2 Current Sensor (MAX9938)

A current sensor is a device that detects and converts current to an easily measured output voltage, which is proportional to the current through the measured path.

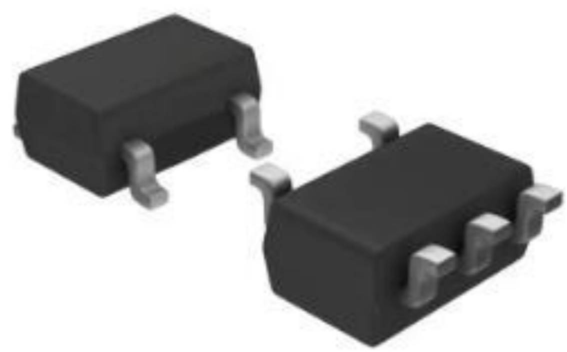


Figure 3.29: Current sensor

Features

1. Ultra-Low Supply Current of 1µA (max)
2. Low 500µV (max) Input Offset Voltage
3. Low < 0.5% (max) Gain Error
4. Input Common Mode: +1.6V to +28V
5. Voltage Output
6. Four Gain Versions Available
7. 25V/V (MAX9938T)
8. 50V/V (MAX9938F)
9. 100V/V (MAX9938H)
10. 200V/V (MAX9938W)

11. Tiny 1mm x 1mm x 0.6mm, 4-Bump UCSP, 5-Pin SOT23, or 2mm x 2mm x0.8mm, 6Pin µDFN Packages

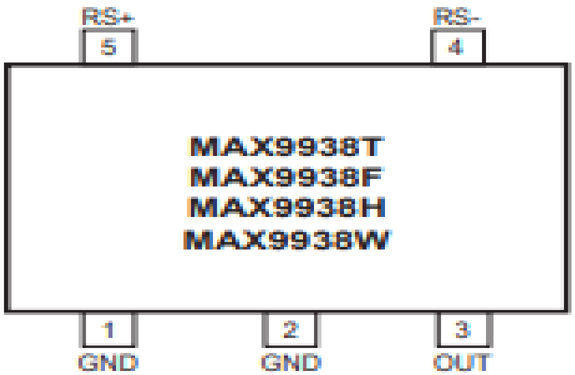


Figure 3.30: Pin out of current sensor

Applications

1. Cell Phones
2. PDAs
3. Power Management Systems
4. Portable/Battery-Powered Systems
5. Notebook Computers

General Description

1. The MAX9938 high-side current-sense amplifier offers precision accuracy specifications of VOS less than 500µV (max) and gain error less than 0.5% (max). Quiescent supply current is an ultra-low 1µA. The MAX9938 fits in a tiny, 1mm x 1mm UCSP™ package size or a 5-pin SOT23 package, making the part ideal for applications in notebook computers, cell phones, PDAs, and all battery-operated portable devices where accuracy, low quiescent current, and small size are critical.

2. The MAX9938 features an input common-mode voltage range from 1.6V to 28V.

3. The MAX9938 unidirectional high-side, current-sense amplifier features a 1.6V to 28V input common-mode range. This feature allows the monitoring of current out of a battery with a voltage as low as 1.6V. The MAX9938 monitors current through a current-sense resistor and amplifies the voltage across that resistor. The MAX9938 is a unidirectional current-sense amplifier that has a well-established history. An op amp is used to force the current through an internal gain resistor at RS+, which has a value of R1, such that its voltage drop equals the voltage drop across an external sense resistor, RSENSE. There is an internal resistor at RS- with the same value as R1 to minimize offset voltage.

4. The current through R1 is sourced by a high-voltage p-channel FET. Its source current is the same as its drain current, which flows through a second gain resistor, ROUT. This produces an output voltage, VOUT, whose magnitude is $ILOAD\ x\ RSENSE\ x\ ROUT/R1$. The gain accuracy is based on the matching of the two gain resistors R1. Total gain = 25V/V for the MAX9938T, 50V/V for the MAX9938F, 100V/V for the MAX9938H, and 200V/V for the MAX9938W. The output is protected from input overdrive by use of an output current limiting circuit of 7mA (typical) and a 6V clamp protection.

Entire Equivalent Circuit

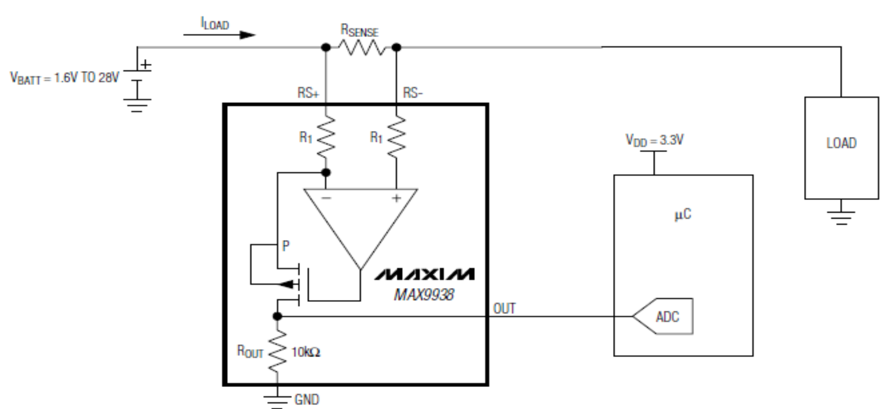


Figure 3.31: Typical Operating Circuit of current sensor

3.6.3 Over Current Protection (LTC4361)

Many electronic devices have a rated current. Once the device exceeds the rated current, it will burn out the device. Therefore, these devices do a current protection module, when the current exceeds the set current, the device automatically power off to protect the device, which is over-current protection.

Figure 3.32: Over current protection

Features

1. 2.5V to 5.5V Operation
2. Overvoltage Protection Up to 80V
3. No Input Capacitor or TVS Required for Most Applications
4. 2% Accurate 5.8V Overvoltage Threshold
5. 10% Accurate 50mV Overcurrent Circuit Breaker
6. <1μs Overvoltage Turn-Off, Gentle Shutdown
7. Controls N-Channel MOSFET
8. Adjustable Power-Up dv/dt Limits Inrush Current
9. Reverse Voltage Protection
10. Power Good Output
11. Low Current Shutdown
12. Latch off (LTC4361-1) or Auto-Retry (LTC4361-2) After Overcurrent
13. Available in 8-Lead Thin SOT™ and 8-Lead (2mm × 2mm) DFN Packages

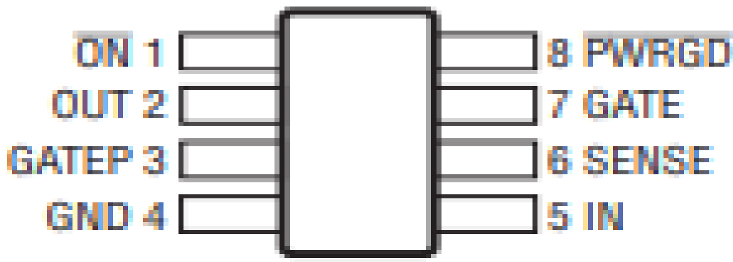


Figure 3.33: Pin configuration of current protection

Applications

1. USB Protection
2. Handheld Computers
3. Cell/Smart Phones
4. MP3/MP4 Players
5. Digital Cameras

Pin Functions:

GATE: Gate Drive for External N-Channel MOSFET. An internal charge pump provides a 10µA pull-up current to charge the gate of the external N-channel MOSFET. An additional ramp circuit limits the GATE ramp rate when turning on to 3V/MS. for slower ramp rates, connect an external capacitor from GATE to GND. An internal clamp limits GATE to 6V above the OUT-pin voltage. An internal GATE high comparator controls the PWRGD pin.

GATEP: Gate Drive for External P-Channel MOSFET. GATEP connects to the gate of an optional external P-channel MOSFET to protect against negative voltages at IN. This pin is internally clamped to 5.8V below VIN. An internal 2M resistor connects this pin to ground. Connect to IN if not used.

GND: Device Ground

IN: Supply Voltage Input. Connect this pin to the input power supply. This pin has an overvoltage threshold of 5.8V. After an overvoltage event, this pin must fall below VIN.

OV) – ΔVOV: to release the overvoltage lockout. During lockout, GATE is held low and the PWRGD pull-down releases.

ON: On Control Input. Logic low at ON enables the LTC4361. Logic high at ON activates a low current pulldown at the GATE pin and causes the LTC4361 to enter a low current sleep mode. An internal 5µA current pulls ON down to ground. Connect to ground or leave open if unused.

OUT: Output Voltage Sense Input for GATE Clamp. Connect to the source of the external N-channel MOSFET to sense the output voltage for GATE to OUT clamp**.**

PWRGD: Power Good Status. Open-drain output with internal 500k resistive pull-up to OUT. Pulls low 65ms after GATE ramps above VGATE(TH).

SENSE: Current Sense Input. Connect a sense resistor between IN and SENSE. An overcurrent protection circuit turns off the N-channel MOSFET when the voltage across the sense resistor exceeds 50mV for more than 10µs.

Entire Equivalent Circuit

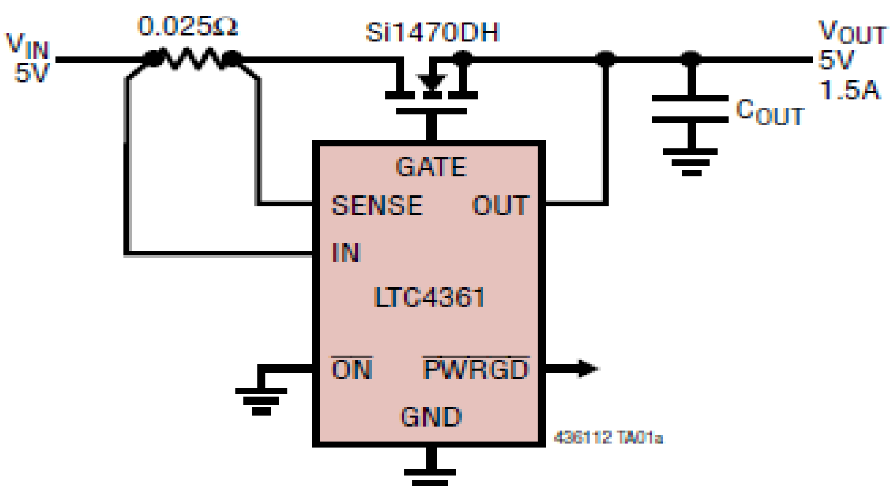


Figure 3.34: Typical Operating Circuit of current protection

3.6.4 Booster Converter (LT3757)

A booster converter is a DC-to-DC power converter that steps up voltage from its input (3.3V) to its output (5V).

Work at the circuit

The booster converter used at the circuit to increase the volt of the circuit from3.3volt to 5 volts because the used LNA work at input 5volt output 3.3volt

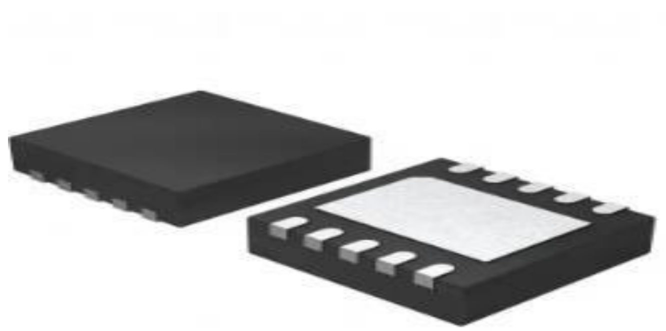


Figure 3.35: Booster converter

Features

1. Wide Input Voltage Range: 2.9V to 40V
2. Positive or Negative Output Voltage Programming with a Single Feedback Pin
3. Current Mode Control Provides Excellent Transient Response
4. Programmable Operating Frequency (100kHz to1MHz) with One External Resistor
5. Synchronizable to an External Clock
6. Low Shutdown Current < 1µA
7. Internal 7.2V Low Dropout Voltage Regulator
8. Programmable Input Under Voltage Lockout with Hysteresis
9. Programmable Soft-Start
10. Small 10-Lead DFN (3mm × 3mm) and Thermally Enhanced 10-Pin MSO Packages

Applications

1. Automotive and Industrial Boost, Fly back, SEPIC and Inverting Converters
2. Telecom Power Supplies
3. Portable Electronic Equipment

Pin Configuration

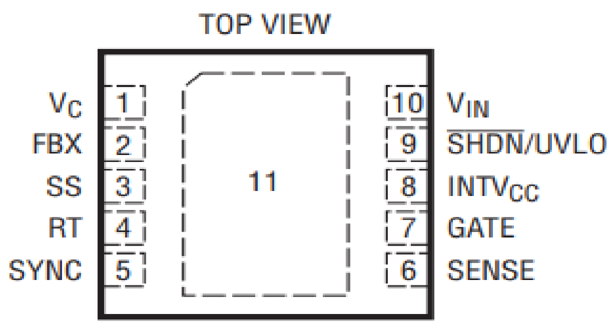


Figure 3.36: Pin configuration of booster converter

Entire Equivalent Circuit

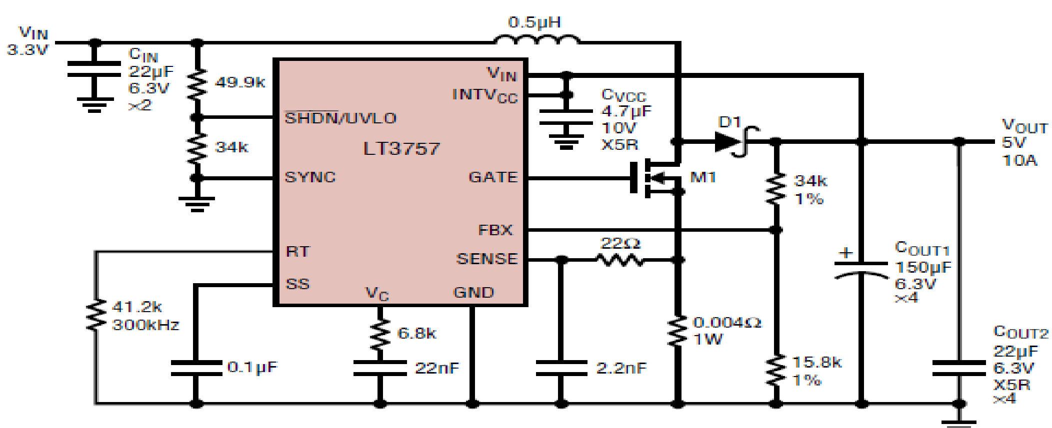


Figure 3.37: Typical operating circuit of booster converter

Pin Functions

1. **VC (Pin 1):** Error Amplifier Compensation Pin. Used to stabilize the voltage loop with an external RC network.

2. **FBX (Pin 2):** Positive and Negative Feedback Pin. Receives the feedback voltage from the external resistor divider across the output. Also modulates the frequency during start-up and fault conditions when FBX is close to GND.

3. **SS (Pin 3):** Soft-Start Pin. This pin modulates compensation pin voltage (VC) clamp. The soft-start interval is set with an external capacitor. The pin has a 10μA (typical) pull-up current source to an internal 2.5V rail. The soft start pin is reset to GND by an under-voltage condition at SHDN/UVLO, an INTVCC under voltage or overvoltage condition or an internal thermal lockout.

4. **RT (Pin 4):** Switching Frequency Adjustment Pin. Set the frequency using a resistor to GND. Do not leave this pin open.

5. **SYNC (Pin 5):** Frequency Synchronization Pin. Used to synchronize the switching frequency to an outside clock. If this feature is used, an RT resistor should be chosen to program a switching frequency 20% slower than the SYNC pulse frequency. Tie the SYNC pin to GND if this feature is not used. SYNC is ignored when FBX is close to GND.

6. **SENSE (Pin 6):** The Current Sense Input for the Control Loop. Kelvin connects this pin to the positive terminal of the switch current sense resistor in the source of the N-channel MOSFET. The negative terminal of the current sense resistor should be connected to GND plane close to the IC.

7. **GATE (Pin 7**): N-Channel MOSFET Gate Driver Output. Switches between INTVCC and GND. Driven to GND when IC is shut down, during thermal lockout or when INTVCC is above or below the OV or UV thresholds, respectively.

8. **INTVCC (Pin 8):** Regulated Supply for Internal Loads and Gate Driver. Supplied from VIN and regulated to 7.2V (typical). INTVCC must be bypassed with a minimum of 4.7µF capacitor placed close to pin. INTVCC can be connected directly to VIN, if VIN is less than 17.5V. INTVCC can also be connected to a power supply whose voltage is higher than 7.5V, and lower than VIN, provided that supply does not exceed 17.5V.

9. **SHDN/UVLO (Pin 9**): Shutdown and under voltage Detect Pin. An accurate 1.22V (nominal) falling threshold with externally programmable hysteresis detects when power is okay to enable switching. Rising hysteresis is generated by the external resistor divider and an accurate internal 2µA pull-down current. An under-voltage condition resets sort-start. Tie to 0.4V, or less, to disable the device and reduce VIN quiescent current below 1µA.

10. **VIN (Pin 10):** Input Supply Pin. Must be locally bypassed with a 0.22µF, or larger, capacitor placed close to the pin.

11. **Exposed Pad (Pin 11):** Ground. This pin also serves as the negative terminal of the current sense resistor. The Exposed Pad must be soldered directly to the local ground plane.

Chapter 4: Link Budget and Simulation

4.1 Link Budget

This section will describe the link budget analysis. The link budget analysis determines whether it is possible to establish a communication link with given systems parameters (power, frequency, data rate and the bandwidth).

The link budget calculates the gain and loss of a RF signal from the modulation in the transmitter to the demodulation in the receiver. The result is a value known as Signal to Noise Ratio (SNR).

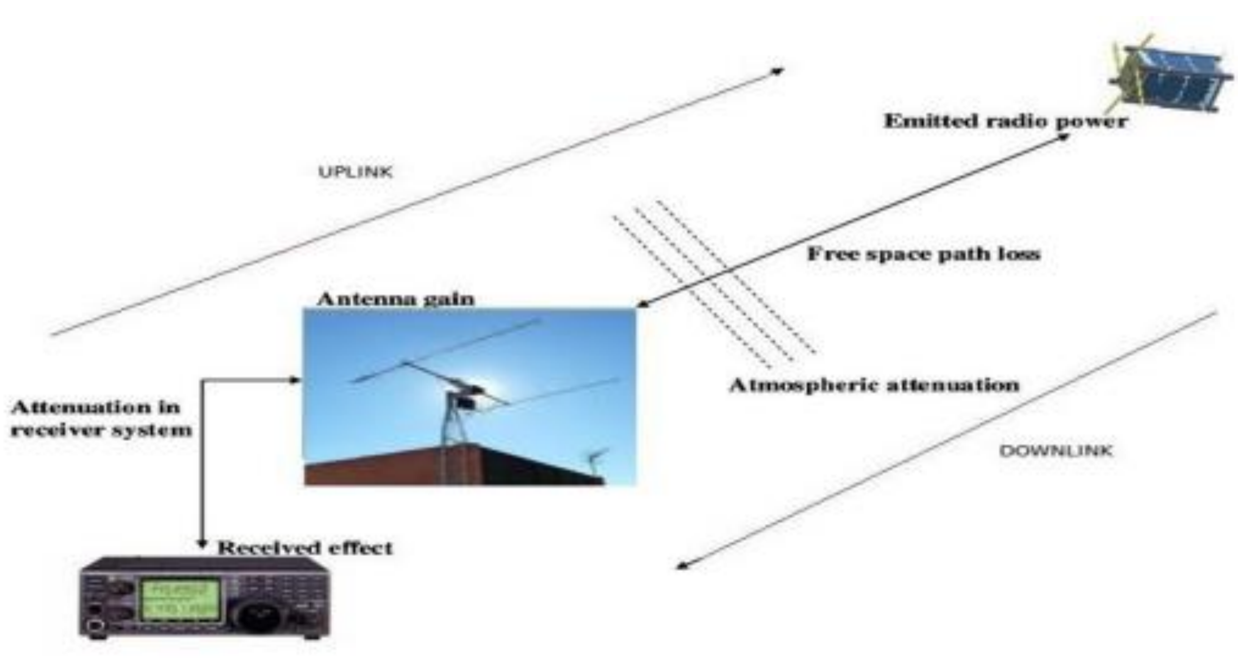


Figure 4.1: Satellite link

4.1.1 Link Budget Parameters

1- Transmit Power (P_t) and Bit Energy (E_b)

$$E_b = P_t T_b = \frac{P_t}{F_b} \; (\mathrm{J/s \; bit/s = J/bit})$$

Equation 4.1

Energy per bit (E_b) is the energy contained in one bit.

E_b: Energy of a single bit (joules per bit)

P_t : Total output power of HPA (watts or joules per second)

T_b: Time of a single bit (seconds)

F_b: Bit-rate (bps)

2- Effective Isotropic Radiated Power (EIRP)

EIRP is defined as an equivalent transmit power of antenna

$$\mathrm{EIRP} = P_{in} A_t \qquad\qquad \mathrm{EIRP} = [P_t] + [A] \; (\mathrm{dBw})$$

Equation 4.2

EIRP: effective isotropic radiated power (watts)

P_{in}: antenna input power (watts)

A_t : transmit antenna gain (unitless ratio)

3- Noise density (N_0)

Noise density is the noise power normalized to a 1-Hz bandwidth, or the noise power present in a 1 Hz bandwidth.

$$N_0 = \frac{N}{B} \qquad\qquad N = K T_e B$$

Equation 4.3

N: Total noise power (watts),

B: Bandwidth (Hz)

K : Boltzmann's constant (1.38×10^{-23} J/Kelvin)

T_e: Equivalent noise Temp. (kelvin)

$$N0 = \frac{KTe}{B} B = K\, Te$$

Equation 4.4

4- Path Loss

- **Backoff loss (L_{bo})**

The amount the output level backed off from rated levels is equivalent to a loss

- **Branching Loss (L_b)**

Due to branching effect when multiple transmitters' signals are combined to be transmitted through single channel. Similar effect occurs at the receiver when separating them again

- **Feeding Loss (L_f):**

Loss in the transmission line that connected to the antenna

5- Energy of Bit-to-Noise density Ratio (E_b/N_0)

E_b/N_0 is independent of bandwidth and modulation scheme, so it is a convenient method for comparing the probability of error performance of two digital radio systems.

$$\frac{Eb}{N0}\,(\text{dBw}) = \frac{C}{N}\,(\text{dBw}) + \frac{B}{Fb}\,(\text{dBw})$$

Equation 4.5

6- Signal to Noise ratio (SNR)

The signal to noise ratio is the ratio between the power of the information carrying the signal and the power of the noise present in the channel. It can be expressed as:

$$SNR\,(dB) = [Gt\,] + [Gr\,] - [Lfs] - [L]$$

Equation 4.6

This value will determine the threshold of the system, it will indicate whether or not the information from the received signal can be extracted or not. In digital communications, the figure of merit is the energy per bit to noise power spectral density ration , it is a normalized version of the SNR.

$$SNR\ (dB) = [\frac{Eb}{N0}] + 10 \cdot \log\ (\mathrm{fb}) - 10 \cdot \log\ (B)$$

Equation 4.7

where (fb) is the frequency of symbol, and B the bandwidth and Eb/N0 is a normalized value of the SNR, it is common to use this value to compare digital communication links.

7- Slant Range:

Slant range is the maximum distance between a ground station and a satellite. The slant range is defined by the height of the orbit of the satellite and the minimum elevation of the ground station antenna. The slant range can be calculated using equation:

$$\mathbf{dmax} = \sqrt{(\mathbf{R} + \mathbf{h})^2 - \mathbf{R}^2\cos^2\theta} - \mathbf{R}\sin\theta$$

Equation 4.8

Where

R = is the Earth’s radius (R = 6378.140 (km))

h = the satellites height above the Earth’s surface

θ = the elevation angle for the ground station antenna

8- Doppler Shift:

Doppler shift is a phenomenon where a constant frequency is changed because the receiver is moving relative to the transmitter. The change in frequency is proportional to the relative speed between the receiver and the transmitter.

The frequency will increase when the receiver is moving towards the transmitter and decrease when moving away.

A common analogy is a train sounding the whistle, when moving towards you the sound of the whistle will be higher pitched than when the train moves away.

Doppler shift is explained in equation:

$$\mathbf{f}_r = \left(1 + \frac{v}{c}\right) \mathbf{f}_t$$

Equation 4.9

Where:

fr = received frequency

v = the speed of the transmitter relative to the receiver

c = light speed

ft = transmitted frequency

$$\Delta f = \mathbf{f}_t \frac{v}{c} = \mathbf{f}_r - \mathbf{f}_t$$

Equation 4.10

where:

Δ f = frequency deviation or Doppler shift

Satellite communication coverage will experience a Doppler shift equal to ± (Δf)max

Uplink Equation

$$\frac{C}{N0} = \frac{\text{Pin At Ar}}{\text{Lp Lu K Te}} = \frac{\text{Pin At}}{\text{Lp Lu K}} * \frac{G}{Te}$$

$Lp = (\frac{4\pi D}{\lambda})^2$ is the free space path loss where D is the propagation distance and λ is the wavelength.

Lu : additional uplink atmospheric losses

$$\frac{C}{N0} = \text{EIRP} - Lp - Lu + \frac{G}{Te} - K \qquad \textbf{Equation 4.11}$$

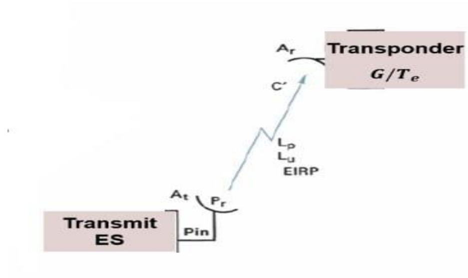


Figure 4.2: Satellite Uplink

Downlink Equation

$$\frac{C}{N0} = \frac{Pin\ At\ Ar}{Lp\ Ld\ K\ Te} = \frac{Pin\ At}{Lp\ Lu\ K} * \frac{G}{Te}$$

$Lp = (\frac{4\pi D}{\lambda})^2$ is the free space path loss where D is the propagation distance and λ is the wavelength.

Lu : additional downlink atmospheric losses

$$\frac{C}{N0} = \text{EIRP} - Lp - Ld + \frac{G}{Te} - K \qquad \textbf{Equation 4.12}$$

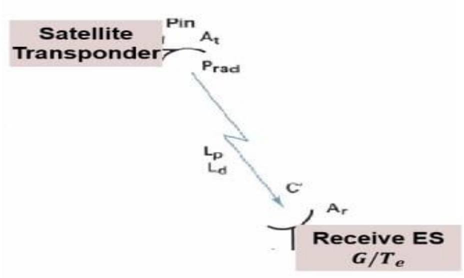


Figure 4.3: Satellite downlink

4.1.2 Uplink Budget Calculation

Input Parameters

Parameter	Value
Satellite altitude	700Km
Uplink Data Rate	1.2 Kbits/s
Frequency Band	436 MHZ
Transmit Power	37dBm
Antenna Gain	13 dB
Antenna Feeder Loss	-2.7 dB
On-board receiver noise temperature	570 K
On-board Antenna Gain	0dB
On-board Antenna Feeder Loss	-1 dB
Eb/N0	12 dB for BER 10^-3

Table 4.1: Uplink Input Parameters

Calculated Data

Parameter	Value
Free space path loss	-153.4 dB
Polarization loss	-4.25 dB
Total loss	-159.56 dB

Table 4.2: Uplink Calculated Data

4.1.3 Downlink Budget Calculation

Input Parameters

Parameter	Value
Satellite altitude	700Km
Uplink Data Rate	1.2 Kbits/s
Frequency Band	436 MHZ
Transmit Power	27dBm
Antenna Gain	13 dB
Antenna Feeder Loss	-1 dB
Receiver noise temperature	500 K
Antenna noise temperature	200 K
On-board Antenna Gain	0dB
On-board Antenna Feeder Loss	-1 dB
Eb/N0	12 dB for BER 10^-3

Table 4.3: Downlink Input Parameters

Calculated Data

Parameter	Value
G/T	-20.8
Free space path loss	-153.4 dB
Polarization loss	-4.25 dB
Total loss	-159.56 dB

Table 4.4: Downlink Calculated Data

4. 2. Simulation

4.2.1 AWR Design Software

The AWR Design Environment platform provides a comprehensive suite of software tools for end-to-end circuit and system design; however, engineers sometimes need a specialized tool for a specific design challenge.

To that end, AWR software has been specifically designed to easily integrate with industry-leading software and hardware point-tool providers in order to offer streamlined design flows that help customers increase productivity and deliver optimized designs to market faster.

AWR Visual System Simulator (VSS) software enables us to design and analyze end-to-end communication systems. We can design systems composed of modulated signals, encoding schemes, channel blocks and system level performance measurements.

We can display BER curves, ACPR measurements, constellations, and power spectrums, to name a few VSS software provides a real-time tuner that allows us to tune the designs and then see our changes immediately in the data display.

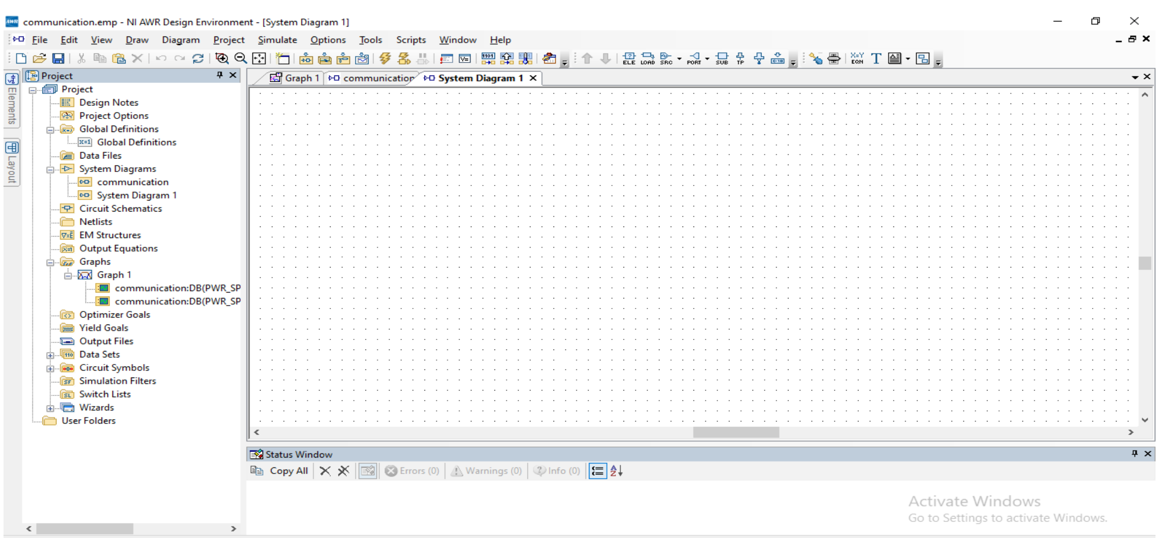


Figure 4.4: AWR interface

1. Adding/Placing an Element

Add/Place an element by pressing Ctrl+L or choosing Draw > More Elements to filter a list of elements by name, description, or path. Ctrl-click a column header to filter by that column. Searches can use multiple words: "micro line" displays matches for both words.

1. Setting up a Sweep

- Create a sweep for a parameter or variable by right clicking the parameter or variable and choosing Setup Sweep.

- Edit the sweep parameters of an existing sweep by right clicking the element parameter using the swept variable. You can change the sweep type (linear or log), the way the sweep is specified (step size or number of points), and the range of the sweep.

2. Elements on Schematics/System Diagrams

Select an element and right-click its symbol (not the parameter text) to display a context menu to:

- Edit element properties/parameters in the Element Options dialog box.
- Toggle enables or disables the element in the schematic or diagram.
- Swap the element with another element.
- Rotate or flip or freeze in place the element.
- Zoom In/Out, View Area, View All to change the view.
- Display the Help for the element.
- Select or place the element in the layout for the schematic. • Edit the element symbol in the Symbol Editor

4.2.2 Simulation of the system

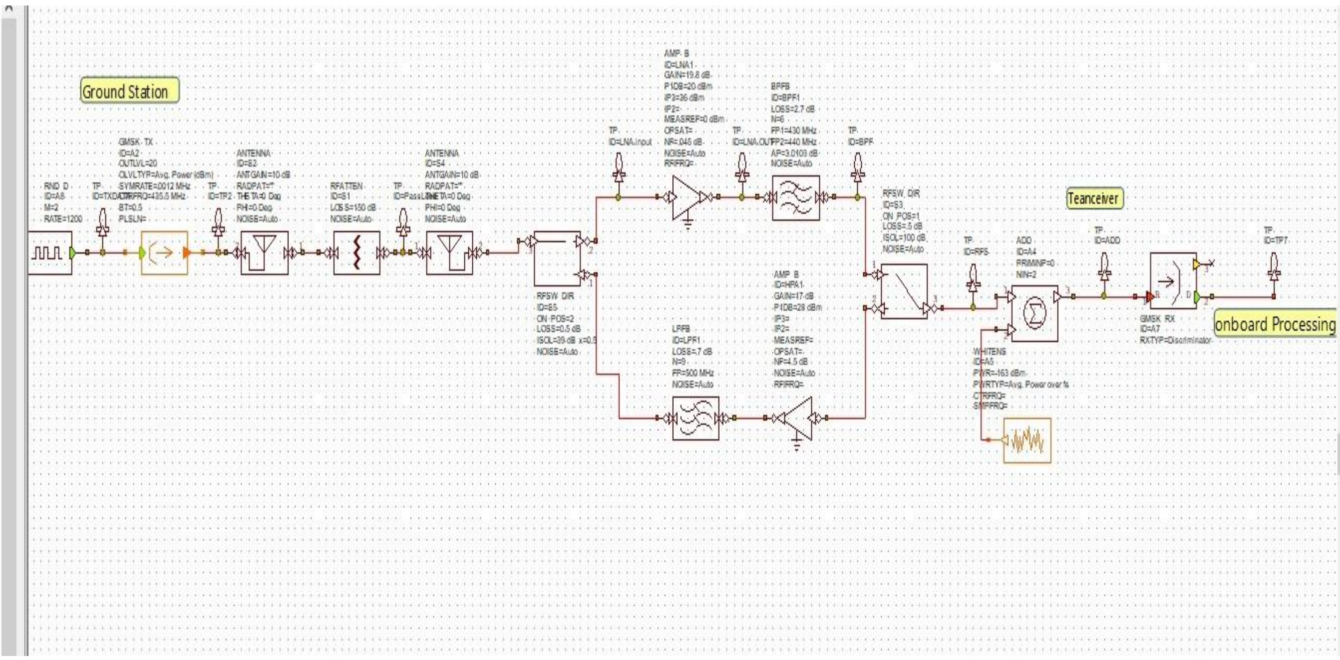
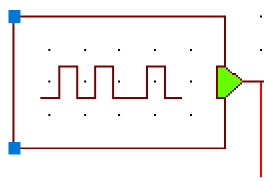
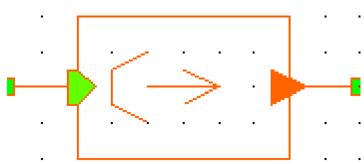
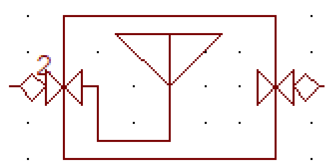
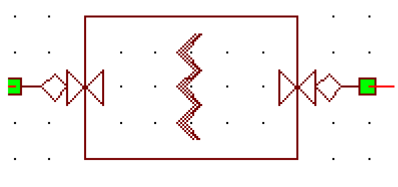
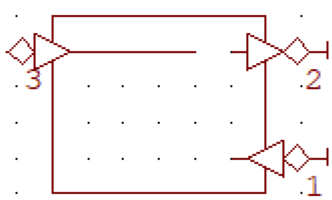
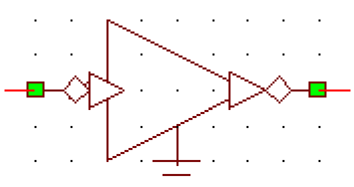


Figure 4.5: System diagrams

The gain and loss blocks, including the Free Space Path Loss block and the Receiver Thermal Noise block, determine the data rate that can be supported on the link in an additive white Gaussian noise channel.

Structure of the model: The model highlights both the satellite link model and test points and BER meter. The model consists of the Satellite communication sub system, Path, and Ground station Transmitter and receiver (simplified).

Symbol	Name
	**Random digital source**
	**GMSK (Gaussian Minimum Shift Keying)**
	**RF Antenna**
	**Channel Noise**
	**RF Switch**
	**Low Noise Amplifier (LNA)**

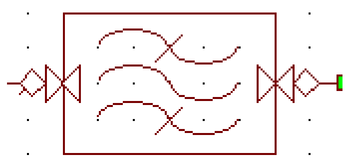
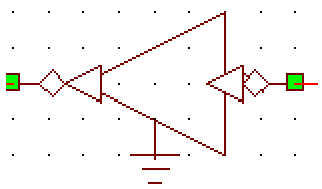
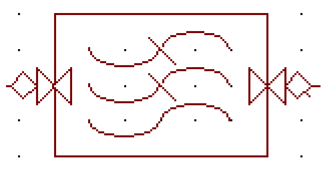
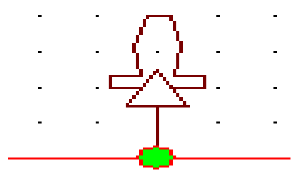
	**Band Pass filter (BPF)**
	**High Power Amplifier (HPA)**
	**Low Pass Filter (LPF)**
	**Test Point (TP)**

Table 4.5: Components in system diagram

The main goal of simulation is to receive the correct data from ground station and transmit data to it again.

The figure below shows the received data and transmitted data considering ignore the time delay which the transmitted data in blue and received data with pink.

The figure below shows the spectrum of LNA -BPF In this configuration the LNA sees all signals received from the antenna including the strong ones and BPF limit the required band And show the received signal

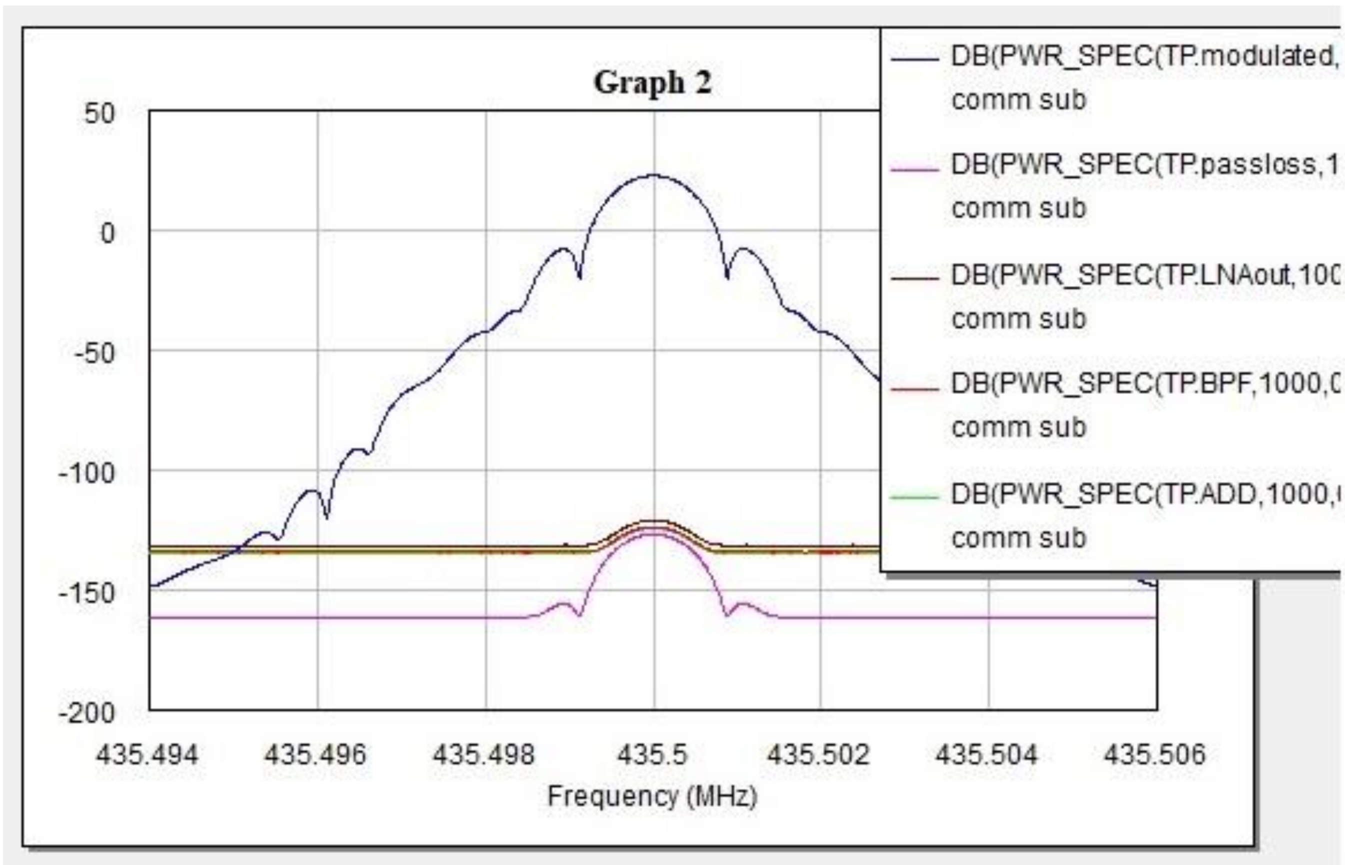


Figure 4.6: Spectrum of LNA- BPF

This figure show spectrum of the signal through uplink path after adding doppler shift The problem can be solved by dynamic doppler compensation where the frequency of the signal is changed progressively during transmission, it is used so the satellite receives a constant frequency signal

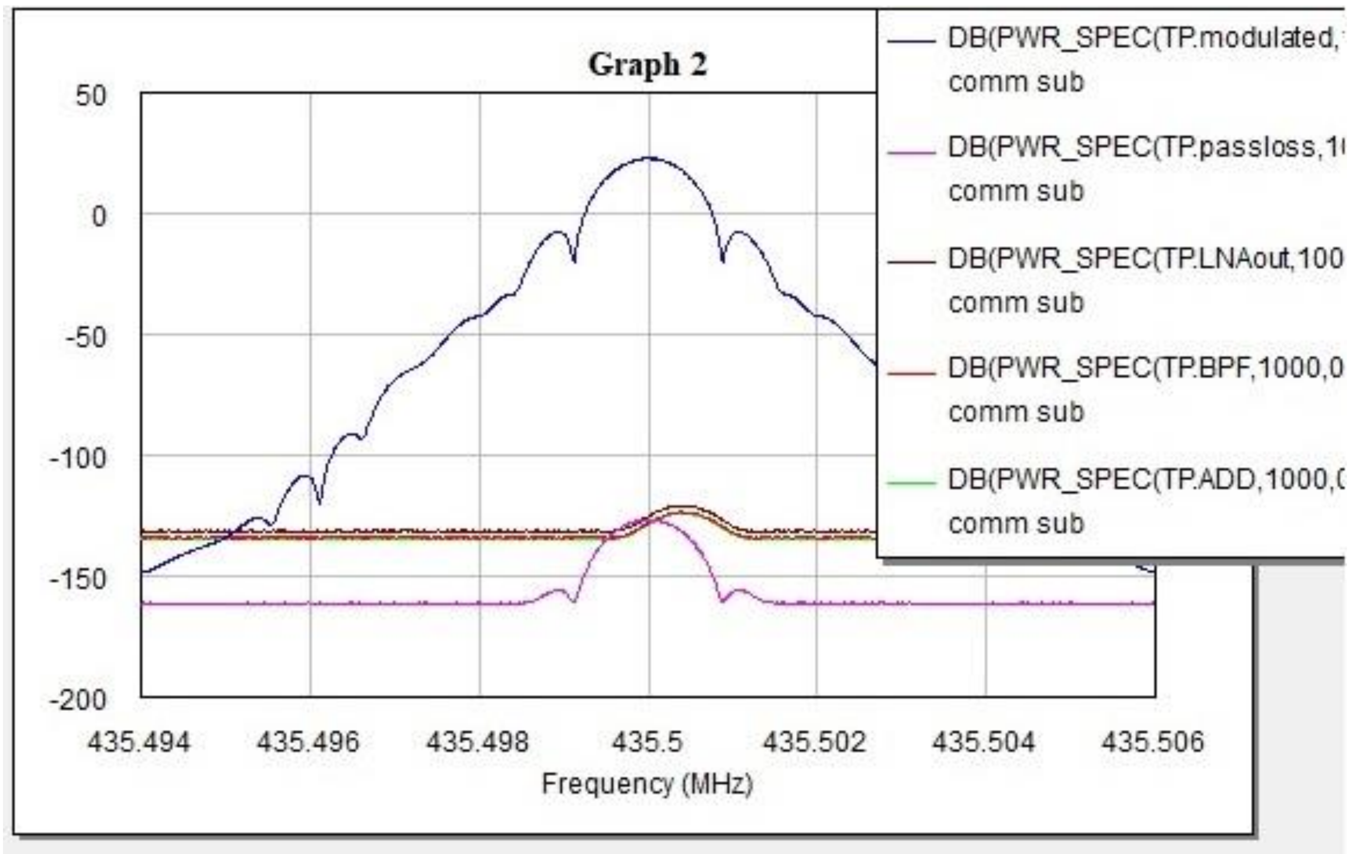


Figure 4.7: Spectrum of uplink signal after adding Doppler shift

The main goal of the simulation is to receive the correct data from the ground station to the communication subsystem then on board computer

The figure below shows the received data and transmitted data considering ignore the time delay which the transmitted data in blue and received data in pink.

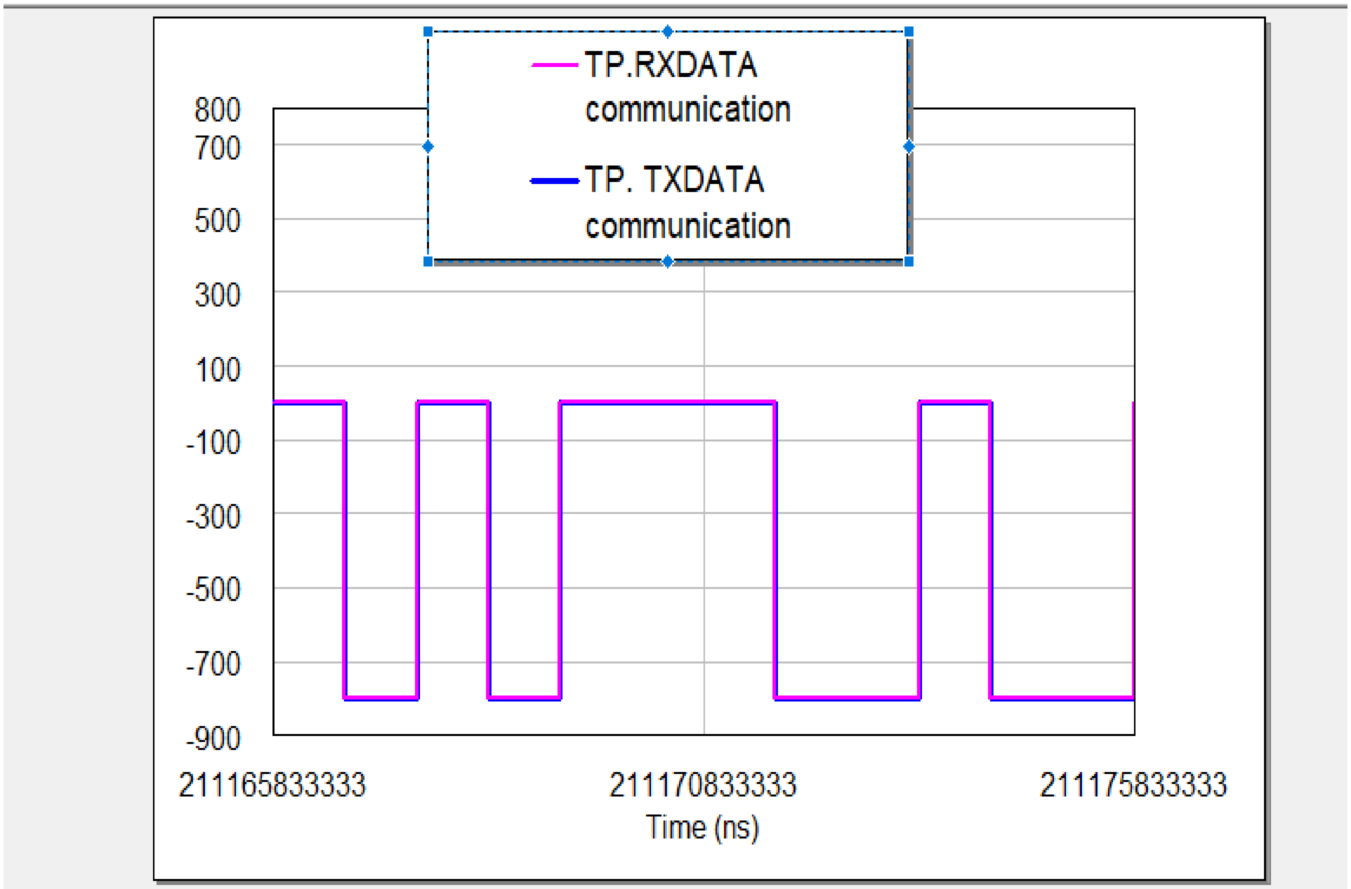


Figure 4.8: TX, RX Signal

Chapter 5: PCB Optimum Design

5.1 Design Programs

We choose software designer program according to

1. User Interface / Navigation
2. Placing and editing components
3. Integration with PCB footprint and PCB library
4. Multi-part schematic component
5. Overall schematic library editor
6. 3D Visual
7. Overall PCB library and PCB editor
8. Error debugging
9. Net management
10. PCB routing

- When the following comparison between the programs was made, it was found that the Altium is the best program that supports all the requirements that we need in this project.
- Approval and documentation of this program with NASA for designing printed circuits for satellites.
- Guidance from the trained masters in the Egyptian Space Agency

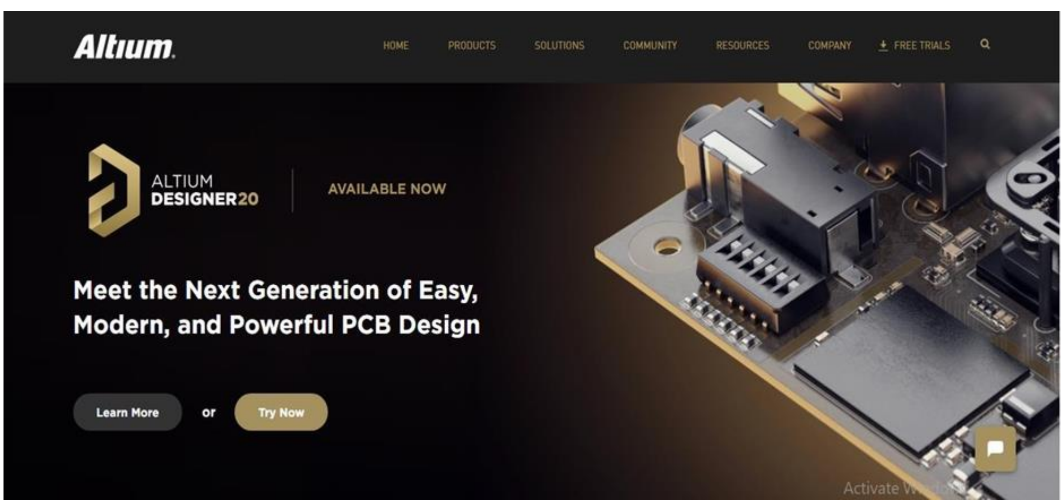


Figure 5.1: Altium Design

Category/Criteria	DipTrace	Eagle	KiCAD	OrCAD	PADS	Altium	Scale
Defining connection type and descriptions	B	B	B	C	C	A	Grade: A – F
Multi-part schematic component	B	C	C	C	C	B	Grade: A – F
Integration with PCB footprint and PCB library	C	C	D	D	C	A	Grade: A – F
PCB Routing	B	C	A	C	C	B	Grade: A – F
Net Management	B	B	B	A	B	B	Grade: A – F
3D Visualization	A	D	B	C	D	A	Grade: A – F
Error Debugging	B	C	A	B	B	A	Grade: A – F
Placing and editing electrical objects (wire, ports, etc.)	B	C	C	B	B	A	Grade: A – F
Placing and editing graphical objects	C	C	B	B	B	B	Grade: A – F
3D visual	A	D	B	C	D	A	Grade: A – F
Defining other layers around footprint (silkscreen, keepout, solder mask, courtyard, etc.)	B	C	C	A	B	A	Grade: A – F
Overall PCB Library Editor	**B**	**C**	**C**	**B**	**B**	**A**	**Grade: A – F**
User Interface/Navigation	B	B	C	D	F	A	Grade: A – F

Figure 5.2: Design Programs comparison

5.2 Open or create a new project on Altium

1. From the Main Menu, select >File > New > Project >PCB Project.
2. Back to the File, select New > Schematic.
3. Back to the File again, select New > PCB.
4. To save your project, just right-click PCB Project 1 > Save Project as a File at anywhere at my computer and you can save the project in the right place with the name you want.

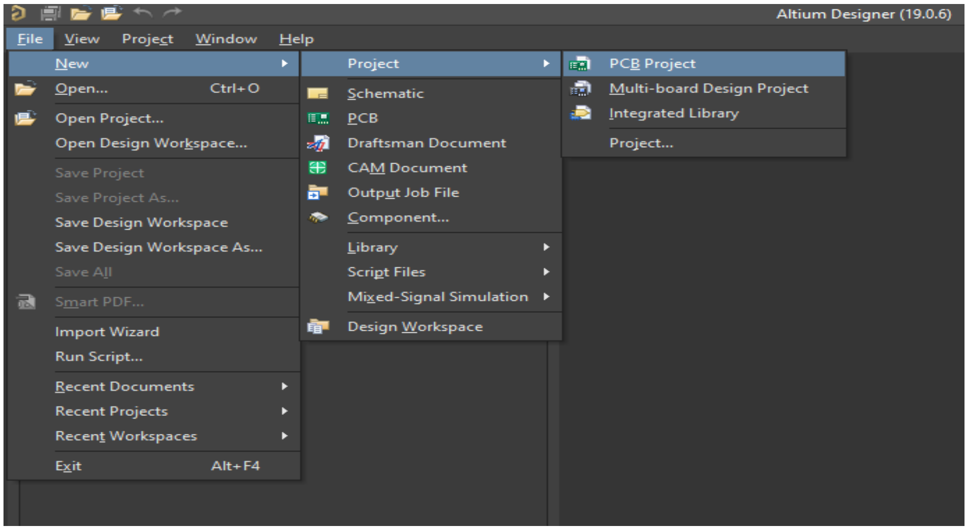


Figure 5.3: Create a new project

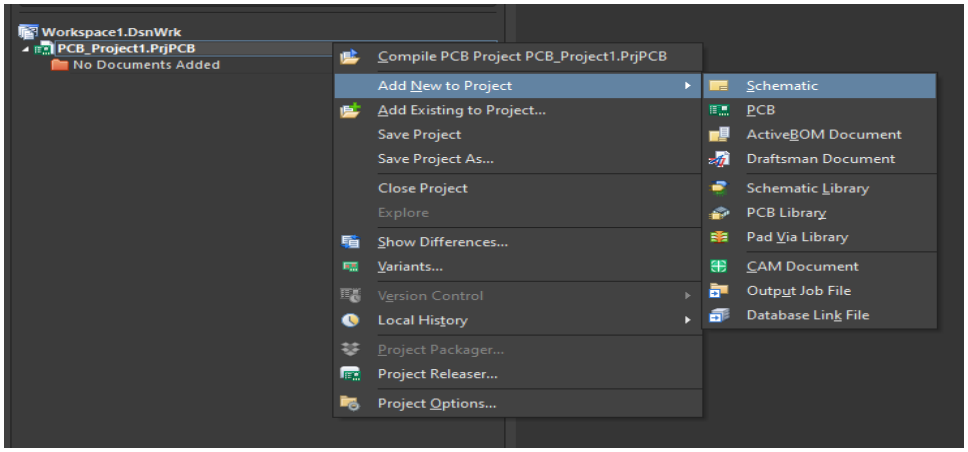


Figure 5.4: Add a new schematic

5.3 Schematic Design

1. Open the schematic file.
2. Create a schematic component
3. Add the schematic component to the schematic library
4. Click Libraries bar, select Libraries and you'll see the components you need in your design
5. To connect schematic to supplier. Copy part number from the supplier and paste in part search >Right click > add supplier link to …..

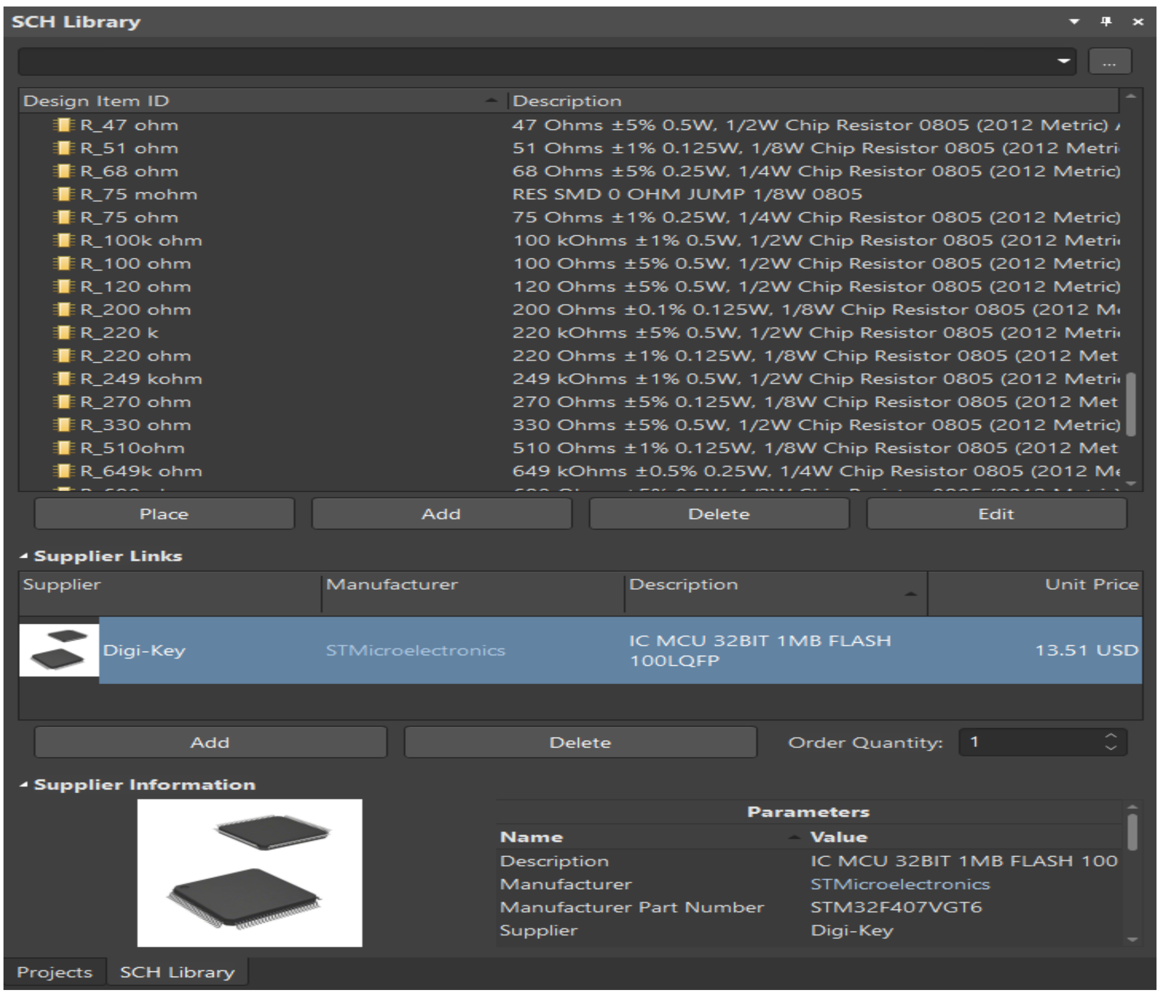
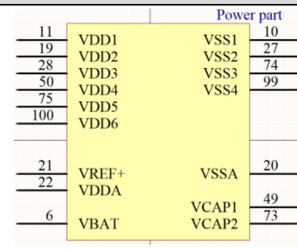
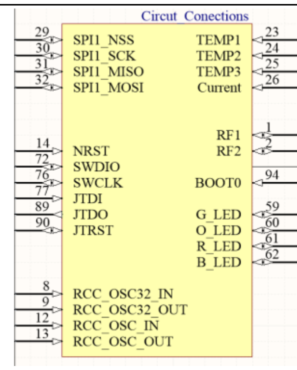
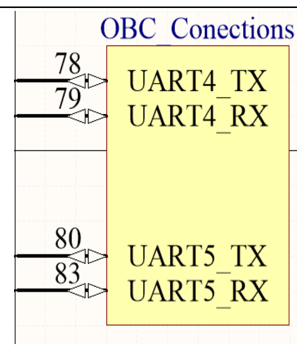
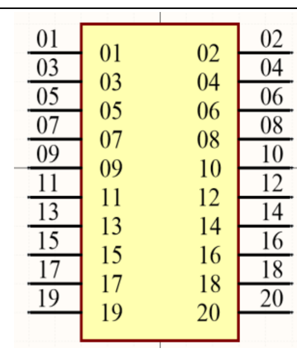
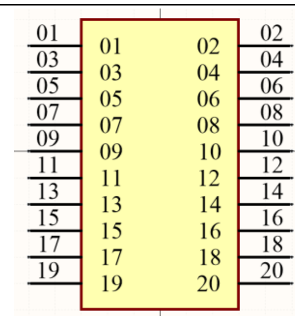
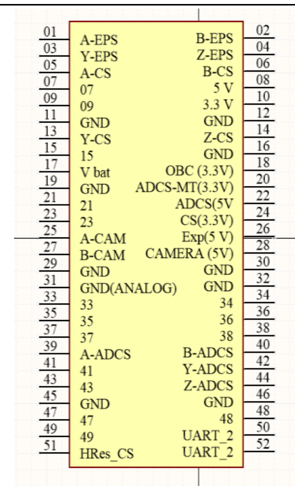
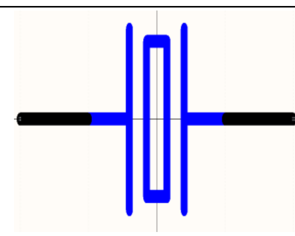
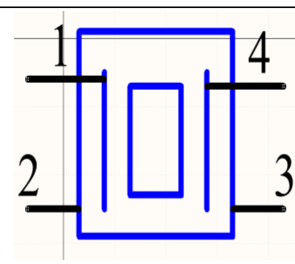
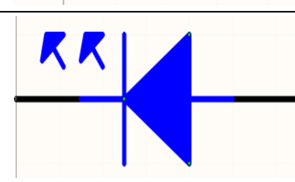


Figure 5.5: Schematic library and Supplier Links

5.4 Schematic Library

Component Name		Schematics Design
Microcontroller	Part 1	
	Part 2	
	Part 3	
RS Converter		

<table>
<tr><td colspan="2">JTAG</td><td>
</td></tr>
<tr><td colspan="2">PC-104</td><td>
</td></tr>
<tr><td rowspan="2">Crystal</td><td>8MHz
26MHz</td><td></td></tr>
<tr><td>32.768kHz</td><td>
</td></tr>
<tr><td colspan="2">Led</td><td></td></tr>
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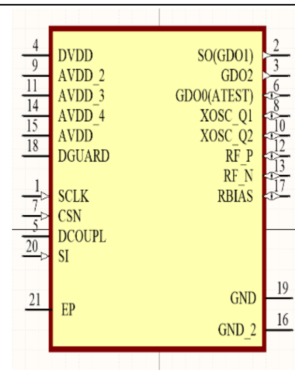
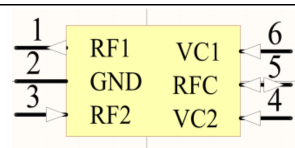
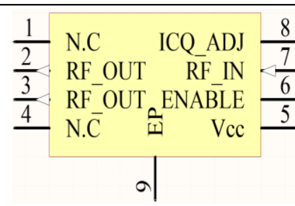
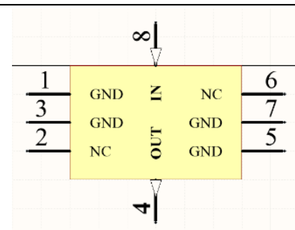
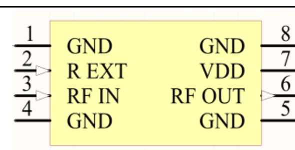
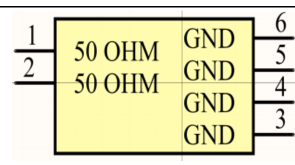
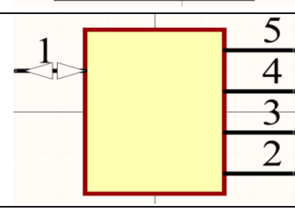
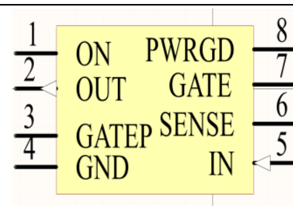
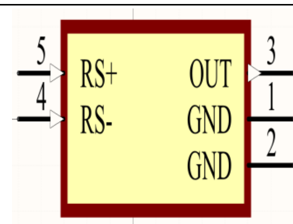
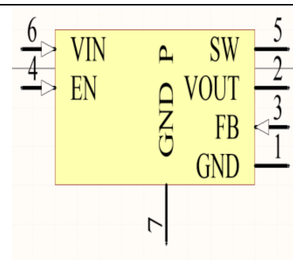
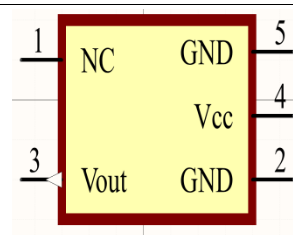
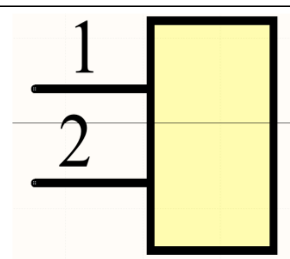
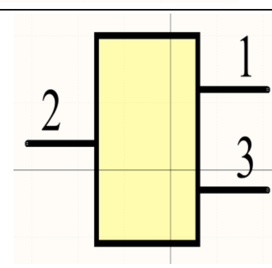
Transceiver	
RF Switch	
High Power Amplifier	
Low Pass Filter	
low Noise Amplifier	
Band Pass filter	
Antenna Connector	

Current Protection		
Current Sensor		
Booster Converter		
Temperature Sensor		
Jumper	2-Pins	
	3-Pins	

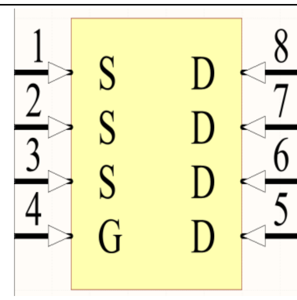
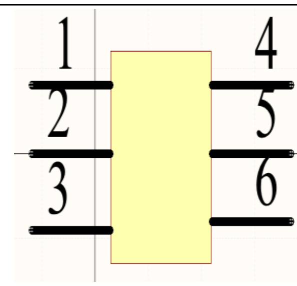
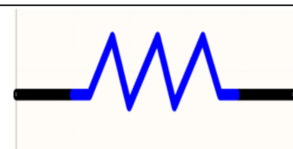
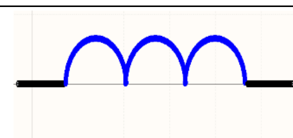
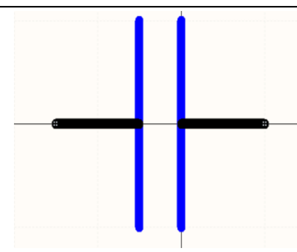
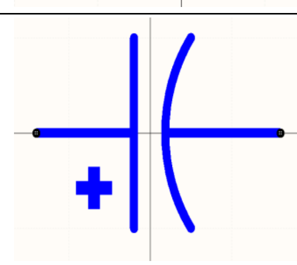
Transistor MOSTET		
Pushbutton Switch		
Resistor		
Coil		
Capacitor	Nonpolar	
	polar	

Table 5.1: Schematic Library

5.5 Schematic Sheets

1. Create schematic sheet
2. Import all schematic components to the schematic sheet
3. Create 3 schematics sheets (Micro, Power, RF)
4. We connect 3 sheets with (Top sheet)

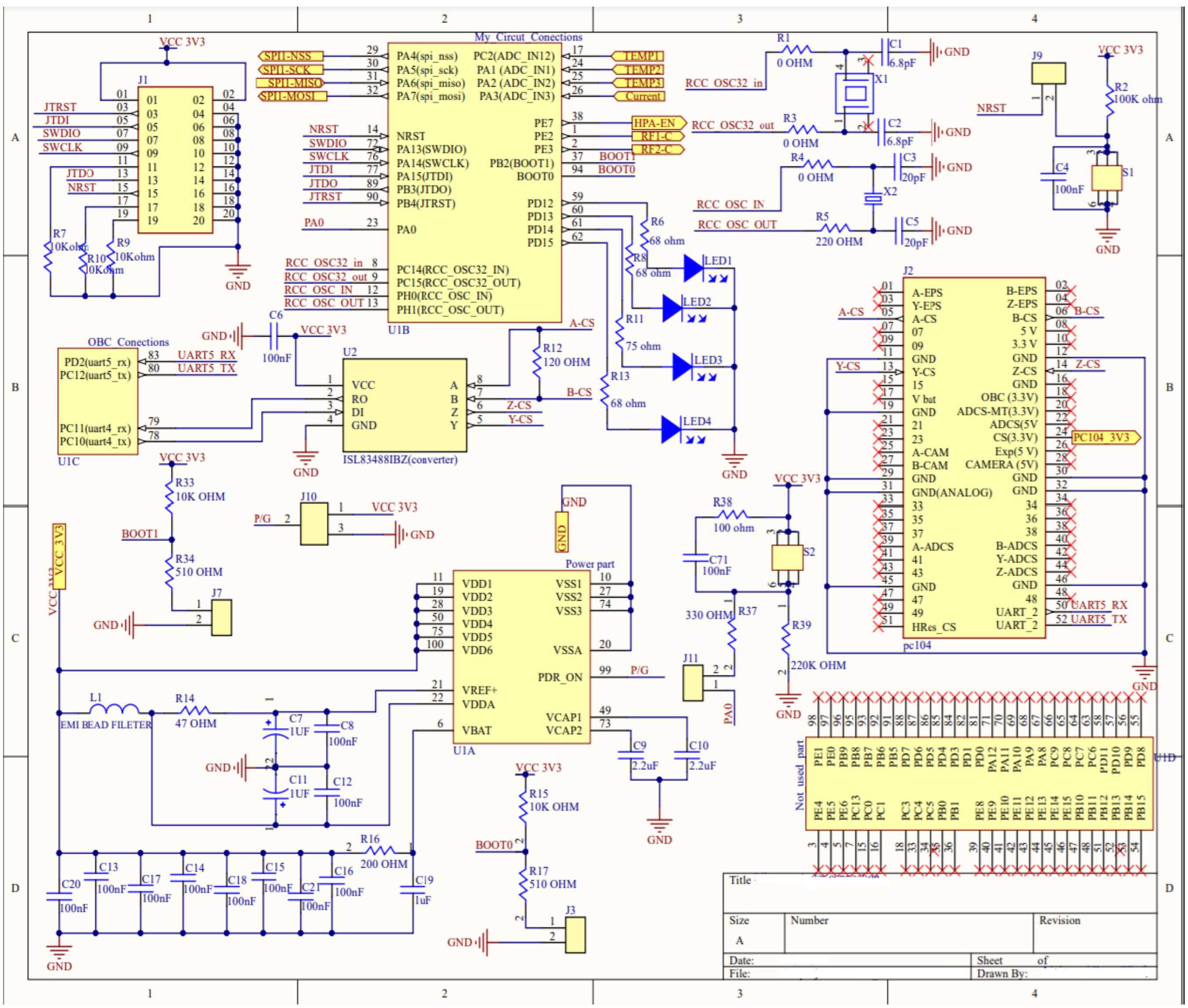


Figure 5.6: Microcontroller connection sheet

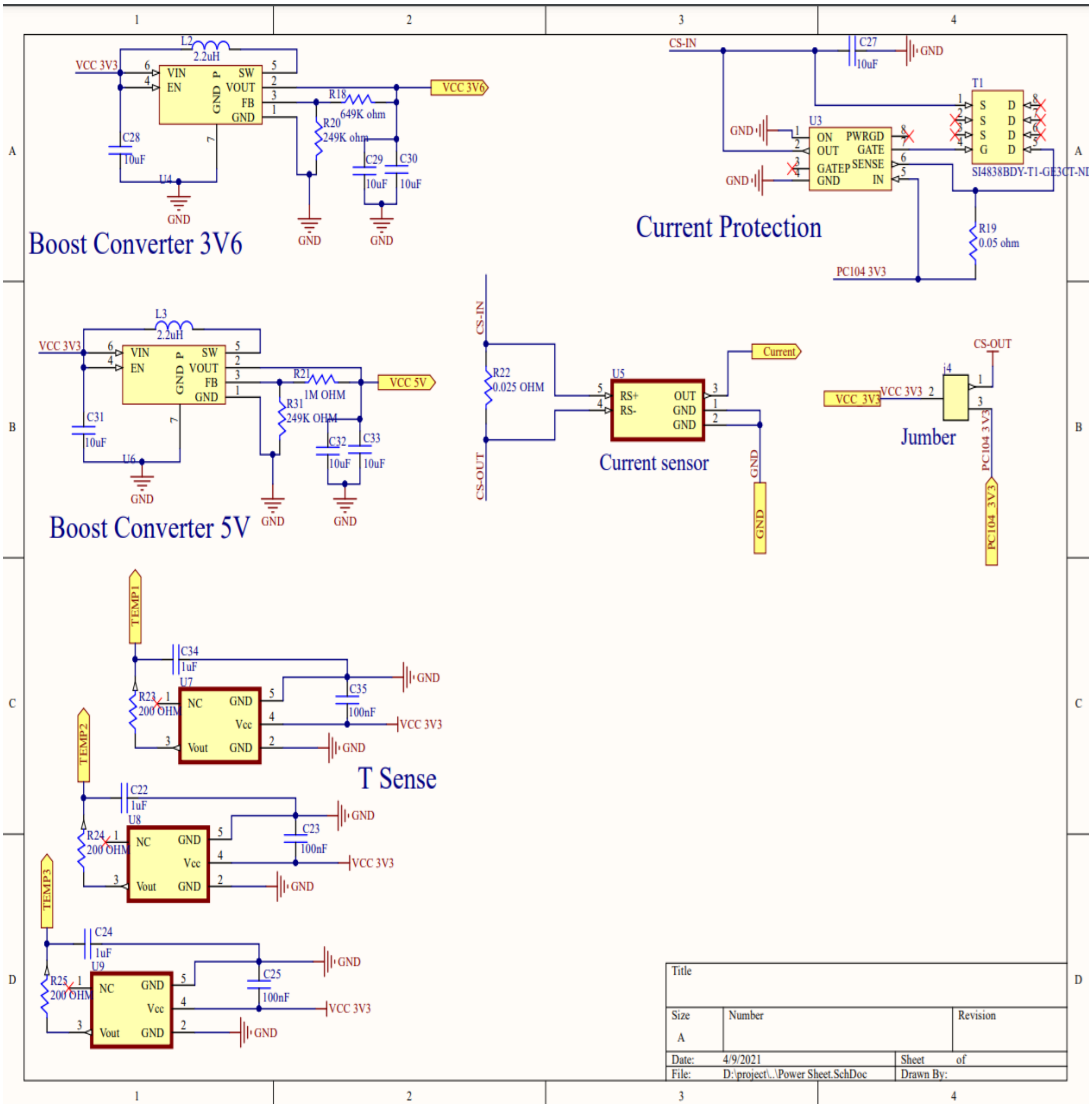


Figure 5.7: Power Sheet

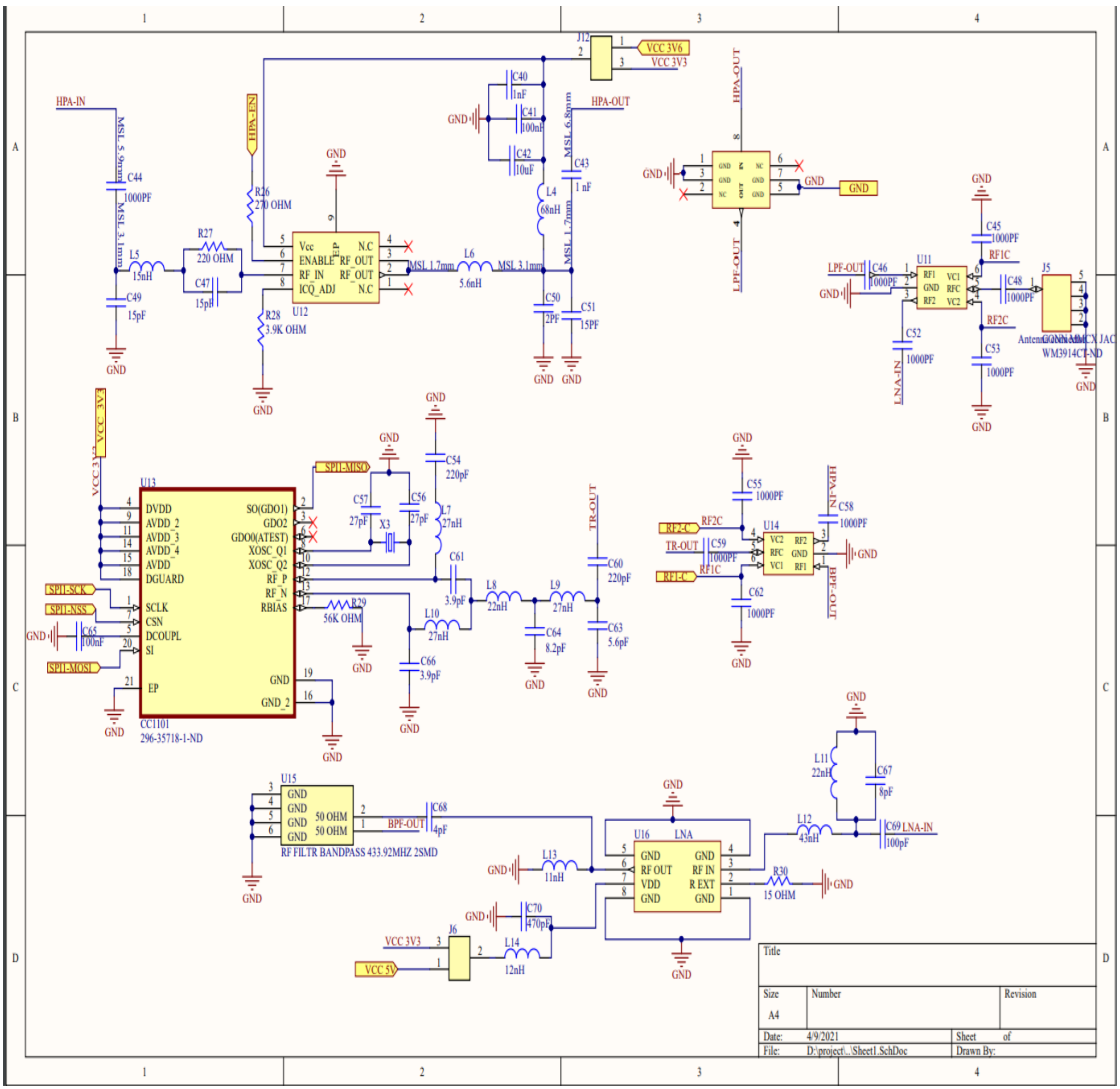


Figure 5.8: RF Sheet

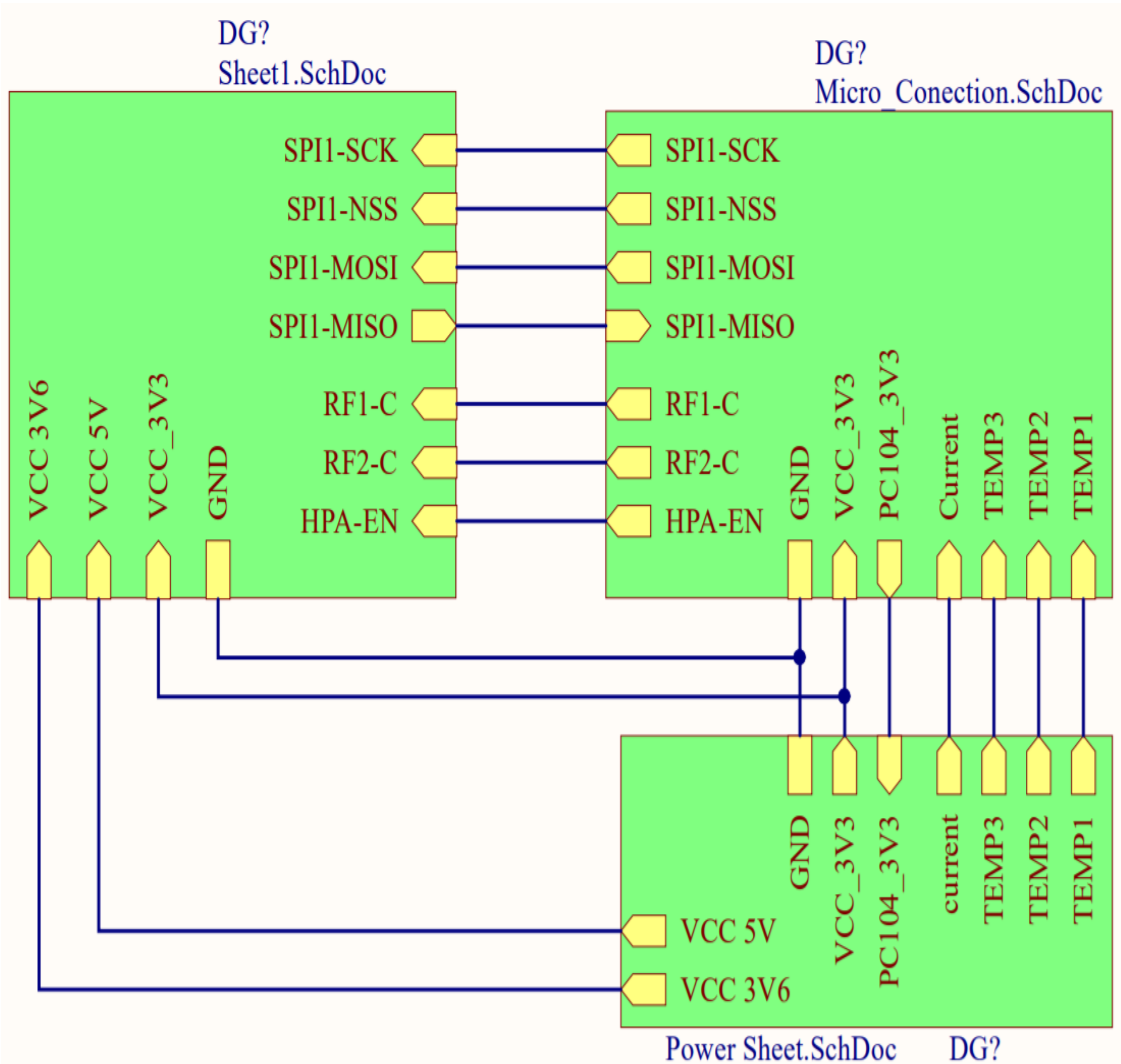


Figure 5.9: Top Sheet

5.6 Footprint Design

1. We get footprint dimensions from the datasheet for each component
3. To import 3D file Place > 3D body > generic > get step file
4. To show the component in the 3D press on the component then press 3 from your keyboard
5. To connect schematic into footprint view. Back to the schematic, double click any component, in the Models, select Footprint, and then add.

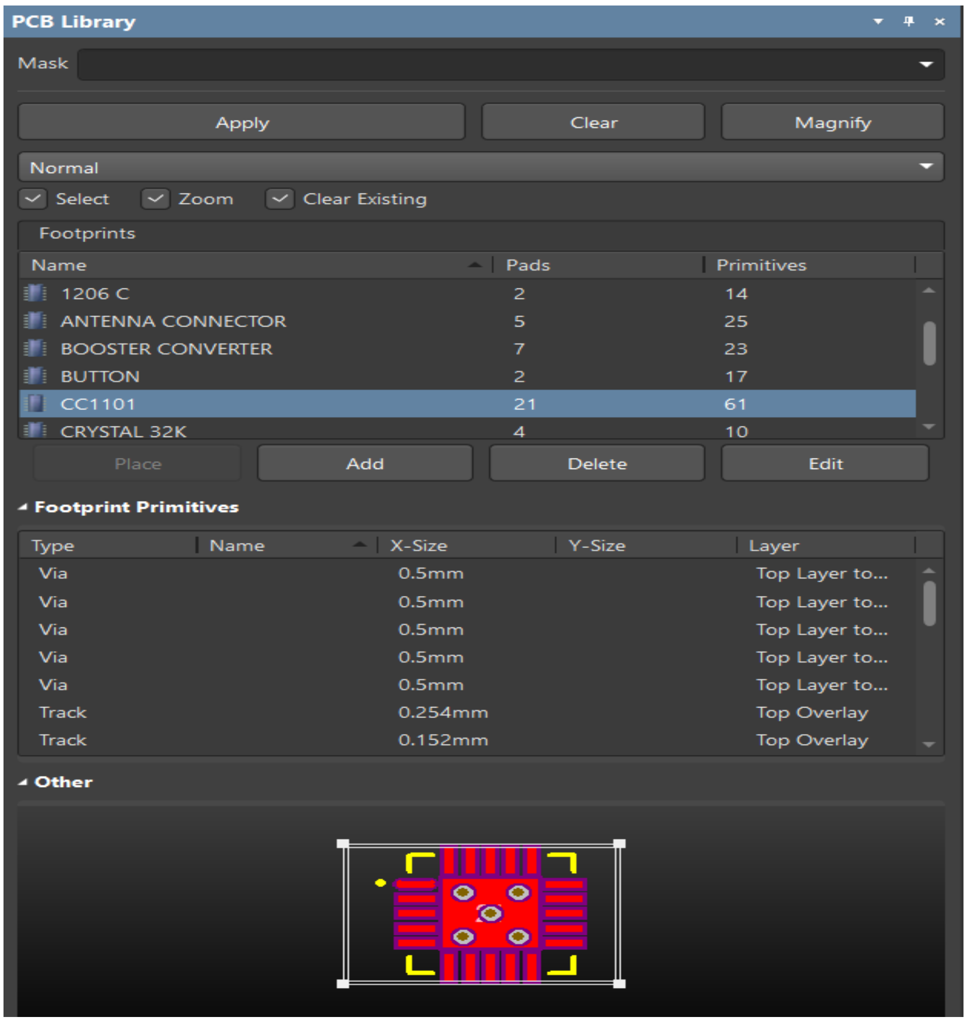
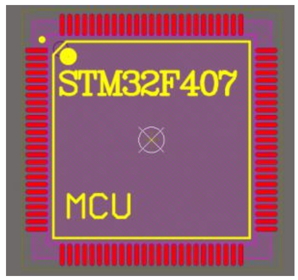
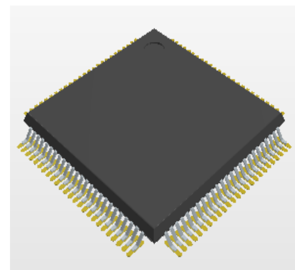
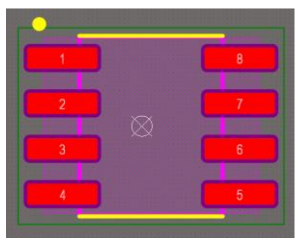
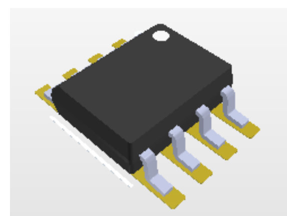
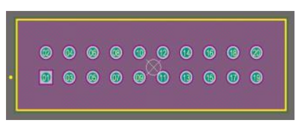
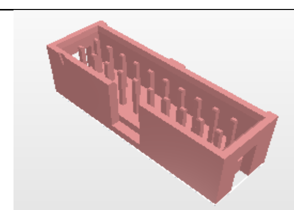
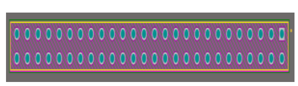
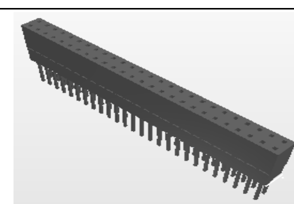
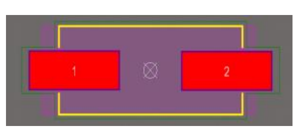
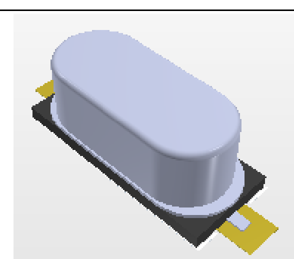


Figure 5.10: PCB Library

5.7 PCB Library

<table>
<tr><th colspan="2">Component Name</th><th>Footprint</th><th>Three-dimensional</th></tr>
<tr><td colspan="2">Microcontroller</td><td>
</td><td></td></tr>
<tr><td colspan="2">RS Converter</td><td>
</td><td></td></tr>
<tr><td colspan="2">JTAG</td><td></td><td></td></tr>
<tr><td colspan="2">PC-104</td><td></td><td></td></tr>
<tr><td>Crystal</td><td>8MHz</td><td></td><td></td></tr>
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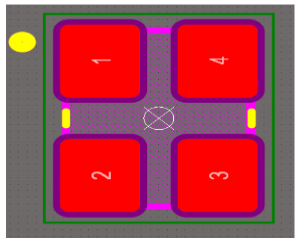
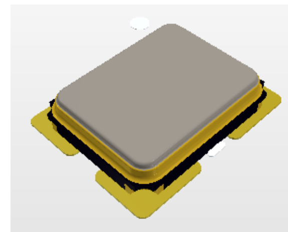
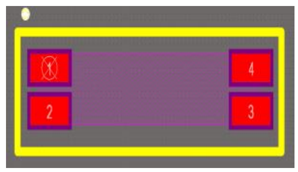
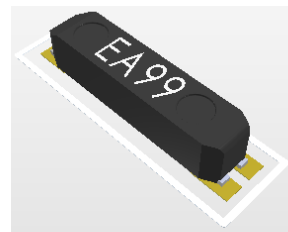
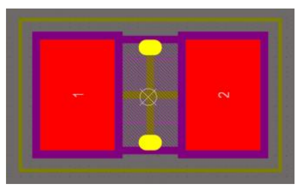
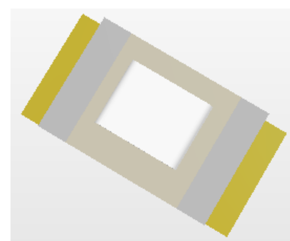
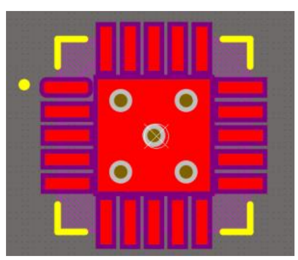
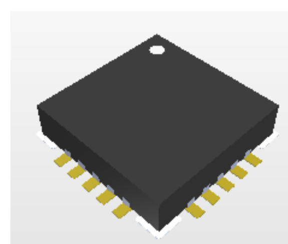
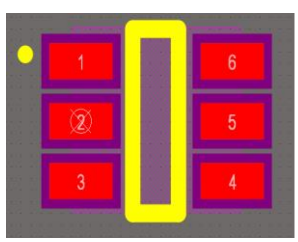
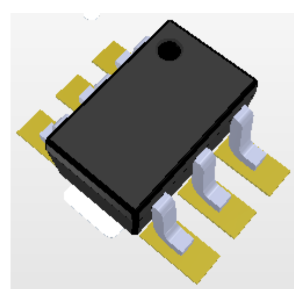
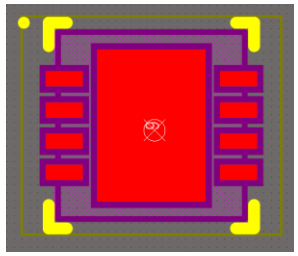
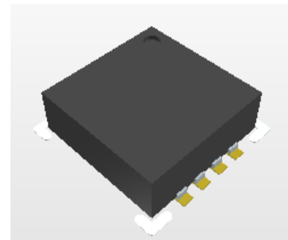
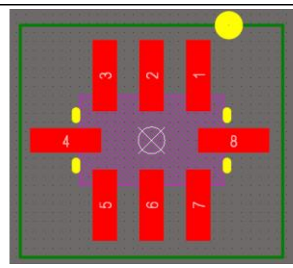
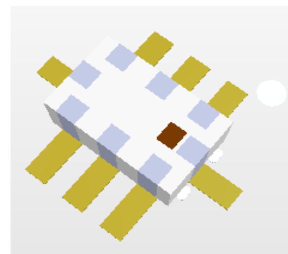
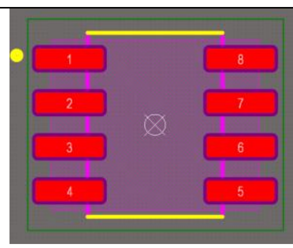
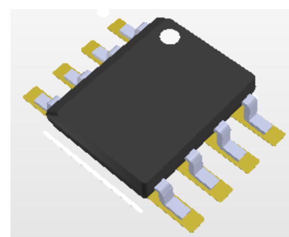
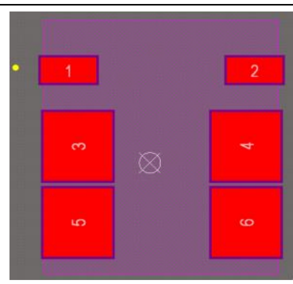
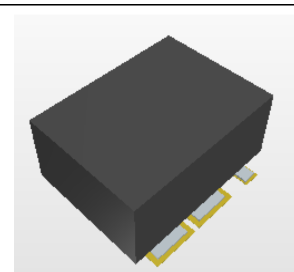
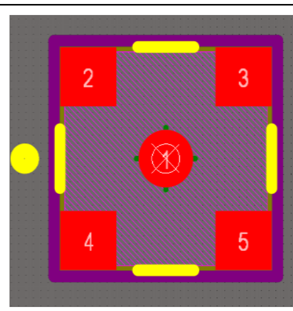
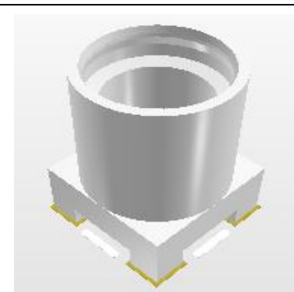
Crystal	26MHz		
	32.768kHz		
LED			
Transceiver			
RF Switch			

High Power Amplifier		
Low Pass Filter		
low Noise Amplifier		
Band Pass filter		
Antenna Connector		

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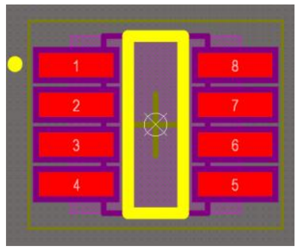
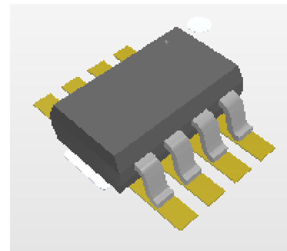
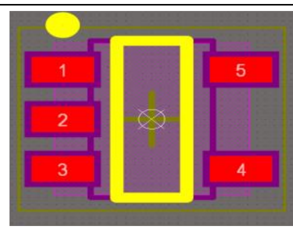
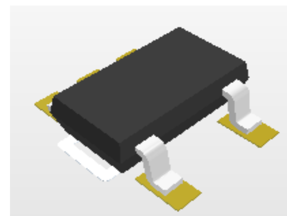
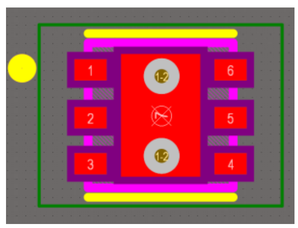
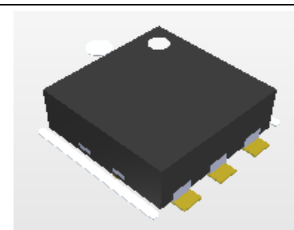
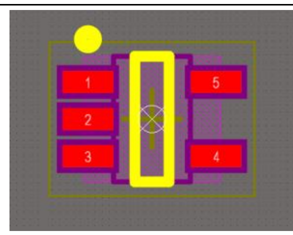
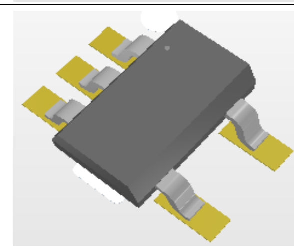
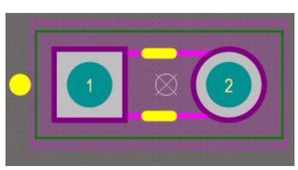
<tr><td colspan="2">Current Protection</td><td>
</td><td></td></tr>
<tr><td colspan="2">Current Sensor</td><td>
</td><td></td></tr>
<tr><td colspan="2">Booster Converter</td><td>
</td><td></td></tr>
<tr><td colspan="2">Temperature Sensor</td><td>
</td><td></td></tr>
<tr><td rowspan="2">Jumper</td><td>2-Pins</td><td>
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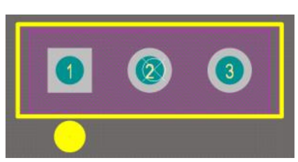
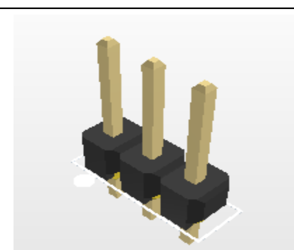
<tr><td>3-Pins</td><td>
</td><td></td></tr>
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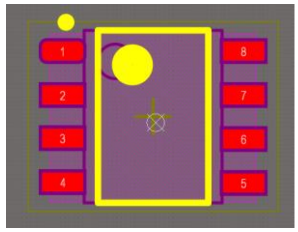
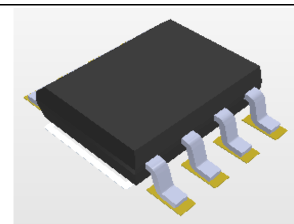
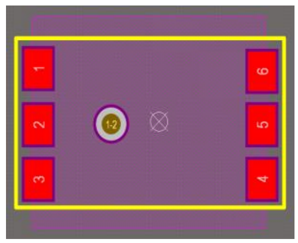
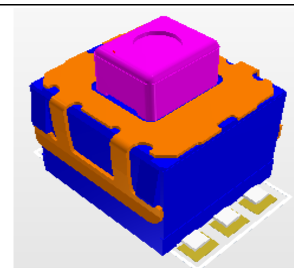
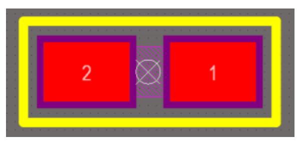
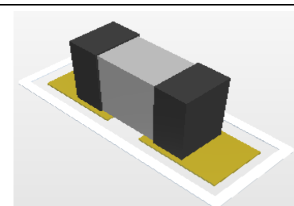
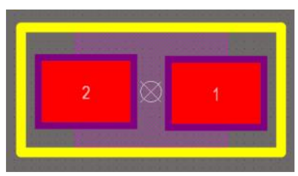
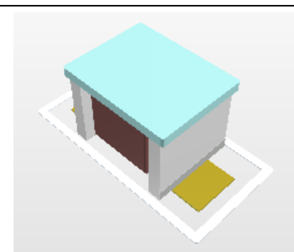
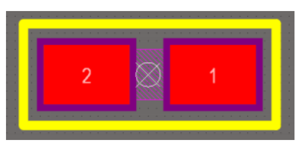
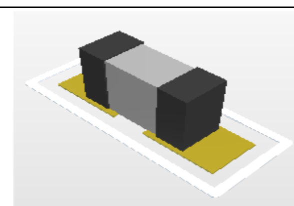
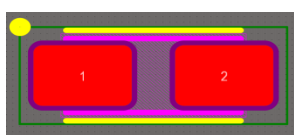
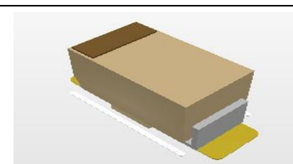
Transistor MOSTET			
Pushbutton Switch			
Resistor			
Coil			
Capacitor	Nonpolar		
	polar		

Table 5.2: PCB Library

5.8 Introduction to PCB:

Breadboards are great for prototyping circuits, but they aren't so good for actually using the thing you're building. At some point, you'll probably want to make a project more permanent. The best way to do that is to put it on a PCB.

PCB stands for printed circuit board and aims to bring electronic circuits to life in physical form. Using layout software, the PCB design process combines component placement and routing to define electrical connectivity on a manufactured circuit board.

Before designing the PCB, it's a good idea to make a schematic design of your circuit. The schematic will serve as a blueprint for laying out the traces and placing the components on the PCB. Plus, the PCB editing software can import all of the components, footprints, and wires into the PCB file, which will make the design process easier.

First, we divide the circuit into three main sections according to their functions, as explained earlier in the Schematic section

- Power sheet
- RF sheet and
- Microcontroller sheet.

Power sheet, RF sheet and, microcontroller sheet. It might help to draw some diagrams at this point to help you visualize the design before you start laying it out.

Trying keep the components in each section grouped together in the same area of the PCB to keep the conductive traces short. Long traces can pick up electromagnetic radiation from other sources, which can cause interference and noise.

The different sections of your circuit should be arranged so the path of electrical current is as linear as possible. The signals in the circuit should flow in a direct path from one section to another, which will keep the traces shorter.

Each section of the circuit should be supplied power with separate traces of equal length. This is called a star configuration, and it ensures that each section gets an equal supply voltage.

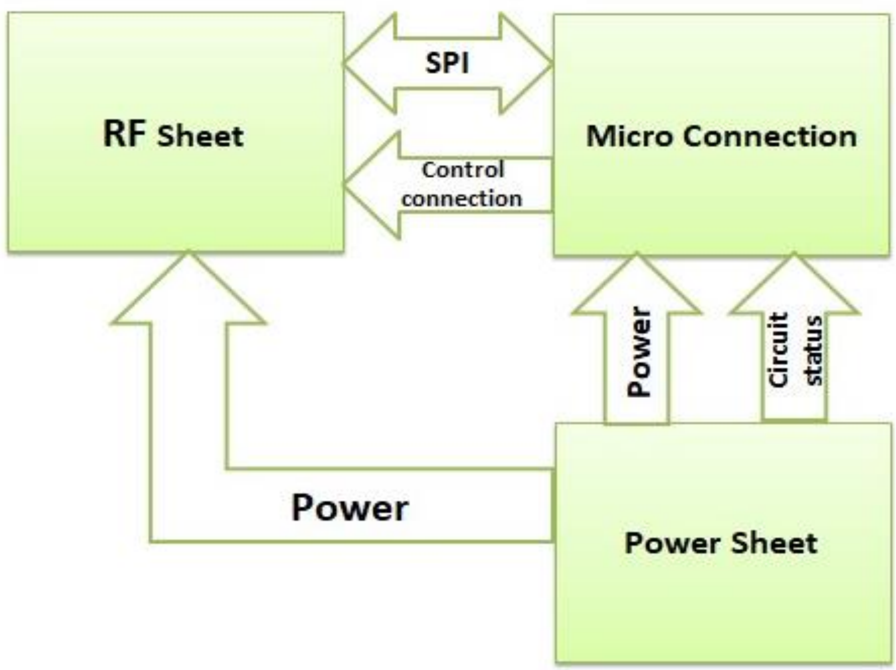


Figure 5.11: Top sheet block diagram

5.9 PCB Layers:

Larger circuits can be difficult to design on a single-layer PCB because it’s hard to route the traces without intersecting one another. The traces on one layer can be connected to the other layer with via.

Via is a copper-plated hole in the PCB that electrically connects the top layer to the bottom layer. You can also connect top and bottom traces at a component through the hole.

Multi-Layer PCB

Multi-Layer PCB have more layer than double side PCB, it has many circuit layer between Topside and Bottom side of PCB and also each layer can connect with via PTH (Plated Through Hole).

The minimum configuration that can be used is 4- or 6-layers stack-up. The PCB is made of FR4 material and has four layers, top layer, ground layer, power layer and bottom layer.

The top signal layer holds all the components and RF transmission lines while the signal lines are evenly distributed on the top and bottom signal layers. The ground layer is situated below the top signal layer where it is easily accessible for ground vias. The power layer is used to freely distribute power to the various3.

In our circuit, we use layer top and bottom layer for my connection -signal layers- and one layer for the ground GND and another for the power VCC

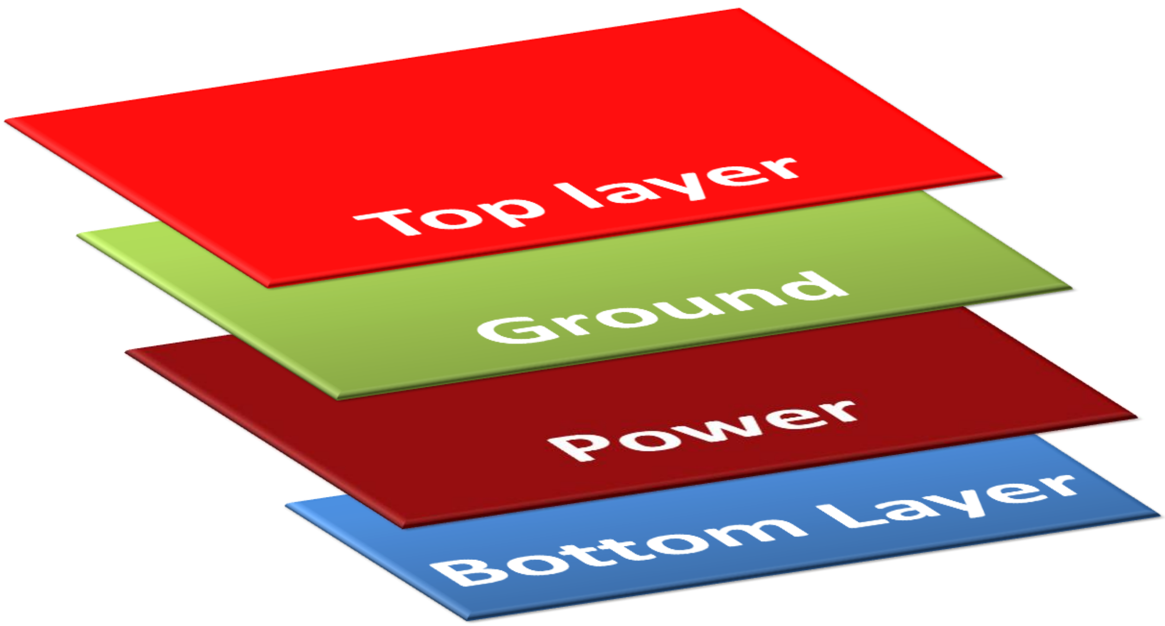
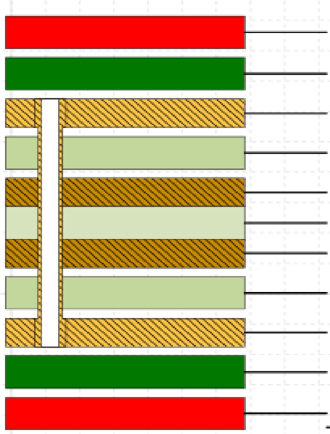


Figure 5.12: For layer PCB stack



Layer Stack Legend

Material	Layer	Thickness	Dielectric Material	Type	Gerber
	Top Overlay			Legend	GTO
Surface Material	Top Solder	0.01mm	Solder Resist	Solder Mask	GTS
Copper	Top Layer	0.04mm		Signal	GTL
Prepreg		*0.17mm*	*FR-4*	*Dielectric*	
Copper	Ground	0.02mm		Internal Plane	GP1
Core		*1.19mm*	*FR-4*	*Dielectric*	
Copper	Power	0.02mm		Internal Plane	GP2
Prepreg		*0.17mm*	*FR-4*	*Dielectric*	
Copper	Bottom Layer	0.04mm		Signal	GBL
Surface Material	Bottom Solder	0.01mm	Solder Resist	Solder Mask	GBS
	Bottom Overlay			Legend	GBO

Total thickness: 1.66mm

Figure 5.13: layer stack of our circuit

5.10 User interfaces

The pc-104 is fixed for all subsystems so we need to put it in same orientations on the circuit to make the connections between the other subsystems and pcb should have specific dimensions.

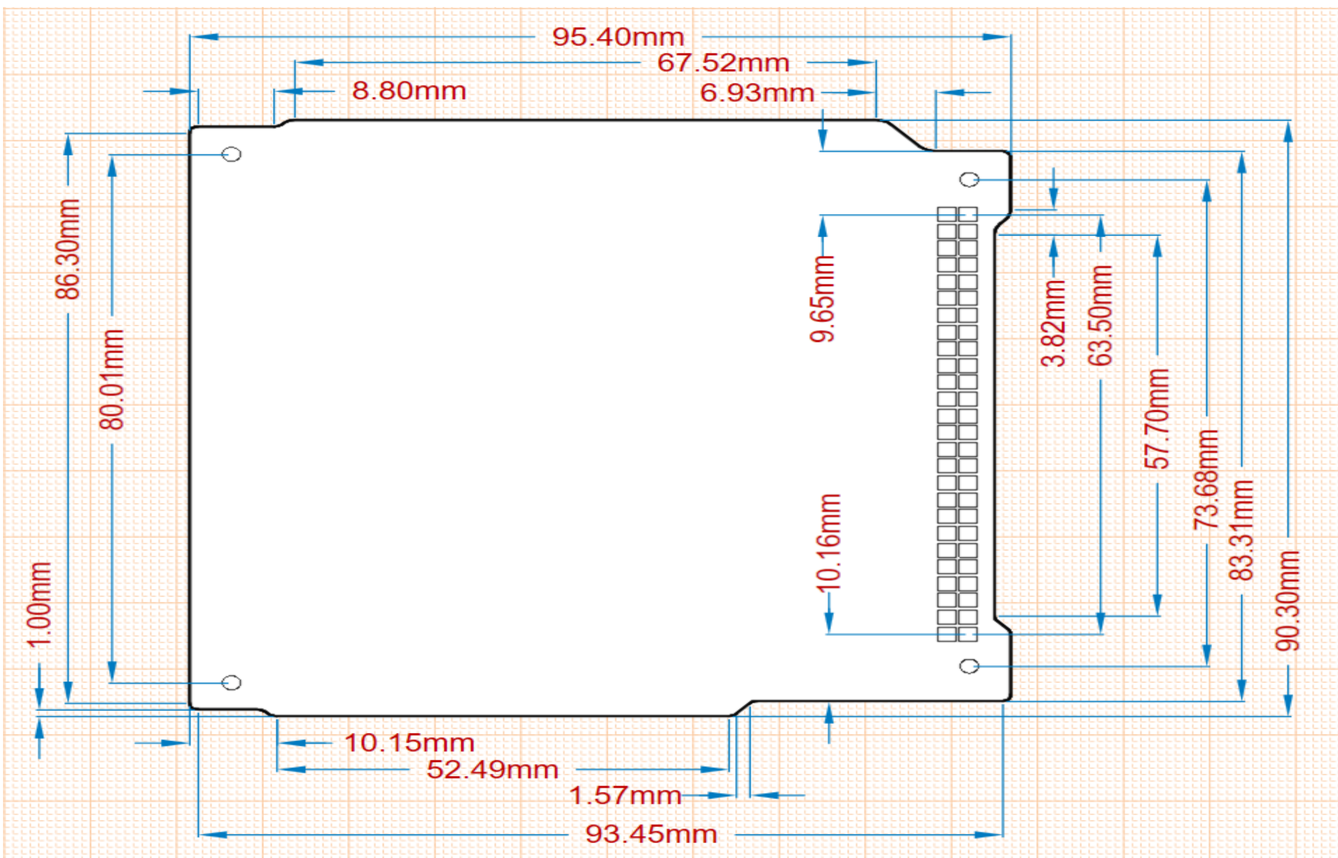


Figure 5.14: PCB dimensions

The microcontroller should be near to the pc-104 to make the RS connections shortest as possible

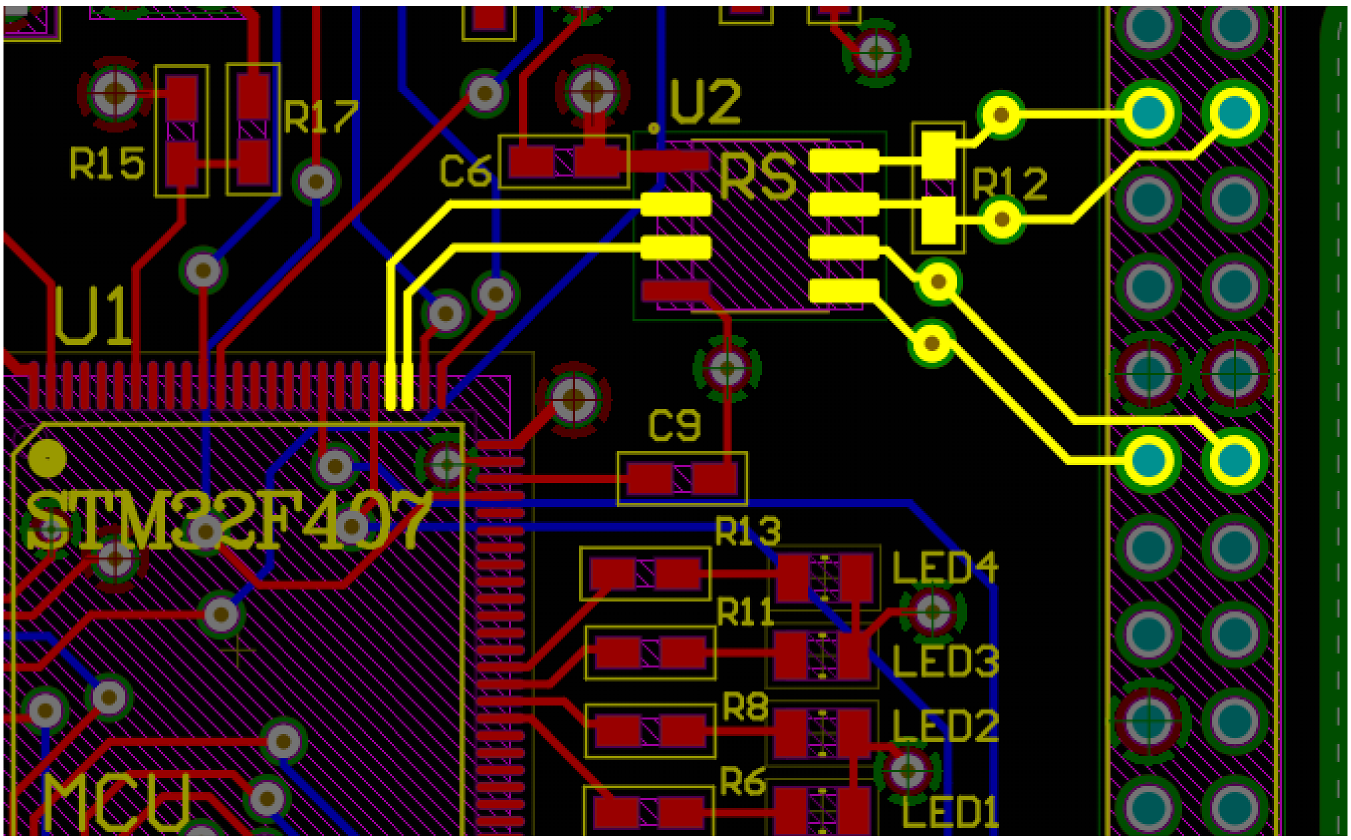


Figure 5.15: RS connections

The JTAG should be near as possible to the microcontroller to make the JTAG connections shortest as possible:

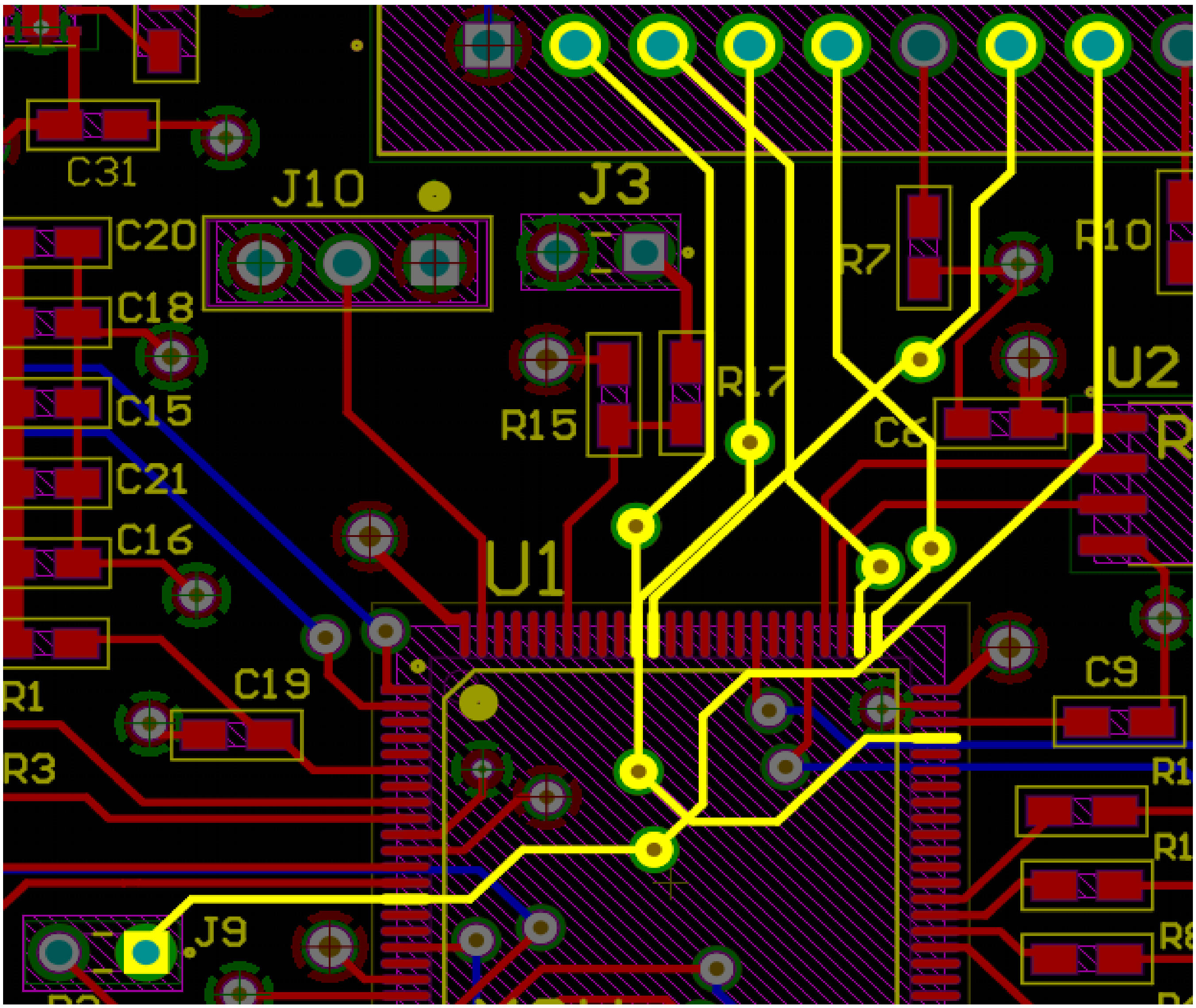


Figure 5.16: JTAG connections in PCB

The transceiver should be near to the microcontroller for make the SPI connections shortest as possible:

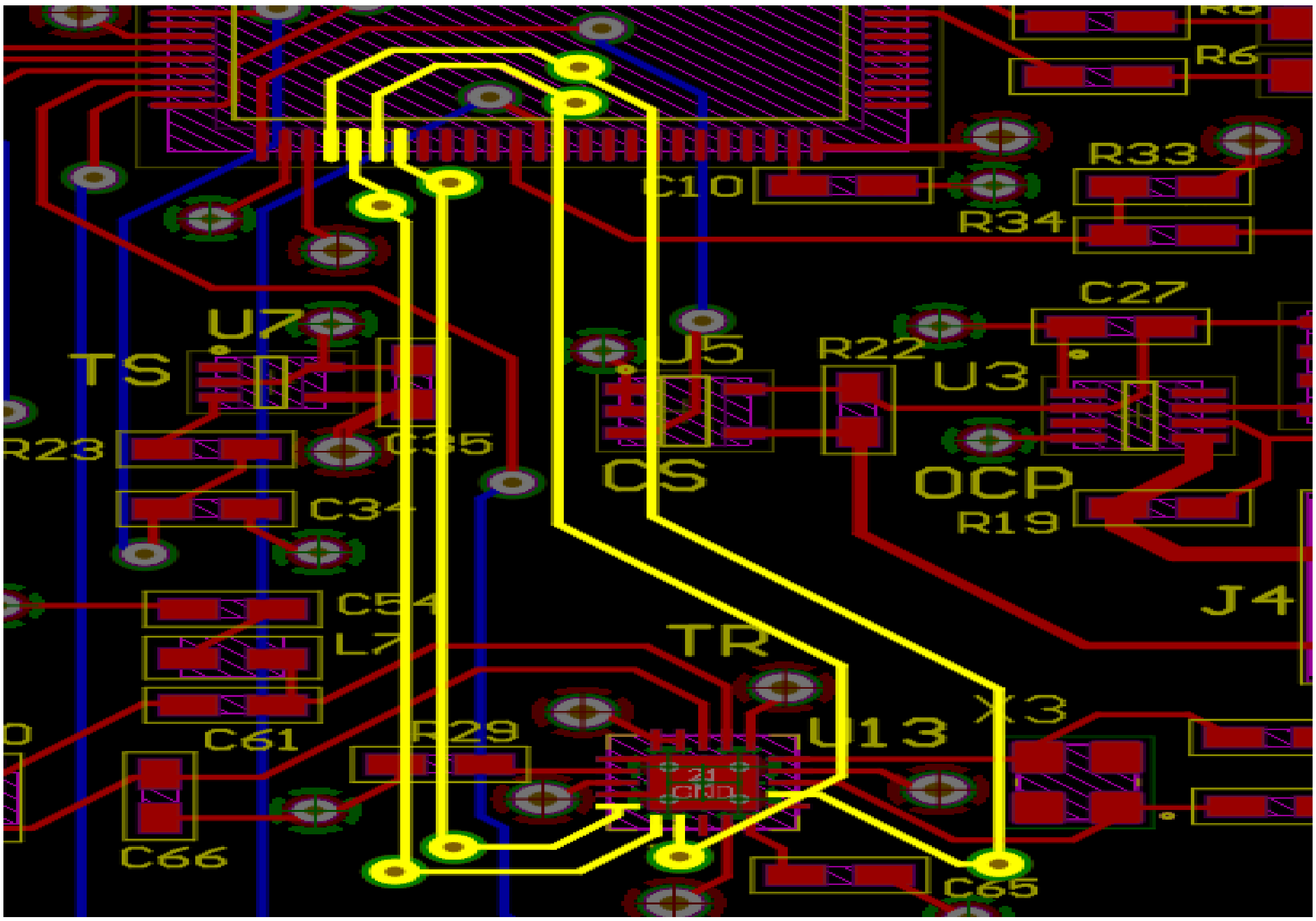


Figure 5.17: SPI connections

High power amplifier should be in isolated place from the entire component to avoid the thermal noise on the other component:

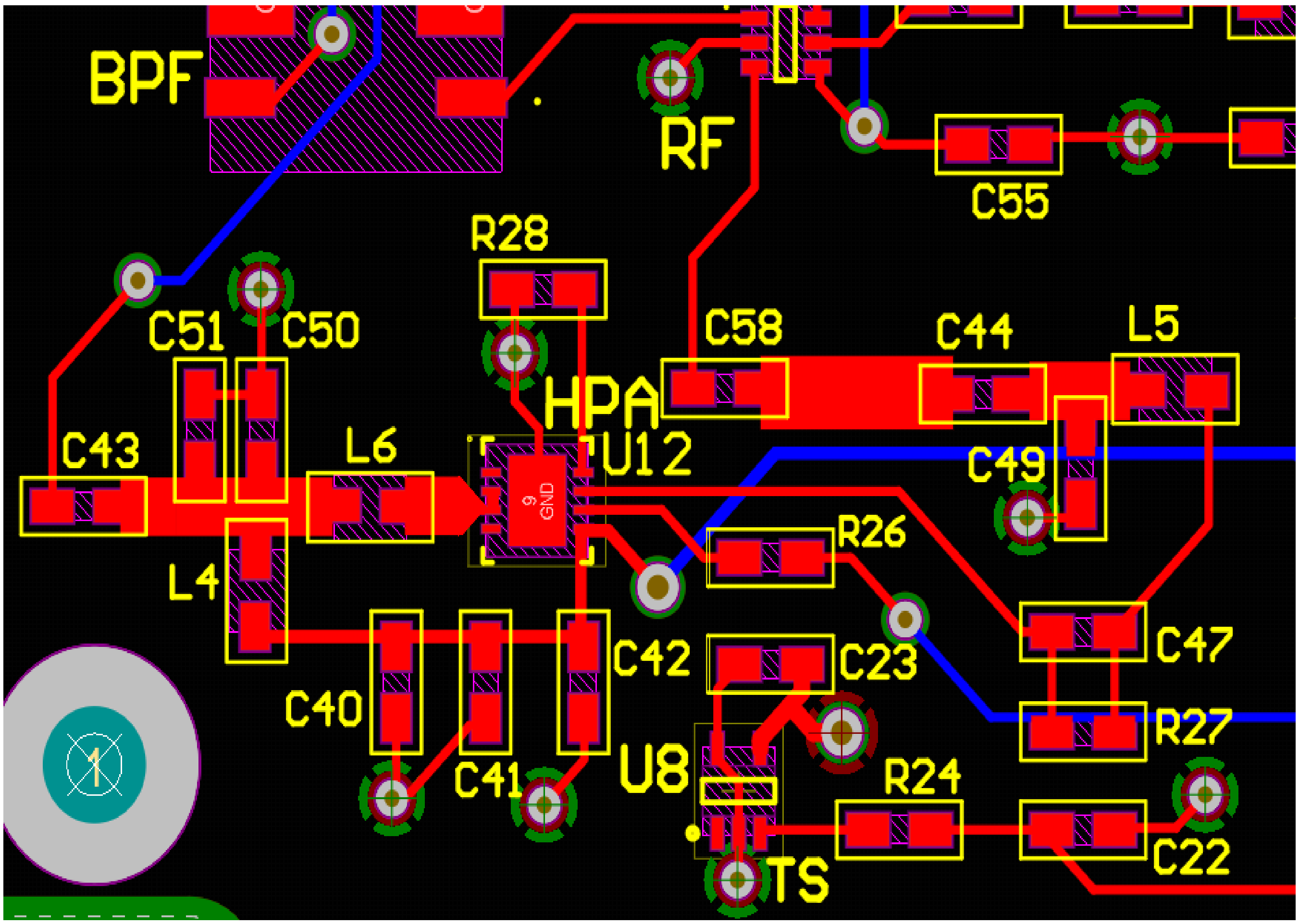


Figure 5.18: HPA Place

Antenna connector also should be in isolated place to avoid and noise from another component

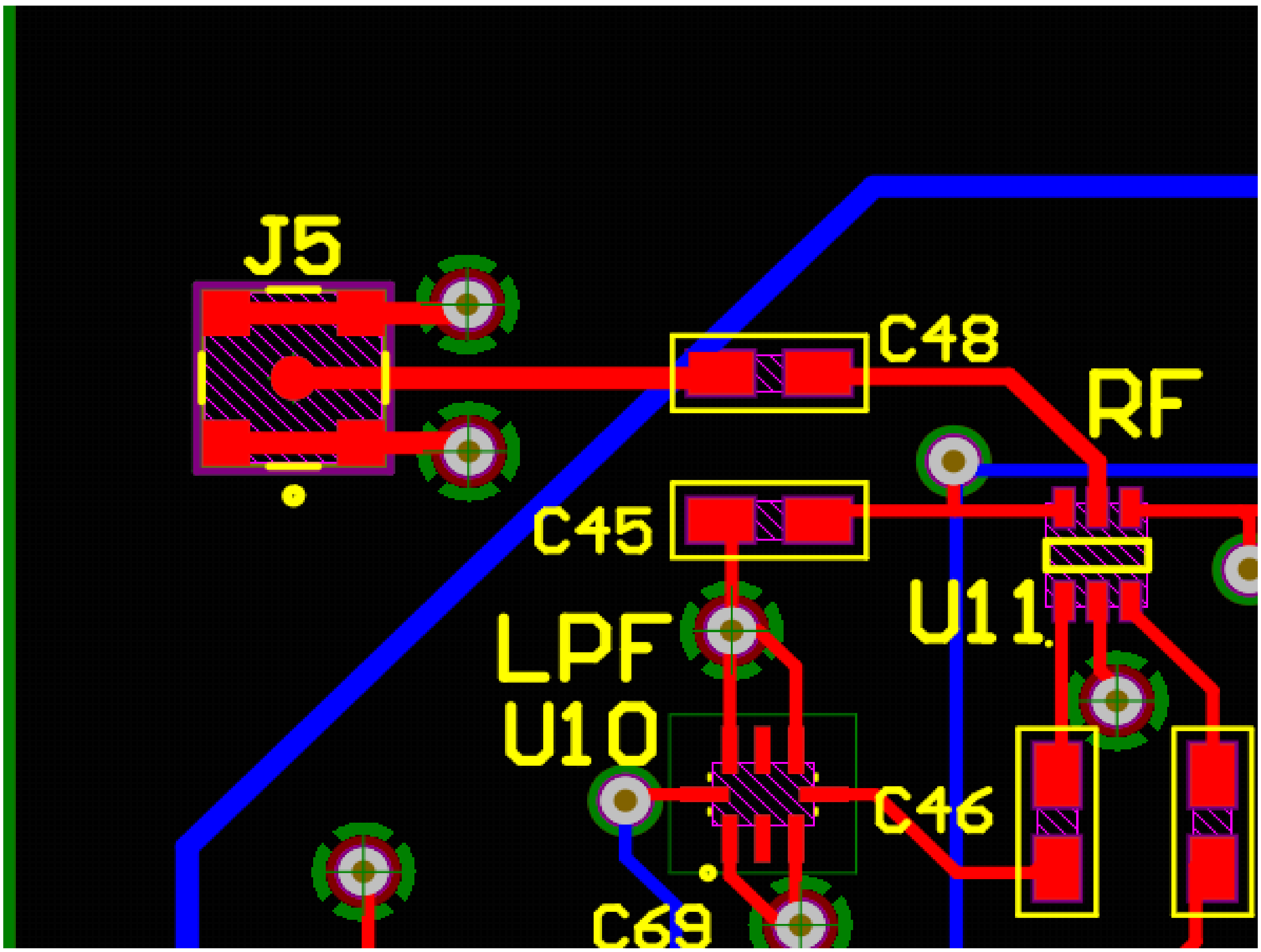


Figure 5.19: Antenna connector place

Make the power track bigger than signal track to avoid any damage:

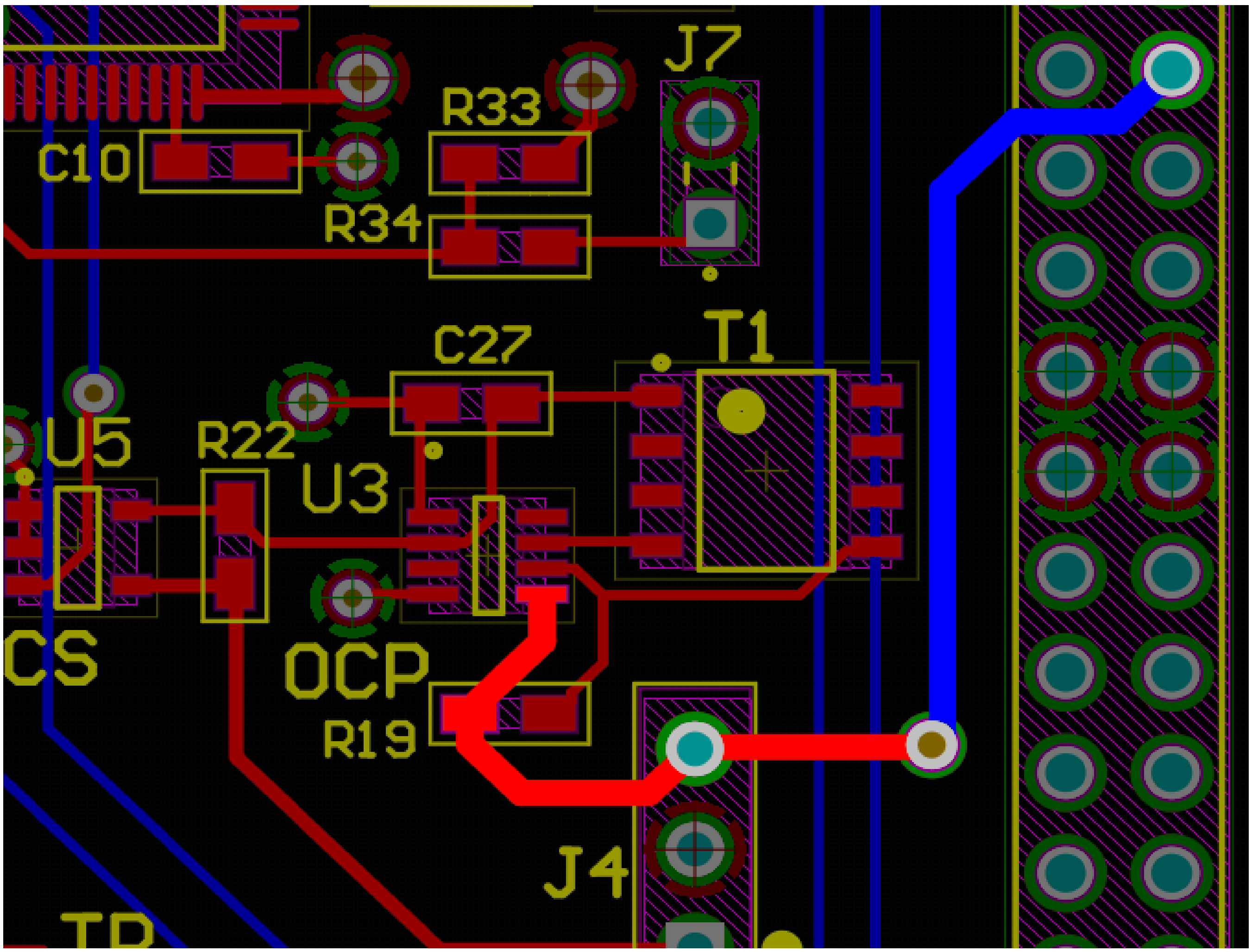


Figure 5.20: Power Tracks

Make polygon and connect it to ground to avoid any additional noise

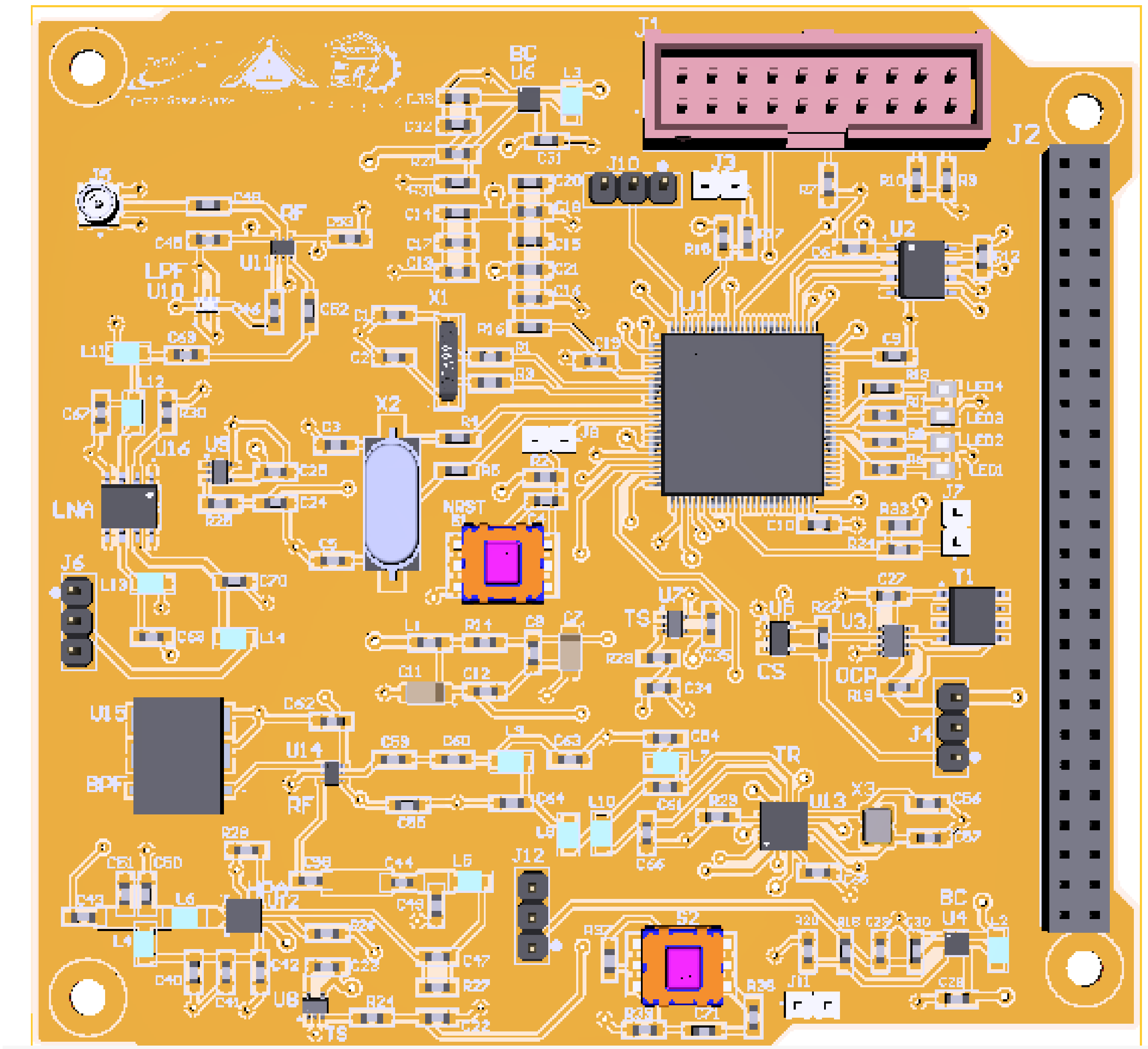
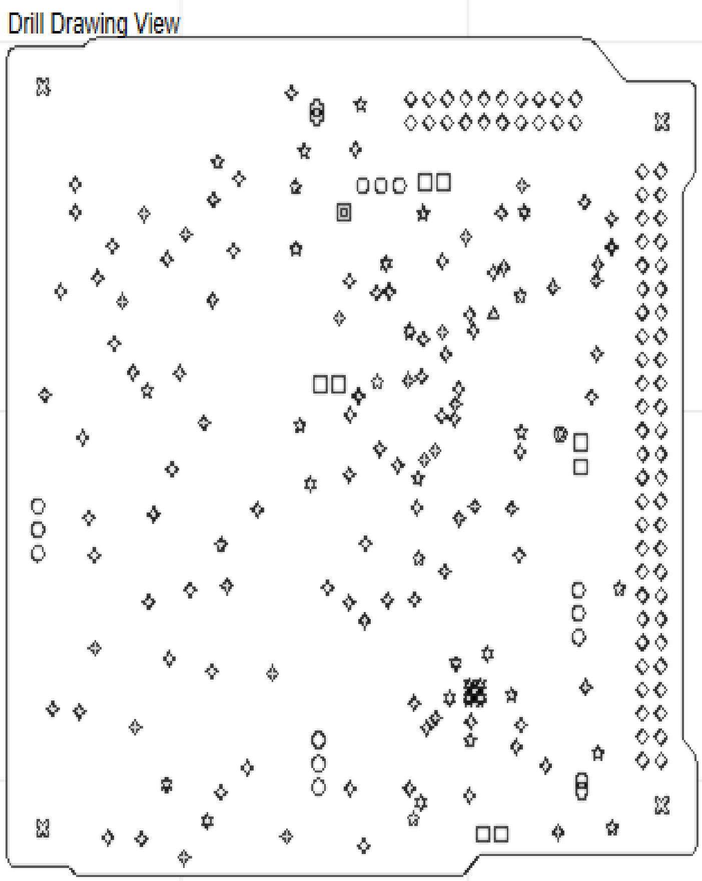


Figure 5.21: Polygon and top view of PCB

Drilling places of the PCB



Drill Table

Symbol	Count	Hole Size	Plated	Hole Tolerance
	8	0.84	Plated	None
	12	0.91	Plated	None
	72	1.02	Plated	None
	4	3.18	Non-Plated	None
	4	0.20	Plated	None
	104	0.50	Plated	None
	20	0.71	Plated	None
	9	0.70	Plated	None
	6	0.30	Plated	None
	1	0.40	Plated	None
	1	0.60	Plated	None
	1	0.71	Plated	None

1 Text element with square border.

2. Text element with no border

3 Text element with circle border

4. Text element with no border

5. Text element with no border

6. Text element with no border

7. Text element with no border

Figure 5.22: Drilling Places on PCB

Deferent views of PCB

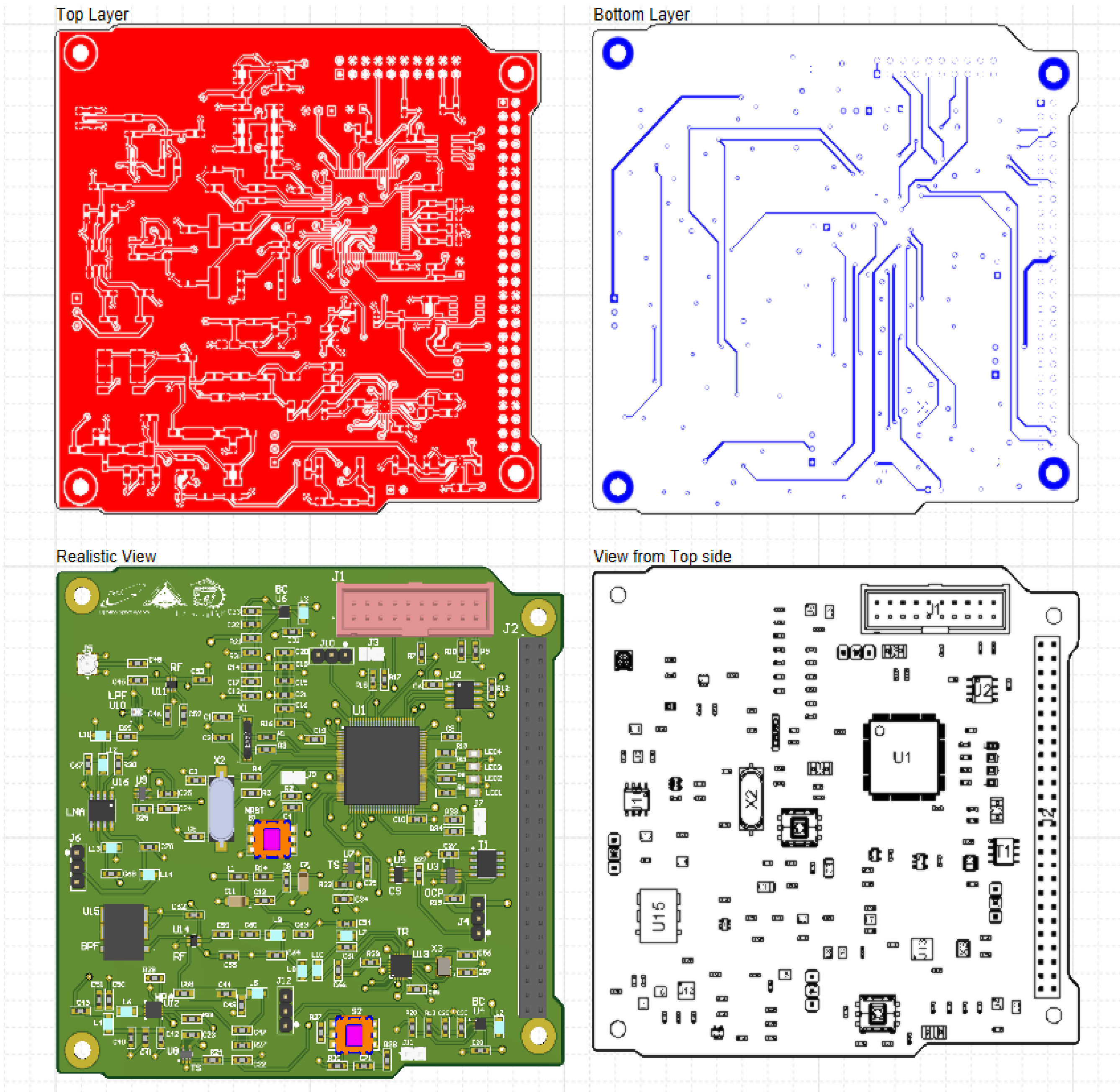


Figure 5.23: Different views of the PCB

5.11 Final Design

Final design which manufactured

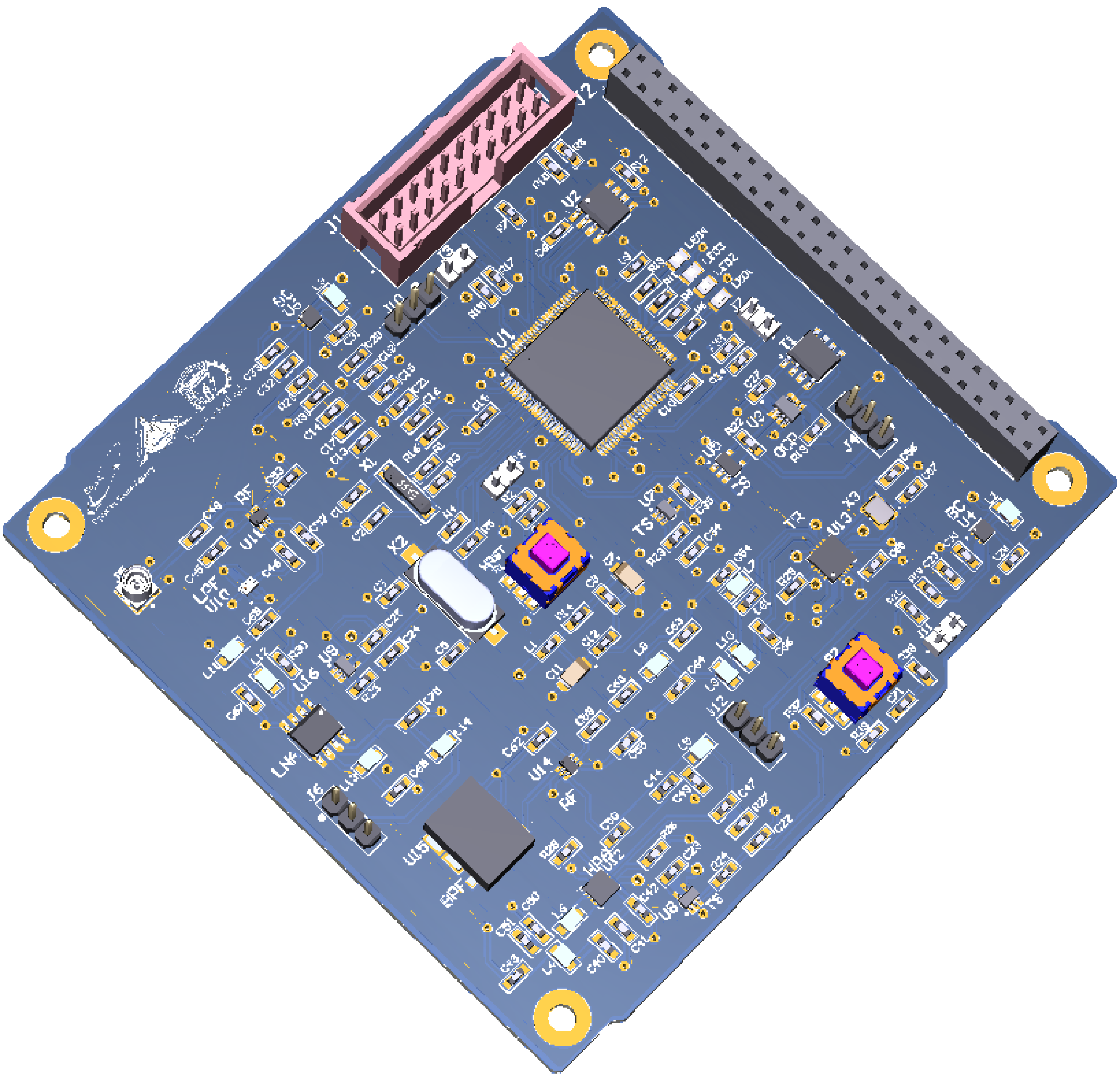


Figure 5.24: Final PCB design

Chapter 6: Calculating and Manufacturing

6.1 Calculating

6.1.1 Component List

Component	Value	Package	Manufacturer Part Number	Supplier	Unit Price ($)	Designator
Micro Controller		100-LQFP	STM32F407VGT6	Digi-Key	12.86	U1
RS Converter		8-SOIC	ISL83488IBZ-T	Arrow	1.47	U2
Current Protection		TSOT-23-8	LTC4361ITS8-2#TRMPBF	Digi-Key	4	U3
Booster Converter		6-WSON	TPS610995DRVT	Digi-Key	1.84	U4, U6
Current Sense		SOT-23-5	MAX9938HEUK+T	Digi-Key	1.39	U5
Temperature Sensor		SOT323-5L	STLM20W87F	Digi-Key	0.99	U7, U8, U9
Low Pass RF Filter		0805	0500LP15A500E	Digi-Key	0.83	U10
RF Switch		6-pin mini mold	CG2179M2-C4	Digi-Key	0.71	U14
High Power Amplifier		8-HVSON	BGA6130,118	Digi-Key	4.11	U12
Transceiver		20-QFN	CC1101RGPR	Digi-Key	4.32	U13
Band Pass filter		2-SMD, No Lead	DBP.433.T.A.30	Digi-Key	1.46	U15
low noise amplifier		8-SOIC	MAAL-008624-TR3000	Digi-Key	5.06	U16
JUMPER 2-Pins		Pitch (2.54mm)	61300211121	Digi-Key	0.12	J1,J7,J9,J11
JTAG		Pitch-Row (2.54mm)	75869-104LF	Digi-Key	1.44	J2

PC104		Pitch-Row (2.54mm)	ESQ-126-49-G-D	Digi-Key	14.6	J3
JUMPER 3-Pins		Pitch (2.54mm)	61300311121	Digi-Key	0.12	J4,J6,J10
Antenna connector		MMCX	73415-2063	Digi-Key	2.24	J5
Push Button Switch		SPEJ	SPEJ110100	Mouser	3.175	S1,S2
Capacitor	6.8pF	0805	GQM2195C2E6R8CB12D	Digi-Key	0.77	C1,C2
Capacitor	20pF	0805	C0805C200J4GAC7800	Digi-Key	0.29	C3,C4
Capacitor	0.1µF	0805	160R15W104KV4T	Digi-Key	0.21	C4, C6, C8, C12,C13, C14, C15, C16, C17, C18, C20, C21, C23, C25, C35, C41, C65
Capacitor	0.1µF	1206	TAJA105K016RNJ	Digi-Key	0.36	C7, C11
Capacitor	1µF	0805	C0805C105J4RACTU	Digi-Key	0.38	C19, C22, C24, C34
Capacitor	2.2µF	0805	C2012X7R1E225K085AB	Digi-Key	0.4	C9, C10
Capacitor	10µF	0805	CL21A106KPCLQNC	Digi-Key	0.13	C27, C28, C29, C30, C31, C32, C33, C42
Capacitor	1000pF	0805	GRM2165C1H102FA01D	Digi-Key	0.27	C40, C43, C44, C45, C46, C48, C52, C53, C55, C58, C59, C62
Capacitor	15pF	0805	GRM21A5C2E150JW01D	Digi-Key	0.38	C47, C49, C51
Capacitor	2pF	0805	GQM2195C2A2R0CB01D	Digi-Key	0.53	C50
Capacitor	220pF	0805	GRM2165C1H221JA01D	Digi-Key	0.19	C54, C60
Capacitor	27pF	0805	GRM21A5C2E270JW01D	Digi-Key	0.31	C56, C57
Capacitor	3.9pF	0805	CC0805BRNPO9BN3R9	Digi-Key	0.17	C61, C66
Capacitor	5.6pF	0805	GQM2195C2E5R6CB12D	Digi-Key	0.77	C63
Capacitor	8.2pF	0805	GQM2195C2E8R2CB12D	Digi-Key	0.84	C64
Capacitor	8pF	0805	CC0805DRNPO9BN8R0	Digi-Key	0.11	C67
Capacitor	4pF	0805	08051A4R0CAT2A	Digi-Key	0.27	C68
Capacitor	100pF	0805	GRM21A5C2E101JW01D	Digi-Key	0.38	C69
Capacitor	470pF	0805	CC0805KRX7R9BB471	Digi-Key	0.11	C70
Capacitor	100nF	0805	160R15W104KV4T	Digi-Key	0.21	C71

Resistance	0 Ohm	0805	CRCW08050000Z0EAC	Digi-Key	0.1	R1, R3, R4,R35,R36
Resistance	100k	0805	ERJ-P06F1003V	Digi-Key	0.16	R2
Resistance	220 Ohms	0805	ERJ-6ENF2200V	Digi-Key	0.1	R5, R27
Resistance	68 Ohms	0805	RPC0805JT68R0	Digi-Key	0.19	R6,R8,R13
Resistance	10 k Ohms	0805	ERJ-P6WJ103V	Digi-Key	0.37	R7, R9, R10, R15,R33
Resistance	75 Ohms	0805	RNCP0805FTD75R0	Digi-Key	0.1	R11
Resistance	120 Ohms	0805	ERJ-P06J121V	Digi-Key	0.1	R12
Resistance	47 Ohms	0805	ERJ-P06J470V	Digi-Key	0.1	R13, R14
Resistance	200 Ohms	0805	ERA-6AEB201V	Digi-Key	0.31	R16, R23, R24, R25
Resistance	510 Ohms	0805	CRG0805F510R	Digi-Key	0.1	R17,R34
Resistance	649 k Ohms	0805	ERJ-PB6D6493V	Digi-Key	0.23	R18
Resistance	50m Ohms	0805	ERJ-6BWFR050V	Digi-Key	0.58	R19
Resistance	249 k Ohms	0805	CRCW0805249KFKEAHP	Digi-Key	0.23	R20,R31
Resistance	1M Ohms	0805	CRCW08051M00FKEAHP	Digi-Key	0.23	R21
Resistance	25m Ohms	0805	ERJ-6BWFR025V	Digi-Key	0.58	R22
Resistance	270 Ohms	0805	ERJ-6GEYJ271V	Digi-Key	0.1	R26
Resistance	3.9k Ohms	0805	ERJ-P6WF3901V	Digi-Key	0.48	R28
Resistance	56K ohms	0805	RK73H2ATTD5602F	Digi-Key	0.1	R29

Resistance	15 Ohms	0805	CRCW080515R0FKEAHP	Digi-Key	0.23	R30
Resistance	330 Ohms	0805	ERJ -P06J331V	Digi-Key	0.11	R37
Resistance	100 Ohms	0805	ERJ -P06J101V	Digi-Key	0.11	R38
Resistance	220 k Ohms	0805	CRCW0805220KJNEAHP	Digi-Key	0.23	R39
Inductor		0805	BKP2125HS600-T	Digi-Key	0.11	L1
Inductor	2.2µH	0805	BRC2012T2R2MD	Digi-Key	0.3	L2, L3
Inductor	68nH	0805	LQW2BAS68NJ00L	Digi-Key	0.23	L4
Inductor	15nH	0805	LQW2BAS15NJ00L	Digi-Key	0.23	L5
Inductor	5.6nH	0805	LQW2BAS5N6J00L	Mouser	0.254	L6
Inductor	27nH	0805	LQW2BAS27NJ00L	Digi-Key	0.23	L7, L9, L10
Inductor	22nH	0805	LQW2BAS22NG00L	Digi-Key	0.24	L8, L11
Inductor	43nH	0805	LQW2BAS43NJ00L	Digi-Key	0.44	L12
Inductor	11nH	0805	LQW2BAN11NJ00L	Digi-Key	0.46	L13
Inductor	12nH	0805	LQW2BHN12NJ03L	Digi-Key	0.44	L14
LED	G	0805	LTST-S220KGKT	Digi-Key	0.26	LED1
LED	O	0805	LTST-C170KFKT	Digi-Key	0.28	LED2
LED	R	0805	LTST-C170CKT	Digi-Key	0.35	LED3
LED	Y	0805	LTST-C170KSKT	Digi-Key	0.31	LED4
Crystal	32kHz	4-SMD, Flat Leads	MC-14632.7680KA-A0:ROHS	Digi-Key	0.38	X1
Crystal	8MHz	HC-49/US	ECS-80-32-5PX-TR	Digi-Key	0.45	X2
Crystal	26MHz	4-SMD, No Lead	TSX-3225 26.0000MF10Z-B6	Digi-Key	0.33	X3
Transistor MOSFET		8-SOIC	SI4838BDY-T1-GE3	Future	1.61	T1
RF Switch		6-pin mini mold	CG2409M2-C4	Digi-Key	0.71	U11

Table 6.1: Component list

6.1.2 Power Consumption

Case	Component	Power Consumption (mw)
Transmitting	Over Current Protection	0.726
	Current Sensor	0.0033
	Micro Controller	79.2
	RS Converter	3.96
	Temperature Sensor	3*0.0264
	RF Switch	0.0033
	Transceiver	96.36
	High Power Amplifier	909
	Low Pass Filter	800
	Booster Converter	68.41935484
	Total Power	1957.75115484
Receiving	Over Current Protection	0.726
	Current Sensor	0.0033
	Micro Controller	79.2
	RS Converter	3.96
	Temperature Sensor	3*0.0264
	RF Switch	2*0.0033
	Transceiver	59.4
	Booster Converter	0.11083871
	Law Noise Amplifier	-2640
	Total Power	143.48593871

Table 6.2: Power Consumption

6.1.3 Components Mass Calculation

Component	Unit weight (mg)	Quantity	Total weight (mg)
Microcontroller	1300	1	1300
Transceiver	70	1	70
High Power Amplifier	22.526	1	22.526
Low Noise Amplifier	6	1	6
Band Pass Filter	37	1	37
Low Pass Filter	5.5	1	5.5
RF-Switch	32.647	1	32.647
Current Sensor	6.3	1	6.3
JTAG	7792	1	7792
Current Protection	12.017	1	12.017
PC104	3.215	1	3.215
Transistor MOSFET	750	1	750
RS Converter	76	1	76
Antenna connector	450	1	450
Crystal 32.768kHz	60	1	60
Crystal 8MHz	575.560	1	575.560
Crystal 26MHz	49	1	49
Boost Converter	12	2	24
Push Button Switch	580	2	1160
Temperature Sensor	6.4	3	19.2
LED	35	4	140
Jumper	180	7	1260
Inductor	10	14	140
Resistance	5.5	39	214.5
Capacitor	5.5	71	390.5
			14592.118

Table 6.3: Components Mass Calculation

6.2 Manufacturing

Upon completion of the PCB design and completion of all design and manufacturing rules checks, the output files will go to the PCB plant. PCB manufacturing is the construction of your board design. This is a two-step process that begins with board fabrication and ends with printed circuit board assembly (PCBA).

We found several agencies that can make our PCB like JLCPCB, NEXTPCB, WELLPCB, ZXHPCB and FASTPCBA.

These agencies have several abilities like the number of layers which can be handled and the material but the best one is JLCPCB it has a free prototype but with its logo on it and it’s the Best price of PCB prototyping in the world and 100% guarantee on PCB Quality with Quick Turn and Fast Delivery

Figure 6.1: JLCPCB agency

The table below shows some of the primary capacities that JLCPCB provides and support. It contains information about the PCB materials, the types of products manufactured, and the offers tolerances.

Materials	FR4, High TG FR4, Halogen Free Material, CEM-3, Rogers HF Material
Min Contour Tolerance	+ / -0.1mm
Layer Counts	2-36 Layers
Min Finished Diameter of PTH Hole	+ / -0.1mm
Finished Copper Thickness	0.5-5 OZ
Max Board Thickness/Hole Ratio	12:1
Finished Board Thickness	0.2-6.0mm
Min Solder Mask Bridge	4mil (Min, SMT Pad Space 8mil)
Min Line/Track Width	3mil
Min Legend(Silkscreen) Track Width	5mil
MIN Drilling Slot Size	0.6mm
Surface Treatment	Leaded HASL, Lead Free HASL, Immersion Gold, OSP, Immersion tin, Immersion Silver
Solder Mask Color	Green, Black, Blue, White, Yellow, and Matt
Other Technology	Gold Finger, Peelable Mask, Non-across Blindried Vias, Characteristic Impedance Control, Riged-flex Board etc.
Solder Mask Hardness	6H
Legend/Silkscreen Color	Black, White, Yellow, and others.
Wrap and Twist	≤0.7%
Flammability	94v-0

Table 6.4: JLCPCB capacities

These agencies request the output files from the PCB Designer program which in our project it's Altium. The output files that can be exported from Altium is (Composite Drill Guides, Drill Drawing Guides, Final Artwork, Prints, Gerber Files, Solder/Paste Mask Prints, NC Drill Files, ODB++ Files, Power-Plane Prints, Test Point Report)

In addition to the output file, the agency requires us to choose what we need from the specifications such as materials, number of layers, dimensions, etc.

PCB specifications:

No of layer	4
Number of PCB copies per subsystem	5
Dimensions	96 mm x 90 mm
Material Details	Fr-4
Board type	Single piece
Minimum separation between tracks	0.12 mm
Minimum track width	0.3 mm
Minimum diameter of through-holes	1mm
Surface Finish	HASL
Solder mask expansion	Both Sides
Solder mask Color	Green
Inner Layer Copper Weight	1 Oz Copper (1.4 Mils)
Outer Layer Copper Weight	1 Oz Copper (1.4 Mils)

Table 6.5: PCB Specifications

After Manufacturing

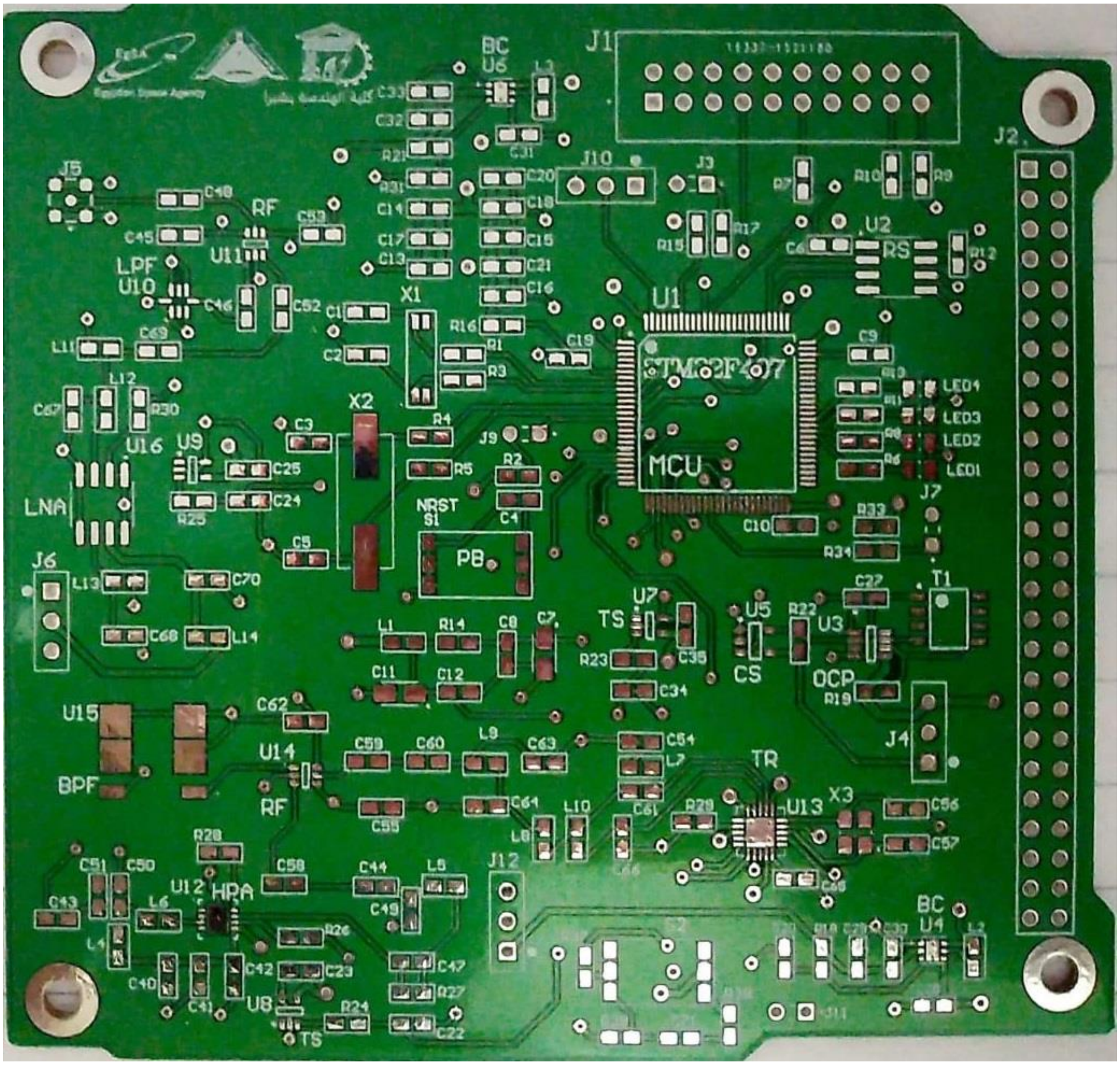


Figure 6.2: PCB after manufacturing

6.3 Assembly

The final stage in the communication board making is the assembly, which is placing the components in their specified place on the PCB board and fixed by tin soldering.

The PCB board was assembled under our supervision at the Benha Electronics co

The following figure shows the final appearance of the communication board

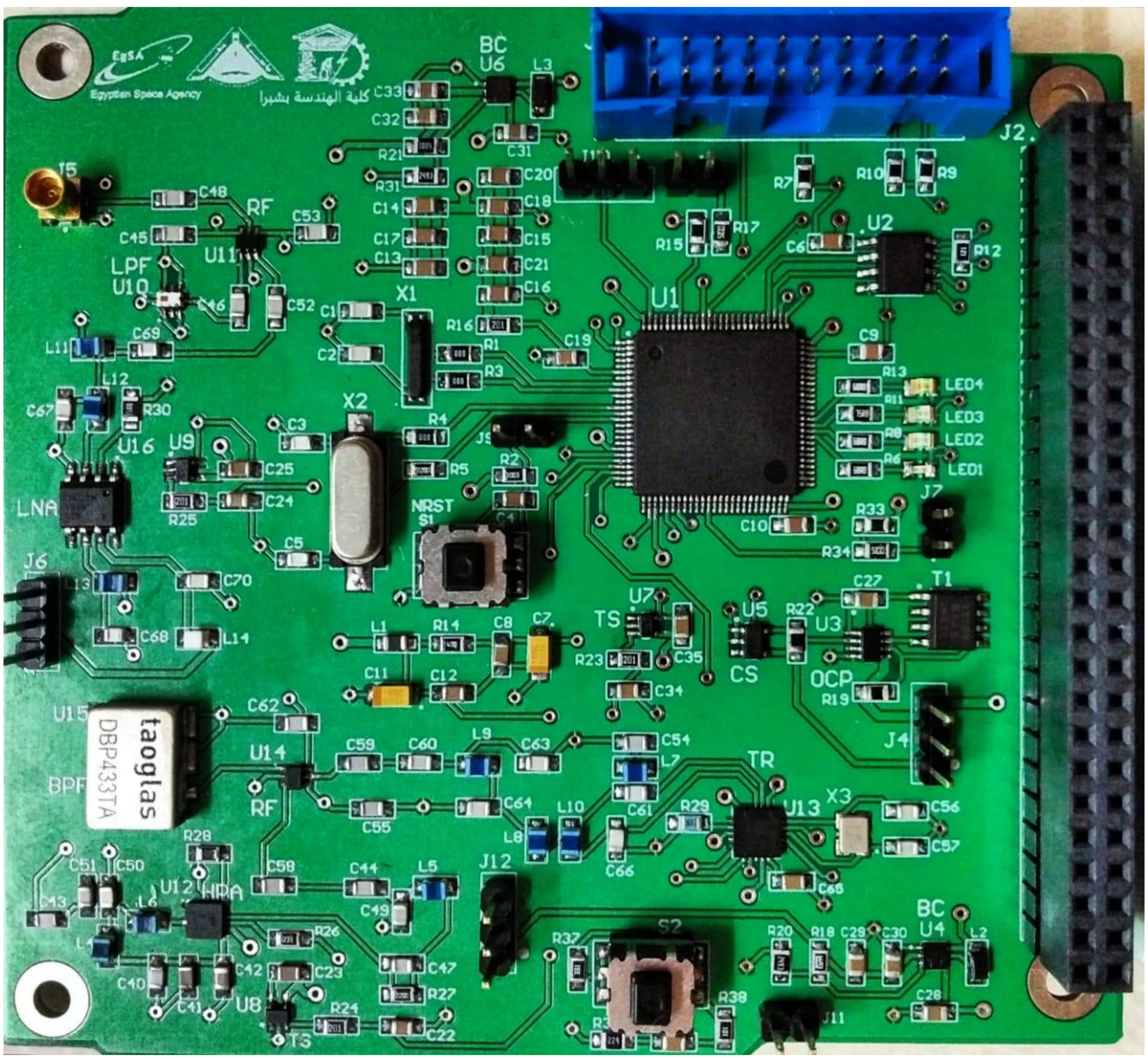


Figure 6.3: Final appearance of the communication board