A SMALL SATELLITE FOR MEASURING ATMOSPHERIC WATER CONTENT; PART I, DOWNLINK AND COMMAND SYSTEMS

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ABSTRACT

This student paper was produced as part of the team design competition in the University of Arizona course ECE 485, Radiowaves and Telemetry. It describes a telemetering system design recommendation for a small satellite capable of conducting scientific research regarding atmospheric water content. This paper focuses on the subsystems required to send the scientific data and monitored operational conditions from the satellite to, and commands to the satellite from, a ground station. A companion paper (Hittle, et. al.) focuses on the cross-link subsystem required to make the scientific measurements and on the power generation and distribution subsystem for the satellite.

KEY WORDS

Satellite, telemetering systems, atmospheric sensing, water vapor, troposphere.

INTRODUCTION

The University of Arizona SSP has been developing a microsatellite for three years (Hammond, et. al). Although the satellite was originally intended to carry lightning and sprite sensor, the satellite could be modified to carry the Crosslink Active Tropospheric Sounder (CATS). CATS is an experimental technique to acquire precise tropospheric profiles of water vapor and cloud liquid water.

The CATS technique uses radio cross-links between two low-orbiting vehicles, the International Space Station (ISS) and University of Arizona Satellite (UASat). These radio cross-links pass through the atmosphere with a measurable absorption. By analyzing the signal after it has passed through the atmosphere, the water vapor profile can then be found. There are several CATS system goals. The moisture sensor must be built and flown by modifying previous models to space applications. The UASat must also be modified to carry the sensor and other related sensors such as GPS, navigation and timing sensors. Also, UASat must be modified for a flight of up to a year in duration, as CATS requires a year to develop a water vapor profile. Other goals are to generate moisture profiles and develop retrieval algorithms and software. [Herman]

The satellite will make 7-10 minute passes over the ground station based at the University of Arizona and transmit up to 25 megabytes/day. Thus, all transmissions are limited to these 7-10 minute "windows". As well as the CATS data, satellite operation data will also be collected. To insure the robustness of the system, these considerations have been contemplated in the telemetering system design. This paper focuses on the subsystems required to send the scientific data and monitored operational conditions from the satellite to and commands to the satellite from a ground station.

SYSTEM DESIGN

The design utilizes a 60 kg microsatellite with several sensor types monitoring satellite health and experimental scientific data as seen in Figure 1. These sensors include sun/horizon sensors, micro-mechanical gyros, magnetometer, GPS receiver, reaction wheels, magnetotorquers, power system sensors, thermal sensors, and a star-tracker. The satellite then transmits this data over an amateur radio band to an earth-based ground station during a seven to ten minute overhead pass. The ground station receives and archives the data. During the overhead pass, the ground station also sends operational commands to the satellite on a separate amateur radio band.

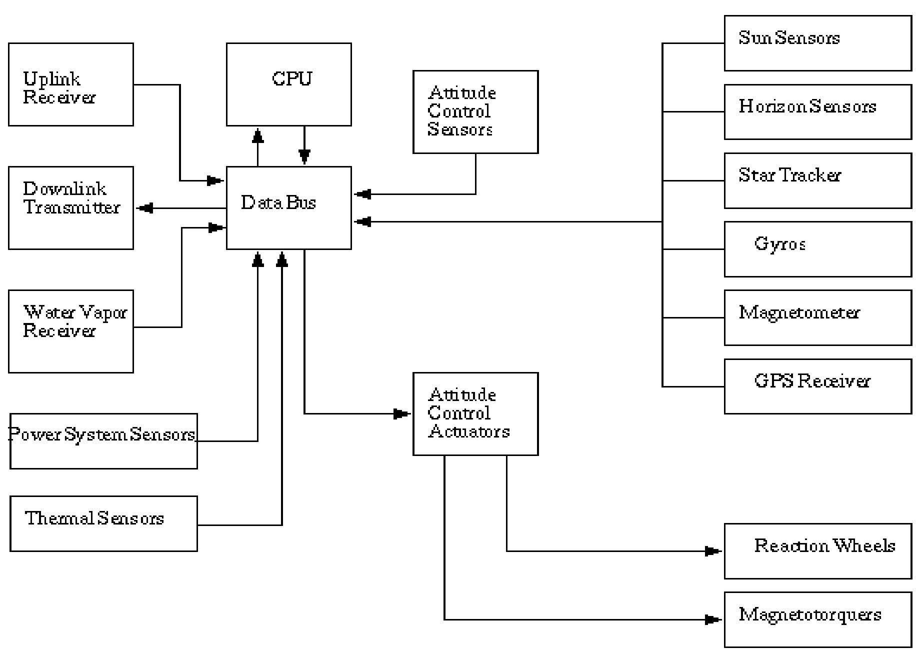

Fig. 1. Satellite Block Diagram

SENSORS

The following sensors will be onboard UASat and require transmission to the ground station:

1) Sun and Horizon Sensors--M three-axis sun sensors and I three-axis horizon sensors are used. Each sensor type will return an azimuth and an elevation angle data with resolution of 0.1 ° and range of 0 – 360°.
2) Micro-mechanical Gyros--A three-axis micro-mechanical gyro with a resolution of 1 mV and a range of +/-100mV is also included in the satellite design.
3) Magnetometer A three-axis magnetometer is also used in the satellite design. This magnetometer will return two different types of telemetry data, which are an angle and a magnitude.
4) GPS Receiver --The onboard computer in the satellite design will convert latitude and longitude information from the GPS receiver into 4 octet words for transmission.
5) Reaction Wheels **--**Three reaction wheels are used for this project. Each reaction wheel will have a resolution of 1 rpm and a range of 0 – 8000 rpm.
6) Magnetotorquers--Three magnetotorquers (MT1, MT2, and MT3) are used for this project. Each magnetotorquer returns two different types of telemetry data, a current and a voltage.
7) Power System Sensors--M power system sensors are used for the satellite design. Each sensor will return four different types of telemetry data, which are a battery voltage (BV), a battery current (BC), a solar cell array voltage (SV), and a solar cell array current (SC). For the battery voltage and current data, resolutions of 0.1V and 0.1A are used, respectively, and ranges of 0-28V and 0-5A, respectively. For the solar cell array voltage and current data, resolutions of 0.1V and 0.1A are used, respectively and ranges of 0-40V and 0-5A, respectively.
8) Thermal Sensors--The thermal sensors used for this project are thermocouples. Each thermocouple will have a resolution of 0.1° and a range of –20 to 50°C. The levels and bits required for each thermocouple can be calculated as follows:
9) Star-tracker--A three-axis star-tracker is also used in the satellite design. This sensor will return azimuth and elevation angle data with resolution of 0.1° and range of 0 – 360°.

TELEMETRY FRAME SPECIFICATION

Telemetry data will be transfered via a 2 Mbps link operating at 2.4 GHz, adhering to recommendations issued by the Consultive Committe for Space Data Standards (CCSDS). The proposed system is packet based for real-time spacecraft health data and telecommand, but uses a private data definition for delivering science data, and occultation information. The packet structure for telemetry and telecommand are described later in this document.

	Transfer Frame ID			Master Channel Frame Count	Virtual Channel Frame Count	Transfer Frame Data Field Status					Data	Frame Error Control Data
00	Spacecraft ID	VC ID	0			0	Sync	0	11	First Header Pointer		
2 bits	10 bits	3 bits	1 bit	1 Octet	1 Octet	1 Bit	1 Bit	1 Bit	2 Bits	11 bits	variable	2 Octets

Fig. 2. Telemetry Frame

The downlink frame consists of 8920 bits. In addition there is a 32 bit Attached Sync Word (ASW). The large frame size was selected to maximize the efficiency of transporting science data. With the high bit rate of this link, the overhead of transmitting such large frames is minimal. Individual occultations can be downloaded in about 500 milliseconds and expected synchronization time is around 20 milliseconds using a privately defined format for the science data with this frame length. See the attached appendix for calculations confirming these values.

The uplink is much slower then the downlink and is expected to handle much smaller data sizes. Only commands and ISS orbit data need to be uplinked. As a result, the uplink frame length needs to be much smaller then that of the downlink. The frame length was selected to be 512 bits. This results in an expected sychronization time of 85 milliseconds.

Both uplink and downlink use a standard search, check and lock sequence. On the downlink, during search and check, idle data is sent. When the uplink achieves lock, the satellite commences sending idle packets. No real data is sent until it is requested.

UPLINK COMMAND STRUCTURE

A standardized transfer protocol for the telecommanding system should be fairly easy to implement by adhering to the CCSDS guidelines. These guidelines allow for a robust, versatile design and can be found in the CCSDS blue books on telecommanding, specifically CCSDS 202.0-B-2 and CCSDS 203.0-B-1. A command-verify-and-execute command protocol was decided upon. Using this strategy, the command must be echoed by the satellite and added to the telemetry stream. This should not pose a problem because of the command packet structure, which is shown in Figure 3.

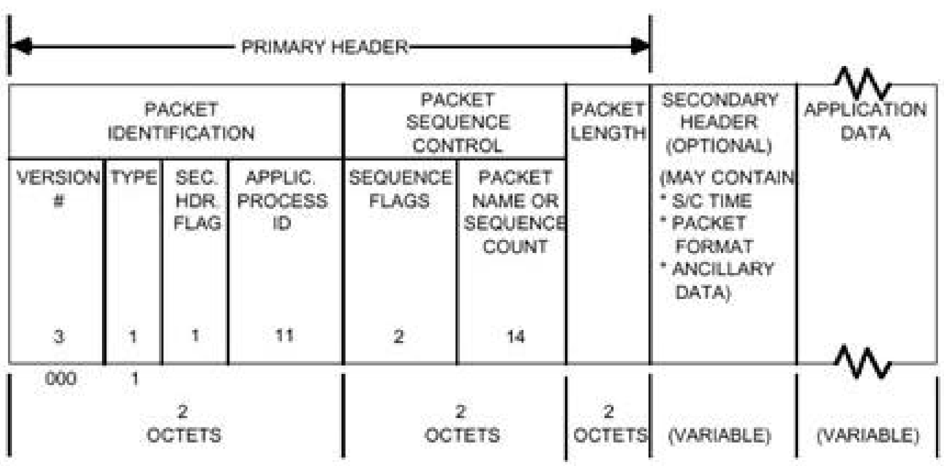

Fig. 3. Command Packet Structure

The application process identifier allows the satellite's onboard computer to know which of the subsystems a command affects. In most instances, the application identifier is identical to the ones used in the telemetry source packets with the additions below. If necessary, there is still an ample amount of combinations for future expandability with 11 bits.

- All sensors 10110110011
- Upload encounter data 00111000111
- Payload transmitter 11100110010

In order for the satellite to know when it needs to point in a certain direction, encounter data must be uploaded to the onboard computer and stored in memory. This data will be sent in the command stream with its own application identification. The application data allows for a start time, a stop time, attitude data, and, if necessary, a memory address. CCSDS guidelines allow for error control in the application data as well, but because a command-verify-and-execute strategy was chosen, error control will be left to the transfer frame. These packets are then transmitted in telecommand transfer frames, which are structured as shown in Figure 4. The frame contains a 40-bit header, the telecommand packet, and a 16-bit error control word. The frame data field contains the telecommand packet. A segment of a packet is allowed if the packet is longer than 1017 bytes, but a single command should not be this long. The last two bytes are used for error control. The method to be used is a Cyclic Redundancy Check (CRC), which is defined in CCSDS 202.0-B-2.

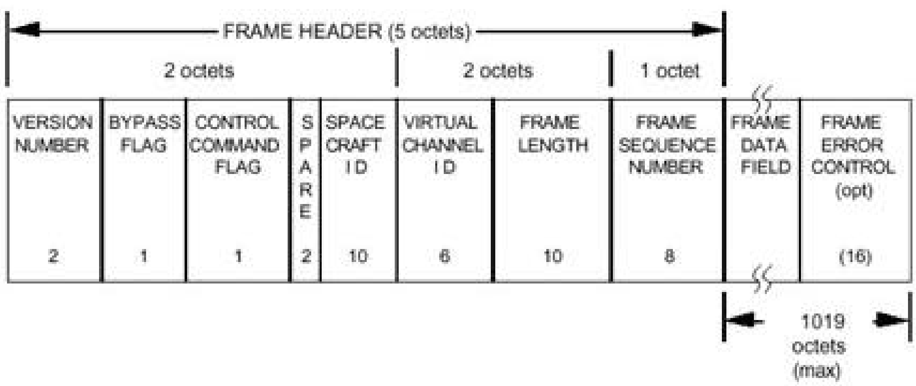

Fig. 4. Telecommand Transfer Frame

SOURCE PACKET DESIGN

The source packet used for this project is shown in Figure 3-1 of the CCSDS 102.0-B-4 recommendations page 3-1. It consists of two major parts, which are packet primary header and packet data field. The packet primary header includes version number, packet identification, and packet sequence control, while the packet data field includes packet data length, packet secondary header, and source data.

There are nine different types of applications used in this project, which are the sun and horizon sensors, micro-mechanical gyros, magnetometer, GPS receiver, reaction wheels, magnetotorquers, power system sensors, thermal sensors, and a star-tracker. These types of applications are identified using an 11-bit application process identifier, tabulated in Table 1 below.

TABLE 1

Application Type	11 Bit Application Process Identifier
Sun and Horizon Sensors	00011100011
Micro-mechanical Gyros	00100100100
Magnetometer	00110011001
GPS Receiver	01010101010
Reaction Wheels	10101010101
Magnetotorquers	11001100110
Power System Sensors	11011011011
Thermal Sensors	11100011100
Star-tracker	11101110111

THE SATELLITE

The height of the satellite is given as a maximum height of 850,000 meters overhead. The face is described as an octagon with a diagonal of 48 cm. This means that the largest parabolic dish that does not obstruct the size of this face is a 45 cm dish. Since this size necessitates a very large ground dish for reliable communications, a new plan is needed.

This paper proposes a parabolic dish antenna that "umbrellas" into a more useful size after the satellite has achieved orbit. By using an umbrella-structured antenna, the ground-based antenna will be much smaller and more able to track a moving satellite across the sky. If this recommendation is unacceptable to the Student Satellite Project, the secondary recommendation is to provide more power for transmission. Reducing ground antenna size is the largest concern.

LINK SUMMARY AND RECOMMENDATIONS

The fade margin included with the known losses left a substantial margin for error and unexpected losses including losses due to rain fading, multi-path fading, ducting, and atmospheric effects. Signal loss due to less static phenomena, such as lightning, adverse cosmic electromagnetic interference, etc. were not considered.

This paper recommends an antenna on the satellite that "umbrellas" open to a 1-meter diameter transmission antenna that is at least 65% efficient. The recommended ground based antenna is a 65% efficient 1.4-meter diameter parabolic dish antenna for both reception and transmission. It must transmit at 64 watts for closure with the satellite's monopole antennas. If the antenna on the face of the satellite must be rigid and smaller than the area of that face, an increase in power from 200 m-watts is recommended. If this is not possible, a higher bit error rate than 10^{-6} must be tolerated.

GROUND STATION DESIGN

The primary ground station will be located on the University of Arizona (UA) campus and possibly other locations such as Taiwan, Hawaii, or Wisconsin. The ground station(s) will collect an average of 25MB/day with the UA ground station managing all communications and control.

All the noise specifications and calculations are found within the link budget. The gain and noise figure specifications used in the link budget are found in the design report (Cramer, et. al.). From this, appropriate commercial components can be found corresponding to the components seen in Figure 5. It was found, however, that the values used in the link budget are difficult to match with readily manufactured components.

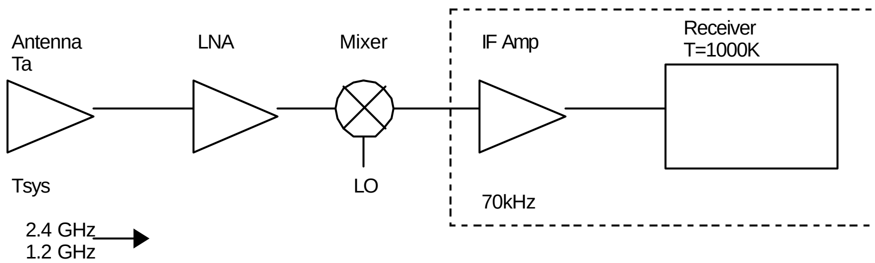

Fig. 5. Receiving Network

In Figure 6, the ground station CPU is shown. The received data from the satellite will be decoded in the data processing section of the CPU the data is processed the experimental scientific data is stored in a database. The database can also be a relatively low cost system like Microsoft Access. As this satellite will be operational for a year, CD-ROM archives can be created as back-up data for the water vapor profiles. The satellite operational data will then be further processed into the command protocol. The command protocol monitors the satellite health and determines if all conditions are satisfactory. If all conditions are acceptable, no commands will be issued from the ground station. If a condition is less than desirable, commands will either be sent automatically or by the user to the satellite. The protocol is command, verify and execute as mentioned previously. Records will be kept to monitor the progress of the satellite throughout the year in orbit. A standard 400MHz desktop computer with a CD-RW, 128MB RAM would be acceptable to run the proposed software.

SUMMARY

The satellite telemetering system described in this paper is designed to be implemented on the University of Arizona Student Satellite Project. The system would provide data recovery from the satellite to the ground station while allowing command access to the satellite from the earth.

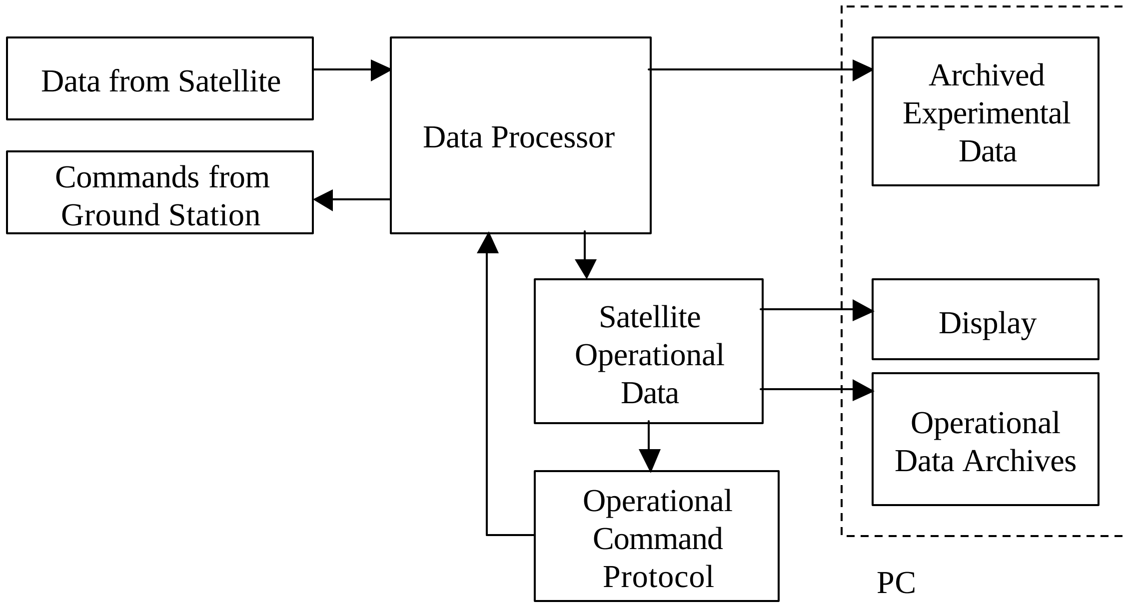

Fig. 6. Major Components of Ground Station CPU.

A variety of sensors were accommodated in the packet structure, with a majority related to the operational status of the satellite. Allowing for a bit error rate of $1x10^{-6}$, it was found that the link budget recommends an antenna on the satellite that “umbrellas” open to a 1-meter diameter transmission antenna that is at least 65% efficient. The recommended ground based antenna is a 65% efficient 1.4-meter diameter parabolic dish antenna for both reception and transmission. It must transmit at 64 watts for closure with the satellite’s monopole antennas. The antenna structure given here could possibly interfere with other satellite functions. If a smaller antenna is needed, an increase in power from 200 m-watts is recommended. If this is not possible, a higher bit error rate must be tolerated.

The ground station receives and processes the data for both the water vapor profile experiment and the operational status of the satellite. Depending on the satellite condition, appropriate commands will be sent back to the satellite via the proper protocol.

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