A DESCRIPTIVE STUDY OF THE REMOTE OPERATION AND AUTOMATION OF
THE VHF/ UHF SYSTEM FOR TRACKING AND CONTROLLING KYSAT-1 AT
MOREHEAD STATE UNIVERSITY

A Thesis

Presented to

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Master of Science
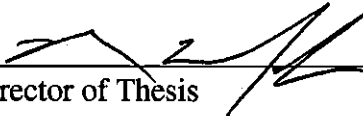
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Director of Thesis

Master's Committee: _____, Chair

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Marc B. Beck, M.S.
Morehead State University, 2009

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The Space Science Center (SSC) at Morehead State University (MSU) will serve as primary Earth station for the student- built CubeSat KySat-1.This research focused on the operational characteristics of remote controlling and automating the VHF/UHF Earth station system that will be used to track and command KySat-1. Remote controlling should be possible over the Internet from the control room in the SSC at MSU or with a laptop at any desired location. In order to enable remote access to the VHF/UHF system it is necessary to control all aspects, from antenna positioning to fine tuning the radio to account for its Doppler shift with software on a PC. This PC is connected to the internet and can be remotely accessed from anywhere. The software package to control the VHF/UHF system remotely consists of several programs that have been evaluated to determine if they satisfy several criteria, such as low cost, reliability, expandability, and compatibility with existing software. Programs that fulfilled those criteria have been implemented and tested, first individually, and then as a complete system. In order to test the remote control system, a satellite was chosen and multiple attempts to track that satellite were made with a laptop from a remote location. The remote control system was found to be performing satisfactorily, with exception of several minor flaws that can easily be worked out. In order to automate the VHF/UHF system, software needs to be implemented to schedule all the tasks normally performed by a human operator. Several different options have been evaluated and two software packages have been considered as possible candidates for implementation.

Accepted by:_____, Chair

Acknowledgements

Table of Contents

List of Figures

List of Tables

CHAPTER I: Introduction

Introduction

The Space Science Center (SSC) at Morehead State University (MSU) in Morehead, Kentucky will serve as the primary Earth station for the student-built KySat-1. The SSC has two antenna systems: A VHF/UHF system and a 21m Space Tracking Antenna (STA). The VHF /UHF system will be used for Telemetry, Tracking, and Command (TT&C) while the STA will be equipped with an S-Band system (Chandler, McClure, Hishmeh, Lumpp, Carter, Malphrus, Erb, Hutchison, Strickler, Cutler& Twiggs 2006). Not only will the S- Band system be used for TT&C, but due to its higher frequency it is also more suitable to receive data and images recorded with onboard instruments. The VHF/UHF system operates on a frequency that is too low for transmitting an image within one satellite pass, due to the large file size of the images. Having the capability to perform TT&C operations with two independent systems will increase the satellite's reliability in case of partial failure. A secondary VHF/UHF Earth station is located at the University of Kentucky in Lexington, Kentucky and several suit-case sized mobile stations exist. These latter stations will be used for public outreach to enable K-12 students to listen to KySat-1 as it passes overhead and command the satellite to take pictures or send telemetry data.

Kentucky Space is a non- profit enterprise consisting of a consortium of six Universities in the state of Kentucky and several public and private organizations. These Universities are Morehead State University, University of Kentucky, University of Louisville, Western Kentucky University, Murray State University, and Kentucky Community and Technical College System (KCTCS). Kentucky Space was founded in

2006 under the name KySat with the goal to build and operate small satellites for space related research, education and public outreach as an economic enterprise. KySat has since changed its name to Kentucky Space and expanded to include a variety of near space, sub-orbital, orbital and deep space missions. Kentucky Space has successfully launched one high altitude balloon in July 2008 and two suborbital rocket missions, Space Express in December 2007, and Garvey in October 2008. A third suborbital rocket mission and a second high altitude balloon mission are scheduled for the summer and fall of 2009, respectively. Kentucky Space is training undergraduate and graduate students to design, manufacture and control small satellites and is currently developing the 1UCubeSat KySat-1(Kentucky Space Homepage 2008).

Development of KySat-1 began in 2006 and the satellite was designed to meet the CubeSat standards defined by the California Polytechnic State University (CalPoly). The CubeSat kit from Pumpkin, Inc. was chosen for the frame and the processor board. The KySat-1CubeSat is consists of the following subsystems of commercially available off-the-shelf items:

1.) EPS Board

2.) VHF/UHF radio

3.) S-Band radio

4.) MSP 430 board

5.) Command& Data Handling beacon

6.) Camera

7.) Photovoltaic system

The following subsystems were designed and manufactured by members of the Kentucky Space student design team:

1.) Payload Interface Module (PIM)

2.) System Support Module (SSM)

3.) Antennas and antenna deployment systems

4.) Solar panels

5.) Antenna matching circuits

KySat-1 is equipped with three quarter wave monopole antennas for communications: S-Band, VHF, and UHF. All three antennas were made from steel tape that had been cut to the appropriate size, stripped, and gold plated. Construction of KySat-1 was completed at the University of Kentucky in Lexington, University of Louisville in Louisville, and Morehead State University (MSU). All communication systems verification tests are conducted at Morehead State University in Morehead, Kentucky (Chandler et al 2006).
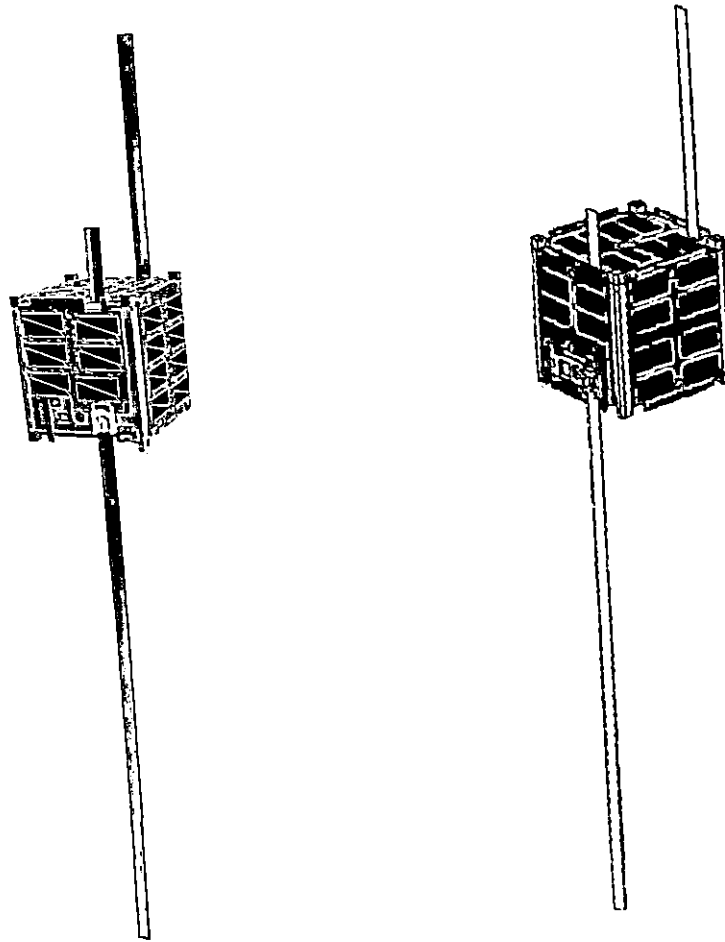
Figure 1-1 KySat-1 with antennas deployed (Photo on left, CAD model on right)

Kentucky Space is planning to launch KySat-1 in 2010 as secondary payload on a major NASA mission. The satellite is equipped with a StenSat VHF/UHF radio system and a Microhard MHX-2400 S-Band radio.

Part of KySat-1's mission Education and Public Outreach (E/PO) for pre-college students and teachers (Chandler et al 2006). The idea is to access a web based server and schedule a variety of operations of the satellite described in the Concept of Operations (ConOps) for E/PO.

According to the ConOps, schools would be able to track KySat-1 as outlined later in this thesis. The user at a school that wishes to participate will need to procure a hardware package consisting of the following:

- Radio

- MP3 Player/Recorder

- Arrow Antenna

- Preamp

- General Instruction Booklet

The user then records an audio file and, using the KySat-1 website, and enters his/her location. This would be either the school's location if audio contact and photo is desired or the target location if the user wishes to take a remote photo. The server kysat.morehead.edu returns possible pass times over next few weeks via web interface. The user then selects the time, sends the previously recorded audio file to Morehead, and selects either the advanced or the basic mode (i.e. Mode 1a or 1b). The user receives a confirmation email containing orbital information needed to establish contact consisting of:

- Time entering horizon

- Horizon enter point (azimuth), known as acquisition of source (AOS)

- Peak elevation in degrees

- Horizon exit point (azimuth), known as loss of source (LOS)

- Time exiting horizon

- Reminder to synchronize clocks with timeserver.morehead.edu

The requested dataset enters the queue waiting for next opportunity for S-Band transmission. The queue is flushed to satellite with full data set including audio, time on/off, advanced/basic mode. Email confirmation of upload and aiming information is resent. The server can operate in either advanced or basic mode:

- Basic mode: At AOS audio telemetry will be requested and the uploaded audio file begins playing. When overhead, picture sequence begins.

- Advanced mode: At AOS, the VHF receiver begins to listen for DTMF. Upon the satellite receiving DTMF, audio telemetry will be requested and the uploaded audio file begins playing. The DTMF command then starts the picture sequence.

At LOS, UHF/VHF links are shut down. Subsequently, on passing over Morehead the pictures and telemetry are downloaded. The server at kysat.morehead.edu builds an audio file "recording" as it was played on the satellite. The server kysat.morehead.edu overlays basic contact signature on images consisting of User requesting pass, Time of contact and the KySat logo. Recording and pictures are e-mailed to the user and archived on the server at Morehead State University (KySatWiki, 2006).

The satellite has store and forward capabilities in which the students can upload an audio file and students at another school can download it. They can use the satellite as a communication node on orbit. The web based server application will be a service that will act as an interface between the two antennas and the public to allow pre college students to access the satellite. The results of this project will be a system that students can use to schedule satellite passes, provide TT&C services and interact with the APRS

system to allow the end user to collect data stored in the satellite's RAM. Currently an

operator is required at the console of one of the two dedicated Earth stations to initiate

commanding and tracking the satellite and to pull down data and telemetry.

Below is a complete list of commands that KySat-1 can perform and parameters that it

will accept. Only operators at the Earth stations will have access to these commands.

Table 1-1: KySat-1 Command List (KySat Wiki, 2008)

Frame ID	Command Name	Command Category
0	Beacon Interval Control	Spacecraft Parameters
1	Digital Uplink Access Period Control	Spacecraft Parameters
2	Beacon Disable Period Control	Spacecraft Parameters
3	Command Acknowledgment Control	Spacecraft Parameters
4	Spacecraft Ping	Spacecraft Actions
5	Real Time Control	Spacecraft Actions
6	System Reset	Spacecraft Actions
7	Power Cycling Control	Spacecraft Actions
8	Photograph Capture Request	Spacecraft Actions
9	Photograph Capture Control	Spacecraft Parameters
10	Continuous Wave Beacon Message Control	Spacecraft Parameters
11	Digital Repeating Control	Spacecraft Parameters
12	S-Band Power Control	Spacecraft Actions
13	S-Band Automatic Power Down Control	Spacecraft Parameters
14	S-Band Direct Register Modification	Spacecraft Actions
15	Beacon Request	Spacecraft Actions
16	Status Report Request	Spacecraft Actions
17	Stop Action	Spacecraft Actions
18	Query Scheduled Commands	Spacecraft Actions
19	Remove Scheduled Commands	Spacecraft Actions
20	Load Recorded Audio	Spacecraft Actions
21	Play Loaded Audio	Spacecraft Actions
22	Create Telemetry Window	Spacecraft Actions
24	Data Transfer Acknowledge	Spacecraft Parameters
25	Laser Fire Control	Spacecraft Actions
26	Command Rejection Control	Spacecraft Parameters
27	Audible Telemetry Request	Spacecraft Actions
28	Transmitter Shutdown Control	Spacecraft Actions
29	DTMF Commanding Control	Spacecraft Parameters
52	Send File	File System Interactions
53	Request File	File System Interactions
54	Report Directory Contents	File System Interactions

55	Delete File	File System Interactions
63	Status Reports	Reserved Frame Identifiers

Note: Command # 25 "Laser Fire Control" is an insider joke and plays an audio file.

Statement of the problem

The MSU SSC VHF/UHF Earth station is located on a hill atop MSU's campus at 38.183° N latitude, -83.432° W longitude, and an altitude of 400meters above sea level. It is very likely that not every time KySat-1 passes over Morehead an operator will be available at the Earth station on the antenna range to track the satellite and communicate with it. This can happen if there is no operator available or the operator is unable to drive to the antenna range due to inclement weather.

The problem is twofold. First, there needs to be a means for the operator in Morehead's Space Science Center to remotely track and control the KySat-1 with the VHF/UHF antennas at MSU's antenna range. It would be useful to be able to track and control the satellite remotely with the VHF/UHF system from any possible location, not only the control room in the Space Science Center. Second, there is a need to automate the system to track KySat-1, send commands, and record beacon and telemetry data during times when there is no operator available. This can happen if the satellite passes at night or on holidays, or if the operator scheduled to track the satellite is unexpectedly unavailable, or if inclement weather makes the station inaccessible. Addressing this issue requires purchasing or creating software that can retrieve a schedule of satellite passes and start all the necessary hardware and software components at the beginning of a pass. This software also has to submit data to the satellite and store the recorded data received from the satellite in a way that it can be easily read and processed. Figure 1-2 summarizes in flow chart form the sequence of operations necessary to track and command a satellite.
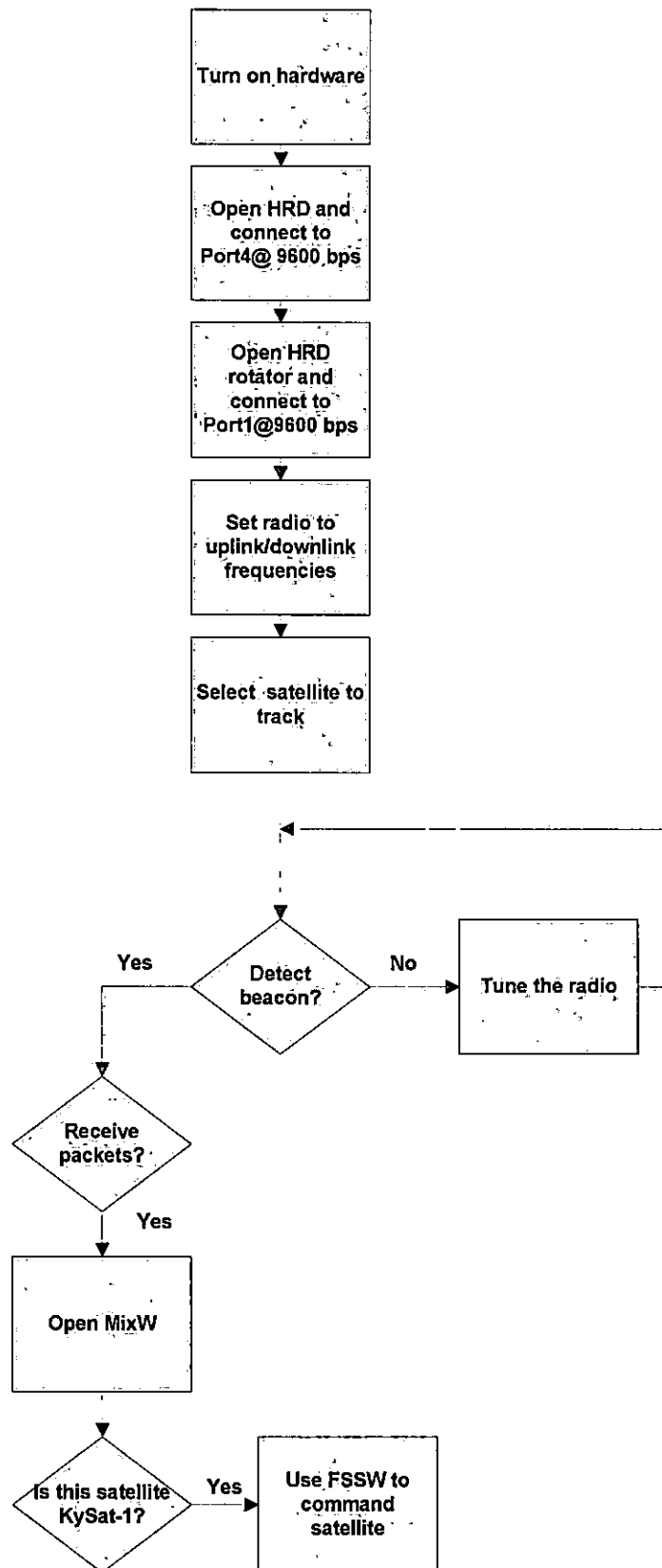
Figure 1-2: Flow chart of satellite tracking procedure

Remote Control

The first challenge is to develop an interface that allows the operator in the control room of the Space Science Center to remotely control the VHF/UHF radio system. The system is currently operated from a small control room located at MSU's antenna range that is connected to the VHF/UHF system. The need to automate the system is driven by the need for constant access to the satellite (KySat-1 initially) to command and control it, perform its functions, downlink data, and to maintain the "health" status (telemetry).

Automation

The second challenge is to develop software that allows one to track and command KySat-1 automatically without an operator being present to execute the necessary programs. It is preferable to communicate with the satellite whenever possible, even during times when there is no operator available. The automation software should perform all the tasks normally performed by a human operator. Automation is the more complex part of this project because the essential goal is to substitute a software program for the presence of a human operator.

Testing and evaluation of software systems

Before writing new code, existing software needs to be evaluated to determine its suitability for use with existing software and hardware. If the software needs to be modified it has to be evaluated as to its ease of modification. Using existing software can potentially save a substantial amount of time compared to writing entirely new code.

Once a method to remotely operate the VHF/UHF system is in place, it needs to be tested thoroughly for functionality and reliability. The same applies to the method of automation. Both systems need to fulfill a list of criteria within certain parameters.

Significance of the study

It is important to be able to track KySat-1 at any time in order to be able to experiment with it as much as possible. With the option to control the VHF/UHF system remotely is possible to track KySat-1 even when the antenna range is not accessible, e.g., due to ice on the road leading up to it. Automating the VHF/UHF system takes this even a step further. Once the system is automated, it is possible to track KySat-1 even without human intervention by running a program that executes all steps necessary to track the satellite and transmit previously stored data up to it as well as recording all information received from the satellite.

Furthermore, although operational, the VHF/UHF system at Morehead Sate University is envisioned as an evolving system. Changes and upgrades will be made and this study can serve as a building block for further improvements. Knowledge and experience gained during this project not only lead to improvements at the primary Earth station in Morehead, but can also be useful in improving the secondary Earth station at the University of Kentucky in Lexington and establishing Earth stations at other partner universities.

In the near future, possibly after the successful launch of KySat-1, other universities and even high schools may wish to join Kentucky Space and operate their own Earth stations. Other student led satellite projects might benefit from this study as well. This document will be a useful reference since it establishes procedures describing

how to set up and test remote control operations and automation for a VHF/UHF system. It also lists the requirements that need to be fulfilled and the necessary hardware and software for such a project.

Assumptions

The most reasonable way to exercise remote control over the VHF/UHF system is by remote controlling the Earth station PC through commercially available off-the-shelf (COTS) software. This software is typically easy to install and to use and comes with standard security features. Control of the radio can be handled by a program named Ham Radio Deluxe installed on the PC at the VHF/UHF system. Ham Radio Deluxe is readily available on the Internet and free of charge. The PC is connected to the Internet through the campus network.

In order to automate the system it is necessary to write a program to execute all tasks related to satellite tracking that would normally be performed by the operator. Writing and testing such a program would be very time and labor intensive. Therefore, attempts should be made to identify and utilize already existing software code used by other satellite Earth stations and modify it so it can be used with MSU's equipment where possible. Functionality of the remote control and automation system is the primary objective of this project.

Limitations

The main limitations to this project are time and cost. The system needs to be operational by the time KySat-1 arrives on orbit. Several design constraints need to be considered. The costs should remain within a reasonable budget. It is also important that the system is compatible with the current hardware and software and has advanced

capabilities for error tracking and discovery. The design should be modular, which means that it should consist of independent parts that can be easily replaced individually during future upgrades without affecting the entire system. This makes it easier for future team members to continue where this project leaves off in case it does not get completed within the given time frame.

The main challenge in developing/implementing the automation software is that it has to work with existing software, such as for example the satellite tracking program, the audio recorder, and KySat-1's flight support software. Some of the existing programs might be set up so that they accept commands from a human user via keyboard and mouse, but might not accept parameters from other programs. Using a batch file would only open the programs, but not command them. A possible way to circumvent this problem would be to write an entire operating program for our Earth station, which is extremely time and labor intensive and could take a team of students with sufficient software development skills several semesters to complete. An operating program has to interface with hardware, which requires writing specific driver software for each hardware component. Another problem is that a software system never functions as effectively as a human operator, especially in situations when unforeseeable problems arise.

The software systems that automate the VHF/UHF Earth station must satisfy the following design constraints:

- Be user-friendly and robust as the primary operators are undergraduate students.

- Be modular in order to be upgradeable and expandable, since this is an evolving system. It would be easier during an upgrade to replace small

parts at a time instead of the whole system. This would reduce the downtime during an upgrade.

- Be translatable to other systems because as KySpace expands, other universities and high schools might want to build their own Earth stations.

- Be scalable. With the plans to launch a satellite every 12-18 months and a satellite lifespan from 1 to 2 years, the possibility exists that more than one KySat will be on orbit at a time. It would be desirable to have the ability to schedule tracking, recording, and commanding for all of them. Other organizations may ask the SSC to track their satellites as well.

Definition of terms

APRS - The Automatic Packet Reporting System (APRS) was developed by Bob Bruninga, integrating GPS position information and the Internet with amateur radio. This two-way tactical real-time digital communications system is not only a vehicle tracking system, but it can be used to share all sorts of information of interest to members of the amateur radio community (Amateur Radio Relay League, 2007). APRS was used by KySpace in the summer of 2008 to track the high altitude balloon Balloon-1.

Amateur Radio -Amateur Radio, also known as ham radio is a way to talk to people across the world using radio equipment. Radio amateurs provide communication during emergencies and disasters. They also use their equipment to track satellites and use some of those satellites for communication. A license is required to become a radio amateur (Amateur Radio Relay League 2007).

AMSAT - The Radio Amateur Satellite Corporation (AMSAT) was founded in 1969 to

build amateur radio satellites. Most of the OSCAR (Orbiting Satellite Carrying Amateur

Radio) satellites were built by AMSAT (Amateur Radio Relay League, 1999).

Azimuth - Azimuth refers to the rotation in the horizontal plane in the clockwise

direction. By definition north is 0 degrees or 360 degrees, east is 90 degrees, south is 180

degrees and west is 270 degrees (Amateur Radio Relay League, 1999).

Bandwidth - Bandwidth is defined as the difference between the upper and lower cutoff

frequencies, which means the range of frequencies transmitted without being strongly

attenuated. In communications and signal processing, bandwidth is usually measured in

Hertz. In computer networking, when processing binary signals, the term bandwidth often

refers to a data rate measured in bits per second.

CubeSat - A CubeSat is a satellite made of cubes measuring ten centimeters in diameter

with a mass of no more than 1 kg for each cube. CubeSats can be a single cube (1U) or

consist of up to three cubes (3U) and are launched as secondary or tertiary payload

together with larger and more expensive satellites (California Polytechnic State

University, 2004).

Doppler Shift - The Doppler Shift is the change in frequency and wavelength of a wave

for an observer moving in respect to the source of the waves. The frequency of satellite

transmissions received by the Earth station increases as the satellite is approaching the

Earth station and decreases as the satellite moves away (Richaria, 1999).

DSN - NASA's Deep Space Network (DSN) is the oldest network of Earth stations and

was designed to track spacecraft outside the Earth's orbit (NASA Jet Propulsion

Laboratory, 2009).

<u>Earth station</u> - An Earth station is the ground-based end of a communications link to an object in outer space. Earth stations are located on, or within 50 km of the Earth's surface and their purpose is to communicate with communications satellites, space probes, and manned spacecraft (Amateur Radio Relay League, 2003).

<u>Elevation</u> - Elevation refers to the angle (in degrees) above the local horizontal plane. It is the up-down angle perpendicular to the plane of the Earth (Amateur Radio Relay League, 1999).

<u>EM spectrum</u> - The electromagnetic (EM) spectrum is the range of all possible electromagnetic radiation frequencies. The electromagnetic spectrum of an object is the characteristic distribution of electromagnetic radiation from that particular object. The electromagnetic spectrum extends from below the frequencies used for modern radio (at the long-wavelength end) through gamma radiation (at the short-wavelength end), covering wavelengths from thousands of kilometers down to a fraction the size of an atom. It is thought that the short wavelength limit is in the vicinity of the Planck length, and the long wavelength limit is the size of the universe itself, although in principle the spectrum is infinite and continuous.

<u>EPS</u> - The Electrical Power System (EPS) for KySat-1 consists of six solar panels, two batteries and the EPS board (KySat Wiki, 2008).

<u>FSSW</u> - The Flight Support Software (FSSW) is a software package written by the KySat team in the programming language C. Its purpose is to send commands to the satellite and retrieve telemetry data and pictures. The FSSW communicates with the satellite either over the VHF/UHF system or the S-band system through the serial port (KySat Wiki, 2008).

GN - The Ground Network (GN) is a network of NASA Earth stations to track orbital satellites. Some of the GN's tasks have been taken over by TDRSS in the 1980's, and the GN was greatly reduced in number of stations. The GN has been renamed to Near Earth Network (NEN) and is now primarily used to support aeronautical and atmospheric research, range safety, and high inclination (high latitude) orbital communications.

Keplerian Elements - The Keplerian Elements contain information used by satellite tracking programs to determine the orbit of a satellite. They are the following:

- Inclination

- Right Ascension of Ascending Node

- Eccentricity

- Argument of perigee

- Mean anomaly

- Mean motion

All of those elements are specified at a certain epoch or reference year, day and time. A drag factor or rate of orbital decay is usually included as well (Amateur Radio Relay League, 1999).

LEO - LEO is an acronym for Low Earth Orbit. Satellites in Low Earth Orbit are orbiting the Earth at altitudes between about 800 and 1200 kilometers and can complete an orbit in about 90 minutes. Satellites that monitor the Earth and amateur radio satellites orbit in LEO. The Space Shuttle and the International Space Station travel in LEO as well (Amateur Radio Relay League, 1999).

LNA - A Low Noise Amplifier (LNA) is an electronic amplifier used at the front end of a radio receiver circuit. Its purpose is to amplify very weak signals captured by an antenna.

Ham Radio Deluxe - This is a satellite tracking software similar to SatPC32. Ham Radio

Deluxe was developed by a radio amateur named Simon Brown. HRD was chosen to

replace SatPC32, because it can be used to tune the radio.

NEN - The Near Earth Network (NEN, formerly known as Ground Network, GN) is a

network of Earth stations operated by NASA to used to support aeronautical and

atmospheric research, range safety, and high inclination (high latitude) orbital

communications (Tsiao, 2008).

PIM - The Payload Interface Module (PIM) was designed and manufactured by members

of the KySat team after realizing that some of the subsystems would not fit on the SSM

due to interference issues with the camera. Consequently, the following subsystems were

moved from the SSM to the PIM: Camera heater control, camera control, camera

interface connector, antenna deployment logic and current control (KySatWiki, 2009).
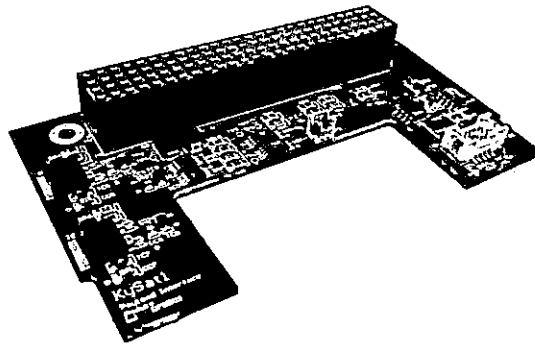
Figure 1-3: The PIM for KySat-1

Polarization - Polarization describes the orientation of the electromagnetic field in an

antenna. The polarization of an antenna depends on if the antenna is positioned

horizontally or vertically in respect to the ground. The polarization of an antenna in free

space is indeterminate, due to lack of a point of reference (Amateur Radio Relay League,

1994).

P-POD - The Poly Picosatellite Orbital Deployer (P-POD) is a standard interface and system for deploying CubeSats developed by CalPoly. The P-POD is a rectangular aluminum box with a door and a spring mechanism for deploying the CubeSats. Each P-POD can either hold three 1UCubeSats, one 1U and one 2UCubeSat, or a single 3UCubeSat (California Polytechnic State University, 2004).
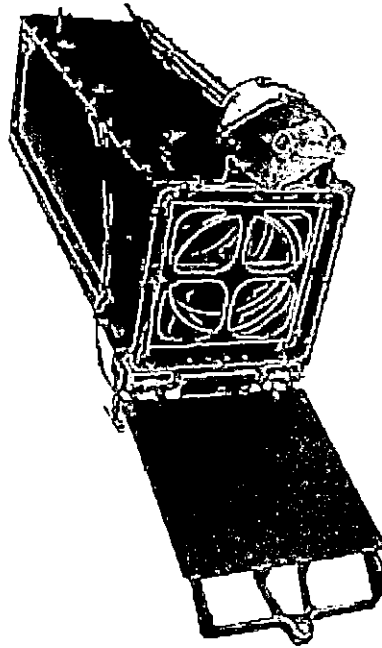
Figure 1-4: The P-POD (California Polytechnic State University, 2004)

RF - RF is an acronym for Radio Frequency. Frequencies within the range of 3Hz to 300 GHz fall into the RF spectrum.

SatPC32 - SatPC32 is a program for satellite tracking and antenna and radio control. This program calculates the tracks of Earth orbiting satellites. The calculations are highly accurate, because they are based on the SGP4/SDP4 model. SatPC displays the audibility-areas of one or several selected satellites within a world-map and shows the results in text-lines below the map. The program updates its calculations continuously in

steps of one second. SatPC steers the antennas and radio frequencies (CAT) for Doppler

correction (SatPC32 Homepage, 2008).
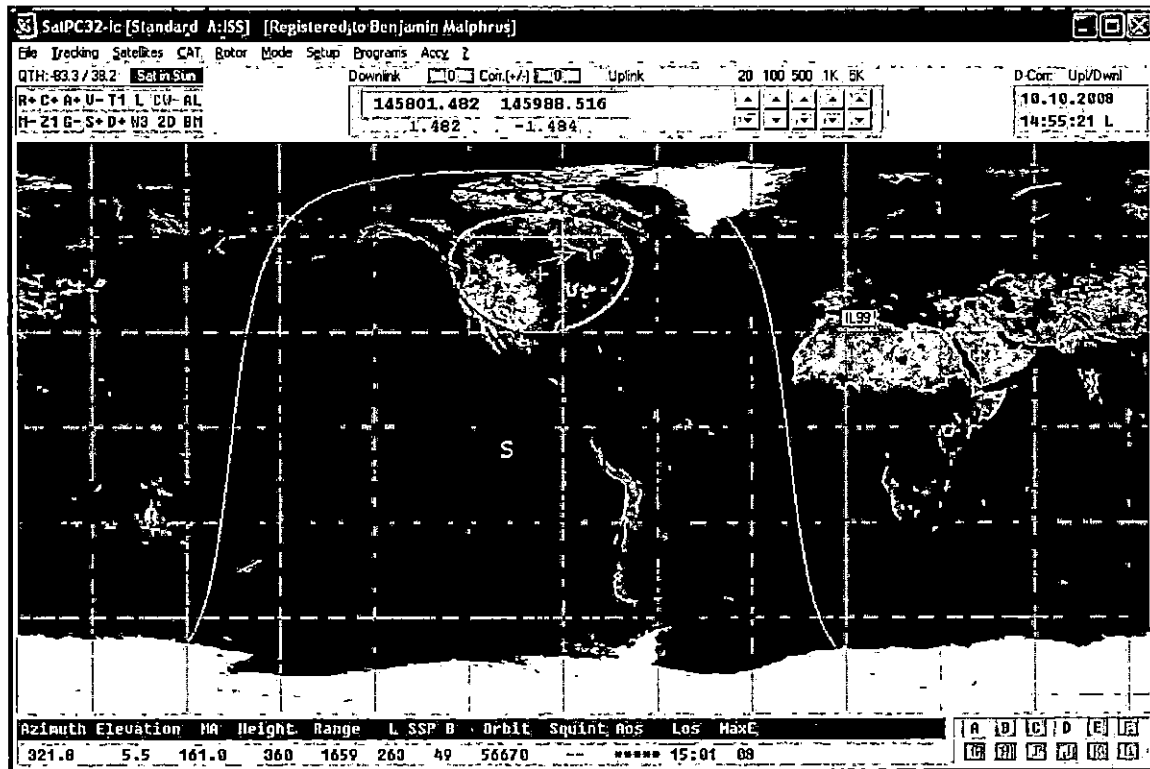
Figure 1-5 Screenshot of SatPC32

SSM - The Systems Support Module (SSM) is an integral part of KySat-1. Its function is

to provide support to the processor module and other systems throughout the satellite. It

includes a real time clock, a watch dog timer, a DTMF receiver, and a supervisory

microcontroller. The SSM was designed and manufactured by members of the KySat

team (Chandler et al, 2006).
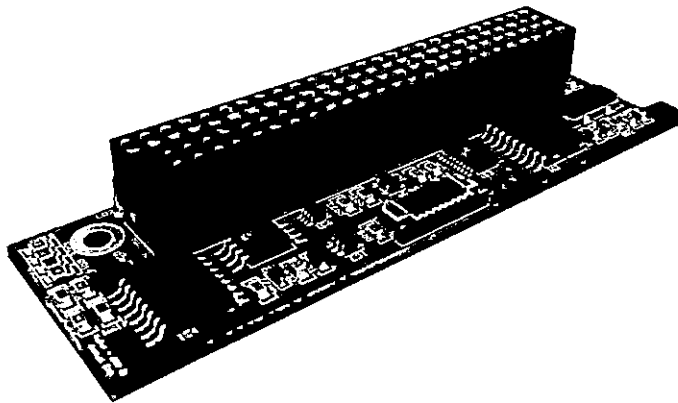
Figure 1-6: The SSM for KySat-1

Wake On LAN – This is a feature in the BIOS of most computers that enables them to be

activated through a Local Area Network (LAN) by sending a "Magic Packet" from

another computer. It is required that the computer to be activated via Wake On LAN has

a static IP address.

WakeOnLanGui – This is a software that provides a graphical user interface (GUI) for

Wake On LAN.

Yagi Antenna - A Yagi Antenna is a directional antenna system that consists of an array

of a dipole and additional closely coupled parasitic elements (usually a reflector and one

or more directors). The dipole in the array is driven, and a second, 10% longer element,

operates as a reflector. Other shorter parasitic elements in front of the dipole usually act

as directors. This arrangement gives the antenna directionality that a single dipole lacks.

Yagi antennas are often used by radio amateurs (Orr& Cowan, 1986).

S-Band - The S-Band is part of the microwave band of the electromagnetic spectrum. It

ranges from 2 to 4 GHz and crosses the nominal boundary between UHF and SHF at 3

GHz.

Signal to noise ratio - The signal to noise ratio is the ratio of a signal power to the noise

power corrupting the signal. The signal to noise ratio has to be positive in order for the

receiver to recover the signal. In digital systems the signal to noise ratio is calculated using E_b/N_o - the energy per bit per noise power spectral density (J. A. Kruth, personal communication, October 8, 2008).

TDRSS - The Tracking and Data Relay Satellite System (TDRSS) was implemented in the 1980's to support Space Shuttle missions. The Ground Network can only provide a small percentage of the coverage for the ground tracking of an orbiting spacecraft, due to the curvature of the earth. The spacecraft could only be tracked when within line of sight of any given Earth station. To overcome this problem, NASA created TDRSS as a network of satellites for tracking orbiting spacecraft (Tsiao, 2008).

TNC - A Terminal Node Controller (TNC) is used as an interface between a computer and a VHF radio for packet radio communication and several other modes of digital communication (Amateur Radio Relay League, 2003).

VHF/UHF system - A VHF/UHF system is a communication system that operates in the Very High Frequency (VHF) and Ultra High Frequency (UHF) bands of the electromagnetic spectrum. These bands are most often used by amateur radio operators. The frequencies in the VHF band range from 50 MHz to 225 MHz, with wavelengths from 6 meters down to 1.25 meters. The frequencies in the UHF band range from 420 MHz to 2450 MHz, with wavelengths from 70 centimeters down to 13 centimeters. VHF frequencies from 144-148 MHz (in the 2 meter band) are often used as uplink frequencies (to transmit from the Earth station to the satellite) for satellites, and UHF frequencies from 420-450 MHz (in the 70 centimeter band) are often used as downlink frequencies (to transmit from the satellite to the Earth station) (Amateur Radio Relay League, 1999).

CHAPTER II: Review of Literature

Background

The Space Science Center (SSC) at MSU operates two satellite Earth stations at the antenna range in Morehead, Kentucky. One is the 21M STA equipped with an S-Band feed built at MSU and a transceiver system based on an MHX-2400 S-Band radio from Microhard. The second Earth station is a low bandwidth VHF/UHF system based on Amateur Radio technology. The purpose of the low bandwidth system is to provide reliable communication with satellites in LEO (Low Earth Orbit). The VHF/UHF Earth station uses amateur radio equipment to communicate in the 2m VHF (Very High Frequency) band at a frequency range from 144 to148 MHz and the 70 cm UHF (Ultra High Frequency) band at a frequency range from 420 to 450 MHz. The VHF band is used as uplink to transmit from the Earth station to the KySat-1 and the UHF band is used as downlink for the Earth station to receive signals from the satellite (Eluru, 2008). The SSC is currently using its Earth stations to track satellites for other organizations, such as Compass-1 for the University of Aachen/Germany and PharmaSat for NASA Ames. Once KySat-1 is launched into orbit, the primary mission of the two Earth Stations will be to track and command KySat-1.

It is more convenient to operate the VHF/UHF station remotely from the SSC than to have an operator directly control the station from the Earth station at the antenna range. Other institutions such as Santa Clara University in California, (Cross, Hornisher, MacKinnon, Masuda, Oranen & Randles, 2002) NOAA in Fairbanks, Alaska, and Narvik University College in Norway (Raymond-Riise, 2003) have developed the capability to

operate their tracking stations remotely and it would be useful to develop the same capabilities at MSU. With greater capabilities, this will also aid the development of an array of VHF/UHF Earth stations at the universities and high schools in Kentucky and beyond.

Historical overview

Amateur radio and satellites

Amateur radio operators have been involved with satellites since the beginning of the space age. After amateur radio operators from all over the world listened to radio signals from the first satellite Sputnik launched by the Soviet Union in 1957, the Jet Propulsion Laboratory (JPL) of the California Institute of Technology in Pasadena invited them to track Explorer1, the first American satellite (J.A Kruth, personal communication, November 21, 2008). In 1961, a group of radio amateurs built the first amateur radio satellite, OSCAR 1. This group built three more OSCARs. Later OSCAR satellites were built by the Radio Amateur Satellite Corporation (AMSAT). Most amateur radio satellites carry the designation Orbiting Satellite Carrying Amateur Radio (OSCAR). The number of OSCARs has increased drastically over the past four decades and there are now over fifty of them in orbit. Other amateur radio satellites launched by other organizations also exist (Amateur Radio Relay League, 1999).

Satellite Tracking and Command Networks

In order to track and command satellites and other spacecraft once they are on orbit, it is necessary to have at least one Earth station. But with only one Earth station, the satellite can only be tracked when it is passing over that station's location. For that reason it is useful to have several Earth stations at different geographic locations all over the

world. The oldest network of Earth stations is NASA's Deep Space Network (DSN). It was designed in 1957 by NASA's Jet Propulsion Lab (JPL) to track spacecraft outside beyond low Earth orbit (LEO). The DSN consists of three Earth stations located 120 degrees apart from each other. These are the Goldstone Deep Space Communications Complex outside of Barstow, California, United States; the Madrid Deep Space Communication Complex, 60 kilometers (37 miles) west of Madrid, Spain; and the Canberra Deep Space Communications Complex (CDSCC) in the Australian Capital Territory, 40 kilometers (25 miles) southwest of Canberra, Australia near the Tidbinbilla Nature Reserve. Each Earth Station consists of several parabolic dish antennas, ranging from 26-meter (85 ft) over 34-meter (111-ft) to 70-meter (230 ft). The DSN is the largest and most sensitive scientific telecommunications system in the world (Jet Propulsion Lab, 2009). It played a significant role during the Apollo program, especially during Apollo 13. After over 50 years of service, the number of missions supported by the DSN is still growing rapidly. The 70-meter antennas are now reaching the end of their lifespan and will need to be replaced soon, probably with an array of smaller antennas.

NASA operates a second Earth station network called the Ground Network (GN, now Near Earth Network, NEN). The GN is a network of NASA Earth stations located in Alaska, Antarctica, Florida, Norway, and Virginia. The GN also includes support from the Network Integration Center located at the Goddard Space Flight Center and the GN scheduling and VHF systems at White Sands, New Mexico. Together with the Space network (SN), the GN is part of NASA's Spaceflight Tracking and Data Network (STDN). The original purpose of the GN was to track orbital satellites and today it is primarily used to support astronautical and atmospheric research, range safety, and high

inclination (high latitude) orbital communications. Some of the GN's tasks have been taken over by the Tracking and Data Relay Satellite System (TDRSS) TDRSS in the 1980's, and the GN was greatly reduced in number of stations. TDRSS was intended to replace the GN, but never really did (Tsiao, 2008).

CubeSats

Originally, NASA and other launch providers would add weights to counterbalance the primary payload when the weight of the primary is unevenly distributed. Professor Robert Twiggs at Stanford University developed the idea to use smaller satellites as a secondary or tertiary payload instead of those weights. With advances in integrated circuit design and the resulting miniaturization of electronic hardware over the past decades it had become possible to build satellites small enough to be accommodated by the space previously devoted to ballast. CubeSats were first conceived of by Stanford University and CalPoly in 1999 with the primary mission to provide access to space for small payloads (R.J.Twiggs, personal communication, June 17, 2008). This gives students at universities the unique opportunity to design and build experiments that can be launched into LEO. CalPoly functions as a launch coordinator with the primary responsibility of ensuring the safety of the CubeSats, and protecting the primary payload as well as the launch vehicle. For this purpose, and to aid the deployment of the CubeSats, CalPoly also developed an orbital deployment system called the Poly Picosatellite Orbital Deployer (P-POD), which has the size and shape of the weights previously used and which can carry and deploy up to three 1UCubeSats (R.J.Twiggs, personal communication, June 17, 2008). The idea of the CubeSat and the P-POD as launcher has evolved from a previous project called OPAL, where a

microsatellite launched six picosatellites in a mothership/daughtership mission (Cutler 2006).

Universities worldwide are now building CubeSats and need an infrastructure of Earth stations to track and command them. Many of them are building their own VHF/UHF antenna system or share systems with others. In 2003, students at Narvik University College in Narvik, Norway built a VHF/UHF Earth station to track the Norwegian CubeSats NCUBE-1 and NCUBE-2. The Earth station in Narvik was able to receive audio signals in English, German, and Russian from several amateur radio satellites (Raymond-Riise, 2003). Due to launch delays, NCUBE-2 was launched in October 2005, several months before NCUBE-1. The University in Narvik and several ham radio operators kept tracking the satellite until the beginning of the following year, but did not manage to receive any signals. Unfortunately, NCUBE-1 was lost along with 13 other CubeSats during a failure of its launch vehicle, a Russian Dnepr rocket, in July 2006 (NCUBE website, 2006). Since the inception of the CubeSat idea, over 100 developers world-wide have begun to develop CubeSats and more than 20 have been launched.

Automated Software Systems for Earth Stations

A group at Stanford University led by Jamie Cutler has developed a software system called GSML (Earth station Markup Language) for commanding a network of satellite Earth stations. GSML is part of the Mercury project for VHF/UHF antenna systems that consists of global networks of Earth stations which support university-based CubeSat missions. Mercury takes advantage of existing infrastructure from universities all around the world. It uses GSML to provide a standard interface for Earth stations that

differ fundamentally in hardware, software, age, and geographic location and enables them to track satellites other than the ones they were initially designed to track. The goal of Cutler's work is to provide on-demand, 24/7 access to orbiting satellites by utilizing idle Earth station resources through the global Mercury network (Cutler, 2006). While an excellent goal, this network has yet to be realized or even initiated.

In 2001 a group of students at the Santa Clara University developed Remote Accessible Communications Environment (RACE). This group used the same radio and the same rotator controller as the system at MSU, but they were using a different satellite tracking program (Nova instead of HRD). The radio used for RACE is controlled through a program written in LabView (a programming environment developed commercially by National Instruments). In each of the following three years, groups of students undertook projects RACE II, RACE III, and RACE IV, each upgrading and expanding the previous system and fixing remaining bugs (Cross et al, 2002) (Jimenez & Lukoskie, 2003) (Cheng & Salas, 2004). This is an example how a research project begun by a group of students can evolve into a much larger project, where each group builds on the efforts of the previous one. This project takes a similar approach.

A system that serves as a role model for this project is the one that has been implemented at the University of Bologna, Italy (Unibo). That system has essentially the same goals as this project, namely the automation of a VHF/UHF Earth station for satellite tracking and command, and it is already fully operational.

Unibo began research initiatives in the field of microsatellite design, manufacturing and space operations in 2003. Their microsatellite laboratory at the School of Engineering in Forli operates a fully automated satellite Earth station that started out at

VHF and UHF bands and was upgraded in 2005 to include S-band downlink capabilities. This Earth station is fully operational and routinely used for the downlink of amateur radio satellites telemetry information, earth images, and store-and-forward packet communication (Tappero, Dempster, Iwata & Totora, 2007).

The team at Unibo has been using a software package called Orbitron combined with the rotor control software WispDDE for the first years. When they started experiencing some limitations due to the unavailability of some important features like the possibility to control two radios at the same time (for example, one at UHF and the other at S-band), they decided to develop their own software modules in LabView, to be used in conjunction with Nova for Windows as satellite tracking software. After using this software combination for a year, they decided to switch to a fully internally-developed software which is currently in an advanced phase of testing. This software was developed in the programming language Java (P. Totora, personal communication, February 10, 2009). It would be optimal if that system could be replicated at MSU and modified to meet the specific needs of the MSU system.

Another system that with similar goals is the Global Educational Network for Satellite Operators (GENSO), which was developed by Justin Foley and Jason Anderson at CalPoly. GENSO is a project to link low-cost Earth stations and was started under the International Space Education Board, a collaboration between CSA, ESA, JAXA, and NASA. It is a system to link Earth stations using the Internet. GENSO consists of three components:

- The Central Servers for authentication and registration

- The Earth station Servers (GSS), which are the actual interface between rotors/radio and the Internet

- The Mission Control Client (MCC) for the scheduling of the Earth station Servers

There are three central servers worldwide: one at CalPoly, one in Europe, and one in Japan. These servers are tasked with authentication and registration only. This includes the registration of IP addresses of GSS and MCC and the handling of statistics. All other functions (scheduling, data transfer) will go peer-to-peer between Mission Control Clients and Earth station Servers. This keeps the load off a single server.

The Earth station Servers are cross-platform compatible with a majority of Earth stations currently operating. They perform the following tasks:

- "Passive"tracking:
  - o Continuously track all satellites it can decode
  - o Supply data to MCC
- "Active"tracking:
  - o Remote operator an MCC actively controls the rotors and radio, looks at the decoded data, and listens to the audio
  - o Satellite pass must be scheduled in advance and cleared with GSS
  - o Requires offline interaction and parties that know each other
- Store data locally and stream to MCC as bandwidth allows
- Possibly act as IRC and/or Skype client

The Mission Control Client is a program that runs on a personal computer that can control Earth station Servers. It uses the Central Servers to get IP addresses for individual GSS, then contacts the GSS's directly to:

- Schedule an active session

- Download decoded data

- Control the radios and rotors to track a satellite during an active session

- Possibly act as IRC and/or Skype client

(Anderson, 2008)

CalPoly's first two satellites CP-3 and CP-4 were launched in April of 2007 and are still functioning. (CP-1 and CP-2 were lost during launch failure of a Dnepr rocket, the same that carried NCUBE-1) Each of the two satellites passes 2-4 times per day. The satellites operate on 70 cm band, LSB, AX.25 packet. The problem is that there are many student/hours to schedule. Due to a communication issue it takes persistence to get an uplink, and there is a lack of motivation to run passes that do not produce much data. The solution is to replace the human with a software system that automates the process of running passes and records the resulting data. This software has to fulfill the following requirements:

- . Constantly calculate satellite Az/El

- Perform Doppler correction

- Serve as radio/rotator serial interface

- Perform Audio analysis for automatic fine-tuning

- Operate multiple passes without human intervention

LabView was chosen as the programming language because it has built-in capabilities for serial communication and audio waveform analysis as well as a DDE interface to satellite tracking programs such as SatPC32 or Orbitron. The program Auto Pass Operator was created, making these features work together. Before the use of Auto Pass Operator the average data downlinked per day was 5KB. With Auto Pass Operator, the amount of downlinked data doubled to an average of 10 KB/day. Without automated operations, the team at CalPoly would have needed people for 30 minutes each day. But with more satellites to track, automated operations become essential (Foley & Anderson, 2009). The VHF/UHF system could possibly start out like the project at Unibo and later evolve into a larger scale project similar to GENSO.

Rationale

The goals of this project are to remotely control and automate the satellite tracking and command capabilities at MSU in a similar manner to the systems at Unibo and CalPoly. In order to achieve these goals, it may be necessary to modify the software used by other groups to suit KySat's needs if possible, or ultimately create new software systems that provide the desired capabilities. Appropriate software needs to be developed, which is very time consuming. When developing software, it is important to choose the programming language that is the most appropriate for this project. Also, it needs to be compatible with existing software and hardware components of the VHF/UHF system without being too dependent on those components. That means that if in the future a decision is made to replace the radio with a different model from a different manufacturer, or if the satellite tracking software gets replaced again, the

automation software will still function. The development of the automation software needs to be well documented, so that it can be easily modified and upgraded in the future. Expandability and clarity should play an important rule not only through detailed documentation, but also during the development and during the coding process itself. It is important to keep in mind that the automation software is not a finished product, but is subject to change and evolution over time.

Chapter III – Methodology

Introduction

To ensure the functionality and reliability of both the remote control system and the automation system, they both need to be thoroughly tested. In order to develop a testing procedure it is necessary to clearly define the operational characteristics of both systems and to identify an appropriate testing method to address each of those characteristics. Any software that is developed as part of this project undergoes beta testing, which means that it is thoroughly tested by different users under several different conditions in a real time environment. The testers attempt to cause a failure to the software by issuing nonsense commands or giving parameters that are out of range, such as, for example, scheduling to track a satellite on February 31st. This is done in order to identify any bugs that threaten the robustness of the system.

Engineering Design

The VHF/UHF system at the MSU antenna range consists of two high gain Yagi antennas (one for the 2m band and one for the 70 cm band) sharing a single Yaesu G5500 Azimuth/ Elevation rotator. The signal received by the antennas is boosted by a low noise amplifier and is directed through a coaxial feed line to the Earth station. A separate feed line is used for transmitting. Each line is connected to a dedicated lightning arrestor which is mounted to a grounding plate inside the Earth station (Eluru, 2008).

Figure 2-1 left: VHF and UHF Yagi antennas at MSU antenna range

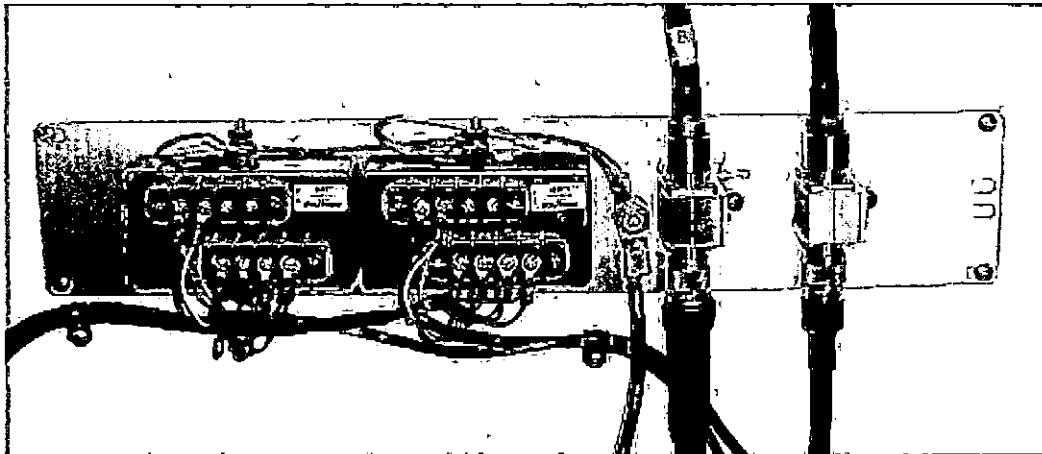Figure 3-2 right: Close-up of VHF and UHF Yagi antennas

Figure 3-3 Lightning arrestors with grounding plate at the Earth station

The transmit and receive lines running from the antennas are connected to an

Icom 910 transceiver. The Azimuth/Elevation rotator is connected via multi conductor

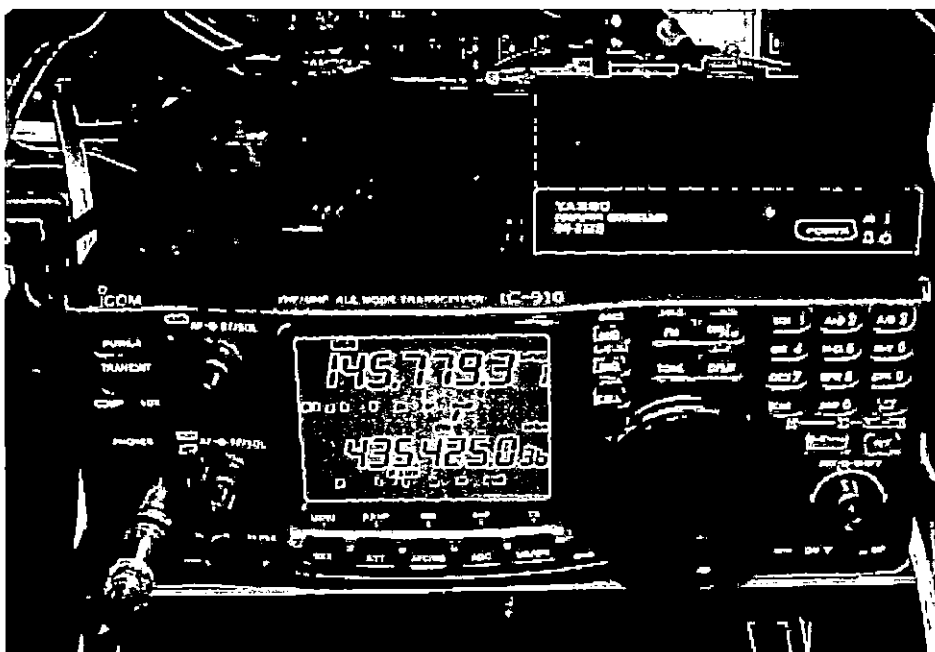cable to a Yaesu GS232B Azimuth/Elevation rotator controller interface.

Figure 3-4 Icom 910 transceiver w. GS232B Az/El rotator controller interface on top

The Icom 910 transceiver and the Azimuth/Elevation controller interface are both

connected to the Earth station PC, a Dell PC with a Pentium IV processor and 256 MB

RAM running Windows XP. The Earth station PC and its software are an integral part of

the VHF/ UHF system, because it performs many functions necessary for effective

communication with a satellite in LEO (Eluru, 2008). The satellite tracking software Ham

Radio Deluxe (HRD) is the most critical software package on the Earth station PC. HRD

calculates the orbit of each satellite based on the Keplerian elements and dynamically

shows the position of selected satellites on the screen. HRD also directs the rotator

controller to point the antenna system at the satellite that is being tracked, which is an

important task since the satellite constantly changes its location as it passes overhead.

The software compensates for the Doppler Frequency Shift in the transmitted and

received signals by constantly correcting the frequencies during the satellite pass.

SatPC32, a similar program was previously used for this purpose, but it was decided to

switch to HRD due to some available features such as fine- tuning the radio. The Earth

station PC is the component of the VHF/UHF system which should be accessed remotely,

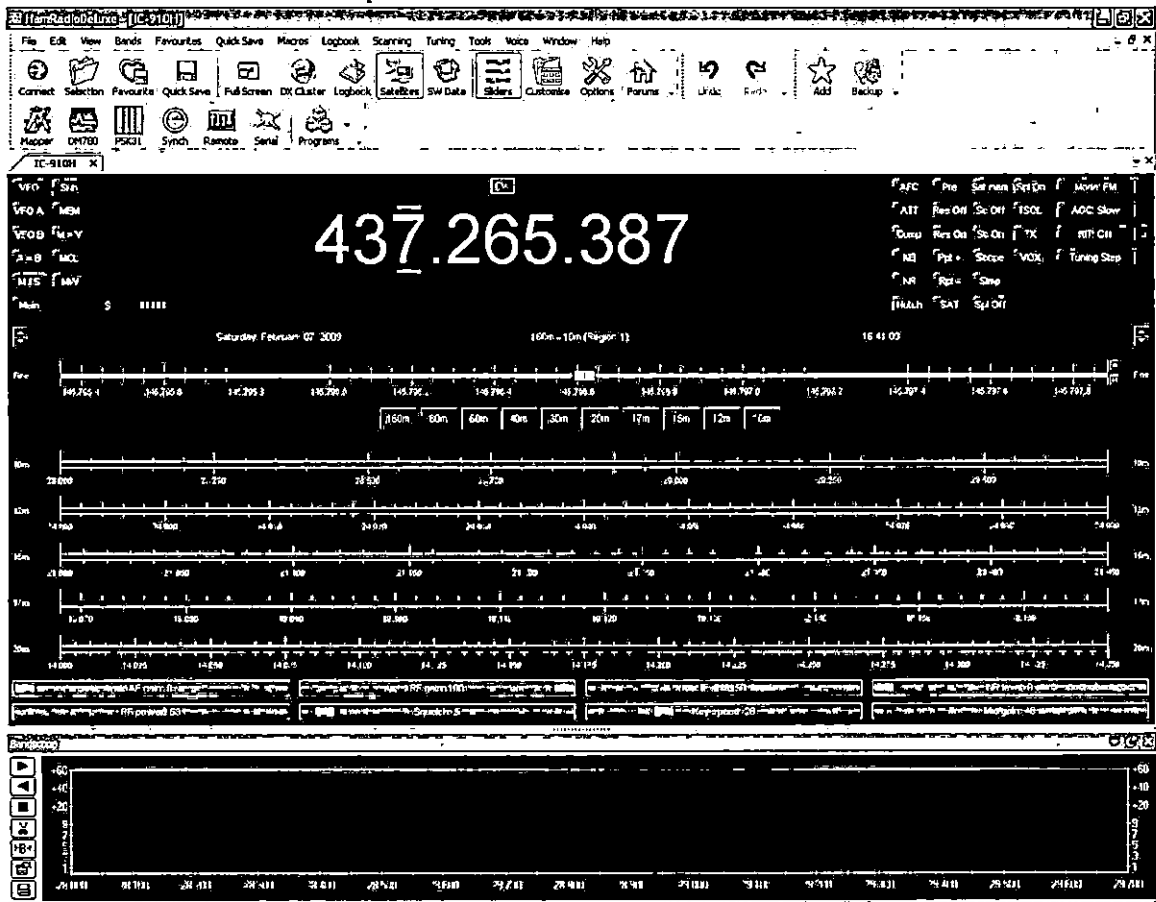since it controls all the other components.

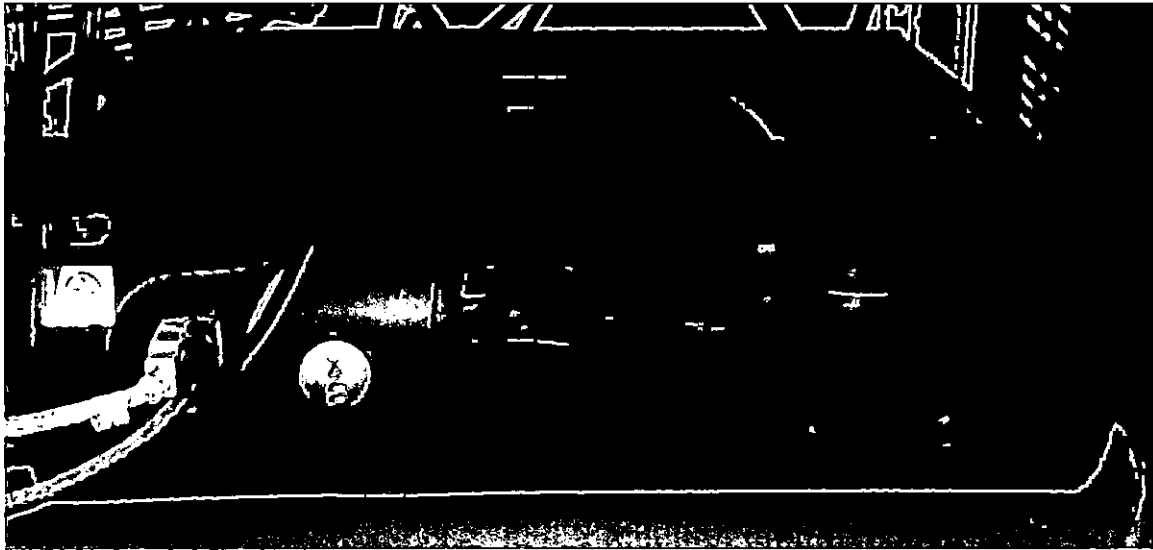Figure 3-5 Screenshot of Ham Radio Deluxe

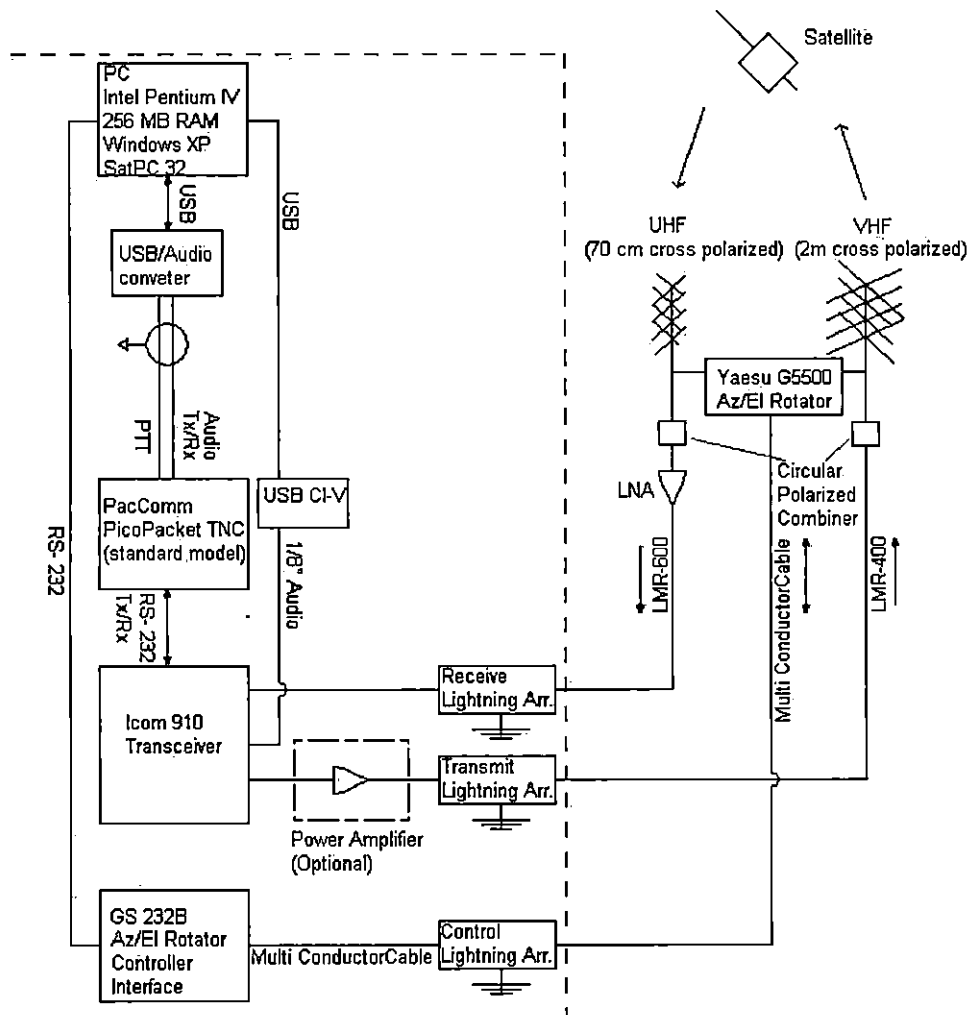Figure 3-6 The computer that controls the VHF/UHF system

Figure 3-7 Schematic of the VHF/UHF system at Morehead State University

Table 3-1 H/W and S/W components used by Kentucky Space Earth Stations

System Component	MSU Earth Station	UK Earth Station
Radio transceiver	Icom 910H	Icom 910H
Azimuth/ Elevation rotator	G5500	G5500
Earth station PC	Dell PC	Dell PC
Terminal Node Control	PicoPacket TNC	PicoPacket TNC
Rotator Controller Interface	GS232B	GS232B
Lightning Arrestors		
Yagi Antennas		
Satellite Tracking S/W	*Ham Radio Deluxe*	*SatPC32*
Flight Support Software for KySat-1	KySat FSSW	KySat FSSW
Audio analyzer	Mix W	Mix W
Audio recording software	Audacity	Audacity
S/W to commands rotators	HRD rotator prog	HRD rotator prog
S/W for remote access	*TightVNC*	*Remote Desktop*
S/W or H/W to remotely power on PC	*WakeOnLanGui*	*remote power switch*
S/W or H/W to remotely power on Radio and other H/W	*5V relay*	*remote power switch*

Table 3-1 shows an overview of the hardware and software components used at

the primary VHF/UHF Earth station in at MSU in Morehead compared to that of the

secondary VHF/UHF Earth station at UK in Lexington. Differences are italicized. Both

Earth stations use identical hardware, with the exception that the UK Earth station uses a

remote power switch for remotely activating the system. The Earth station at MSU

however uses the WakeOnLanGui software to activate the computer, which in turn

powers on the radio and other hardware via a relay. This relay is connected to the 5V

output at the computer's power supply, a connector originally intended to power a floppy

drive. Testing reveals which of the two approaches is more reliable. The superior

approach will be implemented at both VHF/UHF Earth stations.

Research Methodology

The first objective is to find the most effective way to remotely control the VHF/UHF

system, including the following:

- Data Input (TLE's)

- Rotor control

- Potential feedback

- Data collection

- De-modulation

- Data Storage

- Audio

- Control/ operation tasks

Once these goals are achieved, the same requirements need to be fulfilled to

automate the system. The automation of the VHF/ UHF system is the more complex

part of this project.

1. Explicit description of the problem

Automation means that the Earth station computer performs all the tasks

automatically that would be normally performed by a human operator. In order to

accomplish this, the computer needs to know the time of the satellite pass and the

satellite's two line elements (TLEs), which will be stored in a table. When the satellite

pass begins the computer will start the satellite tracking program (currently HRD), tell the

rotor controller to move the antennas in the right position to match the trajectory of the

satellite, set the radio to the uplink and downlink frequencies used by the satellite, and

start the audio recording software. If the satellite being tracked is KySat-1, the

automation software would also start the KySat flight support software (FSSW) and submit a previously stored command to the satellite. The first goal is a semi-automatic system, with a path forward to a fully automatic system.

2.   Identify software system operating parameters

A software framework is required that interconnects the various control software components and yield a seamless operating system that permits local and remote control of the MSU KySat Earth station for attended and un-attended satellite passes.

3.   Develop/identify code

The most efficient method to develop these systems is to find a commercially available software package that can perform the desired functions. Another possibility is to find another satellite Earth Station that has already accomplished the goals of this project and ask them for permission to modify and use their source code. The third option is to completely develop an entire new operating program. This is the most labor intensive and the most time consuming.

4.   Implement code

Once the software is complete and ready to function under normal circumstances, it is installed on the Earth station computer. It can be expected that the Earth station might not perform well during the initial stage of the implementation due to unexpected bugs in the code.

5. Interface with hardware

An operating program has to interface with hardware, which may require writing drivers for each hardware component. This problem could be circumvented by writing

the program in LabView. If the source code for an existing operating program can be obtained, it needs to be modified to work with the hardware at the MSU Earth station.

6.   Beta test code

Any code, no matter if written entirely by KySat students or modified from another Earth station, needs to be thoroughly tested for bugs. During the testing, the tester tries to cause the system to crash and record what happens when it does. It is assumed that the software performs well under normal circumstances. The purpose of the beta testing is to find out how the software performs under special circumstances, for example when the user enters a wrong command, or when one or more of the hardware components is not working.

7.   Analyze results of beta test

The tester identifies the parameters that cause errors and how the system recovers from those errors. Decisions are being made regarding what defects should be fixed, rejected (i.e. found software working properly) or deferred to be dealt with at a later time. If defects in the software are to be fixed, it needs to be decided how to fix them.

8.   Iterate to improve

Once defects in the code have been found, the code is modified to eliminate those defects and the code will be tested again. This cycle repeats until the software performs satisfactorily.

Instrumentation

In order to test the remote control system a laptop with Windows XP is required. The laptop should have WakeOnLANGui and TightVNC installed to be able to activate and to access the Earth station PC, respectively.

There is no special equipment required to test the automation system, since all hardware and software components are already in place and data is recorded as during normal operations.

Software development/evaluation of remote control system

The first step was to evaluate existing software and then to develop code as necessary. Using existing software is preferable, since software development is a very time consuming process. Software was evaluated by the following factors:

- cost effectiveness

- compatibility with existing hardware and software systems

- user-friendliness

- ability to modify, expand, and upgrade

- security features

The following programs were originally considered for remotely controlling the PC at the VHF/UHF system:

PC now from Webex: This software costs $10.35/ month and a free 30 day trial is available. It seems to have necessary security features and can use a Mac to access a PC and vice versa.

PC Anywhere from Symantec: This program costs $199 for one remote user in a one time payment. This was decided to be impractical for KySat, since each user would have to purchase a remote user access.

Remote Desktop from Microsoft: This software is free, because it is already included in Windows XP. The downside is that it cannot transmit audio recorded at the remote site to the local site and may not have sufficient security features.

WinRemotePC: This program costs $35 for one remote user, in a one time payment. The quality of the security features is disputed. A free trial is available for evaluation.

MOXA nport: This package was found to be too complicated to use and too time consuming to evaluate.

TightVNC: This software was chosen as remote control software because it is available free of cost and it is easy to install and to use.

Remote Desktop was originally selected to control the PC remotely because it is already built into Microsoft Windows XP. Anyone on campus with Windows XP or OS 10 and a Virtual Private Network (VPN) can access the Earth station PC remotely. The only problem is that Remote Desktop is unable to detect audio signals from an external source. It is important to be able to transmit audio signals with the smallest possible lag, because the operator needs to tune the radio by ear. Different solutions have been tried to overcome this problem. Internet radio and Windows Media Player have been tested, but the time lag was too long (>1 second) for those solutions to be acceptable. An experiment to use Skype for transmitting audio signals was conducted and several significant flaws were found. This led to changes in software which solved all previously encountered problems. Remote Desktop was replaced with TightVNC, which is able to transmit sound using Skype.
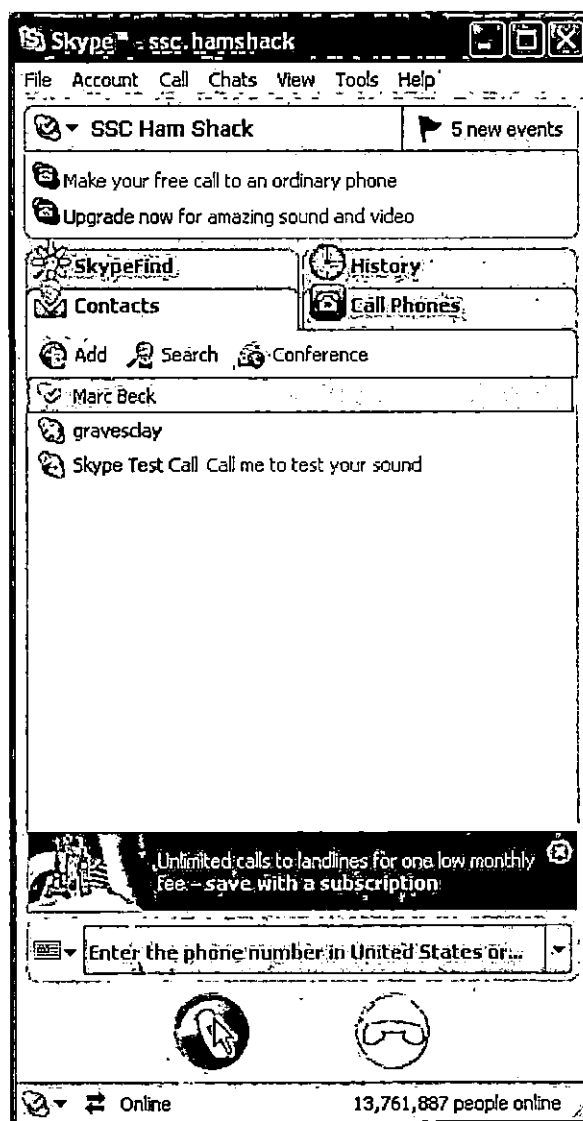
Figure 4-1 Screenshot of Skype

Sat PC32 was replaced as satellite tracking program by Ham Radio Deluxe, which

is freely available on the Internet. This decision was made because Ham Radio Deluxe

can be used to for fine-tuning the frequencies on the radio, allowing access to the radio

from the Earth station PC, which can in turn be accessed remotely via TightVNC. It was

at first considered necessary to write a LabView program or to modify an existing one to

perform this operation. The combination of Ham Radio Deluxe and Tight VNC offers a

greater number of useful features than SatPC32.
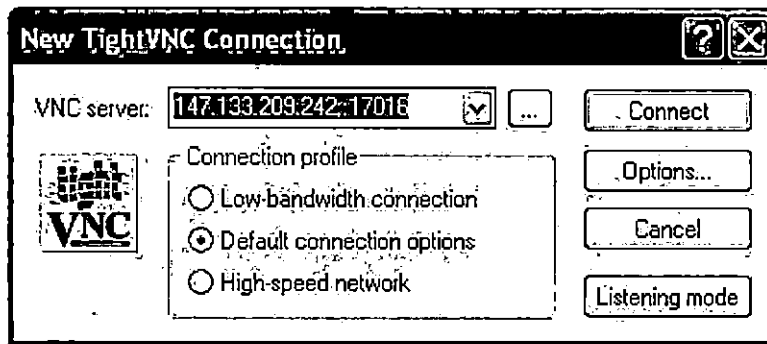
Figure 4-2 Screenshot of TightVNC (before connecting to the Earth station PC)

The Earth station PC was given a static IP address in order to use its Wake On

Lan function to turn it on remotely. This is accomplished by transmitting a so called

"Magic Packet" to the Earth station PC via LAN. The Magic Packet can be sent using a

software called WakeOnLanGui or from a website. Once the computer has been

activated, the remote operator can now use TightVNC to access it. Due to a small glitch

that requires some further investigation, TightVNC disconnects after logging into the

Earth station PC. The operator then needs to connect again. Once a remote operator has

control over the Earth station PC, the desktop background image disappears.
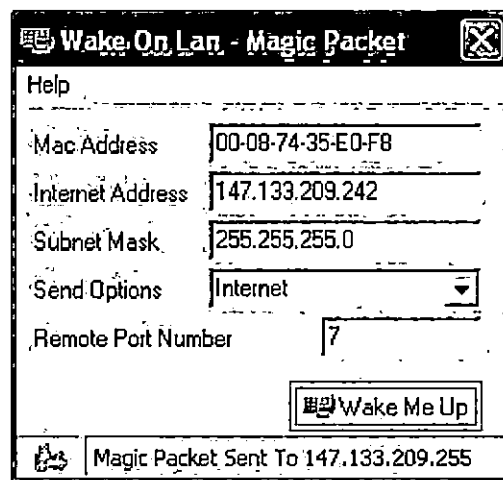
Figure 4-3 Screenshot of the WakeOnLanGui software

In order to remotely power on the radio, a relay was built that receives a 5V signal from

the Earth station PC. The on/off button of the radio still needs to be hardwired, so that the

radio will power on without the on/off button being pushed as soon as the radio receives

power. During a preliminary test the relay activated the radio, but then it failed to

disengage properly when the computer was shut off.
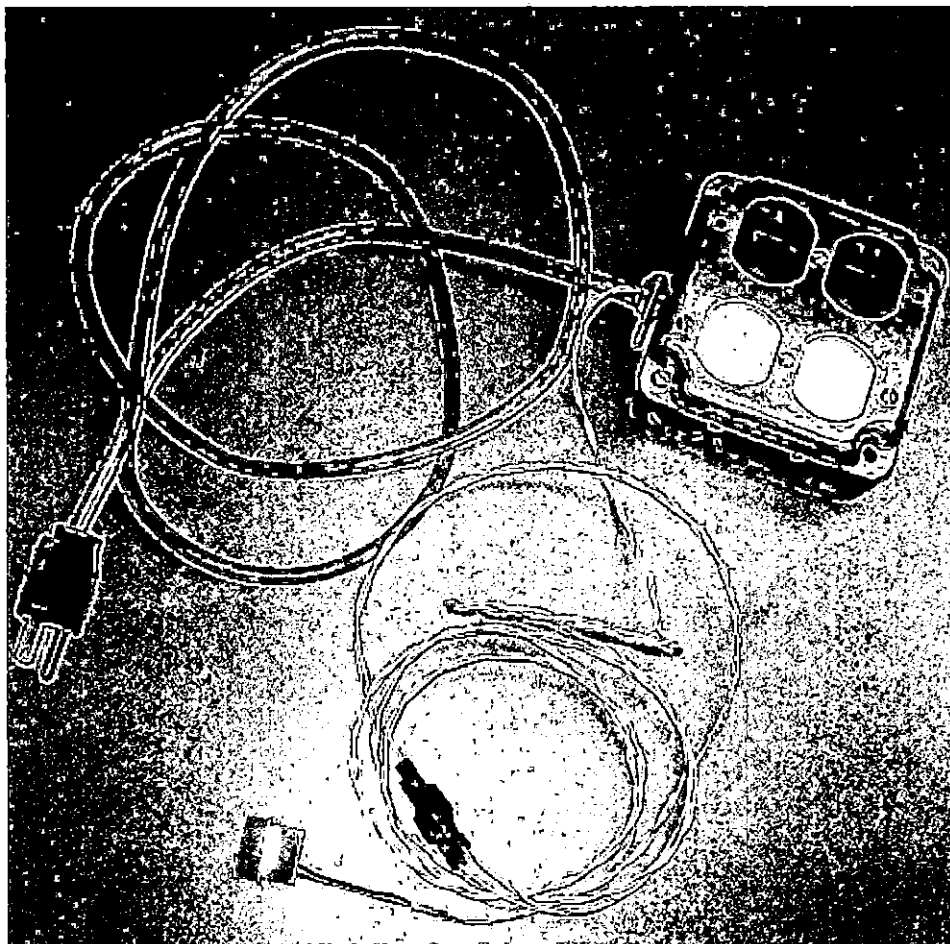
Figure 4-4 The relay used to activate the radio and the rotator controller

The relay was repaired and a second preliminary test was conducted. This time

the relay performed flawlessly. After performing several preliminary tests to ensure that

each component of the system was functioning, the actual testing of the system as a

whole began.

Software development/evaluation of automation system

Commercially available software is often expensive and inflexible. The problem (beside cost) is that the software needs to be customized to fulfill the specific needs of the Earth station at MSU. Especially if the Earth station is going to be improved and expanded, it is very likely that the source code will have to be modified. The developer of the software is most likely not going to share the source code with the SSC at MSU.

Creating an entire software package would require a team of three to five students with a background in Computer Science or significant experience with hardware and software. Time for the software development can take anywhere from two to four semesters, if not longer. The problem with a project that complex and time consuming is to find students that have taken the necessary courses and have plenty of programming experience. By the time students are qualified enough to work on the development of this software package, they will most likely be ready to graduate. The ideal situation would be to get students involved during their junior year and keep them through their senior year.

For writing code, the following programming languages are considered appropriate:

C++: C++ is widely used in the software industry, but is very complicated to use.

JAVA: Java is also an object oriented programming language and very modular, but much easier to use than C++, because it is less complex and because it does not use pointers.

Python: Python is easy to use, but modularity could be a problem. It is more readable than other programming languages, which means that during future expansions of the

code it is easier for programmers to understand and expand previous work done by others.

Visual Basic: This programming language is very easy to use and useful for making GUI applications, but slow and inefficient. Visual Basic only works under Windows.

LabView: This software has been successfully used for the same purpose by at least three other Earth stations, one at Santa Clara University in California, the second at the University of Bologna in Italy, and the third at CalPoly for GENSO. The first two are using it in combination with the satellite tracking software NOVA (Cross et al, 2002) (P. Totora, personal communication, February 10, 2009). LabView was designed to control external hardware and might be useful to avoid having to write driver software for hardware components.

Data collection

In order to test the remote tracking system, data was collected by repeated attempts to track satellites remotely over the Internet using each set of commercially developed software. These tracking attempts were undertaken from a laptop at the SSC or various other locations. The satellite COMPASS-1 built by the University of Aachen, Germany was chosen for the remote tracking attempts because it passes multiple times per day.

The following data was collected:

- Ability to connect to PC at Earth station

- Delay

- Ability to fine- tune Icom-900 radio over remote

- Ability to detect audio

- Ability to access all software and hardware components of the system remotely

- Response to a simultaneous attempt of several local computers to remote control the system.

To test the automated tracking process, a satellite is selected (typically COMPASS-1). The automation program is given the time and data for the next pass of the selected satellite, as well as an audio file to be transmitted. Observers are present at the antenna range during the time of the satellite pass. One observer watches the PC in order to see if the necessary programs start and the radio set itself to the right frequency. The observer also listens to determine if the automation program transmits the audio file. A second observer stands outside the Earth station and watches the antennas to determine if they move into the right position. The observers do not interfere with the operations of the computer. The screen saver needs to be turned off in order for the observers to determine if the programs are being executed correctly.

Table 3-2: Testing procedure for remote control of the VHF/UHF system

Task	Expected outcome	Desired specs
Connection	PC at any given location is able to connect to PC in Earth station	>95% of attempts
Rotor control	Remote user is able to position antennas correctly	Within 1 degree
Accessibility	Remote user is able to access all software and hardware components of the VHF/UHF system	>95% of attempts
Delay	Delay between remote PC and Earth station PC should be negligible	<2 sec
Radio tuning	Remote user is able to tune the radio	->S/N
Audio	Remote user is able to hear and record audio	->S/N
Commanding the satellite	Remote user can send commands to the satellite and the commands are executed properly	>90%
Data storage	Audio data is stored in a readable format in a specified location	>95% readability

Table 3-3: Testing procedure for automation of the VHF/UHF system

Task	Expected outcome	Desired specs
Scheduling	Automation software activates all components of the system at the time when pass begins	>95% of attempts
Rotor control	Antennas position themselves correctly	Within 1 degree
Radio tuning	Radio is set to correct frequencies and adjusts itself for change of satellite location. Doppler shift	->S/N
Audio software	Audio software begins to record beacon and telemetry at the beginning of the satellite pass	->S/N
Commanding the satellite	Previously stored command is sent to the satellite and executed properly	>90%
Data storage	Audio data is stored in a readable format in a specified location	>95% readability

Data Analysis

Observers at the Earth station watch the equipment both during the remote

tracking attempts and the automated tracking attempts and record their findings. Data is

analyzed by comparing the number of failed tracking attempts with the total number of

attempts made.

Any problems to fulfill the criteria mentioned previously are analyzed for possible

causes. Audio data recorded from the passing satellite is examined to determine if it is

readable and has been stored correctly.

CHAPTER IV: Findings

Remote Control

Table 4-1 Results of tests for remote control of the VHF/UHF system

Task	Expected outcome	Desired specs	Actual Results
Connection	PC at any given location is able to connect to PC in Earth station	>99% of attempts	70%*
Rotor control	Remote user is able to position antennas correctly	Within 1 degree	Perfect
Accessibility	Remote user is able to access all software and hardware components of the VHF/UHF system	>99% of attempts	40% of total attempts**
Delay	Delay between remote PC and Earth station PC should be negligible	<2 sec	Delay negligible, but slow CPU
Radio tuning	Remote user is able to tune the radio	->S/N	Perfect
Audio	Remote user is able to hear and record audio	->S/N	Perfect
Commanding the satellite	Remote user can send commands to the satellite and the commands are executed properly	>90%	N/A since no S/W to command COMPASS-1
Data storage	Audio data is stored in a readable format in a specified location	>95% readability	100% readability

* Three of the tracking attempts were performed from off-campus locations. All three of those failed. It was not clear from the beginning that the location would have an effect on the success of the tracking attempt.

** Out of the remaining seven tracking attempts, four were completely successful. Two attempts were partially successful because Skype lost connection for unknown reasons, but the connection could be re-established after a few minutes. The remaining attempt was a failure due to a problem unrelated to the remote control software (a computer virus).

Table 4-2 List of tracking attempts to test remote control system

Date	Time of pass	Beacon	Notes
03/28/2009	10:48-10:57	No	Computer too slow due to virus
04/02/2009	10:51-11:05	4x	Full success
04/02/2009	12:28-12:42	3x	Full success
04/05/2009	10:57-11:09	No	Unable to connect from off-campus location
04/11/2009	11:10-10:17	No	Unable to connect due to network problems
04/14/2009	11:51-12:01	No	Unable to connect due to network problems
04/16/2009	11:58-12:07	3x	Full success
04/17/2009	12:18-12:30	2x	Skype disconnected at start of pass
04/18/2009	11:00-11:14	1x	Skype disconnected at start of pass
04/18/2009	12:36-12:48	3x	Full success

During the first tracking attempt, it was found that the Earth station computer had been infected by a virus and was too slow to perform a successful tracking attempt. After the virus had been removed, the computer was still fairly slow when being remotely controlled, but fast enough to perform satisfactorily during the second tracking attempt. The current network cable, a CAT V Ethernet cable, will be replaced with a fiber optics cable, which is expected to solve this problem. Two tracking attempts were unsuccessful due to network problems. These problems were due to external factors independent from the remote control system. It was also discovered that Skype disconnected during two tracking attempts the moment when the satellite came within tracking range. This issue requires further investigation.

It was not possible to use the remote control system over wireless LAN from locations away from MSU's campus. A cause for this was first assumed to be the firewall on MSU's campus network, which blocks certain types of incoming traffic for security reasons. This was later found to be not the case, when it was discovered that it is possible to use the remote control system from a cell phone. On April 29th 2009, the satellite COMPASS-1 was remotely tracked by Kentucky Space student design team member

Clay Graves using an HTC FUZE cell phone with Windows Mobile 6.1 Professional to

establish a connection with the Earth station computer.

Automation

Software for the automation of the VHF/UHF system was evaluated, but not

implemented and tested, due to time and money constraints. After evaluating the different

options of either buying commercially available off-the-shelf software, adapting software

from another Earth station, or writing software in-house, the decision was made to buy

software from an existing Earth station. A decision against buying off-the-shelf software

was made due to lack of flexibility. Writing the software in-house was found to labor

intensive and too time consuming. The University of Bologna in Bologna, Italy was

contacted and asked for a quote on their ALMASpace JTracker S/W, since they use

similar hardware. The developers of the GENSO project at CalPoly were also asked for

permission to use their software. Decisions regarding which of the two solutions to

choose will be made depending on functionality and cost, with GENSO being the lower

cost option.

Table 4-3 List of features of the ALMASpace JTracker S/W (P. Tortora, personal

communication, March 2009)

Feature	Description
Wizard	At the start-up, it is possible to configure the Earth station parameters, download the Keplerian Data – TLE (in this way the user will always have the latest Keplerian Data) and select which and how many satellites should be tracked.
Summary Window	The main Panel includes two jTabs: • The first one is the "home" of the SW • The second one, once the user selects the

	satellites to be tracked, shows the relative information
2D and 3D view	The main screen of the software is the 2D view. Here the position of the ground tracking station and the satellite being tracked is reported. Each satellite is represented with a label and a symbol and the ground track per orbit and its footprint is shown. The main Earth station is fixed in the 2D map with its real latitude and longitude coordinates. There is also the possibility to have a 3D view: this functionality has been implemented by using the NASA World Wind libraries. In the 3D view page all satellites and the main tracking station are also shown.
TLE download and update	The main screen of the software is the 2D view. Here the position of the ground tracking station and the satellite being tracked is reported. Each satellite is represented with a label and a symbol and the ground track per orbit and its footprint is shown. The main Earth station is fixed in the 2D map with its real latitude and longitude coordinates. There is also the possibility to have a 3D view: this functionality has been implemented by using the NASA World Wind libraries. In the 3D view page all satellites and the main tracking station are also shown.
Earth station information	Set of latitude, longitude and height of Earth station.
Performance	CPU optimization: the CPU in use, is always under 5 mega, thanks of the optimization of the S/W
Satellite schedule information and auto tracking	
Rx/Tx control	• Set Uplink and Downlink frequencies manually or automatically • Computation of Doppler effect • Only ICOM transceivers are supported so far
Rotator control	Yaesu gs500, AlfaSpid RAS Rotators

CHAPTER V: Summary, Conclusions, and Recommendations

Summary

Morehead State University is part of the Kentucky Space consortium which developed and built a nanosatellite -the 1U CubeSat KySat-1 for education and public outreach. The VHF/UHF system operated by the Space Science Center at MSU, along with the 21 meter STA will be the primary Earth station for KySat-1. In order to be able to track and command the student-built satellite at any desired time, it is necessary to remote control and automate the VHF/UHF system. Remote controlling the VHF/UHF system is defined as the ability to perform all satellite tracking operations from a remote location, such as the SSC. Automation means that satellite tracking operations can be scheduled and then run automatically without human intervention. Both components of the project required the evaluation of several different software solutions. The possible choices were either to use commercially or freely available software, purchase software written by users of another Earth station, or to develop the software internally. After investigating the different options, it was decided to use freely available software for the remote control system and to consider the purchase of software from another Earth station for the automation. The implementation and testing of the automation software will possibly be subject of a future student project that will continue the work begun with this research. The ALMASpace JTracker software from the University of Bologna, Italy was taken into consideration for this purpose. GENSO from CalPoly needs to be further investigated as a possible alternative. The remote control software was tested and found to be functional, with the exception of a few minor errors. Final decisions about the purchase of the automation software still need to be made.

Conclusions

The freeware programs TightVNC, WakeOnLanGui, and Skype were selected to be used in combination with the satellite tracking software on the Earth station computer in order to enable remote control of the system. The software for the remote control has been implemented and tests have revealed it to be functional. However, a number of smaller problems still need to be worked out. For example, the Earth station computer slows down considerably when controlled remotely. This problem will most likely be solved once the Earth station is connected to the network via fiber optics cable instead of copper wire. The second problem that has been discovered is that Skype occasionally disconnects in during a tracking attempt. Third, it is currently not possible to remotely access the Earth station computer from some off-campus locations, most likely due to firewall settings at these locations.

Possible options for an automation system have been investigated and it was decided to consider purchasing ALMASpace JTracker, a software packet from the University of Bologna in Italy. Final decisions about this purchase will be made after some details have been clarified and funding has been allocated. The developers of GENSO at CalPoly have been contacted for further information about their software as a possible alternative in case decisions are made against the purchase of ALMASpace JTracker. Once the automation software system has been purchased, it needs to be implemented and tested.

Recommendations and Implications

A solution may need to be found to be able to remote control the system from off-campus locations. This will require collaboration with MSU's IT-department, because

they are responsible for maintaining and modifying the firewall that prevents remote access from off campus.

The implementation and testing of the software packet for the automation of the Earth station at MSU is a project that still needs to be completed. Guidelines for the testing of the automation software have been established in this study.

One issue that has not been addressed in this study is security. The VHF/UHF system at MSU should only be accessed by authorized personnel (members of the Kentucky Space design team and Space Science Center staff). Passwords are not sufficient to prevent access by experienced hackers. A possible solution is to encrypt the data being sent between a remote user and the Earth station computer. Research needs to be undertaken to find the most suitable algorithm for this purpose.

Another suggestion for future projects is the idea that the earth station at MSU could evolve to become a node of a virtual global network like Mercury.

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