A SMALL SATELLITE FOR MEASURING ATMOSPHERIC WATER CONTENT; PART II, CROSSLINK AND DATA COLLECTION

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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 cross-link subsystem required to make the scientific measurements and on the power generation and distribution subsystem for the satellite. A companion paper (Cramer, et. al.) 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.

The central objective is to validate a new technique for precisely measuring water vapor profiles of clouds throughout the troposphere. This method involves the detection of 4 SHF tones sent out from the International Space Station (ISS), providing high-resolution amplitude and phase delay data.

KEY WORDS

Small 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 sensors, 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 the 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). This paper focuses on the cross-link subsystem required to make the scientific measurements, and on the power generation and distribution subsystem for the satellite.

SCIENCE DATA

In accordance with the CATS objective the science team requires a method to utilize four SHF tones (9.8, 13.6, 17.3, and 22.6 GHz) to develop water vapor profiles of earth's atmosphere. The four tones will be transmitted from the International Space Station (ISS). The objective of the science team is to receive these four signals and be able to provide high-resolution amplitude and phase data to the ground station. From the received amplitude and phase data the ground station will be able to generate profiles of atmospheric water vapor, refractivity, pressure, temperature, and other related quantities.

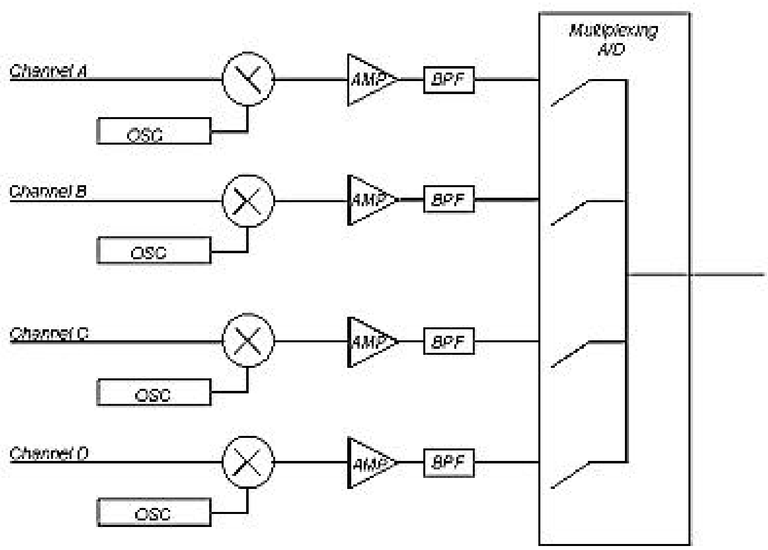

Figure 1: Science Receiver Functional Diagram

The detection method begins with UASAT receiving the four transmitted signals from ISS. The receiving antenna and the signal conditioning is explained in the transmit and receive section of this paper. Amplitude and phase data will need to be multiplexed and digitized for transmission to the ground station. To accomplish this task the four high frequency signals must first be down converted to a low enough frequency, such that present A/D converters can reasonably maintain the conversion rate. Figure 1 shows a functional block diagram of the science receiver.

As shown in Figure 1 signal conditioning is also required after the mixer. Band pass filtering is used to remove any product harmonic signals that will be generated from the mixer.

Requirements

Oscillator

This instrument is required to provide a stable high frequency output that will be used to down convert the four science data signals. The chosen oscillator must also be able to provide an output power level high enough to drive the LO port of a mixer. The required frequency range and power level of the oscillator are 9-23 GHz and 8-18 dBm.

Mixer

This instrument is required to down convert the four input frequencies. The mixer shall be capable of RF and LO frequency range of 9-23 GHz.

Amplifier

This instrument is required to compensate for the conversion loss of the mixer. The gain should be 5-15 dB.

Band Pass Filter

This device is required to remove any product harmonic signals that will be generated from the mixer. Four band pass filters will be required for the receiver. Each filter will have a different center frequency. The required center frequencies are 5, 15, 25, and 35 KHz. Each filter shall have a pass band of 6 KHz.

Multiplexing A/D converter

This instrument is required to multiplex and digitize the down converted analog signal. The converter must have the capability to multiplex at least four channels.

Recommendations

Oscillator

For this application an oscillator-multiplier was chosen from Communication Techniques Inc. This device is a high-Q mechanically tunable cavity oscillator that uses a multiplier to achieve the higher frequencies. The oscillator-multipliers have an output power range of 5mW – 500mW. Communication Techniques Inc will customer configure the unit, thus special model numbers will be issued. For the task of down converting the four signals we will need four separate oscillator-multiplier combinations. Below is a table listing the required frequencies and output power.

Required Frequency (GHz)	Required Power Output (dBm)
9.799995	15
13.599985	15
17.299975	15
22.599965	15

Mixer
For this application two mixer dies were chosen from Hittie the HMC203 and the HMC144. Two separate dies were required to meet the RF and LO frequency range requirements. The HMC144 can handle a RF and LO frequency range of 5-20 GHz and requires a LO drive of 15 dBm typical. The conversion loss for HMC144 and HMC203 is a 12dB maximum. The HMC203 can handle a RF and LO frequency range of 14-23 GHz and requires a LO drive of 15 dBm typical.

Amplifier
For this application the Mini-Circuits MAR-2SM was chosen. This amplifier operates from a frequency range of DC-2000 MHz and has a gain 12 dB.

Filter
The filter must be custom designed because no commercial part exists that would meet the required center frequency or bandwidth. A suggested supplier is Microwave Filter Company Inc. This company will custom manufacture filters to the customers specifications.

Multiplexing A/D converter
Each of the 4 analog signals has been mixed down to an appropriate frequency, amplified with enough gain, and filtered. Therefore, these signals are ready to be converted into a form suitable for the telemetry system without losing any vital information. The signals will be converted into digital data to fit the telemetry frame or packet. After transmission, the station can recover all signals and extract the measurements. Creating a digital output from 4 analog inputs requires 3 major steps: analog multiplexing, sampling-holding, and analog-to-digital conversion. Figure 2 displays the three steps of signal processing to obtain the digital output.

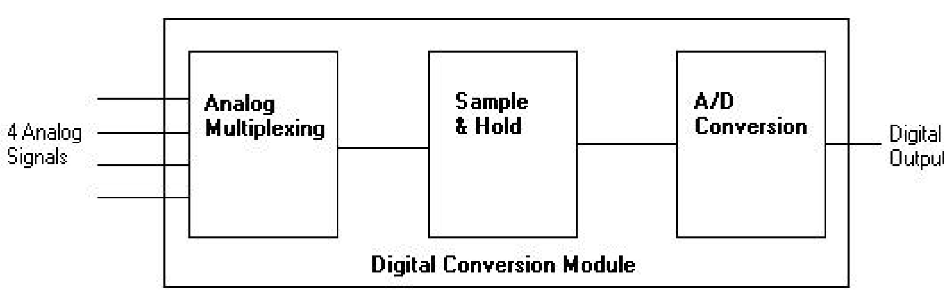

Figure 2: Stages of signal processing

Commutation allows the analog signals to time-share the channel before they are sampled. The 4 tones are transmitted to the sampler exactly as received. During sampling-and-holding the signal is being tracked. Then the last value is held stable for the A/D conversion hardware to measure it. The A/D converter finalizes the process by producing the digital output that describes each of the 4 tones. The accuracy of the digital representation depends on the accuracy of the A/D converter. The basic types of digital-to-analog converters are: successive approximation, dual slope integrating, charge balancing, flash, and sigma-delta ADCs.

Fortunately, today manufacturers can integrate the three stages of the conversion process into one device. As a result, component count is reduced and power consumption is reduced. In addition, component matching is achieved and frequency response is guaranteed.
At this stage, the analog signals have been converted to digital data. An address has been added to each set of digital data; this will tell the ground station to which tone each set of data corresponds.

SIGNAL TRANSMISSION/RECEPTION

Science Data Receiving Antenna

Specifications/Requirements

The design of the science data antenna must be constrained to the specifications provided by the ISS transmitter. These specifications are based on parameters predicted for the worst cross-link case.

- Transmitter Power (Watts): 10.0
- System's Losses (dB): 0.1
- Frequency (GHz): 22.6 (λ= 0.01327m)
- Transmitter EIRP (dBW): 38.0
- Height (Km): 800
- Worst Slant Range (Km): 6586
- Atmospheric Losses (dB): 4
- Receive Noise Temperature, K: 101 (20dB)
- Two Level Sampling Loss (dB): 2.5
- Data Rate (Hz): 50
- Required SNR at Transmitter: 3400 (in 1 sec)

Space Loss (Ls)
The space loss is the result of the 1/R2 fall-off of the RF signal picked up at the receiver. It is also a function of the center wavelength of the link, i.e.:

$$[Ls]=10\log[\{(4\pi\ Rs)/(\lambda)\}^2] \quad (1)$$

For λ= 0.01327m and Rs = 6586000m, Ls is equal to 196 dB.

Atmospheric Losses (Lp)
Atmospheric losses are estimated to be no more than 4dB. Since a main purpose of the cross-link received signal is measuring occultation, atmospheric absorption cannot be added to the loss term. Therefore, Lp should be mostly due to atmospheric scattering.

Receiver C/No
Since the desired SNR has to be at least 3400, and the data rate is 50 Hz, the required receiver's C/No will be:

[C/No] = [3400/50] = 68 dB

Crosslink Power Budget
The cross-link power budget can then be calculated using the following equation:

$$[C/No]=[EIRP]-[Ls]+[G/T]-[k]-[Lp]-[L2s] \qquad (2)$$

In equation 2, [k] = -228.6 dBW/ K-Hz is the Boltzman constant, and L2s is the two level sampling loss, as specified. Solving the equation for [G/T]:

[G/T]= 68 - 38.0 + 196 - 228.6 + 4 + 2.5 = 3.9 (or 4 dB)

Receiver Gain
The gain of the receiver must be at least:

[Gsys]= [G/T] + [Tsys] = 4 + 20 = 24

Antenna Gain
The antenna gain is calculated from [Gsys] as:

[Gant]=[Gsys]-[Gamp]

In the above equation, [Gamp] is the gain due to additional amplification elements introduced in the system.

If we use [Gamp] = 5dB, then [Gant] = 19 dB (or ratio 80).

Antenna's Diameter
The diameter of the antenna comes from the relation between antenna gain and its effective area Ae:

$$Gant=(4\pi Ae)/(\lambda^2)$$

where $Ae=\eta Ap$, where η is the antenna efficiency, which we will assume to be approximately 15 % at 22.6 GHz, and Ap is the physical aperture.

Therefore, the diameter is: $Dant=[(\lambda)/(\pi)][sqrt(Gant/\eta)] = 0.09m$

Recommendation

This antenna design shows some improvements compared to the R/P antenna choice previously proposed (Herman, et.al). The most significant advantage is the reduction in size to 1/2. On the other hand, this reduction is only possible at the expense of adding an extra amplifier to the system, which may eventually increase Tsys, thus increase the noise power of the system. However, depending on the choice of antenna, Tsys may just turn out to be less if the new antenna has a sufficiently smaller Tant compared to the 0.2m antennas. Standard horn antennas do not suit these requirements, and therefore, we endorse the choice of a modified version of the Black Jack by JPL, which was used in the GRACE mission, as described in the proposal.

POWER GENERATION AND DISTRIBUTION

The power generation and distribution (PGD) is a subsystem in the UASat that is responsible for generating, controlling, and distributing DC power to other subsystems. PGD consists of:

- Photovoltaic (PV) panels or solar panels.
- Battery.
- Solar charger/regulator.
- DC regulator.

This subsystem will require further specification and design in order for the mission to be successful. The purpose of this portion of the paper is to identify and discuss some of the unresolved issues. Further details about the recommendations and about alternatives considered may be found in the design report (Hittle, et.al.).

The PV Solar Panel

The solar arrays will consist of eight-sides mounted around the satellite body. Each array has dimensions of 18 x 51.5 cm. The UASat will be rotating around the earth 6 times a day. In each rotation, a little more than 50% of the solar arrays will be facing the sun. The types of solar cells preferred are GaAs Cells. These solar arrays have to be capable of generating 28-35 W, and providing an output voltage of 34-38 Volts. Usually, these cells have an efficiency of 24%, and they must be thermally isolated.

The Battery

The desired battery is a Lithium Ion type. As has been mentioned earlier, the solar panel can only provide 28-35W under sunshine. If we want more power, we must draw from the battery. Before deciding on the power, current, and voltage specifications for the battery that will be used, peak power requirements, without the addition of 28-35 W from the solar panel, are needed from each team. To calculate the exact power budget, each team has to draw a graph that explains their power needs for one complete revolution. How often they need power and the duration of use/not-in-use are all critical values needed. An example of the current vs. time graph for one revolution in shown in figure 3.

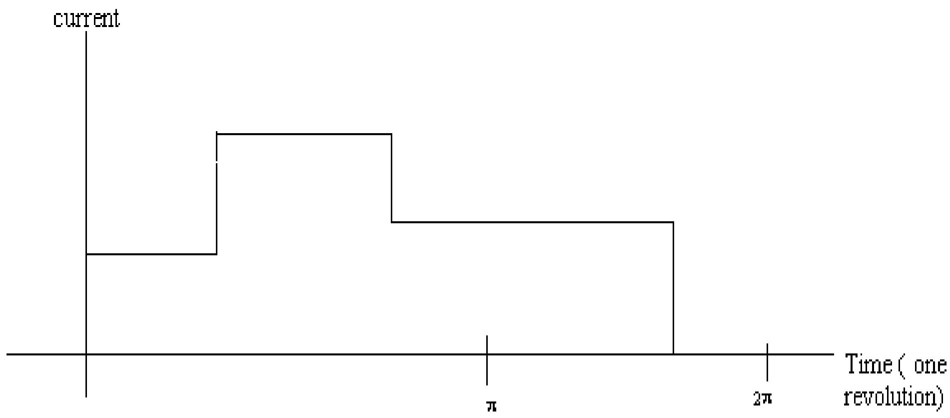

Figure 3: Arbitrary current profile for a subsystem in 1 revolution.

The Solar Charger/Regulator

Its main function of this device is fully charging the battery without permitting overcharging. If a solar array is connected to lead acid batteries with no overcharge protection, battery life will be shorter. The Lithium Ion batteries proposed are even more sensitive to charge regulation. The charger/regulator is a control system that opens the charging circuit, terminates the charge at a pre-set high voltage. Once a pre-set low voltage is reached, it closes the circuit, allowing charging to continue. Tapered charge profiles may also be programmed.

The solar charger/controller are rated and sized to the systems they protect by the array current and voltage. Most common are 12, 24, and 48-volt regulators. Amperage rate run from 1 amp to over 100.

The three stage charge controllers features the following: adjustable control set points, internal temperature condensation, surge protection, reverse polarity protection, electronic- short circuit, and over temperature and overloading protection. The Trace C12 Solar Charge / Load Controller charge the battery with 12 VDC, and 12 amp, while only weighing only 3 lbs.

DC/DC Converter

The voltage generated by the solar array and the battery has to go through DC/DC converter before it reaches other subsystems. The voltage has to step-up or step-down while maintaining 80-85% typical conversion efficiencies. There is a need for making a consensus of types of voltages of the other devices used in other subsystems. The PGD itself can supply about 28-30 V. To save space for the DC/DC converter and wiring, all devices are better if they have uniform voltages as follows: +15, -15, +5, -5, and +3.3. However, in order to have a device to follow those voltages we must sacrifice money, space, or weight.

The important issues for choosing a DC/DC converter are efficiency and compatibility with step-up and step- down DC-DC conversion for 1-cell Lithium- Ion batteries. It should be capable of supplying up to 500mA output current, at a fixed or user selectable output voltage. The range of input, and output voltage options should match Lithium- Ion, or any other battery application. The input voltage range spans above and below the regulated output voltage. The ILC6360 by Impala Linear Corporation meets these requirements.

DC Regulator

The Power subsystem gathers extensive telemetry about its own components. Temperature of the battery and the solar panels are monitored. Currents from each solar panel are monitored individually, as well as the current coming in or out of the battery. Bus and battery voltages are also monitored. The most important telemetry values (battery voltage, temperature and current, as well as bus voltages) are sent directly to the CPU, while the rest is sent through a multiplexer to the CPU in the satellite. From all the previously mentioned measurements, the regulator can regulate the input / output voltages and currents of each device according to the desired operational status. The regulator will be PWM switching regulators designed for high efficiency and high power density. The XC62G series regulator from Blue Sky Electronic Components Ltd. meets these requirements.

SUMMARY

This paper has presented design recommendation for the cross-link subsystem of a small satellite capable of conducting scientific research to measure atmospheric water content. It has also identified some issues that require further study regarding modification of the power generation and distribution subsystem for the satellite

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