Design Review of Satellite Telemetry based on CCSDS standards and Proposed Hardware Implementation of CanSat

Waqas Afzal, Adnan Mahmood

Abstract— "**Satellite Communication is one of the most impressive spin-offs from the space programmes and has made a major contribution to, indeed totally altered, the patterns of International communication. Communication by satellite evolved from the simple technology of "Early Bird" to the highly sophisticated present-day satellites" [1]. The potential of the outer space as a communication hub is great and at the heart of this is the satellite. This paper aims at developing a micro-satellite, which can be used for educational purposes as well as a stepping stone for further complex developments. Data from this satellite will be formatted on the basis of the CCSDS (Consultative Committee for Space Data Systems) standards before transmission. We will also highlight one of the simplest designs of the micro satellite CanSat (Satellite in a can) at university level with most cheaply and easily available resources ever highlighted for the Space Education in Asia.**

***Index Terms*— Satellite, Telemetry System, CCSDS, CanSat, Microcontrollers, Sensors**

I. Introduction

Technology is advancing at a rapid pace. Many factors are contributing to this pace but the most fascinating aspect that is considered as the pinnacle of modern achievements is the exploitation of the outer space to achieve goals like global communication, weather predictions, surveillance, planetary imaging and so on. At the heart of this revolution is the satellite, a complex system which encompasses nearly all the different technologies, its each subsystem is based on a different technology and its cost can exceed hundred of millions. Although satellites have eased many a problem, but to manufacture and then maintain a satellite especially during operation in the outer space when it is on its own is a big ask. For this purpose a series of parameters and satellite conditions are continuously transmitted to a ground station from the satellite where it is monitored and actions are taken accordingly by sending a command back to the satellite. It sounds simple but the satellite can be stationed thousands of miles away and the data sent has to pass through different atmospheric conditions and degradation. So a series of measures are taken to send this data securely to ground as a small error can lead to billions going to waste. It is specifically for this purpose, a satellite contains a telemetry subsystem. This subsystem obtains health data i.e. data from sensors and the mission data from payload and then formats the data and transmits it so that it reaches its destination error free.

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II. Satellite Telemetry

Telemetry is a technology that allows the remote measurement and reporting of information of interest to the system designer or operator. The word is derived from Greek roots *tele* = remote, and *metron* = measure. Systems that need instructions and data sent to them in order to operate require the counterpart of telemetry, telecommand [2].

The telemetry sub-system is responsible for collecting data from a wide variety of sensors within the satellite and transmits this data/information to the controlling earth station. There may be several hundred sensors located on the satellite, which collect information inorder to monitor pressure in the fuel tanks, voltage and currents in the power conditioning unit, current drawn by each subsystem, critical voltages and currents in the communication electronics, and temperature variations in different sub-systems [3, 4]. Reference [3] states that, "the sensor data, the status of each subsystem, and the positions of switches in the communication system are reported back to the earth via the telemetry system. The sighting devices used to maintain the attitude are also monitored via the telemetry link: this is essential in case one should fail and cause the satellite to point in the write direction. The faulty unit must then be disconnected and a spare brought in, via the command system, or some other means of the controlling attitude devised".

III. CCSDS Telemetry

The purpose of a telemetry system is to, "reliably and transparently convey measurement information from a remotely located data generating source to users located in space or on Earth. Typically, data generators are scientific sensors, science housekeeping sensors, engineering sensors and other subsystems on-board a spacecraft. The advent of capable microprocessor based hardware will result in data systems with demands for greater throughput and a requirement for corresponding increases in spacecraft autonomy and mission complexity" [5]. These facts, along with the current technical and fiscal environments, create a need for greater telemetering capability and efficiency with reduced costs. "The intent of the CCSDS Telemetry System is not only to ease the transition toward greater automation within individual space agencies, but also to ensure harmony among the agencies, thereby resulting in greater cross-support opportunities and services"[5].
The CCSDS Telemetry System is broken down into two major conceptual categories: a *Packet Telemetry* concept and

a *Telemetry Channel Coding* concept. "Packet Telemetry is a concept which facilitates the transmission of space-acquired data from source to user in a standardized and highly automated manner. Packet Telemetry provides a mechanism for implementing common data structures and protocols which can enhance the development and operation of space mission systems" [6]. Telemetry Channel Coding is a method by which, "data can be sent from a source to a destination by processing it in such a way that distinct messages are created which are easily distinguishable from one another. This allows reconstruction of the data with low error probability, thus improving the performance of the channel" [7]. Together, Packet Telemetry and Telemetry Channel Coding services provide to the user reliable and transparent delivery of telemetry information.

"The CCSDS system design technique known as layering was found to be a very useful tool for transforming the Telemetry System concept into sets of operational and formatting procedures. Layering allows a complex procedure such as the telemetering of spacecraft data to the users to be decomposed into sets of peer functions residing in common architectural strata. Within each layer, the functions exchange data according to established standard rules or "protocols". Each layer draws upon a well defined set of services provided by the layer below, and provides a similarly well defined set of services to the layer above" [5].

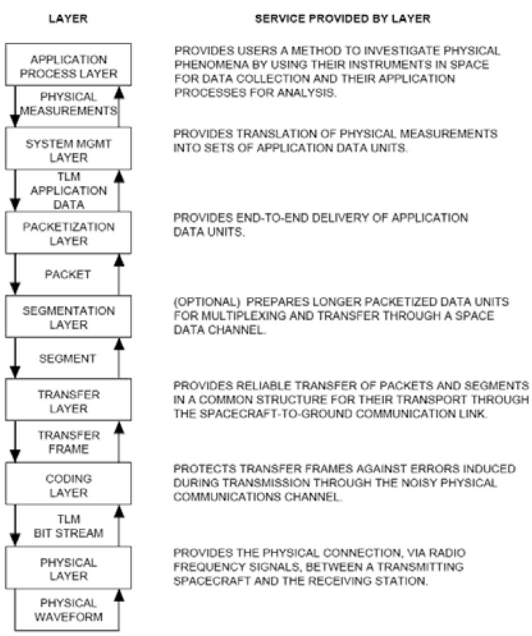

Figure 1: Layered Telemetry Service Model [5]

IV. CANSAT – SATELLITE IN A CAN

"Micro satellite is an attractive topic in both of space science and space education. The short period and low cost for its development are major advantages for university educational programs" [8]. There are several projects of micro satellites in universities which include CanSats. CanSat, short for satellite in a can, is a micro satellite which is used for educational purposes. CanSat is a simulation of a real satellite. It performs a mission and collects data. Typical missions can be atmospheric measurements, video capture, picture taking, communications, or navigation. The missions can be simple or complex. The only requirement is that the mission must fit in a twelve ounce soda can. It includes most subsystems found in satellites. CanSat is launched on a high-powered model rocket. The rocket is 4" in diameter and about 7' tall. It is capable of reaching over a mile in altitude. CanSat is stowed in the upper airframe below the nose cone. The rocket is launched and when it reaches the apogee, the rocket breaks apart to eject the main parachute. This causes the upper portion of the rocket to point down, the nose cone will fall out and the CanSat will fall afterwards. The parachute brings the CanSat gently back to earth [9, 10]. The CanSat Launch is diagrammatically shown in figure 2.

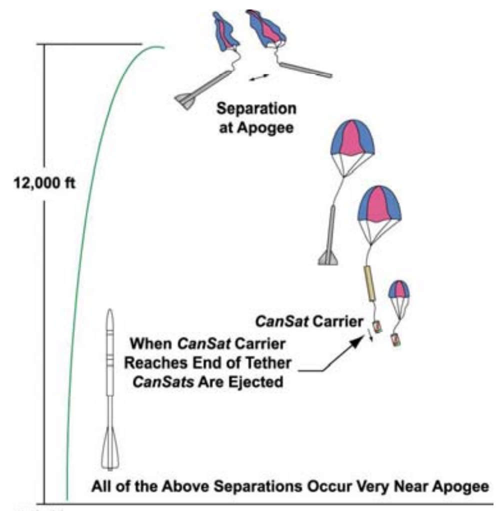

Figure 2: Launching of a CanSat [10]

V. CANSAT SYSTEM DESIGN

Normally, the CanSat bus contains most of the same subsystems or components as a typical spacecraft bus. The power system is a battery which powers the rest of the bus. The microcontroller is the data handling unit that provides interfaces to the sensor payload. The communications subsystem is the transmitter used to send data to the ground station. Figure 3 shows a typical design of CanSat. In this design, the microcontroller module or the data handling unit consists of the *PIC 18F452* circuitry. The circuit is designed such that PORTA/ADC module used for analog inputs and their conversion to digital data using the compatible 10 bit analog-to-digital converter module. PORTE and PORTC have been used as inputs, as well for communicating with external devices (temperature sensor, MAX7219 eight digit 7 segment display controller, MAX232 UART). PORTB and PORTD are used for outputs. The port description is mentioned in the PIC18FXXX Reference Manual [11]. There can be two testing modules for CanSat. An *LED Interface:* This is a simple interface which takes advantage of the electrical characteristics of the MCU. The PIC 18F452 I/O pins can drain and source up to 25mA of current. Hence LEDs with current limiting resistors in series can be used to check the status of the I/O pins. Secondly, *Eight Digit Seven Segment Display:* This testing module is developed to get a logical value of the output. The eight digit display is interfaced to the MCU using the MAX 7219 display driver. The MAX7219 is a compact, serial input/output common-cathode display driver that interface microprocessors (µPs) to 7-segment numeric LED displays of up to 8 digits, bar-graph displays, or 64 individual LEDs [12].

The CanSat payload consists of three major sensors. Motorola's MPX4115A series pressure sensor, the DS18S20 High-Precision 1-Wire Digital Thermometer and the Surface Mount Micro-machined Accelerometer (MMA2202). The sensors are together on the sensor module. The pressure sensor and the accelerometer are connected to the microcontroller's analog-to-digital converter because the devices generate a voltage based on their measurements. Whereas the temperature sensors gives digital output.

Motorola's MPX4115A [13] series sensor integrates on–chip, bipolar op amp circuitry and thin film resistor networks to provide a high output signal and temperature compensation. The small form factor and high reliability of on–chip integration make the Motorola pressure sensor a logical and economical choice for the CanSat system designer. The best feature of this sensor is 1.5% Maximum Error over 0° to 85°C, Temperature Compensated from –40° to +125°C and Durable Epoxy Unibody Element or Thermoplastic (PPS) Surface Mount Package: which justify its best selection for CanSat design

The most suitable temperature sensor for a CanSat is DS18S20 [12] Digital Thermometer which provides 9-bit centigrade temperature measurements and has an alarm function with nonvolatile user-programmable upper and lower trigger points. The DS18S20 communicates over a 1-Wire bus that by definition requires only one data line (and ground) for communication with a central microprocessor. It has an operating temperature range of –55°C to +125°C and is accurate to 0.5°C over the range of –10°C to +85°C.

The MMA series of silicon capacitive, micro-machined accelerometers [13] feature signal conditioning, 4-pole low pass filter and temperature compensation. Zero-g offset full scale span and filter cut-off are factory set and require no external devices. A full system self- test capability verifies system functionality. The major features of these devices are Integral Signal Conditioning, Linear Output, 4th Order Bessel Filter Preserves Pulse Shape Integrity, Low Voltage Detect, Clock Monitor, and EPROM Parity Check Status, Robust Design, High Shocks Survivability.

Since the pressure sensor and the accelerometer give analog output. Hence they are connected to the first and second pin (AN0 & AN1) of the MCU's compatible ADC, respectively. The output from the ADC is then stored for further manipulations.
The last phase of the design tends the CCSDS standard. The data obtained from the sensors is obtained and then stored in the external memory before it is formatted according to the CCSDS telemetry standard. To convert the data obtained from the sensors into packets, they are stored in an array of bytes. The most significant bytes of that array are assigned the header information. This 'packet' is then assigned to the least significant bytes of another array which is the transfer frame. The most significant bytes of the 'transfer frame' contain the spacecraft ID and header information. The development of the CCSDS telemetry standard is already given in the CCSDS Papers which is nearly followed by all agencies of the world [14].

One of the major features of this CanSat design is its affordability and easy accessibility to the involved components. The cost of this whole telemetry system varies from 50-75 USD dollars. Majority of the components are easily available in the Electronic markets at a very affordable rate, and almost all these components can be demanded by their manufacturers as a sample to verify your system and later on use for massive scale production.

VI. Conclusion & Further Scope

This project can be further advanced by developing two key components of a CanSat, Wireless RF Link and Rocket motor to launch it. By creating a reliable wireless link, data can be transmitted from the satellite to ground during its flight and processed in a computer. In this way an observing ground station will be formed. Also this RF link will also be used to send Telecommand signals to the CanSat and different operations aboard the CanSat can be performed. The wireless RF link will also help in tracking the satellite in range (distance). This can be achieved by simply calculating the round trip time of a data packet. The Rocket motor is a vital component if the CanSat is to be launched. The rocket should be designed such that it can lift nearly 400 gm of weight up to an altitude of more than a mile. By completing these two components a micro satellite communication system will have developed and it can be used to gather basic data for a satellite operation. This can, thus, be used as a launching pad for further more complex developments.

The development of these types of systems will help the students to enhance there ideas related to space communication projects. In order to make a marvelous progress in the field of Satellite Communication, it is the responsibility of our researchers to let there students take interest in these projects and serve there nations for a better and brighter future.

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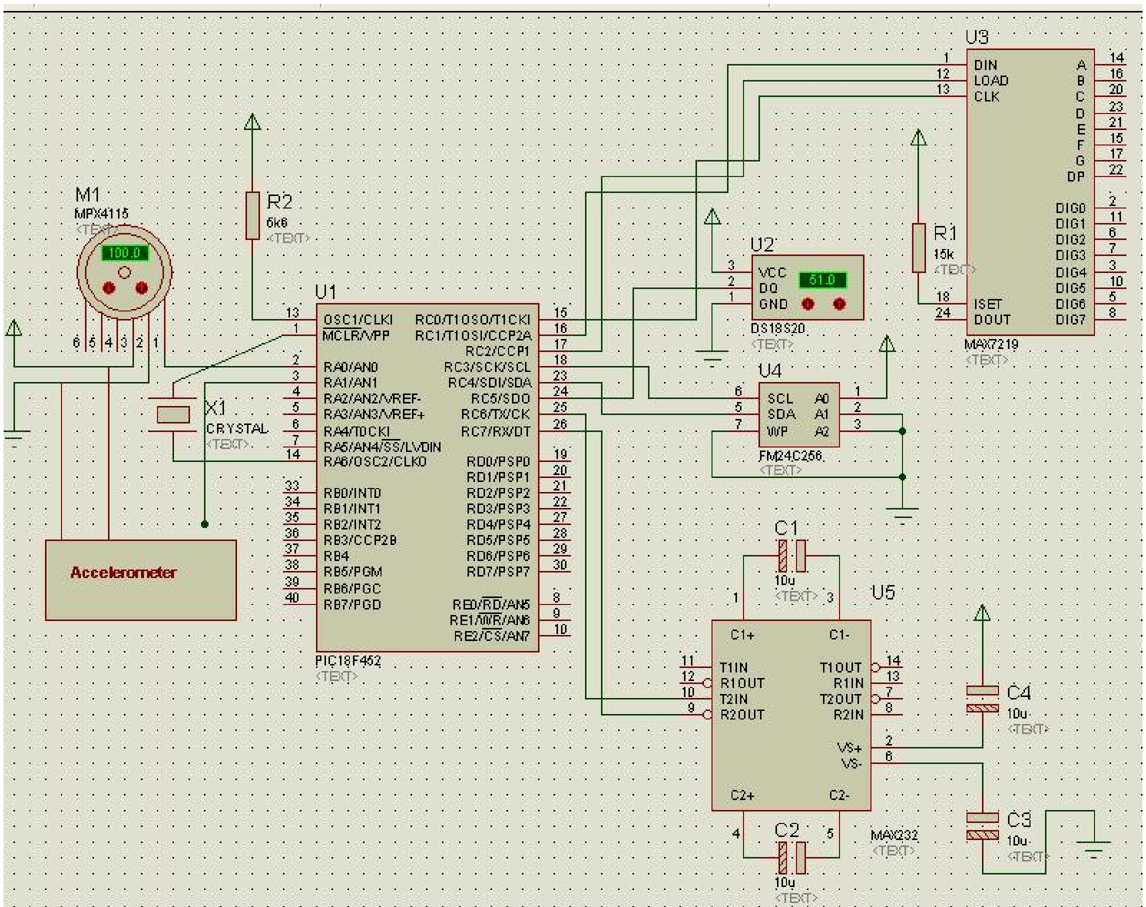

Figure 3: CanSat System Design

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