4.0 Communication Subsystem

The primary goal of the communication subsystem is to provide a link to relay data findings and send commands to and from the CubeSat. Telemetry and command subsystems will ensure continuous communication between the ground station and the CubeSat after ejection from the ARLISS rocket. To better understand the basics of the CubeSat communication architecture, the theory behind the system will be presented first, followed by a timeline of the progress that has been made throughout the semester.

4.1 Background

The CubeSat communication system is composed primarily of the telemetry and command systems, which send and receive data, respectively. Analog and digital data collected by the sensors and payload of the satellite must be relayed to the ground station via the telemetry system, which is composed of a transmitter that acts much like a "modem in a computer". The microcontroller will accumulates data from the sensors and convert these inputs into a stream of 8-bit binary numbers. This numerical string is encoded into AX.25 protocol by the terminal node controller (TNC), which serves to "packetize" the information and key the transmitter. The transmitter then sends the signal to the ground station through the satellite's antenna [Dominguez and others, 2002]. A radio operating in the ultrahigh frequency (UHF) band at the ground station will receive the data signal and encode the stream to a form that may be interpreted by software on a laptop.

Another vital aspect of the communication subsystem is the command/uplink portion. From the ground, moderators must be able to send commands to the system. All incoming signals from the ground station will be compared to all other inputs, and any errant signals are discarded [Dominguez and others, 2002].

The Satellite Solutions CubeSat design will implement commercially available transmitter and receiver packages that operate in UHF, and therefore, care must be taken to ensure that the correct radio-data protocol is followed for the transmission to be efficient, reliable, and robust. Also, the frequency of the signals must be transmitted within the correct FCC license regulations for the system. The most common protocol is AX.25, which was originally developed for amateur radio use as the basis for applications in mobile and radio-data transmission [Thorcom, 1998].

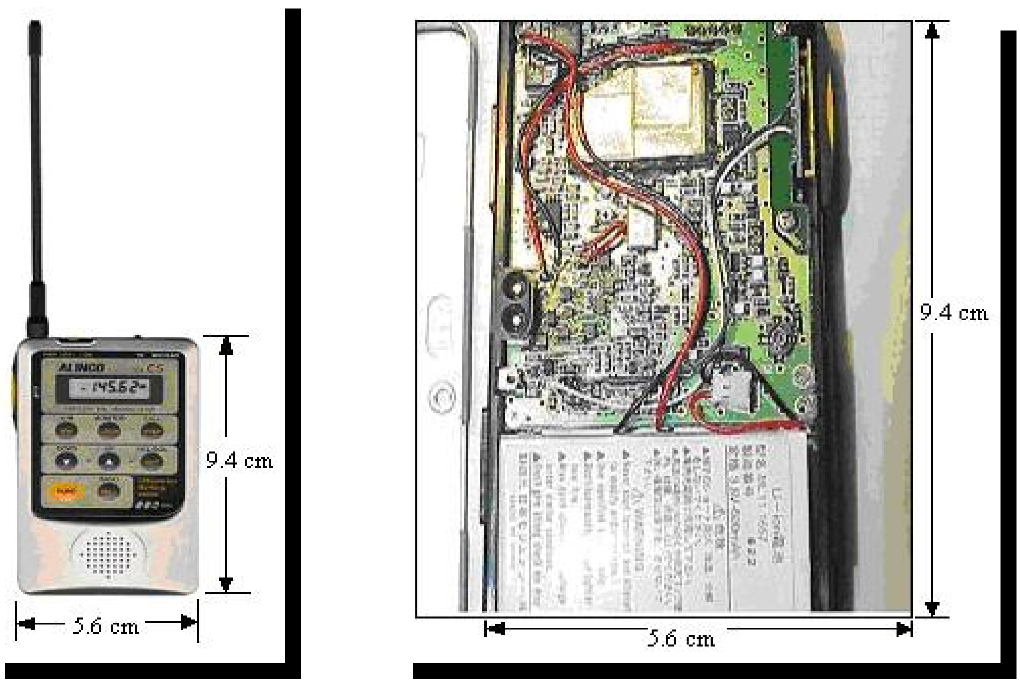
4.2 Requirements and Constraints

As mentioned previously, the CubeSat system must be no larger than 10 cm on each side and weigh less than 1 kg. Therefore, the internal components must be scaled to fit within these constraints. Since only a fraction of the 1000 cm^3 volume is allotted to communications, the team must select a transmitter and terminal node controller (TNC) that are miniaturized. The entire system must also be relatively inexpensive and operate within the designated frequency band allowed under the Federal Communications Commission (FCC) amateur radio guidelines. Finally, for adequate communication time, the data transmission rate is desired to be at least 9,600 baud, and the amount of working amperage drawn by the communication subsystem must not exceed the available power provided by the batteries or solar cells.

4.3 Options and Evaluation

One of the largest obstacles for the Satellite Solutions team was the overall lack of experience in radio communications. Therefore, the CubeSat communication subsystem will consist primarily of commercially available off-the-shelf (COTS) components for both the internal and ground station systems, in order to simplify the amount of modifications necessary to build a working system. Given the requirements listed above, several COTS options have been researched to aid in selection.

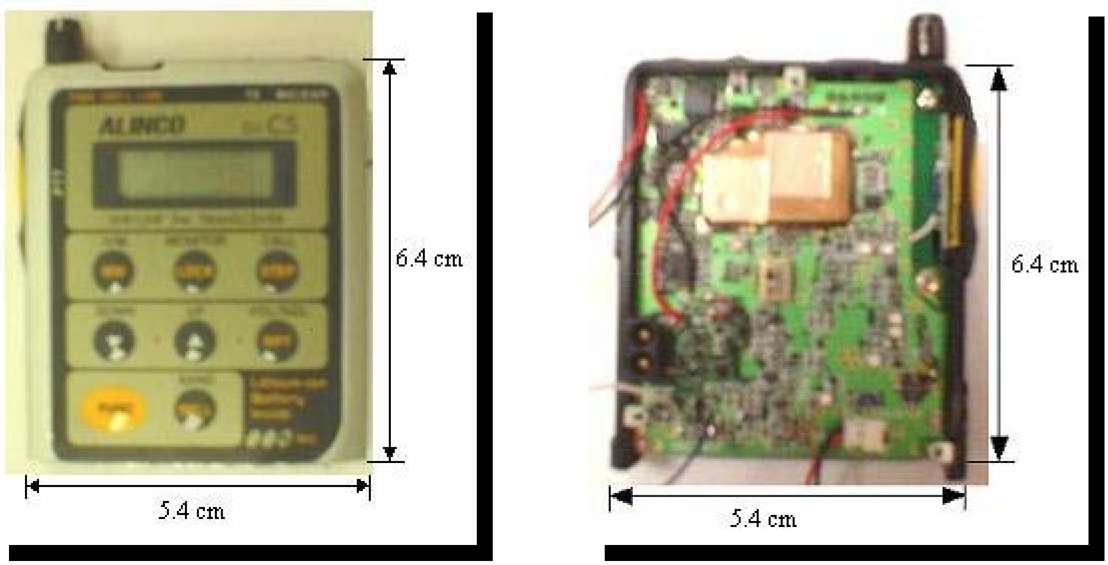
For the internal CubeSat communication system, an Alinco DJ-C5 transmitter was investigated. Figures 9 (a) and (b) show the external and internal view of the Alinco device.



(a) (b)

Figure 9: (a) Outside view of Alinco DJ-C5 transceiver prior to modifications [RigPix, 2001]. **(b)** Internal view of Alinco DJ-C5 transceiver prior to modifications. [PacComm, 2003].

The DJ-C5 is small, lightweight, and versatile, as it can transmit in the 144-146 and 430-440 MHz range [RigPix, 2001]. The CubeSat team disassembled and modified the transceiver to allow for further miniaturization and increased performance. First, the front and back plastic covers were removed. The flexible antenna was unscrewed from its connection point, and the Lithium-ion battery pack was disconnected. Next, a team member cut both sides of the transmitter's case with a Dremel tool to reduce the length of the device by approximately 3 cm. Figures 10 (a) and (b) show the Alinco DJ-C5 after the modifications were made.



(a) **(b)**

Figure 10: **(a)** Outside view of Alinco DJ-C5 transceiver after modifications.
(b) Internal view of Alinco DJ-C5 transceiver after modifications.

After all modifications were complete, the DJ-C5 was connected to the previous CanSat electronics and a power supply, to ensure that the transmitter still had the capability to send a signal despite the changes. The test was successful; the transmitter could indeed still send a data signal.

Next, different terminal node controllers were researched to find one that would work with the rest of the system, including the Alinco DJ-C5 transmitter and the Atmel microcontroller. The best option for this electronics package was the PacComm PicoPacket. This TNC would operate in transparent mode to control the flow of data to and from the microcontroller, as well as radio transmission and reception. The PicoPacket (Figure 11) was attractive because of its electronic capabilities, and since it was the only TNC found that could fit within the strict volume limits, with a total volume of approximately 180 cm^3 [PacComm].

Figure 11: PacComm PicoPacket miniature TNC [PacComm].

Another interesting possibility for the communication system employed a faster, more inclusive package manufactured by MaxStream. The MaxStream XStream™ 900 MHz Wireless OEM (Original Equipment Manufacturers), as shown in Figure 12, is a frequency-hopping module that allows for wireless communication and can sustain a continuous data stream at a given data rate.

Figure 12: Size of MaxStream XStream™ 900 MHz wireless OEM module.

This device has several advantageous features, which include [MaxStream]:

- Frequency-Hopping Spread Spectrum (FHSS) technology
- Noise and interface resistance
- Enhanced sensitivity and range
- Multiple Low-power modes
- Standard serial digital interface connection
- Built-in networking and addressing
- Simple AT command interface
- 9600 and 19200 baud transfer rates available
- Packet retries and acknowledgements

The 900 MHz unit has a transmission range from 7 miles with a dipole antenna to over 20 miles with a high-gain antenna [MaxStream]. This module would also allow for a much faster transmission of data from the CubeSat to the ground station. The XStream™ 900 MHz module was ordered as a "Development Kit," which contained an almost complete communication package for the CubeSat mission, and eliminated the need for a separate modem, TNC, and ground station receiver.

Next, components were investigated for use in the ground station. The first choice for the ground station transceiver was the Kenwood TH-D7 dual-band hand-held transceiver (Figure 13), which was used in the 2002 CanSat project.

Figure 13: Kenwood TH-D7 transceiver [Radiohound, 2003].

The Kenwood TH-D7 has a built-in TNC and would be used to receive data from and send commands to the satellite after launch. This transceiver would then be connected via serial cable to a laptop. The laptop functions as the "control center" for the mission by receiving data with the standard "HyperTerminal" software package. For the Kenwood radio to communicate with the satellite, an antenna is needed. Since the

CanSat 2002 team implemented this ground station system, their 6-element Yagi-Uda antenna could again be used, as shown in Figure 14 [Campbell and others, 2002].

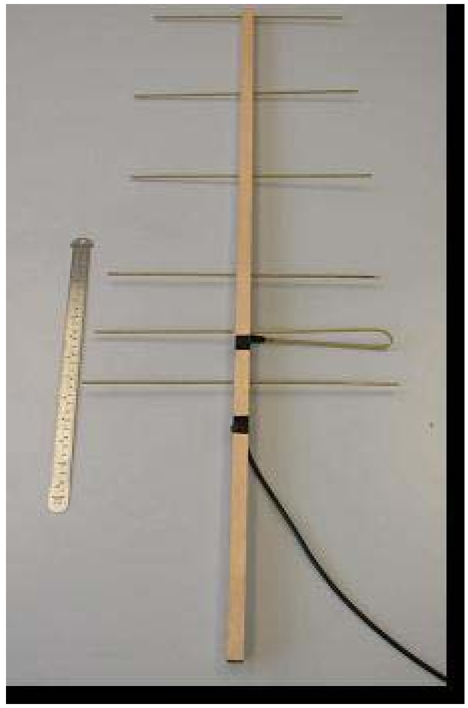


Figure 14: CanSat Ground Station Yagi-Uda Antenna [Campbell and others, 2002].

4.4 Product Evaluation and Selection

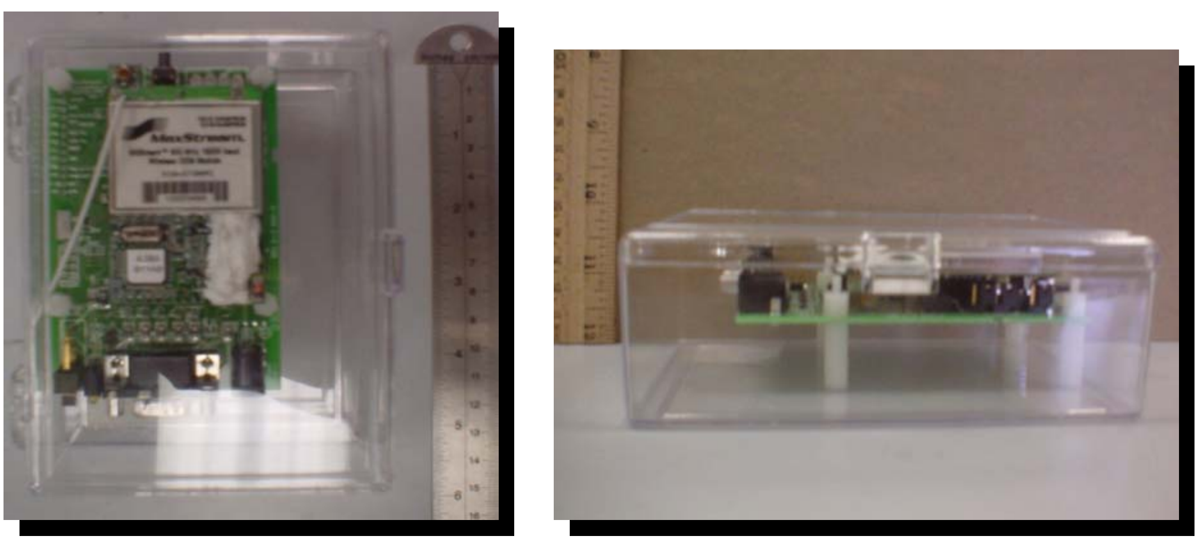
The COTS products listed in the previous section were each studied to determine whether or not they met the design criteria specified above. Table 2 compares some of the key characteristics of each device, and product information sheets may be found in the Appendix C.

Table 2: Devices evaluated for implementation in the communication subsystem [Radiohound], [Campbell and others, 2002], [RigPix, 2001], [PacComm], [MaxStream].

	Kenwood TH-D7	**Alinco DJ-C5**	**PacComm PicoPacket**	**MaxStream XStream™ 900 MHz OEM**
Dimensions (with case)	Length: 119.5 cm Width: 54 cm Depth: 35.5 cm	Length: 9.4 cm Width: 5.6 cm Depth: 1.36 cm	Length: 8.3 cm Width: 6.3 cm Thick: 2.5 cm	---
Dimensions (without case)	---	Length: 6.4 cm Width: 5.6 cm Depth: 1.36 cm	Length: 8.25 cm Width: 6.17 cm Depth: 2.50 cm	Length: 4.06 cm Width: 6.86 cm Depth: 0.89 cm
Weight	---	85 grams (with case, antenna, and battery)	57 grams (without case)	24 grams
Current Consumption	5.5 Watts at 13.6 V	Receiver: 30 mA (VHF), 40 mA (UHF) Transmitter: 240 mA (UHF), 300 mA (VHF)	50 mA to 70 mA	Transmit: 150 mA, Receive: 50mA, Power down: < 1μA
Operating Temperature	---	-10°C to +60°C	---	0°C to 70°C (-40°C to 85°C available)
Supply Voltage	---	Rechargeable 3.7 VDC Li-ion battery	7 VDC to 14 VDC Li-ion battery	5 VDC, ± 0.3V
Bit Rate	Built-in 1200/9600 baud TNC	9600 baud	1200 baud	9600 and 19,200 baud available
Frequency Range	144/430 MHz	144-146 / 430-440 MHz	---	900 MHz range
Cost	$500.00	$150.00	$159.99	$321.75
Order Status	Received	Received	**Discontinued**	Ordered

As Table 2 illustrates, all of the devices meet the size, weight, and performance constraints. The preliminary design of the internal communication system consisted of the Alinco DJ-C5 and the PacComm PicoPacket. However, the PicoPacket has been discontinued by the PacComm Company, and cannot be obtained. Therefore, the MaxStream XStream™ 900 MHz Wireless OEM module will be used as the transmitter. The MaxStream development kit has arrived, and preliminary testing was performed with the software included in the kit. However, additional communication testing between the two OEM devices as well as range tests still need to be completed to ensure a successful CubeSat mission.

With the MaxStream module in place, a new setup for the ground station had to be designed. The Kenwood transceiver cannot operate in the 900 MHz frequency range and therefore, cannot be used to receive data from the MaxStream transmitter. Satellite Solutions will implement the second MaxStream receiver connected to the development board contained in the development kit, as shown in Figure 15 (a) and (b).



(a) **(b)**

Figure 15: **(a)** Top view of the MaxStream 900 MHz OEM inside protective case.
(b) Side view of the MaxStream 900 MHz OEM inside protective case.

A small plastic box was purchased to protect the bare components from the desert environment, as shown in the above figure. Modifications must be made to this case to allow a high-gain antenna to be connected to the MaxStream OEM.

However, for adequate communication over a large distance, the OEM must be outfitted with a high-gain Yagi-Uda antenna to receive and transmit data from the ground station. The MaxStream Company was contacted regarding the type of antenna which would be successful with the OEM devices, and the technician recommended a 4-element high-gain Yagi. A design for the Yagi antenna was calculated using the “Yagi Antenna Design Program” based on the work of Gunter Hock, an amateur radio enthusiast, as published in Chapter 9 of the ARRL (Amateur Radio Relay League) UHF/Microwave Experimenter’s Manual (1990). The program required the boom and element diameters, the operating frequency, and the number of elements as inputs and returned all of the values needed to construct an antenna. Program inputs are given in Table 3.

Table 3: Yagi element preliminary design inputs.

Design Parameter	**Value**
Number of Elements	4
Operating Frequency	900 MHz
Boom diameter	1 inch
Element diameter	0.375 inches

The output file given by the design program may be found in Appendix A. An AutoCAD drawing was then prepared, and materials were purchased for the elements and boom to begin the construction phase (Figure 16).

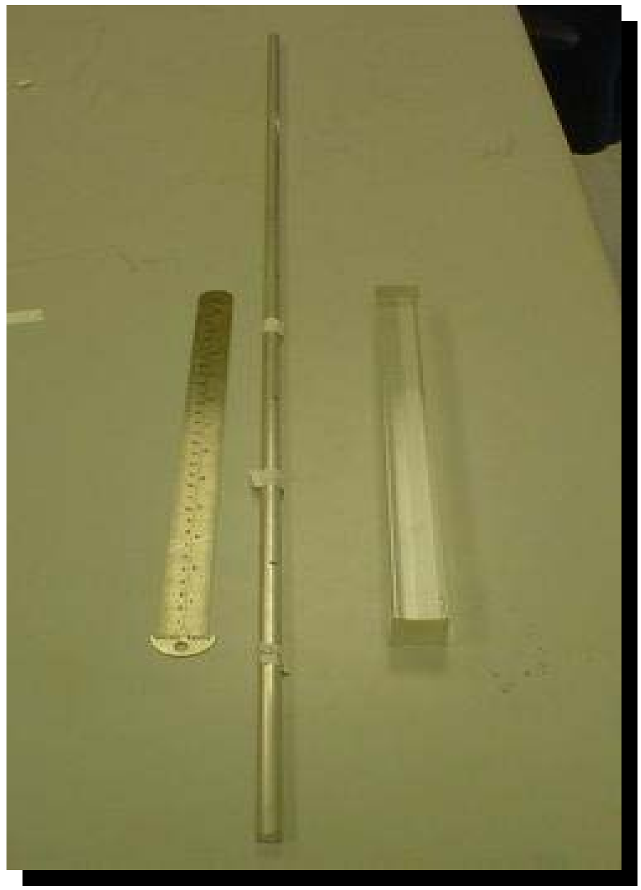


Figure 16: Materials for construction of the Yagi antenna. The Aluminum rod for the elements is pictured in the middle, and the acrylic rod for the boom is on the far right.

A general schematic of the final antenna design is shown in Figure 17 and a dimensioned drawing is in Appendix A.

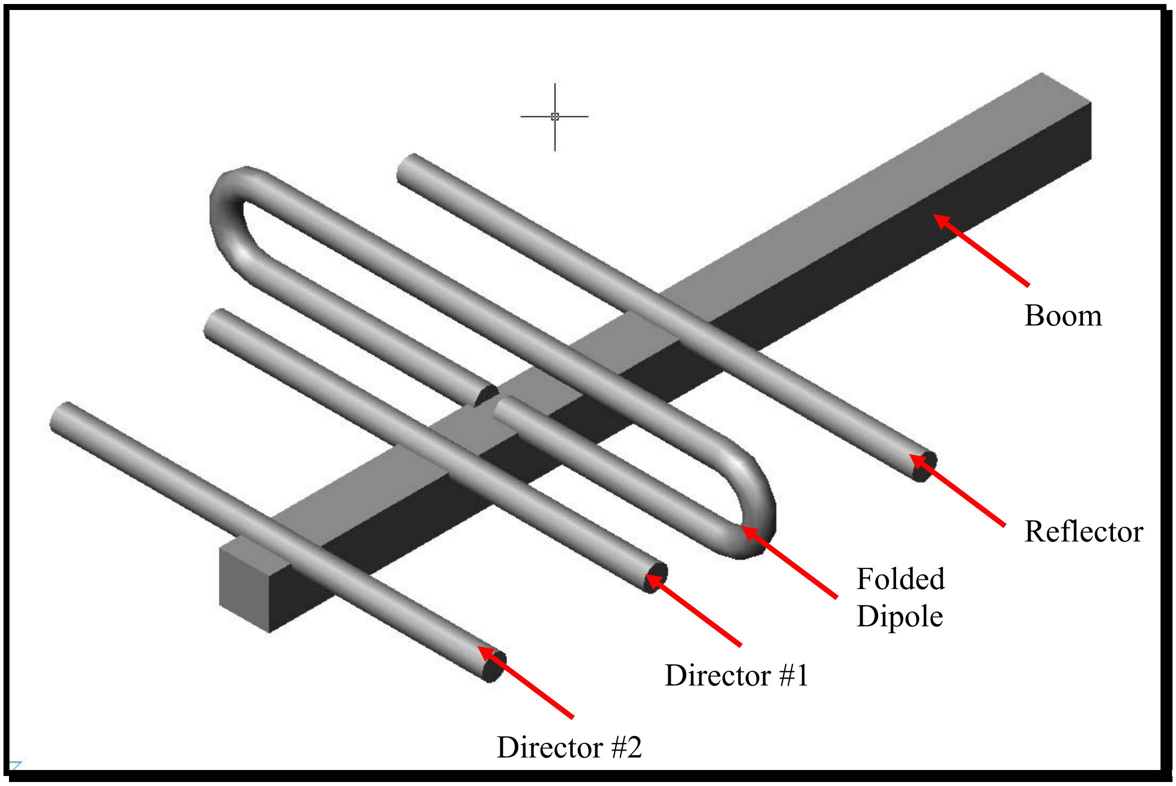


Figure 17: Yagi antenna design.

The coaxial cable and connectors, known as a "pigtail" cable, to link the antenna to the OEM module still needs to be purchased. Once the construction is complete, the Yagi antenna and ground station transceiver must undergo range tests to communicate with the MaxStream OEM that will be employed inside the CubeSat.

The Satellite Solutions team made good progress in laying the ground work for the communication subsystem. Future work that must be accomplished by the summer team is included in the management section.