Low-Power Active RFID System Using nRF24L01

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Abstract— A low-power active Radio Frequency Identification (RFID) system based on nRF24L01 RF transceiver is designed and implemented. The nRF24L01 is used to act as both reader and active tag of RFID system respectively. The nRF24L01 is chosen due to its low-power and it also operates at 2.4 GHz in which lies on ultra-high frequency (UHF) band. Significant power consumption is reduced by operating in standby mode, transmitting mode and receiving mode at 29µA, 10.25mA and 6.92mA current rating respectively. In addition, nRF24L01 can interact with microcontroller which retain the circuit simplicity.

Keywords—Radio Frequency Identification (RFID); nRF24L01; Standby Mode; Active Tag

1. INTRODUCTION

RFID is the wireless use of electromagnetic fields to transfer data, for the purposes of automatically identifying and tracking tags attached to objects. Since 1980s, it has been a hot automatic identification technology. What makes it so widely used is because of its low price and power consumption, small sizes, and etc. RFID system consists of two main parts which are tag and reader. Tags have unique identifications stored in them and equipped to the objects meanwhile a reader executes the tag interrogation process to interpret an object by releasing wireless RF signals to interpret the identification (ID) of the equipped tags. Aside of RFID, barcode was also commonly used. From automatic identification perspective, both share a couple of common characteristics. One of the characteristic of RFID over barcode is that it can read multiple items equipped with RFID tags simultaneously. Unlike earlier barcode technology, RFID enables identification from a distance without the requirement of line of sight [1]. This feature is crucial to the application that involves reading and identifying important objects such as in supply chains.

In the applications where power supply is limited, power consumption is always a remarkable criterion in the design of tags. One drawback of the active RFID systems is the precise synchronization requirement between the reader and tags. Tags are put to sleep mode most of the times in this study, in which all circuitry of tags are turned off. One tag is only activated by the reader command in the small fraction of one reading cycle. So, tag is basically inactive for most portion of the time.

Similar studies on power consumption were conducted in [2]-[5]. These studies have used different approaches and equipment. However, the problem with these studies are they have significantly higher power consumption. In this paper, we optimize the complexity of RFID system by using nRF24L01 RF transceiver.

Method of power supply equipping in tags is one of the most important classification of RFID. Passive tags don't have any internal power source. They will only be activated when the reader is around by withdrawing the energy from the reader wave. Short-range applications such as smart cards is the application that this type of RFID is used for. Contrary to passive RFID tags, active RFID tags are designed having their own power source, which is our work is all about. They even act out the range of magnetic field of the reader. RFIDs are designed at the standard frequency ranges: low-frequency (LF), high frequency (HF), Ultra High Frequency (UHF) and Microwave. In the comparison of different types of RFIDs, lower frequencies don't penetrate or transmit around metals, handle only small amounts of data and slow the data transfer. The main advantages of microwave frequencies are smaller size, smaller antenna and higher data range than other frequencies [6].

The automation such as in freight consignment in harbors is essential due to advance technology and improving the economy of the world as a whole. Large amount of time and cost will be restored and the safer transportation method is provided by using RFID. The RFID interrogate zone should be large enough to cover a broad range of huge area at the ports [7,8].

2. HARDWARE DESIGN

A. Control Unit

The Arduino Uno was selected as the microcontroller unit (MCU), which is a cost-efficient device and has low-power technology from Nordic Semiconductor. It also based on ATmega328P chip. It is a low-power, highly integrated, high-performance and applications-oriented. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. The block diagram of the microcontroller is shown in Figure 1 [9]. The MCU is used for data management and processing, interaction with the reader and tags. It operates all the commands for the reader and tags through libraries uploaded in its flash memory. The communication with the reader and tags is provided via USB interface. Other communication processes with the host system are carried out by USB interface.

B. RFID System

The project is focus on nRF245L01 RF transceiver as RFID system which are consist of reader and tag respectively. It operates at 2.4 GHZ which classified as UHF. It has low power consumption which is very helpful for the work. It also has all the data link layer operation and physical layers. For the project, it is responsible for transmitting (TX) and receiving (RX) data. It also used as data storage. Just in case if internal storage memory is insufficient, additional external storage can be used as backup. One of many the benefits of using nRF24L01 is that it only needs small amount of peripheral devices such as rectifier, crystal oscillation circuit, filter circuit and reset circuit. Figure 2 below shows the circuit diagram of an nRF24L01 and microcontroller. Figure 3 shows the block diagram of nRF24L01 [10].

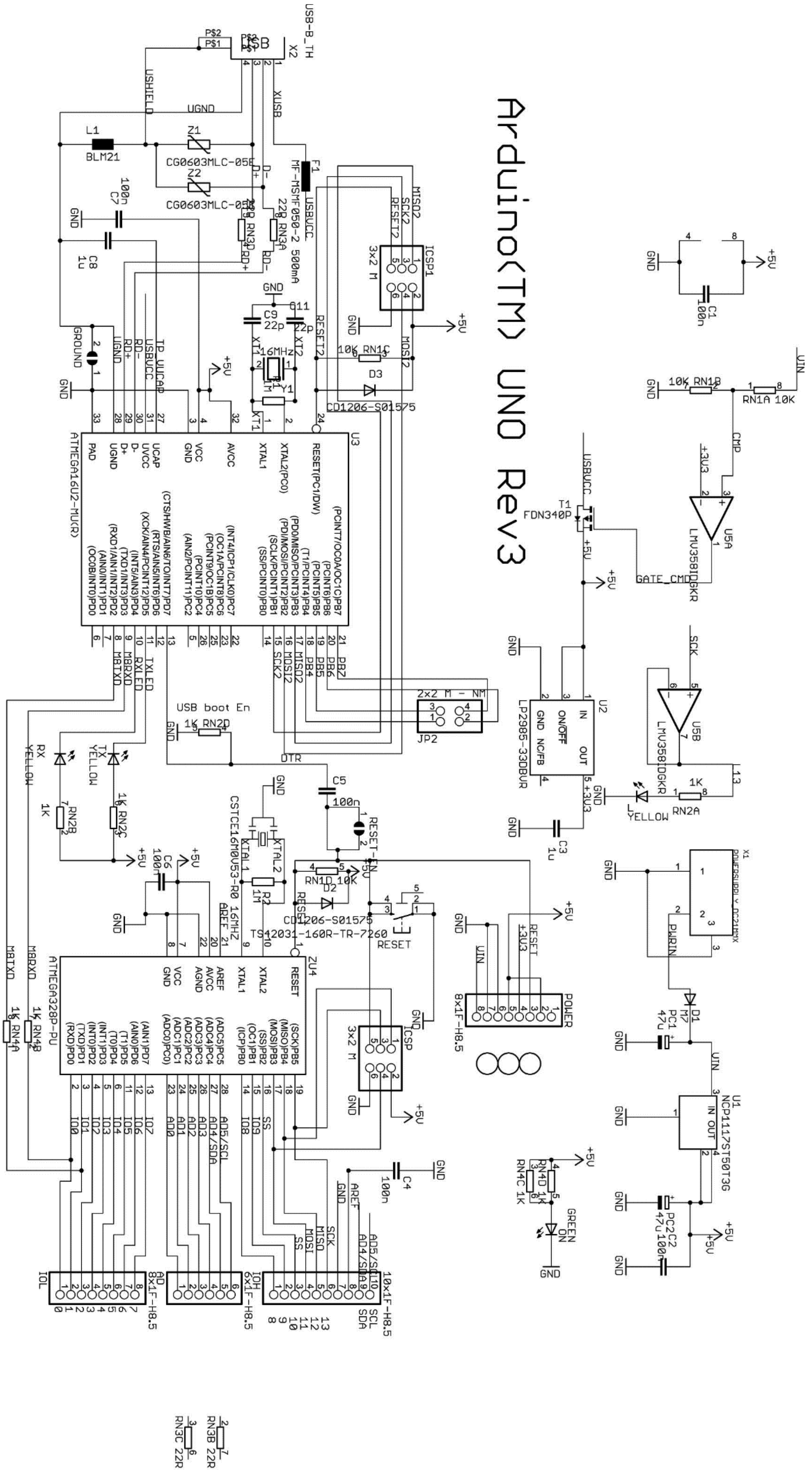

Figure 1: The block diagram of the microcontroller [9]

The SPI bus for nRF24L01 are CSN pin, SCK pin, MOSI pin, and MISO pin. These pins responsible for communication between microcontroller and nRF24L01 as they stimulate SPI bus timing sequence. These four pins also connected to 7 pin, 13 pin, 11 pin and 12 pin of microcontroller respectively. Other important pins are IRQ pin and CE pin. Both are connected to 6 pin and 7 pin of microcontroller respectively. IRQ is an interrupt pin. The nRF24L01 has an active low interrupt IRQ pin. The IRQ pin is activated when TX_DS IRQ, RX_DR IRQ or MAX_RT IRQ are set high by the state machine in the STATUS register. The IRQ pin resets when microcontroller writes '1' to the IRQ source bit in the STATUS register. The IRQ mask in the CONFIG register is used to select the IRQ sources that are allowed to assert the IRQ pin. By setting one of the MASK bits high, the corresponding IRQ source is disabled. By default all IRQ sources are enabled. CE pin represents the activity of the nRF24L01. Basically when CE mode is set as high, the current mode is either TX mode or RX mode. However, when CE pin is set as low, it is currently in standby mode.

RF circuit can communicate with microcontroller in the shock burst mode meanwhile nRF24L01 chip at the low speed. Arduino Uno can still access FIFO register without activation that eventually reduces the overall power consumption. RFID system that is implemented has all capabilities of a microcontroller and RF transceiver module in the same single integrated circuit chip. So, the function of all RF processing and all baseband can be executed together. On top of that, it can prevent any noise when interfacing process between microcontroller and RF transceiver.

Normally, RFID tags are located in the environment where the resource is deficient as memory storage, computational capacity and power consumption are limited. Some issue need to be addressed when dealing with active RFID [11]. The lifetime of active RFID tag is key to overall system performance especially in power department. Since active RFID tag is powered by internal supply, how long the lifetime of the tag simply depends on the internal supply itself. With peak RX/TX currents lower than 14mA, a sub µA power down mode, advanced power management, and a 1.9 to 3.6V supply range, the nRF24L01 provides a true power saving solution enabling months to years of battery lifetime when running on coin cells or AA/AAA batteries. Hence, explains the reason behind why is nRF24L01 is chosen in the first place. It has low-power and with microcontroller that can put the system to power down mode to save power.

3. SOFTWARE DESIGN

A. RFID System

The RFID system is a communication system between two non-equivalent nodes: the RFID reader and the RFID tag. The most important function of the software design is to communicate between tags and reader [12]. When tag is absent, a lot of power loses occur due to constant process of powering-up the component blocks of the reader for example the demodulator and RF generator. This is basically a norm due to the typical system tries to read/detect the tag. So, in order to save power, algorithm and hardware to detect the presence of the RFID tag is proposed and subsequently will give continuous supply to all the blocks of the circuit in the presence of the tag.

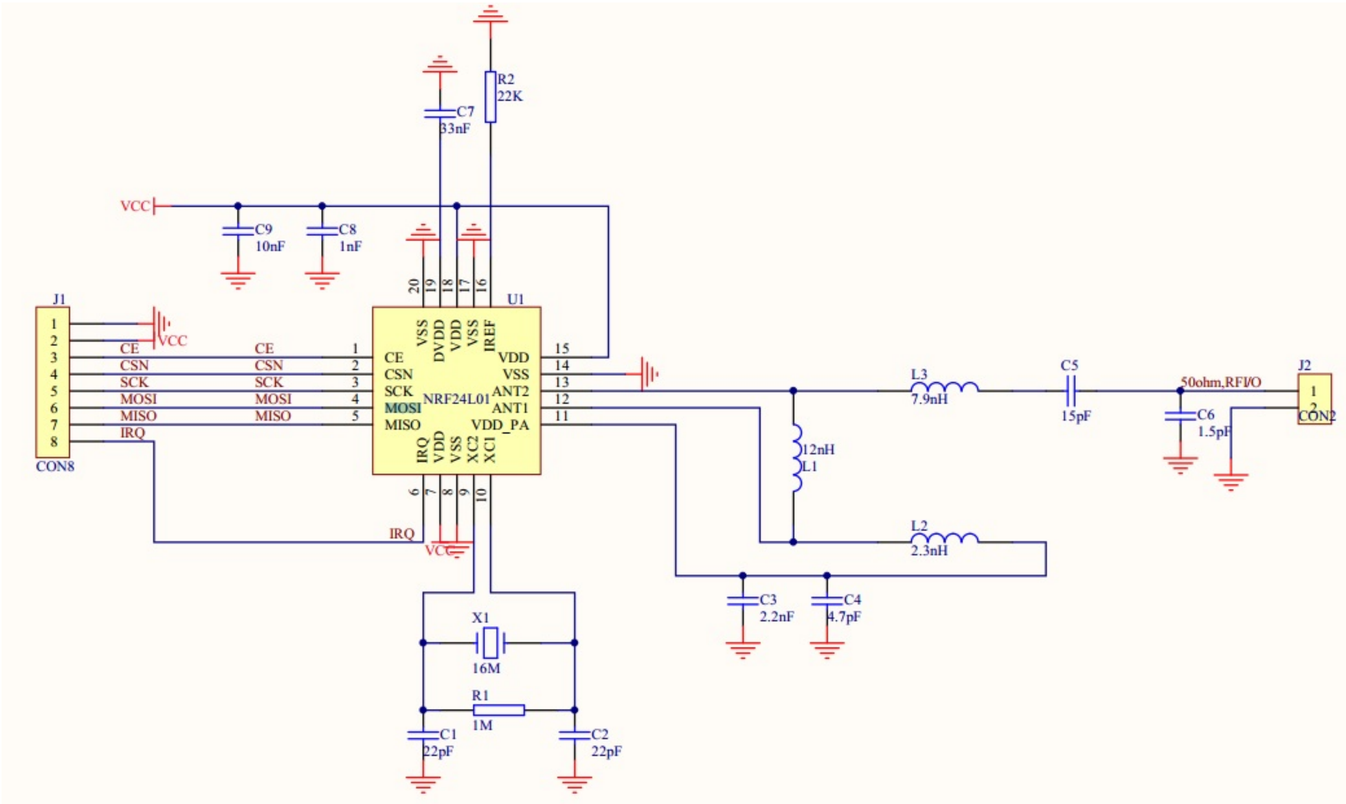

Figure 2: Circuit diagram of nRF24L01 and microcontroller

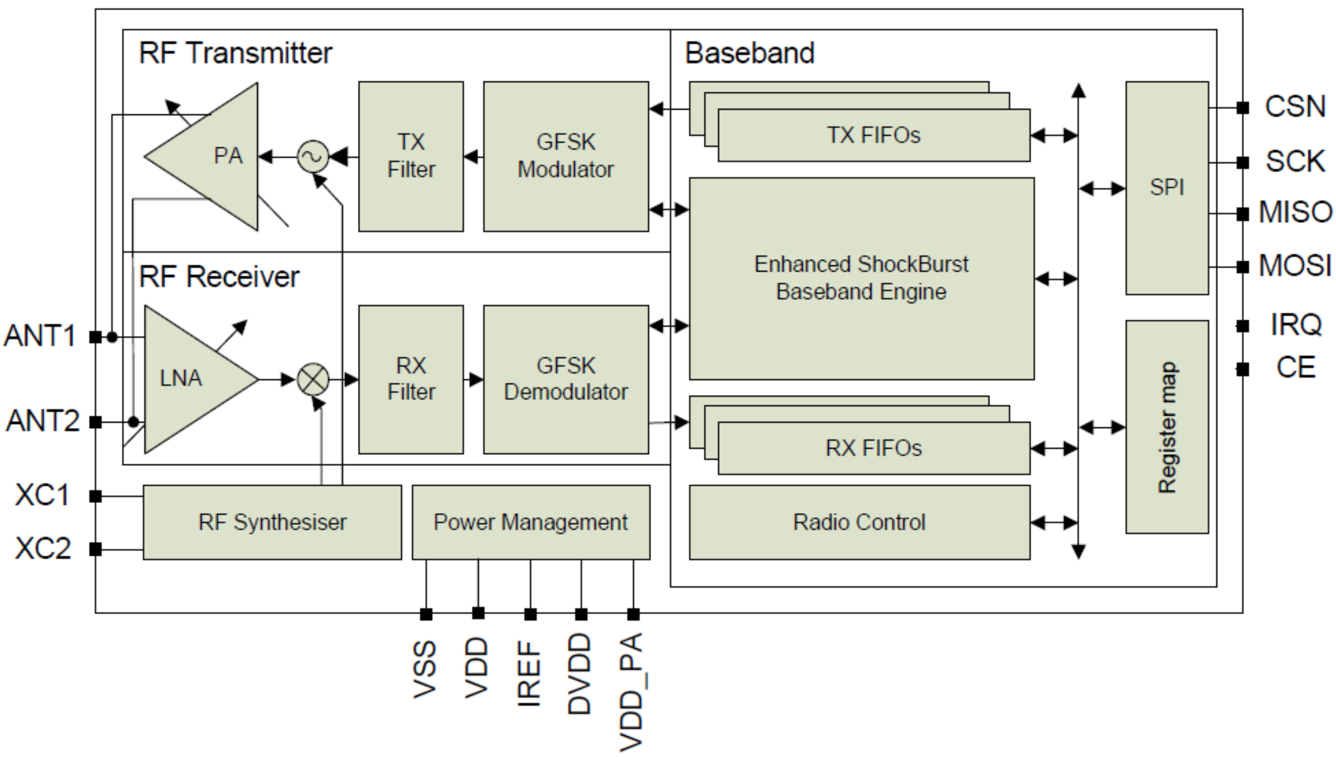

Figure 3: Block diagram of nRF24L01 transceiver [10]

B. Communication Protocol

Reader can detect easily when just one tag in its range. However, when multiple tags present in the reader's range of transmission, data-collision will occur and this will make the reader unable to identify the tags present. This problem occur due to the tags attempt to communicate with the reader simultaneously. We used ALOHA-based protocol as the foundation of our proposed-own protocol. nRF24L01 RF transceiver nature of automatic transmission is essential to the project to overcome the anti-collision problem. The Figure 4 below shows the flow chart of anti-collision protocol algorithm.

The format of data link layer of nRF24L01 are payload field, CRC field (in Shock-Burst™), packet control field, preamble field and address field. After the system receives the packet, both CRC and preamble bits are automatically created before the packet is transmitted and disassembled.

4. EXPERIMENTAL RESULTS

To get the idea of how RF signal of nRF24l01 react to the distance between them is important. In Figure 5, a distance (20 cm) is set properly for nRF24L01 signal strength. By using Keysight's spectrum analyser, the outcomes is very precise. The distance is the critical parameter in power consumption. The rest distances are shown in Figure 6. As the result shown, the as the distance further, the signal strength of nRF24L01 is weaker as expected. Figure 7 shows the power consumption of nRF24L01 in 3 modes, standby mode, transmit TX mode and receive RX mode.

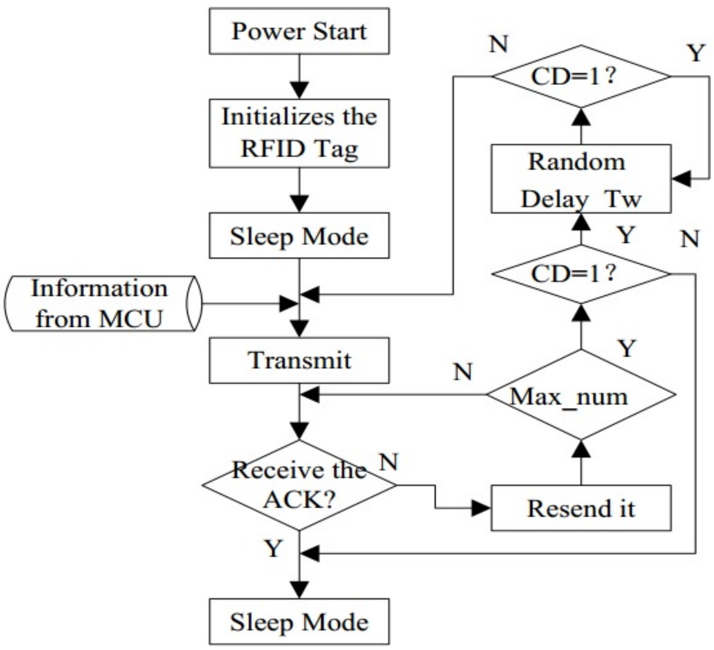

Figure 4: Flow chart of proposed anti-collision protocol algorithm.

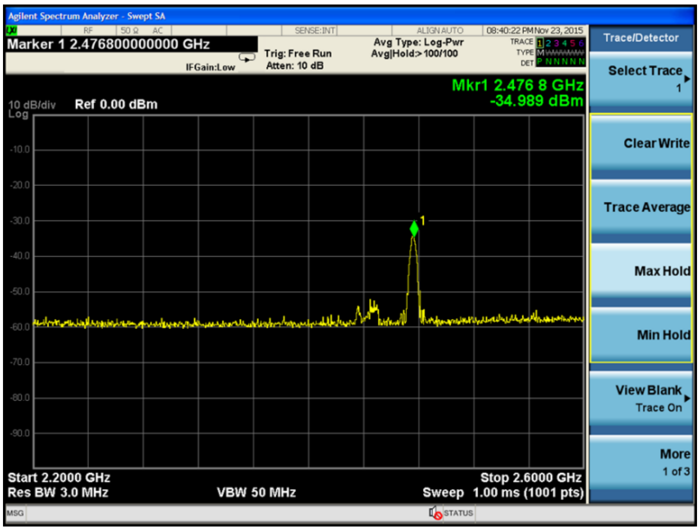

Figure 5: nRF24L01 Signal strength versus distance (20 cm)

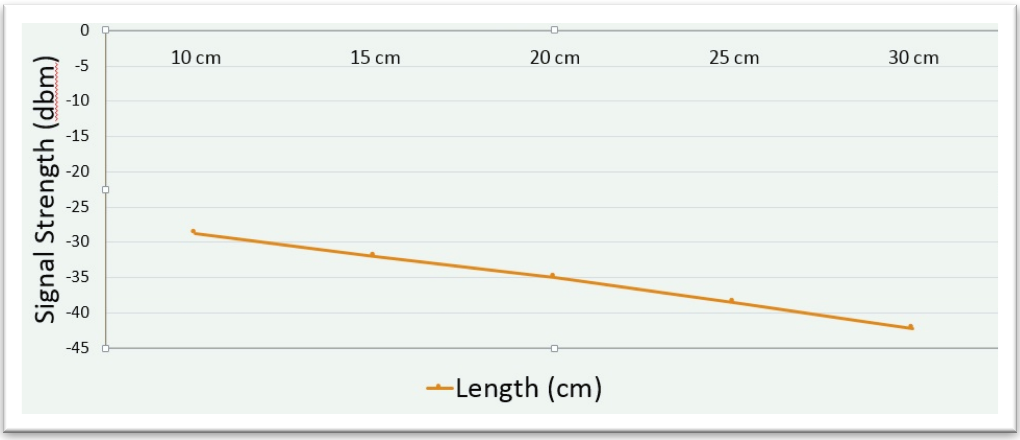

Figure 6: nRF24L01 Signal strength versus various distances

References	*Standby Mode (µA)*	*TX Mode (mA)*	*RX Mode (mA)*
This work	29	10.25 at 0dBm output power	6.92 at 2Mbps air data rate
[5]	32	11.3 at 0dBm output power	12.3 at 2Mbps air data rate

Table 7: Result comparison of current consumption in three different modes

5. Conclusion

In this work, a low-power RFID system based on nRF24L01 RF transceiver is implemented and designed. The power consumption of the system is reduced due to tag is standby mode in most of times. Current consumption of three modes at 29µA (standby mode), 10.25mA (TX mode) and 6.92mA (RX mode) are significantly lower than reference [5]. A couple of reference values and the circuit diagram are given. The chosen nRF24L01 as active RFID tag has fast read-write-speed and high data rate. This system can be used for various applications such as activation access, vehicle transportation and freight tracking and so on.

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