ENG4000 Engineering Project
YuSend Nanosatellite Communications Subsystem

Design Specification Report

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Abstract

The following document contains any specific information that is known about the Cubesat program, picosatellite communication systems, and the YuSend mission. Specific parts and hardware requirements are described in detail. This project will provide the design for a reliable communication system for use in the Cubesat spacecraft.

Table of Contents

List of Figures

List of Tables

1 Introduction

1.1 The YuSend Mission

YuSend is a project at York University led by Dr. Regina Lee. The project aims to prove York's ability to produce spacecraft capable of surviving in the space environment. The mission will carry a small camera, a smart power management system, and a mangnetometer.

1.2 The Cubesat Program

Cubesat is a standard being developed by the national Science Foundation in the United States. It is a small form factor for a picosatellite, designed for use in an educational environment. Measuring only 10 x 10 x 10 cm and having a mass of about 1kg, these picosatellites are too small for more sophisticated science missions but are adequate for basic sensors and small cameras.

Figure 1 – A completed Cubesat satellite. This model was developed by California Polytechnic State University.

Thirty-one cubesats have made it into space. Of these, about half have failed to transmit any data back to earth. Most transmitting cubesats have only delivered about 100kB of data before failure. This has been due to power and communication failures that happened during or shortly after launch. Failure to deploy antennas, intermittent transmission, lack of dedicated ground stations and electronics faults are all common causes of failure.

Several cubesats have been very successful. Both XI-IV and XI-V (built by students in Japan) have delivered hundreds of photos, and continue to operate today.

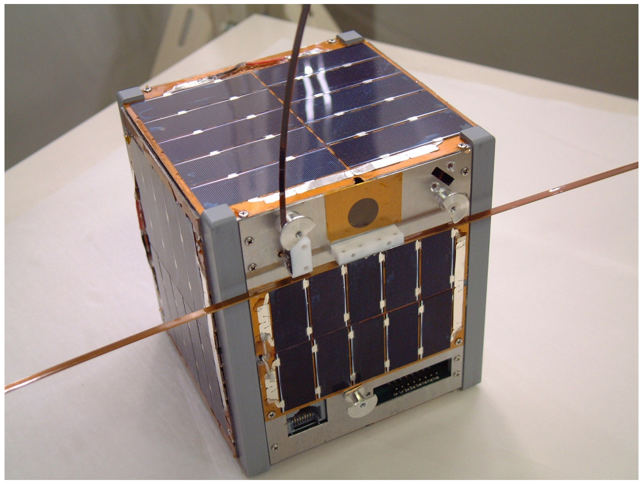

Figure 2 – University of Tokyo's XI-IV

1.3 Cubesat Communication

Most successful cubesats have several traits in common. Firstly, the CW beacon of a successful cubesat is almost continuously transmitting [Bryan & Kolas, 9, 14]. This enables ground stations to continuously track the satellite and easily download data. This continuous beacon contains system information and diagnostic data. A higher-throughput, high-power signal is then transmitted to dump images and other mission data that is requested on-demand.

Another problem that has caused failure of a communications system is the lack of a reset command. Operators on the ground must be able to instruct the satellite to completely reboot itself.

Below is a table of previous satellites, their communication system features and resulting data delivery.

Satellite	Object	Radio	Frequency	License	Power	TNC	Protocol	Baud Rate/Modulation	Amount Downloaded	Antenna
AAU1	27846	Wood & Douglas SX450	437.475 MHz	Amateur	500 mW	MX909	AX.25 on Mobitex	9600 Baud GMSK	1 kB[1]	dipole
CanX-1	27847	Melexis	437.880 MHz	Amateur	500 mW		Custom	1200 baud MSK	0[2]	crossed dipoles
Cute-1 (CO-55)	27844	Maki Denki (Beacon)	436.8375 MHz	Amateur	100 mW	PIC16LC73A	CW	50 WPM	N/A	monopole
		Alinco DJ-C4 (Data)	437.470 MHz	Amateur	350 mW	MX614	AX.25	1200 baud AFSK	?[3]	monopole
DTUsat-1	27842	RFMD RF2905	437.475 MHz	Amateur	400 mW		AX.25	2400 baud FSK	0[2]	canted turnstile
QuakeSat-1	27845	Tekk KS-960	436.675 MHz	Amateur	2 W	BayPac BP-96A	AX.25[4]	9600 baud FSK	423 MB	turnstile
XI-IV (CO-57)	27848	Nishi RF Lab (Beacon)	436.8475 MHz	Amateur	80 mW	PIC16C716	CW	50 WPM	N/A	dipole
		Nishi RF Lab (Data)	437.490 MHz	Amateur	1 W	PIC16C622	AX.25	1200 baud AFSK	?[3]	dipole
XI-V (CO-58)	28895	Nishi RF Lab (Beacon)	437.465 MHz	Amateur	80 mW	PIC16C716	CW	50 WPM	N/A	dipole
		Nishi RF Lab (Data)	437.345 MHz	Amateur	1 W	PIC16C622	AX.25	1200 baud AFSK	?[3]	dipole
NCube-2	28897[5]		437.505 MHz	Amateur			AX.25	1200 baud AFSK	0[2]	monopole
UWE-1	28892		437.505 MHz	Amateur	1 W	Integrated[6]	AX.25	1200/9600 baud AFSK	?[3]	dipole
Cute-1.7+APD	28941	Telemetry Beacon	437.385 MHz	Amateur	100 mW	H8S/2328[7]	CW	50 WPM	N/A	dipole
(CO-56)		Alinco DJ-C5	437.505 MHz	Amateur	300 mW	CMX589A	AX.25/SRLL	1200 AFSK/9600 GMSK	0	dipole
GeneSat-1	29655	Stensat (Beacon)	437.067 MHz	Amateur	500 mW		AX.25	1200 baud AFSK	N/A	monopole
		Microhard MHX-2400	2.4 GHz	ISM	1 W	Integrated[6]	Proprietary		500 kB	patch
CSTB1	31122	Commercial[8]	400.0375 MHz	Experimental	<1 W	Integrated[6]	Proprietary	1200 baud AFSK	6.77 MB[9]	dipole
AeroCube-2	31133	Commercial[8]	902-928 MHz	ISM	2 W	Integrated[6]	Proprietary	38.4 kbaud	500 kB[1]	patch
CP4	31132	TI CC1000	437.325 MHz	Amateur	1 W	PIC18LF6720	AX.25	1200 baud FSK	320 kB[1]	dipole
Libertad-1	31128	Stensat	437.405 MHz	Amateur	400 mW		AX.25	1200 baud AFSK	0[10]	monopole
CAPE1	31130	TI CC1020	435.245 MHz	Amateur	1 W	PIC16LF452	AX.25	9600 baud FSK	0[11]	dipole
CP3	31129	TI CC1000	436.845 MHz	Experimental	1 W	PIC18LF6720	AX.25	1200 baud FSK	1.6 MB[9]	dipole
MAST[12]	31126	Microhard MHX-2400	2.4 GHz	ISM	1 W	Intgrated[6]	Proprietary	15 kbps	>2 MB[1]	monopole

Figure 3 – Summary of Spacecraft Transceivers [Bryan & Kolas, 5]

2 YuSend Ground Station

As part of the YuSend project we will be responsible for the assembly, testing and documentation of the ground station that will be used to communicate with the YuSend1 cubesat and other nanosatellite based missions and research. Apart from its primary purpose the proposed ground station would also allow:

- Students to have hands-on experience with space communication as a club activity in Space Exploration and Development (SEDS). It is further proposed that operation of the station be incorporated in the undergraduate and graduate program curriculum in space science and engineering.
- CRESS researchers and faculty members to participate in a number of international, university-led space projects, including the Global Educational Network for Satellite Operations.

2.1 Location

The ground station that is being built according to the requirements of the YUSend project will be setup on the Observatory deck on the 4th floor of the Petrie Science and Engineering Building (PSE) at York University, Toronto. The construction and assembly of the hardware itself will take place in room PSE 405. It is constructed with a tripod like structure as its base, while the antenna and part of the antenna rotator assembly itself are expected to be raised approximately 10 feet above the roof during operation. The main location for processing data will also be at PSE 405. Its primary purpose is to act as the communication link to YuSend1 however, will also provide support for multiple other missions in the future, thus the choice in location.

2.2 Ground Station Design

2.2.1 Functional Description

The function of the ground station is to find, track and/or follow the position of a specific satellite (YUSend1 in this case) along its orbital path. It should also be able to transmit and receive signals to and from the satellite. This communication will be achieved through the use of the amateur radio UHF and VHF bands.

2.2.2 Physical Description

The ground station is based on a modular design with off the shelf components to allow for standardization and compatibility with other ground stations and satellite communications, with certain customization to suit the specific needs of YUSend1.

The ground station consists of hardware and software to transmit and receive data. The components include the antenna system, the antenna rotator and controller, and the VHF/UHF Transceiver. The VHF/UHF is connected to the Terminal Node Controller (TNC) which acts as the modem, modulating and demodulating the digital data packets sent to and received from the satellite. It also consists of the mast mounted low noise amplifier and VHF power amplifier designed for 2 metres. Other supporting components include power supply, sequencers required for powering and controlling RF power Amplifiers and the structure itself used to support the antennas and most of the components.

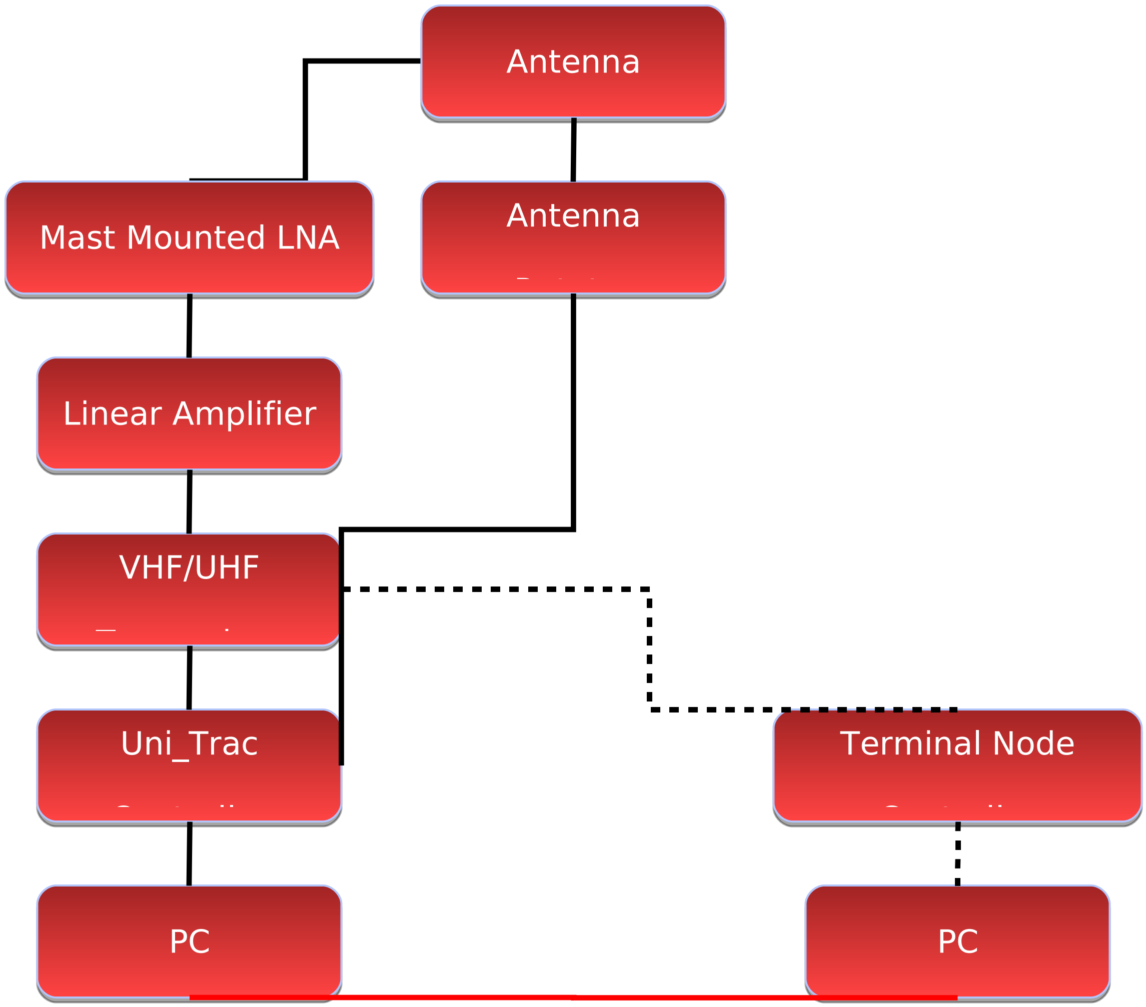

Figure 4 – Block diagram of the ground station

2.2.2.1 Structure

The main base structure is designed in the form of a tripod, constructed using pressurized wood. Its base dimensions are 1m x 1m x 1.5m. This is sufficient to hold the weight of the 10 foot antenna stand. The tripod base houses the main power supply (+13.8V), LNA, the azimuth rotator and the control electronics for the antenna rotator.

2.2.2.2 Antennas

The YuSend ground station will be using a combination of two Yagi-Uda antennas for the bidirectional UHF and VHF communication with the satellite one of the reasons being due to its high gain. One is the M2 2MCP22 circular polarized antenna for 2 metres with an antenna system gain of 21.5 dBi at 145.9MHz and the other for 70cm is the M2 436CP42UG, setup based on an L configuration used in milder climates. These antennas are mounted on rotator motors to change antenna azimuth and elevation to allow tracking of the satellite for the entire duration of the pass.

2.2.2.3 Radios

Information between YuSend1 and the ground station will be transmitted and received utilizing ICOM America's VHF/UHF All Mode Transceiver IC-910H. The frequency of communication will be on the amateur radio UHF/VHF band. We can eliminate the need for an external high power amplifier for satellite uplinks as the IC-910H contains a full 100 watts of power on VHF. For mode-J satellites, ICOM provides 75 watts of output on UHF. Unlike the transceiver on the satellite, power and weight are not limitations on the ground station transceivers.

Figure 5 - ICOM IC-910H: UHF/VHF Transceiver

2.2.2.4 Rotator & Controller

2.2.2.4.1 Rotator

For the antenna azimuth-elevation rotators and controller, Yaesu's G-5500 was chosen. It provides 450 degrees and 180 degrees elevation control of medium- and large-size unidirectional satellite antenna arrays under remote control from the station operating position[1]. One specifically is the azimuth rotator unit while the other is the elevation rotator unit. The rotators will be mounted independently with the azimuth rotator closer to the bottom of the mast, housed within the tripod base, while the elevation rotator will be mounted on the mast, closer to the antennas. The rotators have rotation rate of 67 sec for the elevation rotator unit and 58 sec for the azimuth rotator unit.

2.2.2.4.2 Controller

The controller unit has dual meters and direction controls for azimuth, in compass direction and degrees; and elevation from 0 to 180 degrees. An External Control jack is provided on the rear of the controller for interfacing with the TNC computer for accepting slewing commands and the motor controllers used to drive the rotator actuators. The voltage requirement for the Rotator and controller is 200-240 VAC.

1

Figure 6 - Yaesu G-5500: Antenna Rotators & Controller

2.2.2.5 Terminal Node Controller (TNC)

The TNC is the central point of the ground station. It essentially acts as a modem responsible for modulating and demodulating the digital data packets sent to and received from YuSend1. It also controls the individual ground station components such as the transceiver and the antenna rotator. For our ground station we have decided to use Kantronics manufactured KPC-3 plus. It will be able to provide satellite tracking information used for antenna pointing and it will also be able to calculate the degree of Doppler shift and automatically adjusts the UHF/VHF radio frequency to compensate.

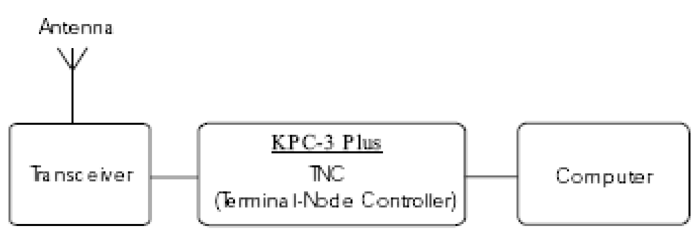

Figure 7 - Block diagram of The TNC and related components

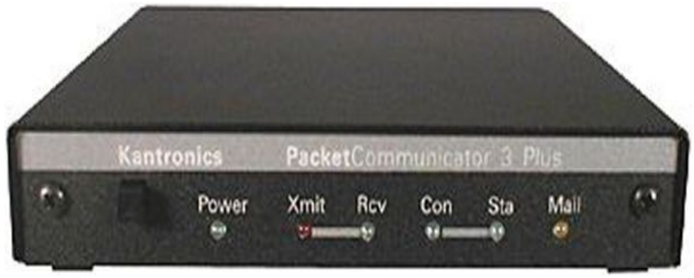

Figure 8 - Kanatronics KPC3+ : TNC

Below is a detailed table of all the parts of the ground station.

Table 1 - Ground station components specifications

Item	Manufacturer	Part Number	Distributor
Antenna	M2	436CP42UG (70cm) 2MCP22 (2m)	SSB Electronics
Antenna Rotator	Yaesu	G-5550B	Radio World
LNA Mast Mounted	MICROSET	SP-2000 (2m) SP-7000 (70cm)	SSB Electronics
Sequencer x 2	SSB	DCW-15B	SSB Electronics
Linear Amplifier	Mirage	B-320G	Durham Radio
Power Supply	Astron	RS-70M	Radio World
Rotator Control	ZL2AMD	UNI_TRAC 2003	Spectrum International
Transceiver	ICOM America	IC-910H	Radio World
TNC	Kantronics	KPC-3+	Radio World
Coax Protectors x 2	Polyphaser	IS-50NX-C2	Hutton Communications
Cable Protectors x 2	Polyphaser	IS-RCT	Hutton Communications

2.3 Fabrication and Assembly

Assembly of the ground station began in late September. This was anticipated to take very little time, but is proving to be a more complicated task as several parts need to be customized. Assembly will continue into October.

3 - Communication System Design for YuSend-1 Mission

3.1 Design Constraints

The primary constraint of this project is size. Cubesats are restricted before launch at 10cm x 10cm x 10cm volume, and approximately 1kg of mass. The satellite size after launch is not restricted, since after ejection from the launch vehicle any deployable parts may be expanded. The antenna will be deployed after ejection from the L.V. The satellite antenna design must be deployable on command and fit within a 10cm length of the structure of the satellite.

This small space will be crammed with electronics, making the power supply vital. The obvious trade-off with the power supply is that the bigger it is, the more battery life- but space is critical. The communications system must have a low-power mode which draws no more than 250mW of power. On battery operation, the spacecraft can produce 10 Watt-hours of energy.

The system must be capable of broadcasting a signal that can be received from an altitude of 300-600km, and broadcast at a data rate sufficient to transmit images and telemetry data. It must also be capable of receiving commands to control the satellite while in flight.

3.2 Link Power Considerations

When planning any communications link, all the signal gains and losses must be accounted for. This allows the minimum transmitter output power to be calculated.

Before antenna gain is considered, we will assume that the satellite will transmit some equivalent isotropic radiated power (EIRP). The ground station antenna will also have some gain (G_R) of 21.5dBi. Along the way, the signal will suffer from various sources of loss.

Expressed in log terms, the received power (P_R) is given below:

$$[P_R] = [EIRP] - [losses] + [G_R] \qquad \text{(Eq. 3.2.1)}$$

The main source of loss is the free space loss (FSL)

$$[FSL] = 10\log\left(4\pi r / \lambda \right)^2 \qquad \text{(Eq. 3.2.2)}$$

At 149.5MHz, the wavelength is 2m. Altitude may range from 300-600km, putting the upper limit on FSL at 125.5-131.5 dB. Other sources of loss include atmospheric absorption, antenna misalignment, polarization mismatch, and receiver feeder loss. Atmospheric absorption in Toronto has been shown to be on the order of 0.2dB [Roddy, 356] and the antenna pointing loss can be estimated at 0.3dB [Roddy, 356]. Since the receiver antenna is circularly polarized, polarization losses can be negligible. Receiver feeder losses are typically 1.5dB, but can be reduced by properly configuring the ground station.

This puts the total losses at approximately 127.5-133.5 dB. From section 2.2.2.3, the transceiver sensitivity at the ground station is -110.5dB. From Eq. 3.2.1 above, this gives a value for EIRP of approximately 0.5dB.

The gain of a ¼ wave monopole antenna is about 1.76dB. This means that the transmitter power of the satellite will need to be approximately -2.5dBW, or 0.5W for an easily useable signal. A lower amount of power could be used for the tracking beacon.

3.3 Modem Selection and Performance

Originally there were two options for a modem/transceiver. One being very expensive and complicated, called the MHX-2420 Development Platform. The other, and tentative choice, is the Yaesu Handheld transceiver and a Paccomm TNC (terminal node controller).

The handheld transceiver package has been coined as a Commercial Off the Shelf (COTS) communications subsystem by successful Montana State University Cubesat project. It uses what is essentially a walkie-talkie as the transceiver, and the Paccomm module to assemble/disassemble packets. Data is packetized and the AX.25 data link protocol is used for the communication link. X.25 is a standard network protocol for wide area networks, AX.25 is a data link protocol derived from it and is now used in amateur radio circles to support packet radio networks.

The Montana EaRth-Orbiting Pico-Explorer (MEROPE) Cubesat communication system operated at 1200baud. This rate will be expected of our system.

3.4 Antenna Options and Design Considerations

Many options are available for the antenna implementation, including monopole, dipole, and turnstile antenna designs. One options currently being considered would be using two monopole antennas, corresponding to the 2m and 70cm ground station antennas. This would provide beacon communication, with very low power usage, while being able to power the larger antenna for larger bursts of data. The power usage could be minimized in this way when data is not being actively transmitted, while still providing a beacon with minimal data for tracking purposes.

In addition to the antenna design itself, there exists the task of antenna deployment. During the launch of YuSend-1, the antenna must be secured and not interfere with launch and deployment of the satellite itself. after launch, the antenna must deploy and the system can begin normal operations. The current best option uses a string or nylon wire to tie the antennas down. A current is then put through a nichrome wire just after satellite deployment. This wire heats up, and burns through the string. This method has been proven to be highly reliable, and used by many Cubesat systems. This option works well with the dual-monopole antenna method, provided that the antennae are small enough to be tied down without protruding from the satellite frame.

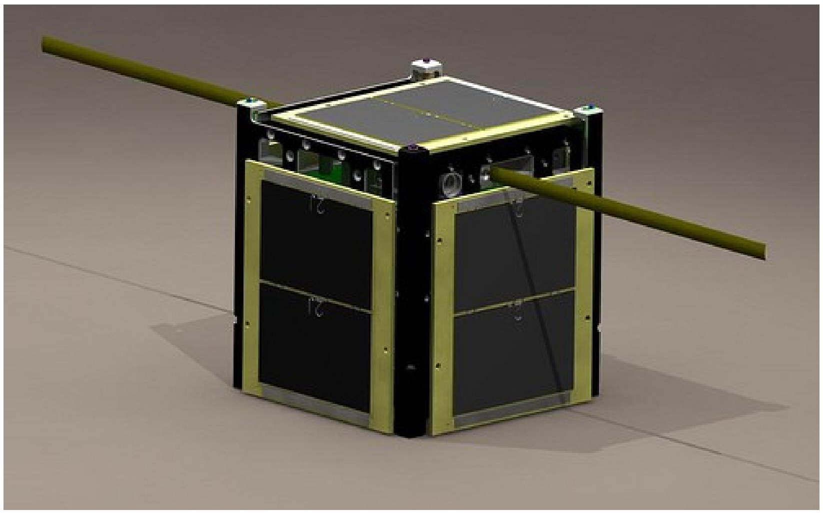

Figure 9 – An example of a tape-measure deployable antenna

(http://flickr.com/photos/27991275@N04/2610199721/)

3.5 Software System Architecture

A Linuxstamp OBC will provide software capability to the Cubesat communication system. In general, a Linuxstamp is a general purpose CPU, an ARM9 in our case, on a very small form factor motherboard. As the name implies, the system runs off Linux and creates a familiar Unix environment that software can be compiled for. The operating system loads off an SD card that plugs into the motherboard.

The specifications of our Linuxstamp:

Table 2 – OBC Specifications

Atmel AT91RM9200 process (ARM9 with MMU @ 180Mhz)
32MB SDRAM
8MB SPI Dataflash
One 10/100mbit Ethernet port
One USB host port
One USB client port (mini USB B)
One SD card slot
Serial debug port (via the USB port actually)
JTAG port
Can be powered over Ethernet cable

The USB host port on the board does not connect directly to the processor; it connects to the FT232R chip which is a USB-to-Serial converter. So to the Linux OS the device (assuming just one) will be seen as serial device at path /dev/ttyUSB0. A command line program called 'Minicom' will likely be the choice way to interact with the serial port.

The USB client port goes through the USB-to-Serial converter chip which then connects it to the serial debug port on the ARM9 processor. So it can be said that the Linuxstamp can be both a USB host (when it is grabbing input) and a client (when another computer is using the debug port).

To interact remotely with files in the Linuxstamp filesystem we will use a NFS (network file system) service running on the device. Other services like SSH can also be run on the Linuxstamp just like any Linux workstation.

To compile a program for the Linuxstamp, a cross compiler on a host computer will be used. So programs will not be compiled locally on the device, but rather on a x86 computer but with the compiler target of arm-Linux.

The operating system and system tools can be gathered and compiled from scratch for a Linuxstamp, but ours came with an SD card preloaded with a good operating system state.

4 - Preliminary Plan for Performance Testing

4.1 Flatsat test plan

The project will require extensive testing before attempting a communications link approaching real-world distances and conditions. The basic prototype will be tested with the ground station from varying distances and line-of-sight, after confirming basic communications functionality.

4.2 Imaging Requirements

The requirements would include the ability to command the system to take a picture, which would then capture the image, and store it locally on the satellite's internal memory. A command would be used to transmit the image (or images) from the on-board memory, down to the ground station for display. The size estimation for an image of 320 pixels by 240 pixels would be roughly 5-10 KB.

4.3 Performance Demonstration plan

The demonstration of the system will utilize a tethered balloon, carrying a prototype system and camera. From the presentation room, a remote link to the ground station will be established, and commands will be issued to take pictures download pictures, and report diagnostic information, which could be a simulation of diagnostic input that will be given from the final sub-systems of YuSend-1.

5 Project Management

5.1 Project Team

Matthew Hughes *Project Manager*	He is responsible for overseeing the completion and integration of hardware and software architecture of the project. He is to be the liaison between the faculty advisors and group members. He will assist and oversee the research and development of the design, assembly & testing of the ground and space segment of the communication system.

Mary Kuruvilla *Primary Researcher/Administrator*	She will be responsible for the research and development of the design, assembly & testing of the hardware/electronic components for the communication link,

	particularly the RF equipment both onboard YuSend1 and the ground station. Her duties will include documentation of the progress of the project.

Tim Crawford *Website and software designer/Treasurer*	He will be providing assistance with regards to the software programming of the OBC. He is also responsible for the testing of the ground station. His duties include the setting up, update and maintenance of the group website.

Dave Ketcheson *Lead Programmer*	His primarily involvement will be the software design and programming of the OBC on YuSend1

5.2 Budget

Cash		**In Kind**	
Item	**Cost**	**Item**	**Cost**
Antenna assembly and deployment mechanism	$150.00	Ground Station	$12,000
Handheld radio transceivers	$200.00	On-board computer	$120.00
TNC/Modem	$220.00	Weather balloon	$80.00
Training Expenses	$50.00	Power supply and other test equipment	$2,000
Wires and other materials	$20.00		
Presentation Supplies	$150.00		
Subtotal	**$790.00**	**Subtotal**	**$14,200**
Total	**$14,990**		

5.3 Timeline

YuSend Communication
Gantt Chart

Tasks / Weeks	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Project Proposal	■																															
Contract Proposal		■																														
Ground Station Assembly	■	■	■	■	■																											
Basic radio operator's qualification				■																												
Design Specification review					■																											
Software development begins					■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		
Advanced radio operator's qualification									■																							
1st design update presentation									■																							
Antenna design and modeling						■	■	■	■	■	■	■	■	■																		
Preliminary design review																	■															
Antenna fabrication																	■	■	■	■												
2nd design update presentation																			■	■												
1st communication link test																				■	■											
Critical Design review																							■	■								
Final design report																													■	■	■	■

6. Conclusion

Now that more specific information is known about Cubesat communication systems, the YuSend group will be able to select the specific parts required for this project. The requirements for a functional communication system are better defined, and found to be attainable within the scope of this project.

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