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CubeSat Communication System, a New Design Approach

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***Abstract*— Many universities are involved in projects related to the design, assembly and operation of nanosatellite (CubeSat) to increase the experience level of researchers and students. The CubeSat is a new concept emerged after year 2000, new standards and regulations were introduced by the different organizations and institutes to control the process of designing, building and lunching the CubeSats. This paper introduces a new design approach for the CubeSat communication system. The design parameters have been carefully chosen for this purpose. The main microcontroller is an Arduino microcontroller that communicates with a commercial of-the-shelf transceiver (RFM22), a half-duplex link which has been designed after performing the required link budget calculations. The frequency chosen for operation is the regulated 435 MHz, with Tx power of 100 mW for the space unit and a data rate of 1200 b/s and 9600 b/s for beacon and payload signals, respectively. The communication algorithm, beacon and payload encoding and decoding algorithms have been designed using the Arduino programming language and a new packet coding technique introduces to increase the communication link reliability.**

***Keywords*— CubeSat, Communication Subsystem, Terminal Node Controller, Nanosatellite, RFM22, KufaSat**

I. INTRODUCTION

The CubeSat is a nanosatellite with more extreme limitations than other satellites in its class in terms of mass, power and volume standards. CubeSat volume is restricted to (10 cm^3), with a mass of no more than 1.33 kg and commonly uses commercial of-the-shelf (COTS) components for its electronics [1]. Many CubeSats have been built and launched into space. To reduce space junk they are usually placed in low earth orbits and fall back to earth within a few weeks or months [2]. The communication system is one major limiting factor for CubeSats. During the previous years a lot of CubeSats have been designed and lunched into orbits. There are common features and some differences between these communication systems.

Based on the information collected from some CubeSats like $50SAT, PW-Sat, Goliat, SwissCube-1 and others the common used choices of regulations and communication system parameters are as follows: the regulated UHF band is the most used in terms of frequency and the 1U CubeSat in terms of size, amateur band is the most used frequency band. This will aid in the choice of the system parameters as the common used choices by more than one team are the safest option to avoid unexpected results [1, 2].

The most important limitation of the communication system for the CubeSat is that transmit power must not exceed 1 W from the space unit. The frequency should be one of the regulated VHF, UHF or S-Band allocated for CubeSat missions, a beacon signal transmission is necessary, and the minimum information data rate is 1200 b/s. The communication protocol AX.25 was introduced by the amateur community and is available for free and widely used for encoding and decoding purposes [1, 2]. Following the regulations, CubeSats are operating in the low earth orbit which allows several universities to develop and place in orbit student-designed, built and operated CubeSats by investigating a scientifically exciting phenomena [1, 2].

The small size of the CubeSat makes it difficult to find a ready-made radio transceiver for communications and the limited surface area restricts the amount of the power generated from the solar panels, restricting thereby the power available for the communication subsystem. Restrictions on space, time, and power necessitate that CubeSats incorporate limited payloads, slow communications links, little redundancy, and minimal information processing capabilities.

The mostly used philosophies of CubeSat design is the use of standard, easy to use, COTS components designed for non-space applications [3, 4]. This allows fast and inexpensive construction and reduce satellite complexity.

Based on these limitations, the problem is to design a vital communication link with the least size and power consumption and within the regulation of frequency, transmit power and communication window time.

The Solution was a communication algorithm designed to make use of the commercial RFM22 data transceiver combined with the Arduino microcontroller to provide a half-duplex communication link and to implement a new coding algorithm for payload and beacon data handling.

The contribution is manifested in the algorithm design of the transceiver combined with the microcontroller as a system Terminal Node Controller (TNC) to provide a software defined communication system, where the system parameters can be changed by software without modifying hardware.

The design of the communication and coding algorithms plays an important role in the success of communication process. For this reason a modification has been done on the communication algorithm based on ideas presented by the RadioHead Packet Radio library which is available online to enhance the algorithm design [5].

The ideas presented in this paper will aid in the design of the communication system of KufaSat which is an Iraqi student satellite project sponsored by the University of Kufa and it will be one the first Iraqi satellites to fly in space [6, 7].

II. DESIGN REQUIREMENTS

Based on the collected information, regulations and standards, a set of requirements must be identified before proceeding to the design process. These requirements are as follows [8, 9, 10]:

1. Since the CubeSat standard is defined for educational purposes, where budget is kept to minimum, and mission development time to be short, most of the Cubesat missions launched have chosen the amateur band as a practical choice. Following this criteria, the frequency chosen for the uplink and downlink is the UHF band operating at frequency of (435 MHz).
2. CubeSats are typically launched in Low Earth Orbits (between 300 and 700 Km above earth surface). According to KufaSat, the orbit altitude is 600 km low earth orbit (LEO).
3. The dimensions are according to the regulations and the choice of KufaSat to be 1U CubeSat (10 x 10 x 10 cm^3), so the communication unit inside CubeSat must not exceed 10 x 10 cm^2 to fit in the Cube.
4. The uplink and downlink data rate should be at least 1200bps and the preferred data rate is 9600bps for payload data.
5. The modulation scheme is FSK.
6. Designing and implementing a data packet encoding and decoding algorithms.
7. A new algorithm to generate an audible CW Morse coded beacon signal.
8. The bit error rate must be less than10^{-4}.
9. The transmission power is 100 mW (or 20 dBm).
10. The payload information is chosen to be the information collected from several sensors (temperature, humidity, brightness, magnetic field and tilt sensor). The choice of information sensor is just to prove the concept, and these information sensors will be replaced by other space-qualified equivalent and other payload sensors such as video camera.

III. COMMUNICATION SYSTEM ARCHITECTURE

The suggested communication system architecture was implemented using COTS components. The RFM22 transceiver was chosen as the main data transceiver controlled by an Arduino Microcontroller with an integrated SD card system and a group of sensors to take the measurements. The block diagram in Fig.1 illustrates the main parts of the communication system.

The adopted solution as we can observe that the uplink, downlink and the beacon signals share a common data link in a half-duplex regime at the frequency of (435 MHz). The advantages gained from this design is to reduce the size, power consumption, cost and complexity of the total system, by adopting a time sharing principle to keep the system efficient. Other CubeSat communication systems incorporate a separated beacon board for transmitting the beacon signal and also some of them chose 2 frequency bands (VHF, UHF or S-Band) for uplink and downlink. Those designs require more power, larger in size and more costly compared to our design

IV. COMMUNICATION SYSTEM PROTOTYPE

Today, CubeSats have evolved to the point where many of the encoders, modulators, filters, and decoders used by these communication systems can be implemented in software to overcome the persistent needs for increasing data rates and to make it easy to alter the system specifications without modifying the system hardware.

To increase our design flexibility to match any future requirements for KufaSat, the suggested communication system is software configurable in terms of an important system parameters including: Tx power, data rate, modulation scheme and frequency of operation. Fig.2 shows the connection among the basic elements of the proposed design.

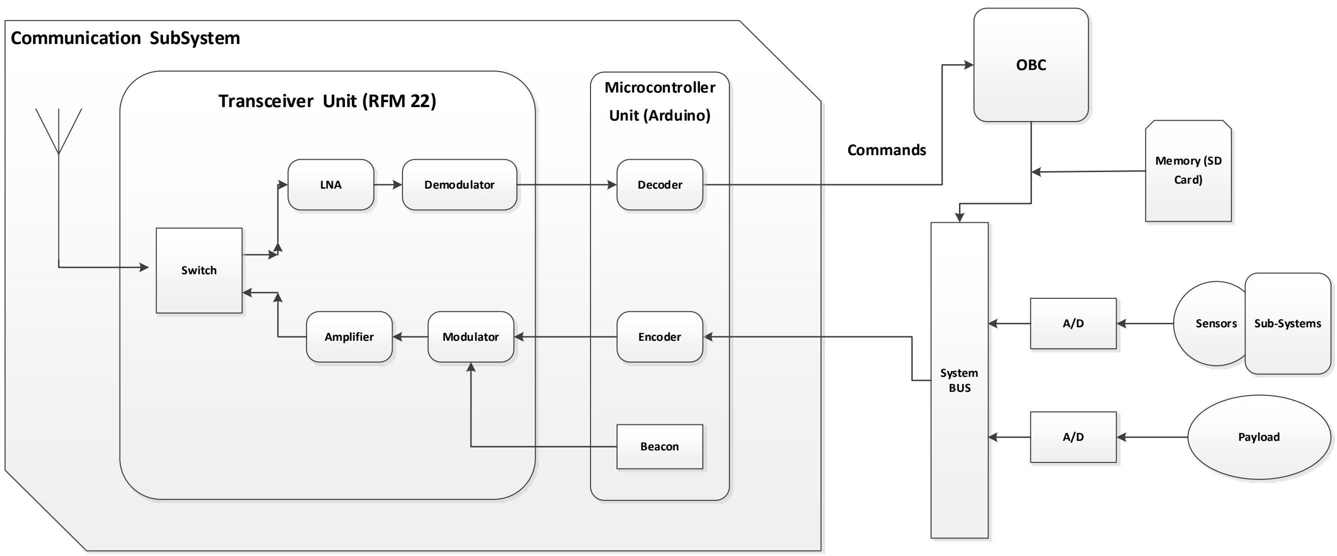

Fig. 1: A block diagram of the proposed communication system.

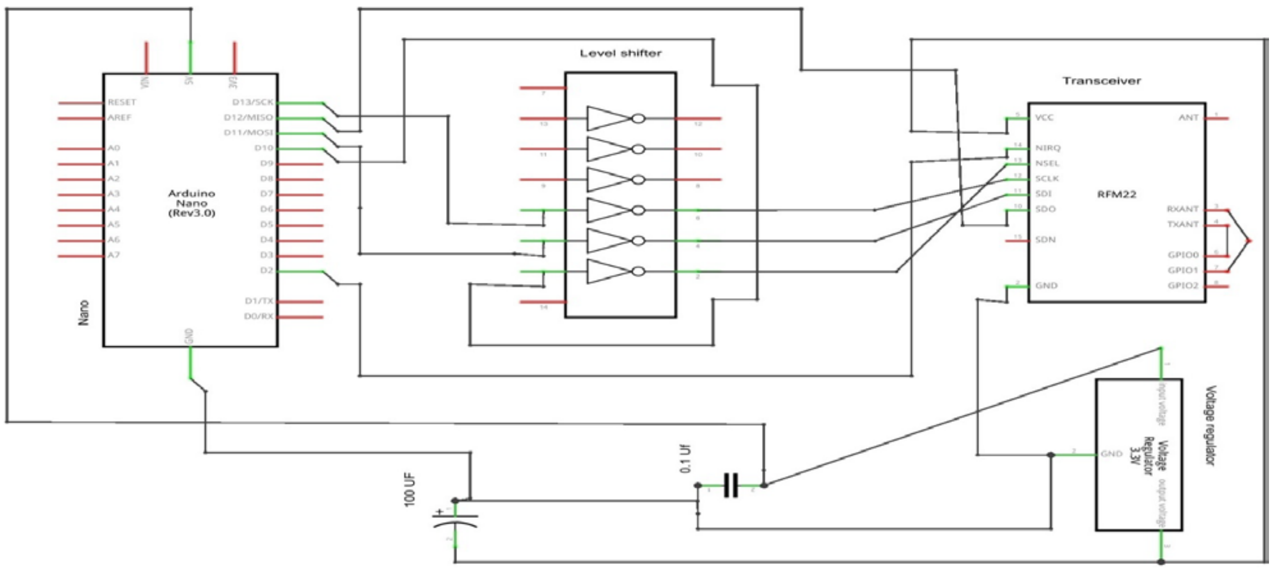

Fig. 2: Schematic of the proposed design.

A. The Microcontroller Unit

The microcontroller board chosen is Arduino board as the main TNC and it has been programmed using the Arduino programming language based on C language. The Arduino board communicates with the computer through a USB interface.

Due to size limitations the Arduino Nano has been chosen for our CubeSat communication system and the Arduino Mega for the ground station since there is no size limitations in the ground station.

B. Transceiver Unit

The RFM22 is low cost ISM transceiver module, and offers advanced radio features including continuous frequency coverage from 240–930 MHz and adjustable output power of up to +20 dBm, the communication between the Arduino and RFM22 is done by 4-wire SPI (Serial peripheral interface) connection [11]. The wide operating voltage range of 1.8–3.6 V and low current consumption (85 mA max. TX current and 0.01µA for standby) make the RFM22 an ideal solution for battery powered applications.

C. Level Shifter Circuit

Since the communication between the Arduino and the RFM22 is done by 4-PIN SPI and the operating voltage of the Arduino pins are 5 V while that of the RFM22 Pins is 3.3 V, the need for a voltage level shifter emerged for which, the 74HC4050 IC has been chosen since it is widely used in HIGH-to-LOW level shifting applications.

D. Voltage Regulator

Due to the fact that the Arduino 3.3 V internal voltage regulator is capable of providing up to 50 mA only which is insufficient for our design because the RFM22 (operating at MAX current) requires 85 mA of TX current, the LD1117 regulator has been chosen as a low-drop voltage regulator able to provide up to 800 mA of output current.

E. SD-Card Memory Unit

The communication time between the CubeSat and the ground station is limited to a communication window of approximately 5 minutes, therefore the SD Card unit has been added to temporary store payload data when the CubeSat is not transmitting to the ground station.

The complete prototype system is shown in Fig.3 where it can be seen that the whole apace unit board size is no more than 10 x 10 cm^2 in area.

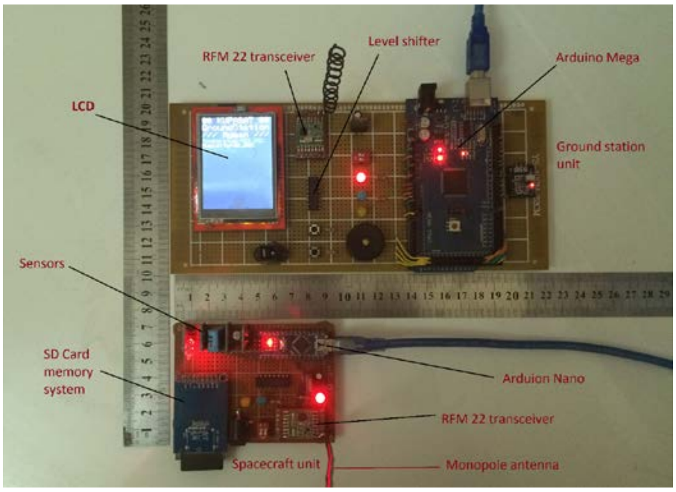

Fig. 3: Complete prototype system.

V. SOFTWARE DEVELOPMENT

The algorithm for encoding payload data, controlling the different communication units and generating the beacon signal has been devolved using Arduino programing language based on C language. It has been developed in a way to make the system and the control of its parameters flexible and re-configurable.

The ideas adopted in the designed system are readily seen in the suggested software. The major advantages of this approach are its flexibility and compatibility with future requirements as illustrated bellow:

- A single communications channel shared for the beacon, downlink and uplink signals leading to a reduction in the size, cost and complexity of the system.
- A timing protocol is introduced to control the information flow over the communication channel.
- A new representation for the Morse coded beacon signals
- A new packet coding technique for the payload data transmission.
- Increasing communication system flexibility by introducing software-defined system parameters such as Tx power, modulation, frequency and data rate. This makes the system capable of matching any future requirement by KufaSat such us increasing data rate, changing the frequency of operation, flexible transmission power handling and so on while maintaining the same designed hardware.

The details of the communication algorithm are shown in Fig.4.An explanation of the beacon generation and payload data coding is given below.

A. Beacon Generation

The Morse beacon signal in the suggested design is generated using the Arduino microcontroller and transmitted with the RFM22 transceiver unit by representing the dots and dashes by zeros and ones.

Morse code characters are all of length six or less, and each element is either a dot or a dash, so it would seem that we can store the pattern in six bits or less. Let's say that dots are zero and dashes are one, and store them so the first element gets stored in the least significant bit, and the next in the second most, and so on.

The only trick is knowing when there are no elements left, because otherwise we can't tell (for example) K (-.-) from C (-.-.). To do that, we store a single extra one after all the other elements are taken care of. Then, when we are looping, we do the following, if the pattern is equal to one, we are done (that's our guard bit). If not, we look at the least significant digit. If it is a zero, we have a dot, if we have a one, it's a dash. We then get rid of that element (by dividing by two, or shifting right) and repeat.

Each character takes only a single byte (8 bits) to store its pattern while the most significant bit is always zero till the guard bit which is one and the reaming bits are the Morse sequence, and decoding is just done in the same way. Table.1 illustrates the Morse code characters representation.

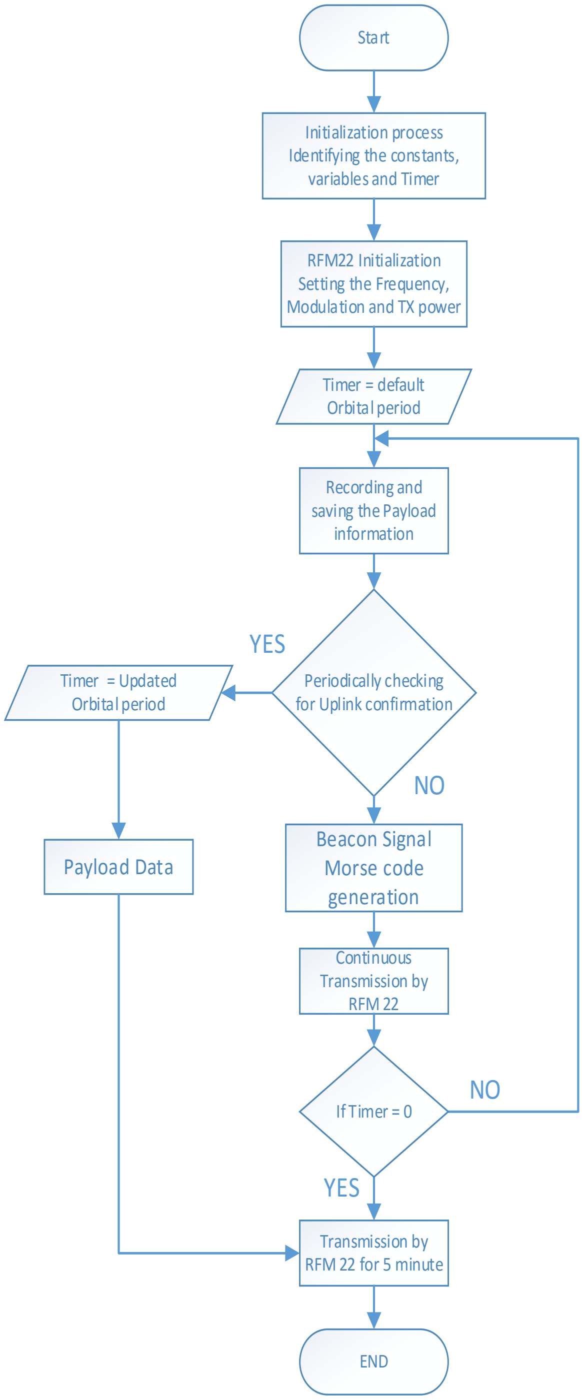

Fig. 4: A flowchart of the communication algorithm.

Table 1: Morse code representation.

Character	Decimal Value	Binary Value	Character	Decimal Value	Binary Value
.	106	1101010	Q	27	11011
,	115	1110011	R	10	1010
?	76	1001100	S	8	1000
/	41	101001	T	3	11
A	6	110	U	12	1100
B	17	10001	V	24	11000
C	21	10101	W	14	1110
D	9	1001	X	25	11001
E	2	10	Y	29	11101
F	20	10100	Z	19	10011
G	11	1011	1	62	111110
H	16	10000	2	60	111100
I	4	100	3	56	111000
J	30	11110	4	48	110000
K	13	1101	5	32	100000
L	18	10010	6	33	100001
M	7	111	7	35	100011
N	5	101	8	39	100111
O	15	1111	9	47	101111
P	22	10110	0	63	111111

B. Payload Information Coding Protocol

The important payload data is encoded in a packet format and transmitted and received as packetized messages. The suggested software provides functions for sending and receiving messages of up to 255 octets on any frequency supported by the RFM22, in a range of predefined data rates and frequency deviations. Frequency can be set with 312Hz precision to any frequency from 240.0MHz to 960.0MHz.

All messages sent and received conform to the packet format in Table.2:

Table 2: Payload packet format.

PREAMBLE	SYNC	HEADER	LENGTH	DATA	CRC
4 Octets	2 Octets	4 Octets	1 Octet	0-255 Octets	2 Octet

The coded messages are unaddressed, reliable, retransmitted, acknowledged messages. The acknowledgement process has the disadvantage of being time consuming but it's necessary to avoid any information loss, and there is no need for addressing process since we have only one transmitter sending to another.

The Preamble and the SYNC Octets are responsible for the synchronization process in the data layer by identifying the start of each frame.

VI. IMPLEMENTATION TESTS AND RESULTS

The designed system has undergone many tests to ensure its compatibility with the different circumstances and issues that may happen during its life time in space, the input and output signals are measured and recorded while different configuration parameters have been modified by software.

The results were viewed using the serial window on a laptop to view transmitted and received information and check if any errors took place. The serial port number 3 was assigned for space segment and serial port 5 for the ground station segment.

Fig.5 shows the serial window of starting transmission when no uplink is received yet and Fig.6 shows the result after the first uplink signal received. The CubeSat responds by sending the information viewed in the previous window in Fig.5 and then the Morse beacon characters are re-transmitted after the uplink command vanishes.

Fig.7 is the ground station reception confirmation, the same information has been received and decoded without missing or errors in data values.

The spectrum of the received signal is shown in Fig.8 which indicates a successful reception at 434 MHz and also after changing the frequency to 435 MHz in Fig.9. This is one of our design main advantages of being software configurable.

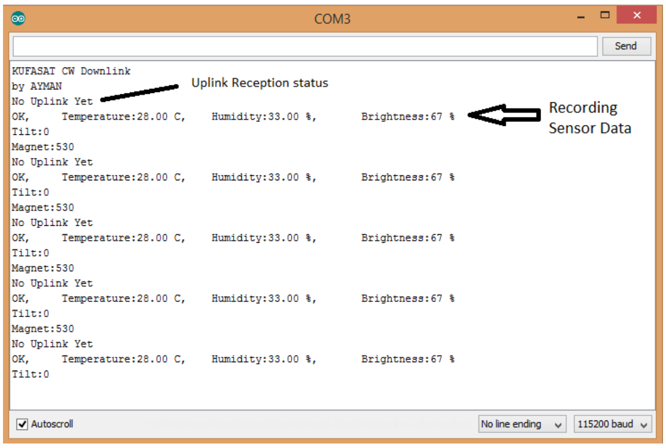

Fig. 5: Starting transmission serial window (serial port 3).

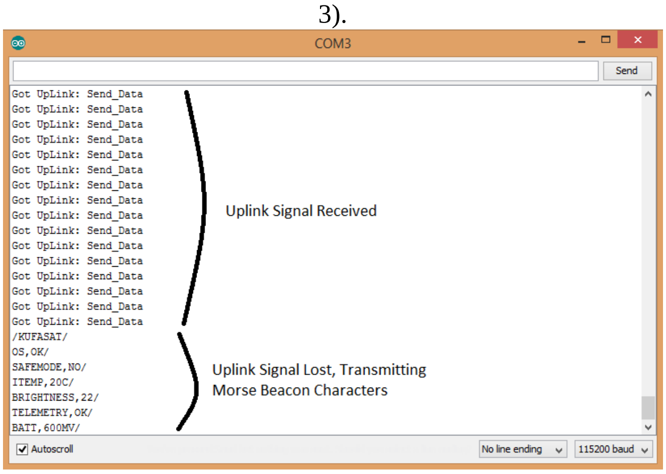

Fig. 6: Uplink signal received window (serial port 3).

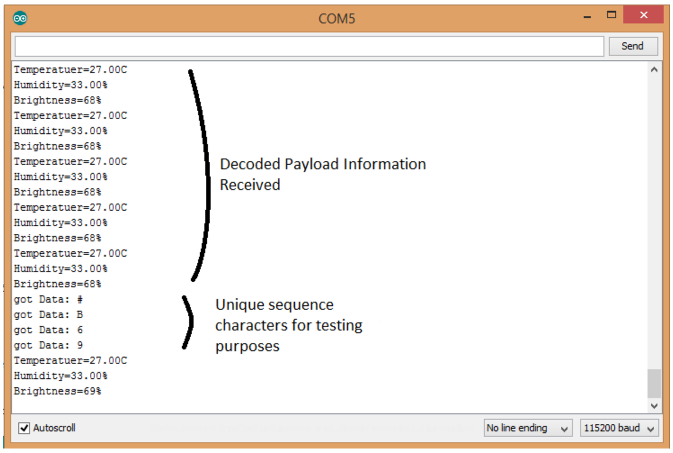

Fig. 7: Data received on ground station (serial port 5).

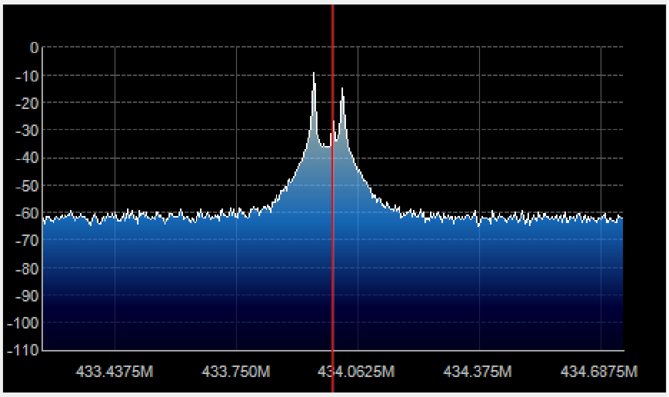

Fig. 8: Received signal spectrum at 434 MHz.

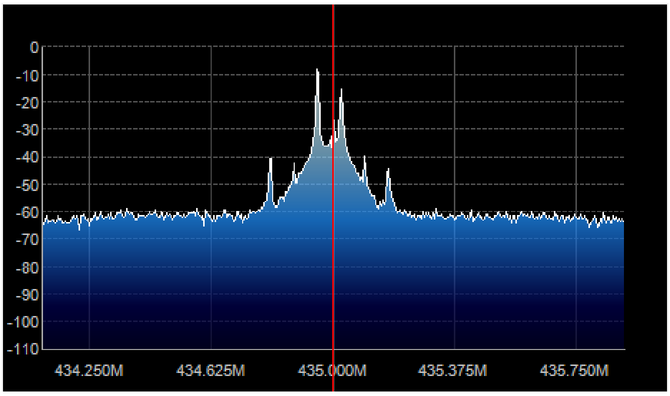

Fig. 9: Received signal spectrum at 435 MHz.

VII. CONCLUSIONS

The frequency chosen for operation is the 435 MHz amateur frequency and a Tx power of 100 mW with FSK as a modulation scheme and a data rate of 1200 bps and 9600 bps for beacon and payload operation respectively. The choice of using COTS components in the designed and implemented communication system makes it easy to modify and upgrade the system components to fit any future requirements and applications.

The overall size of the communication system after implementation is (7 x 9.5 x 1 cm^3) which conforms to the standards and regulations of the CubeSat.

The system software was divided into three primary algorithms which are the communication, beacon and payload encoding and decoding algorithms and the three algorithms are combined together to form the complete system algorithm. The timing approach is proposed to minimize the possibility of losing data and to keep the cycle of communication aligned during the CubeSat passes over the ground station.

The system was designed as a software-defined communication system in terms of frequency, Tx power, modulation and data rate parameters to adaptable to many other CubeSat designs.

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