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Design and Development of a Low Cost Ground System for CubeSat

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Abstract: CubeSats are nanosatellites of standardized dimensions normally built by students that can be operated from a low-cost ground stations installed at the academic institutes. They offer an opportunity to engineering students in designing, developing, testing, and operating a real spacecraft system and its ground segment. The ground station is capable of receiving data from CubeSat and process them to analyse and evaluate system performance. It can also send command to onboard system to control system orientation, power etc. In this student project a low-cost ground system is realised by using UHF data link. All hardware components are from the commercially of the shelf sources. A unique communication protocol and software is developed to establish data exchange between ground station and CubeSat. A provision is made for data representation through python tool box. A proto-model of both ground and onboard system is realised and experimented. The experimental data is plotted by using MATLAB and is analysed to evaluate system performance.
Keywords: CubeSat, Ground Station, Data, MATLAB, Low -cost, UHF, Protocol, Python.

I. INTRODUCTION

Ground Station provides a communication link to the CubeSat by transmitting and receiving radio signals of the Ultra High-Frequency (UHF) bands. Ground station analyses and evaluates received or collected data like from the CubeSat.

A low cost ground station is required to be built [1] to produce them in number. The ground system architecture for Pico and nanosat described in [2] was considered for architecture development. In addition, Our CubeSat is implemented based on Project-based learning concept and is refined with the information obtained from [3]. Ground stations have different features like Telemetry, Tracking, Commanding, and Monitoring (TTCM). The TTCM subsystem is present both in satellite and ground stations. The information related to Cubesat suggested in [4] is studied to configure our system. In general, satellites get data through sensors. Telemetry subsystem present in the satellite sends this data to earth station(s). CubeSats are positioned in Low Earth Orbit (LEO). This makes the visibility time from the ground very short. According to GENSO, the period of contact is about 5 minutes in each rotation, and communication with the satellite can only be established during the 3 % of the lifetime. The transceiver modules at ground system is based on Software Defined Radio (SDR) as suggested in [5] & [6]. The link budget and antenna design are carried out as per different literature and also as suggested in [7]. Most of the knowledge used in the design is work is based on the text book study and also material available online. An attempt is made to design a low-cost satellite ground station for CubeSat application by the student group. The following sections will bring out system architecture, Antenna system, communication segment, tracking segment, data processing and display segment highlighting both software and hardware. It will also discuss about the prototype testing and system analysis as part of system validation.

II. GROUND ARCHITECTURE

The architecture that we planned to implement in our CubeSat project is presented in Fig 1.

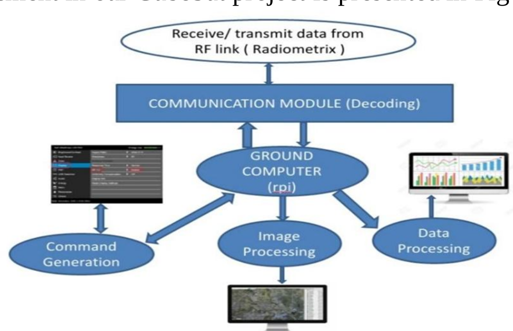

Fig. 1 Architecture of Ground Station

A typical ground station has four segments namely Antenna segment, Communication segment, Tracking segment, Data processing and display segment. Each segment has its importance and correlation between these segments is very essential for the success of the project. System block diagram is shown in Fig 2.

Fig. 2 Implementation of Ground Station

III. ANTENNA SEGMENT

Antenna is the component that is responsible for transmitting and receiving data in the ground station. Antenna in CubeSat operates in the 435-438MHZ frequencies. The antenna in the ground station is directional and provides higher gain.

A half-wave dipole antenna has a nominal gain of about 1.5 db. It is omni-directional and has low directivity. When the reflectors and directors are added to the dipole antenna, its gain starts increasing. But the gain gets saturated at about 15 dB, with the number of directors equal to 11. For further increase in the gain, several antennas can be coupled together using a proper impedance matching network. Horn antennas and parabolic dish antennas have extremely high directionality but they have structural constraints and incompatibility with the antenna rotator system.

We have chosen the Yagi–Uda antenna commonly known as the Yagi antenna. It is a half-wave folded dipole antenna to provide optimum power transfer and desired impedances. The folded dipole is the main element in the Yagi-Uda antenna, to which the antenna feed is given. This antenna has been extensively used for television reception over the past few decades. Thus, this antenna is reliable to use as an antenna in the ground station. A Yagi-Uda antenna is shown in fig 3.

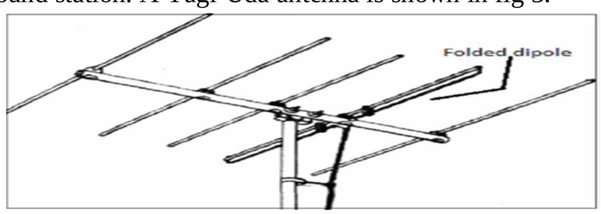

Fig. 3 Yagi-Uda Antenna

Construction of Yagi antenna include two elements namely active element (driven element) and parasitic element (reflectors and directors) as shown in Fig. 4.

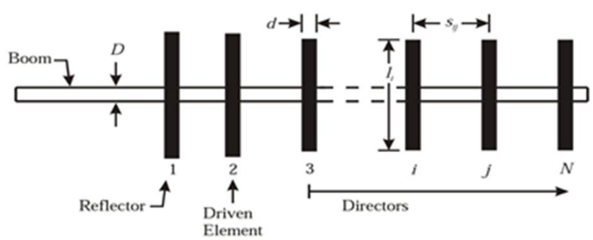

Fig. 4 Construction of Yagi-Uda Antenna

The power is given to the driven element so it's called an active element. The reflectors and directors are used to improve the directionality of the antenna and they don't have any connection to the power supply. The boom is used to shorten the length of the elements and as a result, it shifts the performance of the antenna to a higher frequency.

The specifications of the antenna for our ground station is as follows:

1) Frequency: 433MHz
2) Wavelength: 693nm
3) Directivity: <14dB
4) Gain: 10-12dB
5) Impedance: 50Ω

As per the specifications, the 3 element yagi antenna is sufficient for our Ground station. For the construction of a 3 element yagi antenna, we need to calculate lengths of reflectors, dipole, director, and spacing between reflector to dipole and dipole to director.

The formulas for the above mentioned are as follows:

a) Length of Reflector = 0.495*λ
b) Length of Dipole = 0.473* λ
c) Space between Reflector to dipole = 0.125* λ
d) Space between dipole and Director = 0.125* λ
e) λ = c/f where,
   λ – Wave Wavelength in meters
   c – speed of light in air medium (3*10^^{8} m/s)
   f – Carrier frequency in Hz

For an operating frequency of 433MHz we need

- Length of Reflector: 0.3429m
- Length of Dipole: 0.3277m
- Length of Director: 0.3048m
- Space between Reflector and dipole: 0.0866m
- Space between Dipole and director: 0.0866m

Single antenna transmits/receives signals from the UHF link via a duplexer.

IV. COMMUNICATION SEGMENT

The communication segment in the ground station deals with how the data is transmitted and communication is established between the ground station and CubeSat. For long-range communications and especially for satellite communication wireless communication is the only means of communication. Wireless communication is quite advantageous and it also has the same number of disadvantages when not applied properly. The main issues we face is garbage data or noise reception. So there is a great need for an efficient wireless communication protocol to have proper synchronization between the transmitter and the receiver to reduce the noisy data and improve the signal to noise ratio (SNR) and reduce bit error rate (BER). There is a necessity to develop an efficient communication protocol for our CubeSat ground station.

A. Hardware

1) Radiometrix Receiver (RX2A-433-64)

Fig. 5 Radiometrix Receiver

RX2A-433-64 is a UHF radio data receiver operating at 433.92MHz frequency. It has received signal strength indicator (RSSI) which can be used for tracking to get best signal strength. It allows the simple implementation of data links at speeds up to 64kb/s and distances up to 75 meters on buildings or 300 meters over open ground. The built-in filter provides Electromagnetic Compatibility (EMC) compliance by minimizing spurious radiation and susceptibility. Considering the height of Cubesat this unit is sufficient for communication at a longer distance.

Operating voltage: 2.7 to 16 Volts
Operating current: 12 milliamps
Connection protocol: UHF Communication protocol.

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2) Radiometrix Transmitter (TX2A-433-10)

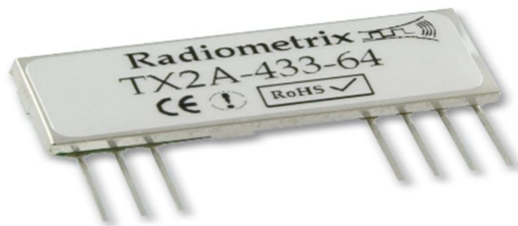

Fig. 6 Radiometrix Transmitter

TX2A-433-64 is the counterpart FM UHF radio transmitter operates at 433.92 Mhz. There is built in filter to provides Electro-magnetic Compatibility. This protects it from spurious radiation and susceptibilities. This module is well suited for one-to-one and multi-node wireless links applications. The Yagi antenna provides additional gain requirements.

Operating voltage: 2.7 to 16 Volts
Operating current: 11Amps
Connection protocol: USART.
Both transmitter and receiver are connected to the controller (Raspberry *pi*) through serial link.

3) OPEK DU-5-00 Duplexer

Fig. 7 Duplexer

This OPEK duplexer (diplexer) is a passive device that has a series of inductance coils and capacitors that act as a band-pass filter. It connects both receive and transmit section with a common antenna. It allows received signal to pass on to the receiver and also gets transmit input to further pass on to antenna. However, the system ensures that at a given time it will be either transmit mode or receive mode.

As a passive device, 'diplexer' allows both input and output in either direction. A built-in band-pass filter provide a high degree of isolation between ports. The functionality is affected when used in a wet environment. Aluminium diecast box prevents the duplexer from electromagnetic interferences. Following are the specifications.

a) Operating frequency: 350 - 540 MHz (UHF)
b) Power Handling capability: 300-Watt
c) Insertion loss: < 0.2dB
d) Isolation loss: 40dB
e) VSWR: < 1.2:1

The duplexer is connected closer to the antenna to reduce transmission loss.

4) Raspberry Pi

Raspberry Pi is a credit-card-sized computer used for processing the collected data and interfacing all the components. It can be used for performing multiple functions simultaneously. It works on Raspbian OS. The memory, I/O can be configured easily. Hence, it is considered as the best controller in satellite applications.

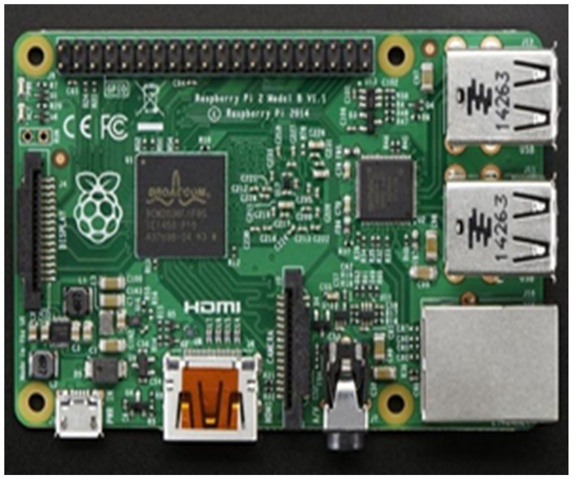

Fig. 8 Raspberry Pi

V. TRACKING SEGMENT

The satellite tracking system in the ground station of a CubeSat has two missions. One is to track the satellite and the other is antenna management. In satellite tracking, the key technique used to track the CubeSat is Global Positioning System (GPS). This allows the ground station to track the CubeSat anywhere around the earth. We make alignment of the satellite antenna with a desired Satellite to establish communication. The tracking system can display the antenna's graphical movement and fix up the direction orientation using Gyroscope and Magnetometer sensors. This device can track almost all the satellites orbiting the earth from anywhere on the globe. To operate this device, any online or data connection is not required as it is completely an offline based system. We are using programmable Microprocessor Raspberry Pi as our mainboard.

VI. DATA PROCESSING AND DISPLAY SEGMENT

The data processing and display operations require specific software requirements. The Ground Software acts as a medium for communication between the satellite and ground station. It acts as the application layer which gives command to the CubeSat for its position and attitude. To explain the functioning in detail, we have organised its functions based on its requirement, specifications and organisation.

A. Software Requirements

The Ground software is ported to Raspberry Pi. It has the following requirements.

1) Get Binary data as per the format listed in the interface document from the communication module.
2) Convert them to the engineering format. Process all parameters.
3) Display all parameters in tabular format in multiple pages.
4) Plot all the data on a time scale.
5) Receive image data packet by packet and form a full-frame.
6) Process image data with decompressing algorithms and display them.
7) Use image processing techniques for object identification using CNN and ML algorithms.
8) Create Menu for command generation.
9) Select a Menu item to generate command. Send the formatted command to the communication module.
10) Select a Menu for local commands.
11) Create a username and password menu at the start of the software.
12) Get Control sensor data
13) Send control command

B. Software Specifications

1) *GSP1:* Create a Start-up screen of SREESAT Ground Station.
2) *GSP2:* Create a User login and password menu.
3) *GSP3:* Create Menu format with several SREESAT commands and Internal commands.
   a) *SREESAT MENUS ARE GB:* Get BME data, GG – Get GPS data, GS – Get Sun Sensor, GG – Get Gas Sensor, GV- Get Voltage, GH- Get Health data, GA – Get all data C1 – cut off solar power.C2 – cut off battery power
   b) *Internal Commands:* Display different select data. Display selected plots, Print data, log data, Read stored data. Display stored data, display image data.
4) *GSP4:* Receive Binary data from the communication module in the given format.
5) *GSP5:* Process Pressure, temperature, humidity, and altitude data.
6) *GSP6:* Process Sun sensor data like Infrared rays, visible light, ultraviolet.
7) *GSP7:* Process GPS data like Longitude, Latitude, Altitude, Time, No of satellites, SNR, etc.
8) *GSP8:* Process GAS sensor data like NO, NO2, NH4, CO, CO2, etc.
9) *GSP9:* Collect image data packets and form a frame.
10) *GSP10:* Process control sensor data, Gyro, Accelerometer, Magnetometer.
11) *GSP11:* Send Control Data
12) *GSP12:* Display Data as per GSP5,6,7,8.10.
13) *GSP13:* Process image data and display
14) *GSP14:* Plot data as per menu selection.
15) *GSP15:* Get Log data.
16) *GSP16:* Display/ Plot log data.

C. Software Organization

There is an executive process that is first created to initialize all parameters. It also initializes all other modules. The following modules are identified as shown in the figure below.

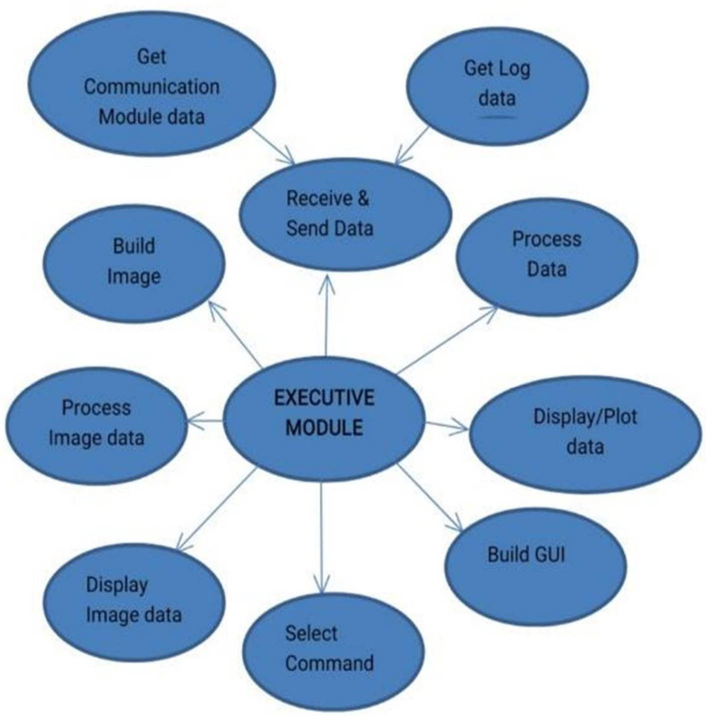

Fig. 9 Software Organisation

D. Implementation Details and Tools Used

Software is coded in python compatible to Raspbian operating system and can be easily ported to Raspberry Pi (RPi). Software is divided four parts like i) Serial data acquisition ii) data presentation iii) Image processing and iv) Graphical User Interface (GUI). Python has built in packages and modules in each case. There is also some third-party software required for image processing and data presentation. Following packages are used.

1) *PySerial:* RPi is connected to the communication segment transceiver through Universal Asynchronous Receive and Transmit (UART) port. PySerial module allows for the use of serial connections with Python.
2) *MATPLOTLIB* : Matplotlib is a Python package used for data visualization. One can make 2D plot from the data set provided in arrays. It works along-with NumPy for numerical computation. It can perform embedded plotting, while interfacing with Python GUI toolkits such as PyQt and Tkinter.
3) *Python-GUI Programming (TKINTER):* Tkinter is an object-oriented GUI library for Python. Python with the combination of Tkinter provides a fast and easy way to create GUI for ground station. The GUI is written in TKINTER.
4) *PyQt:* PyQt is a GUI toolkit. It has flexibility to program with the Python language and customise as per requirement.
5) *NumPy:* NumPy is a Python package. It stands for 'Numerical Python'. It is a library consisting of multidimensional array objects and a collection of routines for the processing of arrays. A Replacement for MATLAB.
6) *OpenCV:* This package is used for the implementation of image processing requirements.
7) *Py2Exe:* py2exe turns Python programs into packages that can be run on other Windows computers without needing to install Python on those computers.
8) *MATLAB:* MATLAB is used for non -Realtime plotting and data analysis.

VII. PROTOTYPE TESTING AND RESULTS

This segment of the paper deals with the results of our Balloon based low cost CubeSat prototype as a proof of concept of our CubeSat project. The payload designed was weighing about 400gms and was launched close to the start of ozone layers in a high-altitude balloon under the guidance of experts at Tata Institute of Fundamental Research (TIFR). Our ground system for CubeSat is realised by the commercial of the shelf products that are easily available.

Realization of a prototype for 1U CUBESAT was accomplished which also had an additional functionality of measuring various environmental parameters was made successful. The balloon reached an altitude of 18 km, floated for about 90 minutes and the flight was terminated once the mission was completed. The system was equipped with GPS, so we were able to monitor its position and could recover the payload and retain the data collected. The proto models are shown in fig. 10 & 11.

Fig 10. Cubesat Proto Model with stacked board

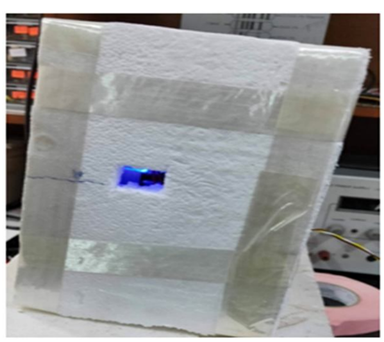

Fig. 11 Onboard System

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The results obtained were compared with the other databases, referred from various papers, who conducted similar experiments for environmental monitoring to ensure that the procured values are reliable. A series of discussions was held with authorities of Telangana Environmental Board and TIFR balloon facility to finalize the configuration.

The graphs are plotted in MATLAB using required conversion algorithms. The data received from the CubeSat is visualised and represented in the form of graphs shown in Fig 12 - 16 These help us in analysing the conditions of the atmosphere and also validating CubeSat and ground system design.

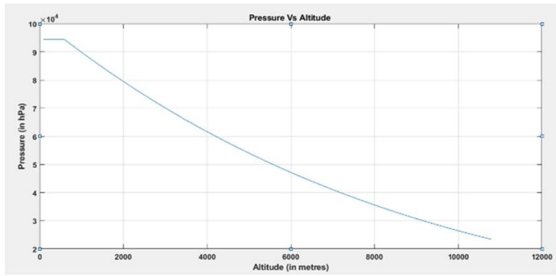

Fig. 12 Pressure vs Altitude

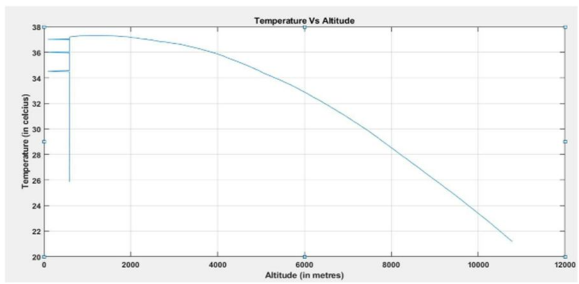

Fig. 13 Temperature vs. Altitude

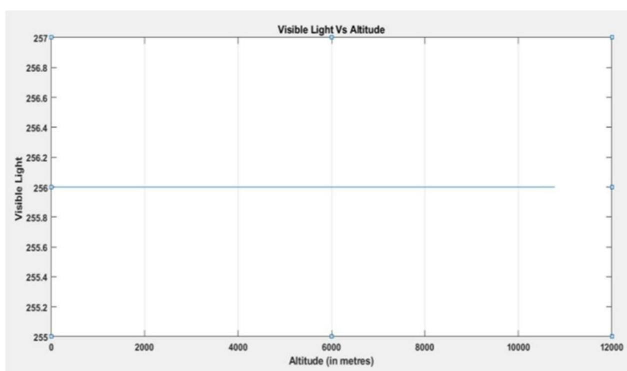

Fig. 14 Visible Light vs. Altitude

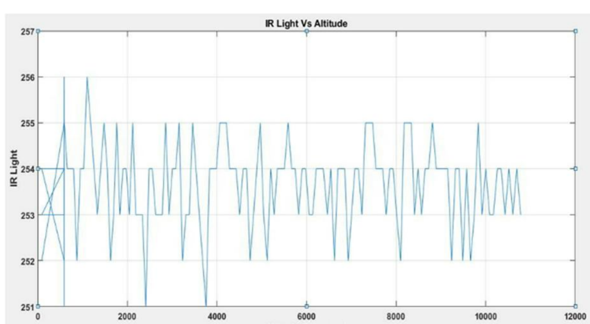

Fig. 15 IR Light Index vs. Altitude

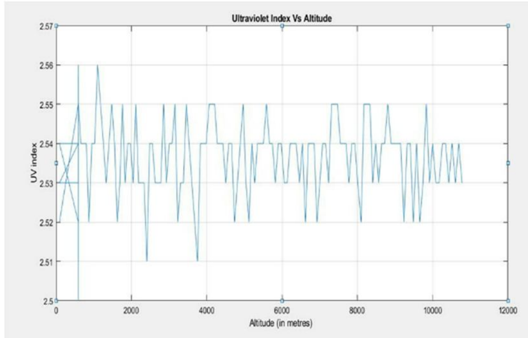

Fig. 16 UV Light Index vs. Altitude

VIII. CONCLUSIONS

The Ground station is an important part of the project as it analyses the received data. This system is realised by the students understanding the detail of communication systems and data transfer. This has brought out an efficient ground system which communicated with the prototype module efficiently and realised in at low cost. Rapid technology growth has contributed towards different advancements in satellite technology which aids in providing a hassle free experience and the functionality. The system performance will be further enhanced to handle higher rate of Data transmission and real time display of most critical parameters.

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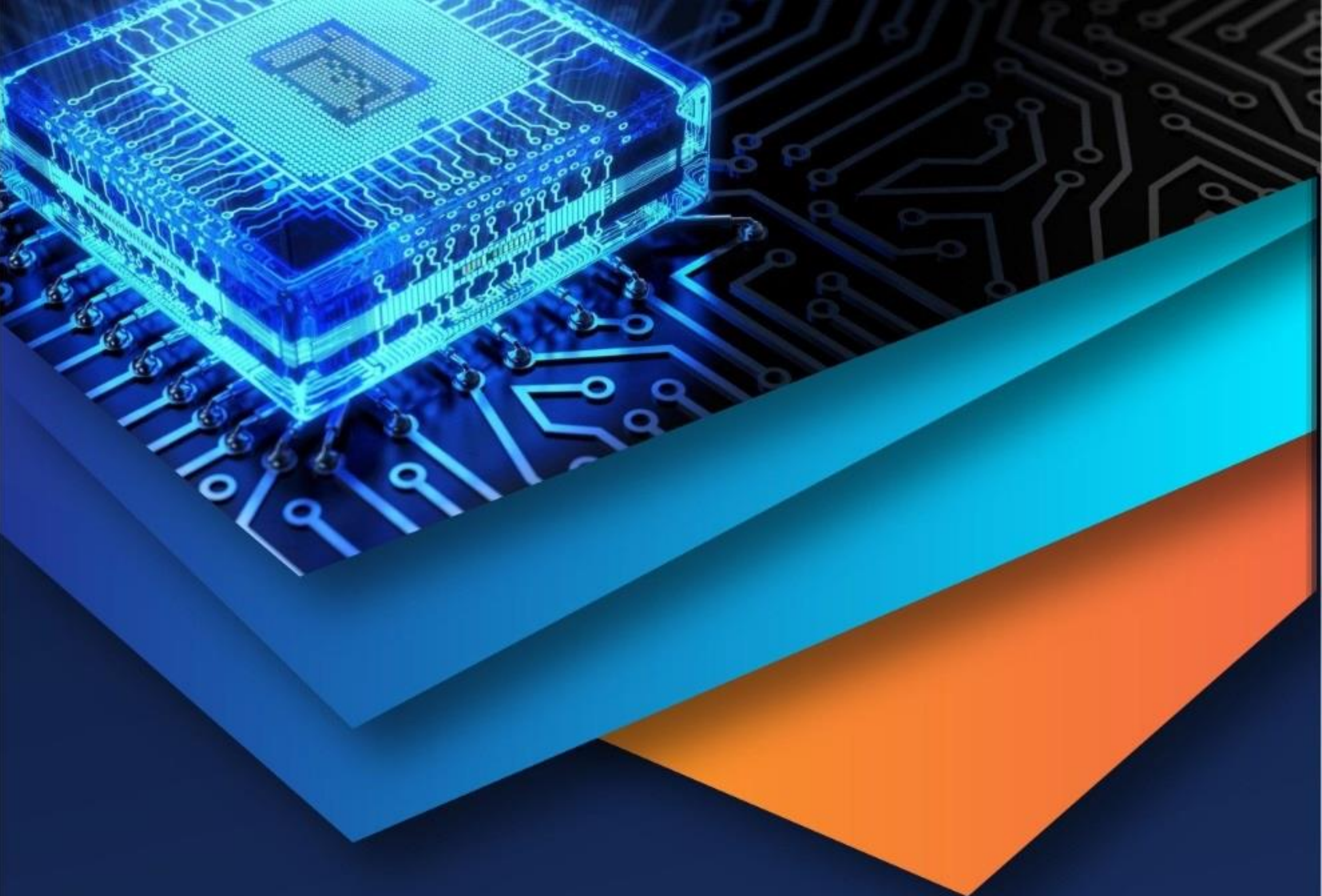

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