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Design of Low-Power Sensor Node for IOT Applications with LORA Capability as an Option

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Abstract: Internet of Things (IoT) becoming an increasingly growing topic of conversation in recent studies. IoT is a basically connecting any device to the internet over different wireless protocols such as Wi-Fi, 3G/4G, ZigBee, Bluetooth, RFID and other new wireless protocols such as BLE, 6LoWPAN etc. Today's challenging part of IoT industry is, to design a low-power sensor nodes which can be interoperable with multiple gateways through some wireless protocols. So here we target to design a sensor node which can work with low-power in energy harvesting situations. We enabled these devices with battery operated one. The sensor node is interfaced with "sensor Nest" by I2C protocol. The "Sensor Nest" is combinations of multiple sensors are mounted in a single board and connected via I2C two wire interfaces. For the current application, we interfaced HDC1008 and BMP180 to measure the atmospheric parameters like Temperature, Humidity and Pressure. The designed sensor node is interoperable with any gateway capable of 6LoWPAN over 868MHz LoRa frequency band.
Keywords: IoT, LoRa (long range), Raspberry PI, Sub-1GHz, Wi-Fi, Python scripting, Real-time, Critical alerting system

I. INTRODUCTION

In the rapid growing of the IoT applications from personal electronic gadgets to industrial, commercial machines in order to get the data and processes the data and serve the data by connecting to internet [1, 4]. The IoT is significant because an object that can represent itself digitally becomes something greater than the object by itself. No longer does the object relates just to its user, but is now connected to surrounding objects and database [2, 5]. When many objects act in unison, they are known as having "ambient intelligence". There are different bands are available in the IoT market, there are few pros and corns to each of the bands. The ISM bands below sub-1GHz are vary from region to region and covering whole region with the same RF radio is not possible. There are few pros and cons for this sub-1GHz. The pros is " better range, than the 2.4 GHz with same output power and current consumption, because of lower frequencies, it can easily penetrate through the steel and concrete walls, hence will have better penetrate power than the 2.4 GHz [12, 14]. Figure-1 shows a standard frequency bands support through worldwide.

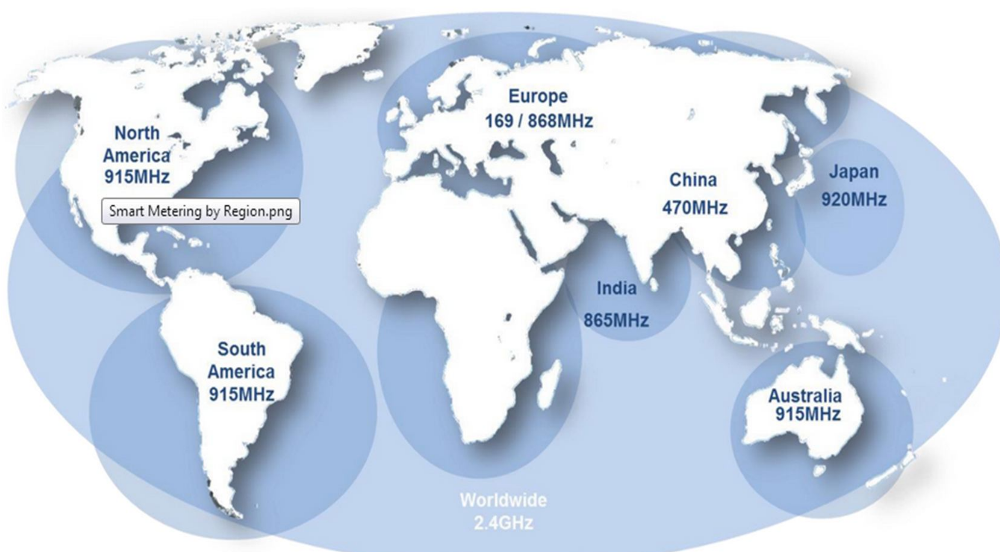

Figure-1: Standard frequency bands through worldwide

The Internet Society (ISOC) recently released a fifty page white paper examining the opportunities and challenges associated with the IoT; ISOC's whitepaper provides valuable informational resource to help people navigate the conflicting dialogue surrounding the IoT. It should encourage further, focused discussion on the few issues, the white paper identifies as major challenges to the IoT, summarised as

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Privacy
Standards
Regulation (Legal, Regulatory and Rights)
Intelligent analysis & actions
Business
Development

According to the new market research report on IoT node and gateway market, this market is projected to reach 17.18 billion units by 2023, growing at a compound annual growth rate **(**CAGR) of 30.9% between 2017 and 2023. The growth of the IoT node and gateway market can be attributed to the improved internet connectivity and growth in use of wireless sensors and their networks, as well as growth in application specific microcontroller units (MCUs). However, the lack of common communication protocols and communication standards across platforms and high power consumption by connected devices are hindering the growth of the IoT node and gateway market. Logic device is expected to grow at the highest CAGR from 2017 to 2023. IoT node and gateway market in Asia Pacific is expected to grow at the highest rate". The report describes the IoT node and gateway market and the related developments in this market in terms of hardware and end-user applications across different regions [2]. This report aims at estimating the market size and future growth potential of this market across different segments such as hardware, end-user application and geography. Here we target to design common node that can be used for any type of sensors with any type of gateways (provided with Sub-1GHz Frequency).

II. FUNCTIONAL DESCRIPTION

A. LoRa

Long range, low power wireless platform is the prevailing technology choice for building IoT networks worldwide [5]. Smart IoT applications have improved the way we interact and are addressing some of the biggest challenges facing cities and communities like: climate change, pollution control, early warning of natural disasters and saving lives.

B. LoRa Technology

Offers a very compelling mix of long range, low power consumption and secure data transmission. Public and private networks using this technology can provide coverage that is greater in range compared to that of existing cellular networks. It is easy to plug into the existing infrastructure and offers a solution to serve battery-operated IoT applications [8-10]. Figure-2 shows the functional block diagram of the design.

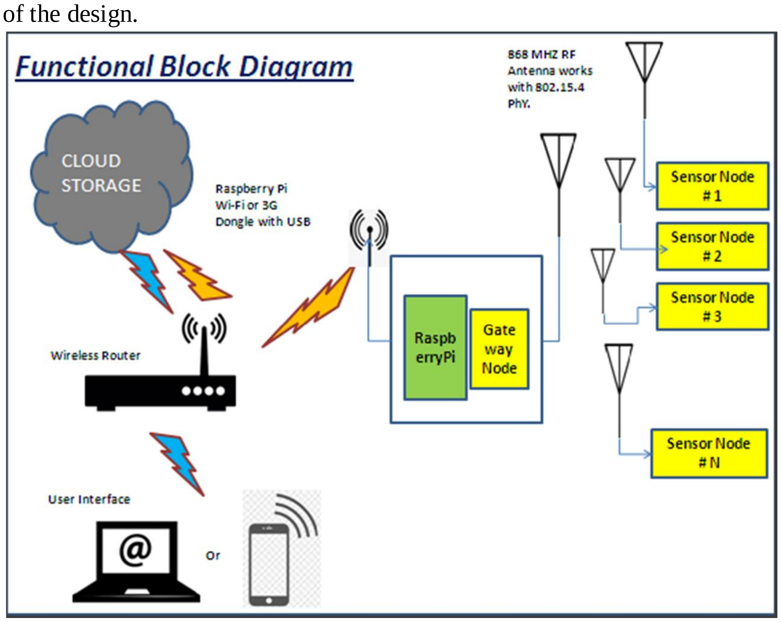

Figure-2: Block diagram of the designed instrumentation

III. HARDWARE DESIGN AND DESCRIPTION

As shown in figure-3, the sensor board design is based on the CC1310 (Evaluation Module Kit) ic device, which is the first device in a Sub-1 GHz family of cost-effective, ultra-low-power wireless MCUs, which consists of very low active RF and microcontroller (MCU), in addition to flexible low-power modes, it provide excellent battery life-time and allows long-range operation on small coin-cell batteries and in energy-harvesting applications [12].

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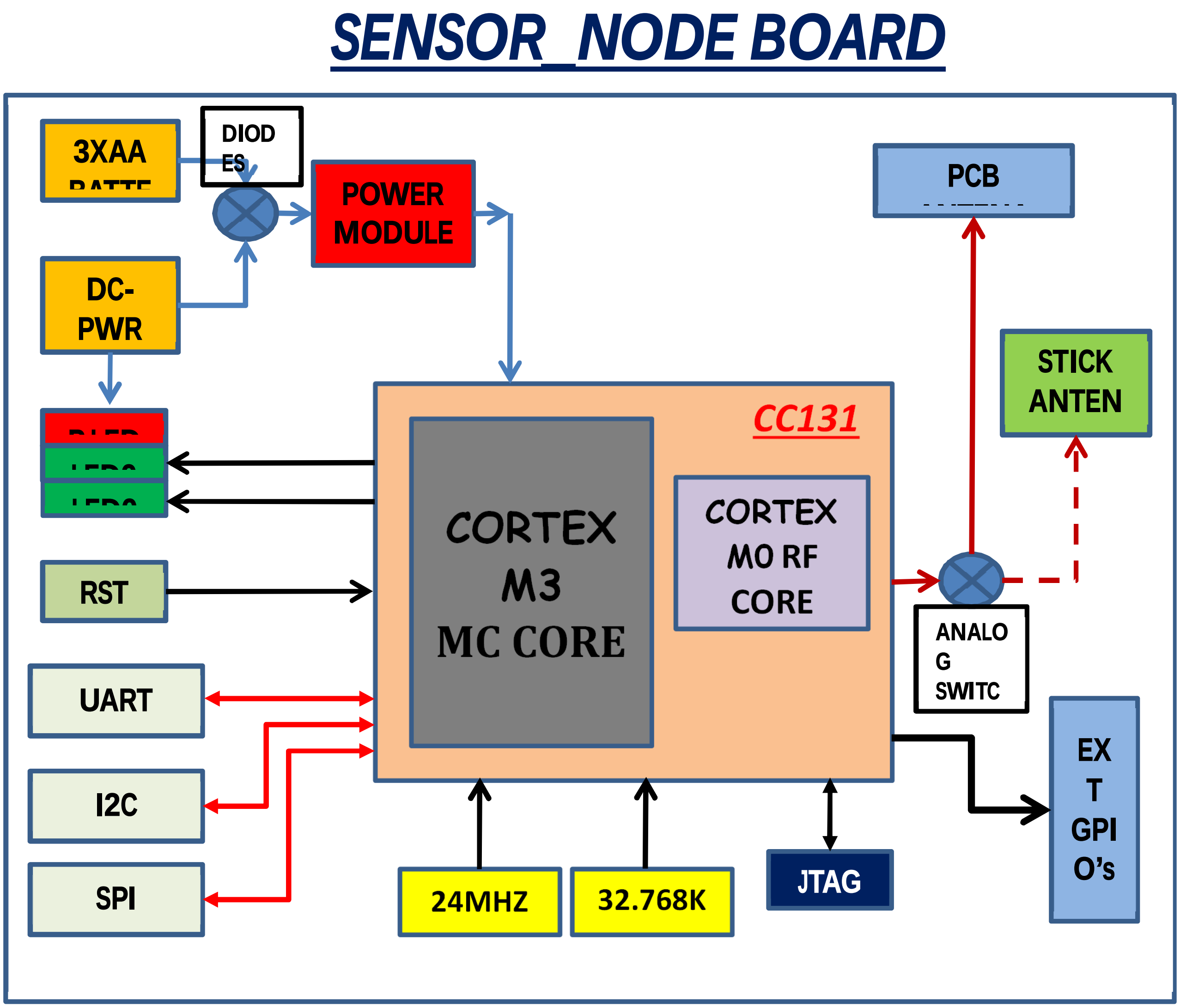


Figure-3: Block diagram of sensor node board

The CC1310 device combines a flexible, very low power RF transceiver with a powerful 48-MHz Cortex-M3 microcontroller in a platform supporting multiple physical layers and RF standards [11]. A dedicated Radio Controller- Cortex-M0 handles low-level RF protocol commands that are stored in ROM or RAM, thus ensuring ultra-low power and flexibility. The low-power consumption of the CC1310 device does not come at the expense of RF performance; the CC1310 device has excellent sensitivity and robustness (selectivity and blocking) performance [14]. The CC1310 device is a highly integrated, true single-chip solution incorporating a complete RF system and an on-chip DC-DC converter. Sensors can be handled in a very low-power manner by a dedicated autonomous ultra-low-power MCU that can be configured to handle analog and digital sensors; thus the main MCU (Cortex-M3) can maximize sleep time [9]. The CC1310 power and clock management and radio systems require specific configuration and handling by software to operate correctly, which has been implemented in the TI-RTOS (Texas Instruments-Real-Time Operating Systems**)**. TI recommends using this software framework for all application development on the device.

The sensor node board designed with minimal interfaces in order to save the power. The board contains Cortex M3 core which is used to connect different sensors by using interfaces - GPIO, Single-wire, I2C and SPI. ADC capability is helps to connect wide variety of analog sensors by using GPIO.

A. Power Supply

Sensor node board was feed the power from two different sources

Through DC-DC power adapter for desktop applications

Through 3XAA batteries for energy harvesting applications

Power module is designed such way that it will source the power either from AA batteries or DC-DC adapter by using low-power loss, high efficiency, high current capability and low forward voltage drop for use in low voltage and polarity protection Schottky diode for high availability functionality [12]. The DC-DC adapter power source is indicated with red colour LED, where as battery power source is not provided any LED indication option, since LED's consume some amount of current when we use the sensor board for the energy harvesting applications.

B. LED's and RST_SW

Sensor board is interfaced with 2 LED's for the purpose of showing the system status of (for future use) RF TX and RX working status, and one switch used for the RESET and two more switches are interfaced for external interrupt purpose (for future use).

C. Clocks

Sensor board is equipped with two clocks. 24 MHZ is used for the system requirement purpose and 32.768 KHZ is used for the internal RTC purpose.

D. JTAG

Sensor board is having JTAG interface for the internal core programming and internal flash programming purpose. The sensor node code program will be done by using this interface.

E. RF Interface

The sensor node is designed by using CC1310, which have two different ARM cores in a single chip. CC1310 have one Cortex M3 is for the purpose of peripheral control and supplying of internal power to RF core, and the other core is ARM Cortex M0 is dedicatedly used for the RF functionality with following features. The Cortex M0 core is with 4 KB RAM and ROM of data rate of 4000 kbps. Receiver Sensitivity is –124 decibel milli-watt (dBm) using long-range mode, –110 dBm at 50 kbps, Selectivity is 52 dB; and blocking performance is 90 dB. Cortex M0 is also have programmable output power up to +14 dBm with single-ended or differential RF physical Interface to Stick Antenna. The advantage of this RF core is, having Wireless M- Bus and IEEE 802.15.4g PHY [4, 8].

For the sensor board, we used IEEE 802.15.4 PHY interface in order to receive and transmit the RF data packets. The RF interface used with single ended RF physical interface with two optional interfaces.

1) *PCB Antenna:* Choosing the correct antenna for the application is crucial if the optimum range is to be achieved. Similarly, for a given distance, the power can be reduced on the transmitter side if the optimum antenna is chosen. Antennas are categorized under the operating frequency (169 MHz, 433 MHz, 868 MHz or 2.44 GHz) and then the type of antenna (PCB antenna, Chip antenna and Wire antenna) [11]. The main focus is on PCB antenna, since these are low-cost and is designed in PCB with helical in shape.
2) *Stick Antenna:* Sensor board is having provision to connect any third party designed Stick antenna with 3dB or 5dB antenna and achieved 800 meters of distance with four concrete walls penetration in line of sight (LOS).

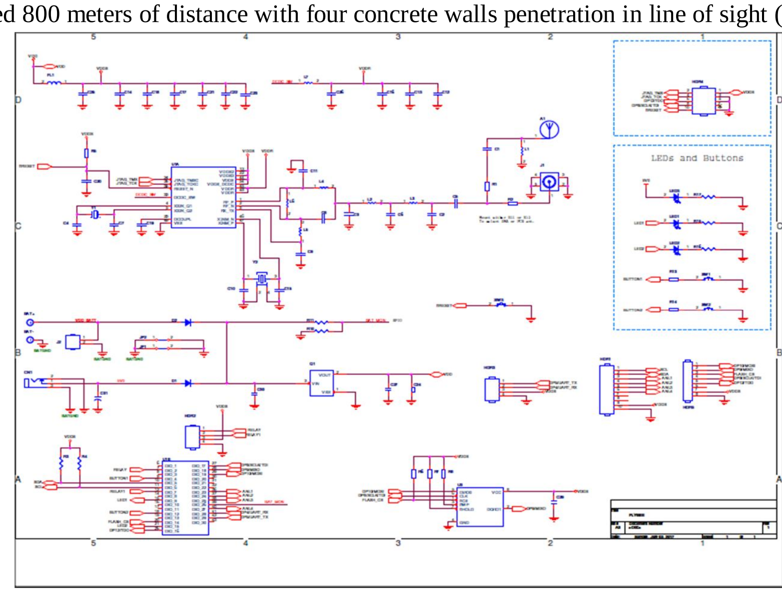


Figure-4: Implementation of the circuit

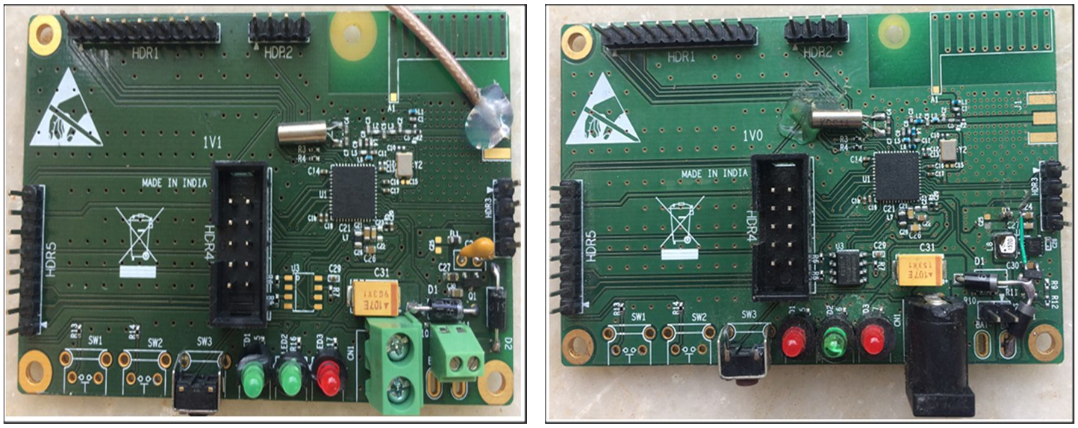


Figure-5: (a) sensor node (b) gateway node

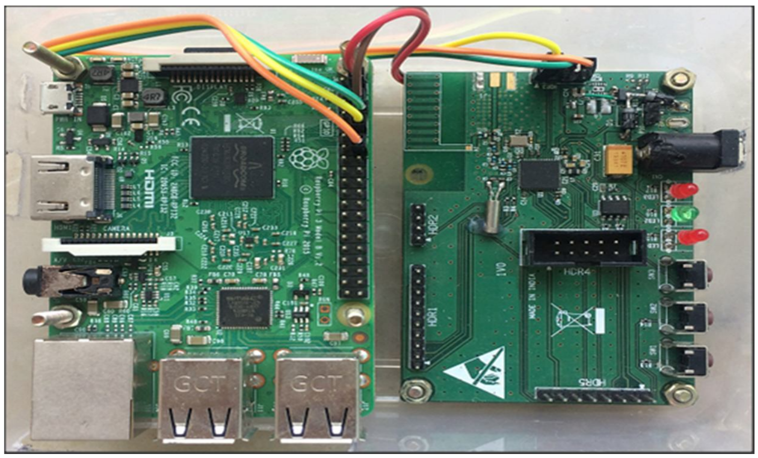


Figure-6: gateway connected with raspberry pi

IV. THEORY OF OPERATION

As shown in figure -6, the sensor node is interfaced with sensor nest by I2C protocol. The Sensor nest is combinations of multiple sensors are mounted in a single board and connected via I2C two wire interfaces [13]. For the current application, we interfaced HDC1008 and BMP180 to measure the atmospheric parameters like Temperature, Humidity and Pressure.

Sensor Node board reads temperature, humidity and pressure from "sensor Nest" by I2C interface and placed in a customized packet called "Sensor Packet". The sensor packet will be sent to Gateway in pre-defined time slots like 60 seconds, 180 seconds or 300 seconds via RF transmitter by using 802.15.4 wireless Phy [7, 9]. Figure-7 shows the packet format, the sensor packet will be merged with the IEEE 802.15.4 packet format.

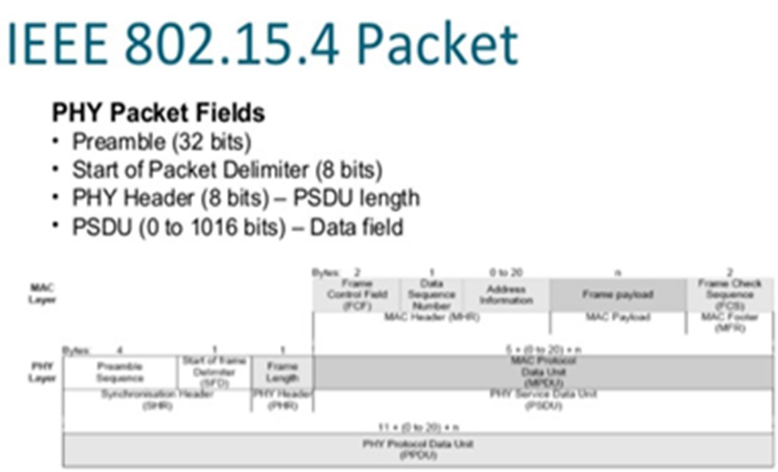


Figure-7: IEEE 802.15.4 Packet format

The transmitted RF packet will be received by the gateway node which is integrated with raspberry Pi through UART interface. Received packet by Gateway will be processed the packet and send to cloud via internet by using Wi-Fi (wireless 2.4 GHz) or Ethernet port [14]. Raspberry Pi keeps packet into cloud server storage by using cloud protocols- MQTT (MQ Telemetry Transport). We used Raspberry Pi (is loaded with ubuntu 12.0 Linux operating system) to communicate with cloud by using MQTT IoT Protocol [2, 5] .The received data by Raspberry Pi is placed in cloud storage and saved n common database. The common database can be accessed by using different MQTT publish / subscribe to protocols to access the data by mobile application or web-service by using REST API's. The same can be achieved by using third party vendors like HiveMQ, CLOUDMQTT and Amazon web services. Figure-8 shows the flowchart for the entire operation.

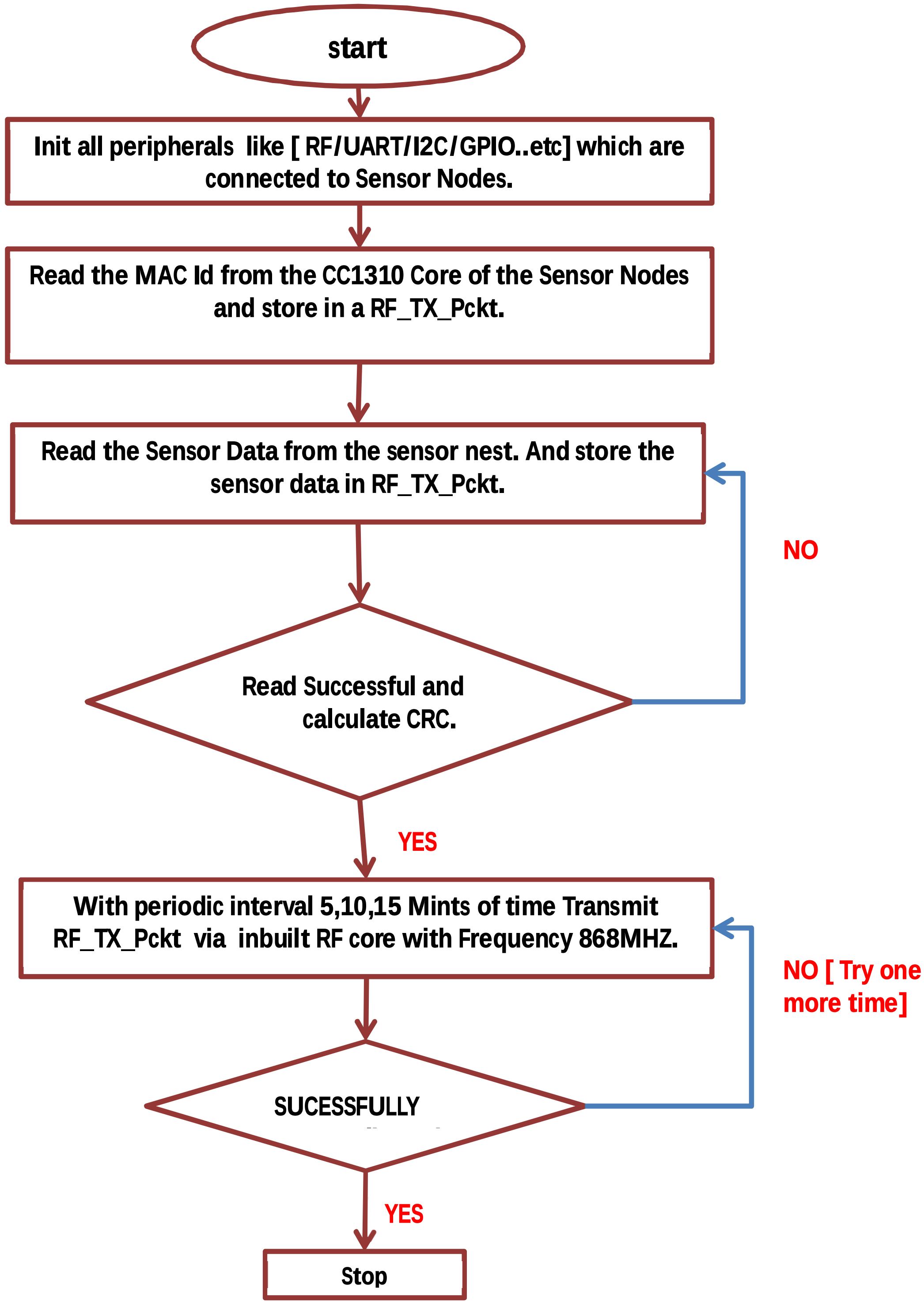


Figure-8: Flow chart – Describes the entire operation

V. BATTERY LIFE CALCULATION

The computation of battery life for this reference design is compelled by the myriad of different applications and use conditions possible for this type of sensor node [10]. The approach taken here computes the average between two different expected likely use conditions and the worst case use condition. These use conditions are described as follows:

A. Case-1: Worst Case

Ten motion events per hour for every hour for the life of the battery. Each of these motion events is a walk through event meaning that an interrupt is generated by a body moving through the field of view, allowing the active timer to expire and re-enter shutdown mode before the next event occurs.

B. Case-2: Busy Room in an Office Environment Case

14 hours in shutdown, 10 hours with constant motion such that the active timer does not expire once activated.

C. Case-3: Room with Intermittent Motion During Business Hours Case

14 hours in shutdown, 10 hours with 10 motion events per hour every hour. Similar to case-1, each of these events is a walk through event. Another available knob in the optimization of battery life for this reference design is the active timer value [12]. The default value in firmware is 1 minute. Since this value can be modified, the battery life for case-1 and case-3 are recalculated using a value of 30 seconds to show the expected improvement. The equations for the expected battery life for the three cases in consideration are as shown in figure-9.

General lifetime equation:

$$\text{Lifetime} = \frac{\text{Battery Capacity}}{\text{Shutdown Current} + \text{Event Current}} \times \frac{1}{8760\text{hr / yr}} \times \text{Derating Factor}$$

where

- $\text{Event Current} = \left[(\text{Delta Current} \times \text{Active Mode Duty Cycle}) + (\text{Radio Transmission Current} \times \text{Duty Cycle})\right] \times \text{Number of Events}$

Case 1

$$\text{Lifetime} = \frac{240\text{ mAH}}{\left\{1.65\ \mu\text{A} + \left[\left((645\text{ nA} \times 60\text{ s / event}) + (1.12\text{ mA} \times 104.1\text{ ms / event} \times 2)\right) \times \frac{10\text{ events / hr}}{3600\text{ s / hr}}\right]\right\}} \times \frac{1}{8760\text{ hr / yr}} \times 0.85 = 9.68\text{ years}$$

Case 2

$$\text{Lifetime} = \frac{240\text{ mAH}}{1.65\ \mu\text{A} + 645\text{ nA}\left(\frac{10\text{ hours}}{24\text{ hours}}\right) + \left[(1.12\text{ mA} \times 104.1\text{ ms / event}) \times \frac{2\text{ events / day}}{(3600\text{ s / hr})(24\text{ hr / day})}\right]} \times \frac{1}{8760\text{ hr / yr}} \times 0.85 = 12.12\text{ years}$$

Case 3

$$\text{Lifetime} = \frac{240\text{ mAH}}{\left\{1.65\ \mu\text{A} + \left[\left((645\text{ nA} \times 60\text{ s / event}) + (1.12\text{ mA} \times 104.1\text{ ms / event} \times 2)\right) \times \frac{10\text{ events / hr}}{3600\text{ s / hr}} \times \frac{10\text{ hours}}{24\text{ hours}}\right]\right\}} \times \frac{1}{8760\text{ hr / yr}} \times 0.85 = 11.85\text{ years}$$

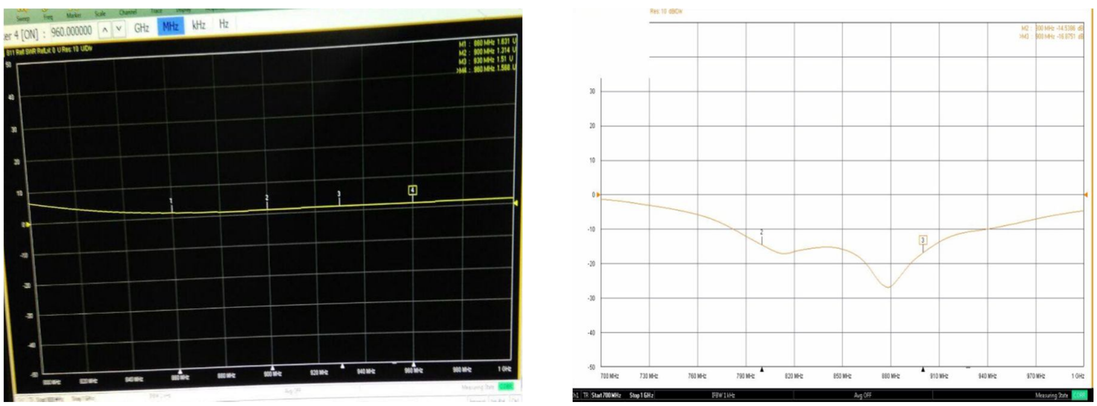
Figure-9: Equation for calculation of battery life-time

VI. RESULTS AND DISCUSSION

Low-power sensor node for IoT applications with LoRa capability was successfully designed and tested. The main features of this design were its low power consumption, long distance communication and secure data transmission. This design uses unlicensed radio spectrum in the Industrial, Scientific and Medical (ISM) bands to enable low-power, wide area communication between remote sensors and gateways connected to the network. This standard-based approach to building a LoRaWAN allows for quick set up of public or private IoT networks anywhere using hardware and software that is bi-directionally secure, interoperable and mobile provides accurate localization [13]. This wireless RF technology is being integrated into cars, street lights, manufacturing equipment, home appliances, agriculture and wearable devices. LoRa technology is making our world a smart planet [5, 6].

Figure-10 shows power consumption at various levels during the operation of the designed instrument, in all the above said three cases, it consumes not more than 0.15 mA. The average expected battery lifetime for this reference design with the active timer set to 1 minute is 11.22 years. Re-calculating, case-1 and case-3 with an active timer set to 30 seconds is 9.9 years and 11.99 years respectively. The average expected battery life with an active timer value of 30 seconds is therefore 11.34 years. By inspection, decreasing the active timer to 17 seconds or less will yield a worst case estimated battery lifetime of at least 10 years.
Graph-1: RF power measurement when external stick antenna attached.
In this research work, the circuit-level implementation phase of the architecture was completed, and currently we are in the process of validating the design decisions.

Figure-10: Power consumption results shown by multimeter in milli-amperes for the above said cases respectively



Graph-1: RF power measurement (when external stick antenna attached) X-axis: Frequency - scale: 30MHz/Div Y-axis: RF power - scale: 10dB/ Div

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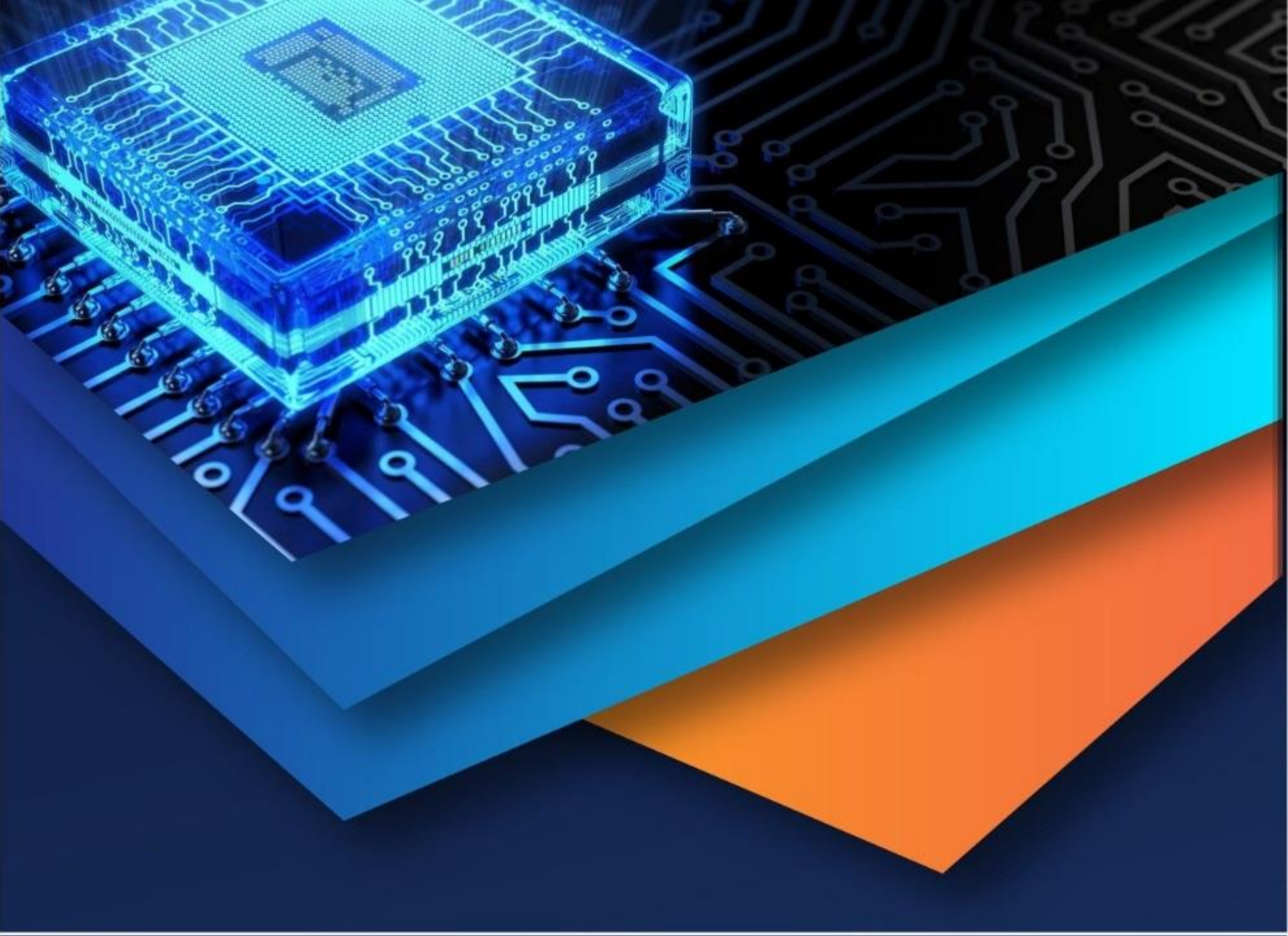

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