RAPID RECONNAISSANCE AND RESPONSE (R^3)

TRACKING STATION SYSTEM

By

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Christopher May

Technical documentation to support the detailed design of:

R^3 Mission
Center for Space Systems
Georgia Institute of Technology

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Lead Designer ____ Date __________

Project Systems Engineer ________________________________Date __________

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GEORGIA TECH CENTER FOR SPACE SYSTEMS

ABSTRACT

Tracking Station Subsystem Technical Design Document

by Wade Birdwell

Principle Investigator: Professor David Spencer
Georgia Tech

An overview of the design of the Tracking Station System for the R^3 mission is presented in detail. The Tracking Station subsystem provides a key component of the Ground Station system. The main function of the Tracking Station system is tracking the R^3 satellite during over flight passes of the ground station in order to receive data and telemetry while transmitting control command sequences. The Tracking Station will accomplish this through computer control of the receiver, transmitter, and rotor assembly.

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ACKNOWLEDGMENTS

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NOMENCLATURE

ARRL	Amateur Radio Relay League
AM	Amplitude Modulation
AZ or Az	Azimuth
CW	Continuous Wave
DEM	Down East Microwave
EL or El	Elevation
FCC	Federal Communications Commission
FM	Frequency Modulation
FSK	Frequency Shift Keying
FSK	Frequency Shift Keying
GT	Georgia Institute of Technology
HDD	Hard Disk Drive
HRO	Ham Radio Outlet
HF	High Frequency
ID	Inner Diameter
IF	Intermediate Frequency
LNA	Low Noise Amplifier
LSB	Lower Side Band
LSK	Limit Switch Kit
MOC	Mission Operations Center
OD	Outer Diameter
PBT	Pass Band Tuning
PSK	Phase Shift Keying
RAID	Redundant Array of Independent Disks
RST	Readability, Strength, Tone
RX	Receive or receiver
SSB	Single Side Band
TLE	Two Line Element
TNC	Terminal Node Controller
TX	Transmit or transmitter
UHF	Ultra High Frequency
ULNA	Ultra Low Noise Amplifier
UPS	Universal Power Supply
USB	Upper Side Band
VHF	Very High Frequency
WFM	Wide Frequency Modulation

INTRODUCTION

The R^3 satellite project began with eight students attending Georgia Institute of Technology in January 2009. The goal of the R^3 project is to win a secondary payload launch opportunity through the Air Force Research Laboratory's sixth University Nanosat Program competition (UNP-6). The mission objectives are to demonstrate same-pass tasking and innovative on-board processing algorithms by detecting a thermal feature of known signature, calculating its coordinates, and down linking them to the Georgia Tech Ground Station in the same pass; and to correlate the radiation environment in space with its effect on a non-radiation-hardened uncooled microbolometer. As a secondary payload, the satellite must be robust to successfully complete its mission in any orbit from 500-1000 km and at any inclination. It must also meet all UNP-6 program constraints, including staying within a size and mass envelope of 50cm x 50cm x 60cm and 50kg.

The R^3 satellite project must have a Ground Station system in order to downlink, store, and process the data and telemetry acquired during the satellite's mission while providing the capability to test and send command sequences to the satellite in order to continue its mission. The Tracking Station system is a key component of the Ground Station system and is responsible for the actual tracking of the R^3 satellite during the satellite's over flight passes of the ground station while providing the means to receive data and telemetry while transmitting command sequences. This will be accomplished through computer control of the receiver, transmitter, and rotor assembly.

CHAPTER 1: REQUIREMENTS FLOW-DOWN

The requirements for the Tracking Station flow down directly from the mission objectives of R^3 through requirements for Mission Operations Systems and Mission Control. The requirements flow down presented in the table below detail the Mission Operations System, Mission Control, and then finally the Tracking Station requirements.

Table 1: Requirements Flow Down

	Mission Operations System (MOS)	**Source**	**Verification Method**	**Status**
MOS-1	MOS shall be capable of full-duplex communications with the R3 satellite	MO-3	Testing	Designed
MOS-1.1	MOS shall have the capability to receive all downlinked science data and R3 satellite telemetry on scheduled passes.	MO-3, MSC-5, SAT-11	Analysis, Testing	Designed
MOS-1.2	MOS shall provide capability to control R3 satellite with uplinked commands during all phases of development and operations	MO-3	Analysis, Testing	In Progress
MOS-2	MOS shall provide facilities, hardware, and software for development of testbed and support final integration test plan	SAT-1	Testing	In Progress
MOS-3	MOS shall be capable of archiving all raw data for duration of primary mission [6 months] and provide support for ground processing and dissemination of science data	MD-1	Testing	Designed
MOS-3.1	MOS shall provide commanding and telemetry capturing capability for mission planning and data processing	MOS-3		In Progress
MOS-3.2	MOS shall provide the science team with facilities for archiving and processing science data	MOS-3	Inspection	Designed
MOS-4	MOS shall provide Public Outreach in the form of workshops and a website	MO-4	Inspection	In Progress
MOS-5	Single point failure in MOS shall not compromise ability to meet full mission success criteria	MSC-8	Analysis	In Progress
MOS-5.1	MOS shall develop mission operations system fault tree, maintain this fault tree throughout operations	MOS-5	Inspection	In Progress
MOS-6	MOS shall develop and execute a plan to generate command sequence products, validate MOS ability to command during testing and operations phases, and to train flight operations personnel	MOS-1.2, MOS-2	Inspection	In Progress

MOS-6.1	This plan shall include capability to command protoflight hardware during test phase of project	MOS-6	Testing	In Progress
MOS-6.2	This plan shall include an Operations Test procedure that verifies commanding ability of all sequence products on satellite systems	MOS-6	Testing	In Progress
MOS-6.3	This plan shall include an End to End Test that validates compatibility of tracking station with flight system	MOS-6	Testing	In Progress
MOS-6.4	This plan shall provide the capability to determine, develop, and verify contingency plans to mitigate mission risk	MOS-6,MOS-5.1	Testing	In Progress
	Mission Control	**Source**	**Verification Method**	**Status**
MC-1	MC shall provide capability to receive and monitor engineering telemetry and science data in real time during testing and flight operations.	SAT-11	Testing	In Progress
MC-1.1	MC shall be able to acquire satellite telemetry within <x-minutes> after end of inhibited phase	MC-1	Analysis	In Progress
MC-1.3	MC shall be able to acquire baseline satellite telemetry within <x-minutes> after first acquisition of an overpass, and within <y-minutes> for each subsequent acquisition during that pass	MC-1	Analysis	In Progress
MC-2	MC shall have the capability to support variable downlink rates between each overpass	COM-2	Analysis	In Progress
MC-3	MC will provide command and control for all phases of the R3 satellite development and operations.	MOS-1.2	Inspection	In Progress
MC-3.1	MC shall be capable of generating, validating, and uplinking R3 satellite commands and sequences for all mission activities during flight operations.	MC-3	Analysis	In Progress
MC-3.2	MC shall verify all command sequence products for resource utilization, constraints, and contingencies before uplink to satellite	MC-3.1	Analysis	In Progress
MC-3.3	MC shall be plan and execute an uplink checkout test after end of inhibited phase	MC-3	Analysis	In Progress
MC-3.4	MC shall shall be able to process, store, and uplink <data volume per time period>	MC-3	Testing	In Progress
MC-4	MC shall provide uplink encoding, downlink decoding, and delivery of data for necessary operational activities.	MOS-1	Testing	In Progress
MC-5	MC shall provide satellite tracking and navigation	MOS-1	Testing	In Progress
	Tracking Station	**Source**	**Verification Method**	**Status**
TRAC-1	All communication shall abide by ITU and FCC regulations. Georgia Tech shall obtain the necessary spectrum licenses for operating its space segment radio communication equipment prior to FCR.	NUG	Inspection	In Progress
TRAC-2	Ground transceivers and antennas shall operate in the UHF and S-Band frequencies.	MOS-1	Testing	Designed

TRAC-2.1	The Ground Receiving antenna shall operate in the amateur S-band for downlink	MOS-1.1	Analysis	Designed
TRAC-2.2	The Ground Transmitting antenna shall operate in the amateur UHF band for uplink	MOS-1.2	Analysis	Designed
TRAC-3	The Tracking Station shall use computer controlled rotors to direct the antenna system.	MC-5	Testing	Designed
TRAC-3.1	The Control Computer will control the automated tracking functions for the antenna system.	TRAC-3	Testing	Designed
TRAC-3.2	A designated computer in the Mission Control Room shall be used to pass command signals to the antenna rotor system.	TRAC-3	Testing	Designed

CHAPTER 2: SUBSYSTEM ARCHITECTURE

DESIGN DRIVERS

The design drivers for the Tracking Station consisted of knowing that the R^3 satellite would require the downlink of large amounts of data which requires operation of ultra high (UHF, 300 MHz to 3,000 MHz) radio frequencies, specifically directed to be in the amateur S-band portion of the radio frequency spectrum. Also knowing that the satellite is fairly small and will have limited power abilities would indicate that the satellite would only be able to transmit low wattage power to send data and telemetry. This would require a large amount of gain on the receiving side in order to successfully capture all the transmitted data and telemetry. So the Principle Investigator directed that the receiving antenna assembly would use a 10 foot diameter dish to provide sufficient gain on the transmitted signal. Finally, the Ground Station system was budgeted for $40,000, which included all items required for the Tracking Station in addition to equipment required for the Ground Data System, while maintaining a high performance yet relatively low cost means to communicate with the satellite.

SUBSYSTEM DESCRIPTION AND COMPONENTS

General Design of the Tracking Station

The Tracking Station provides two main functions for the R^3 mission, the downlink and uplink of signals between the mission operation center and the satellite. The sections below provide an explanation of the design of the downlink and uplink subsystems. In support of these two subsystems, there are some common components that both systems use, such as Tracking Station Main Computer and the rotors. An explanation of the design of the common components follows after the downlink and uplink subsystem section. Finally, common components that provide general functionality to all the other system components are given explanation. These common components generally deal with electrical power and its distribution among the other components.

The figure below is the overall block diagram for the Tracking Station showing the flow of data between components, along with physical connections and which type of power system the components use.

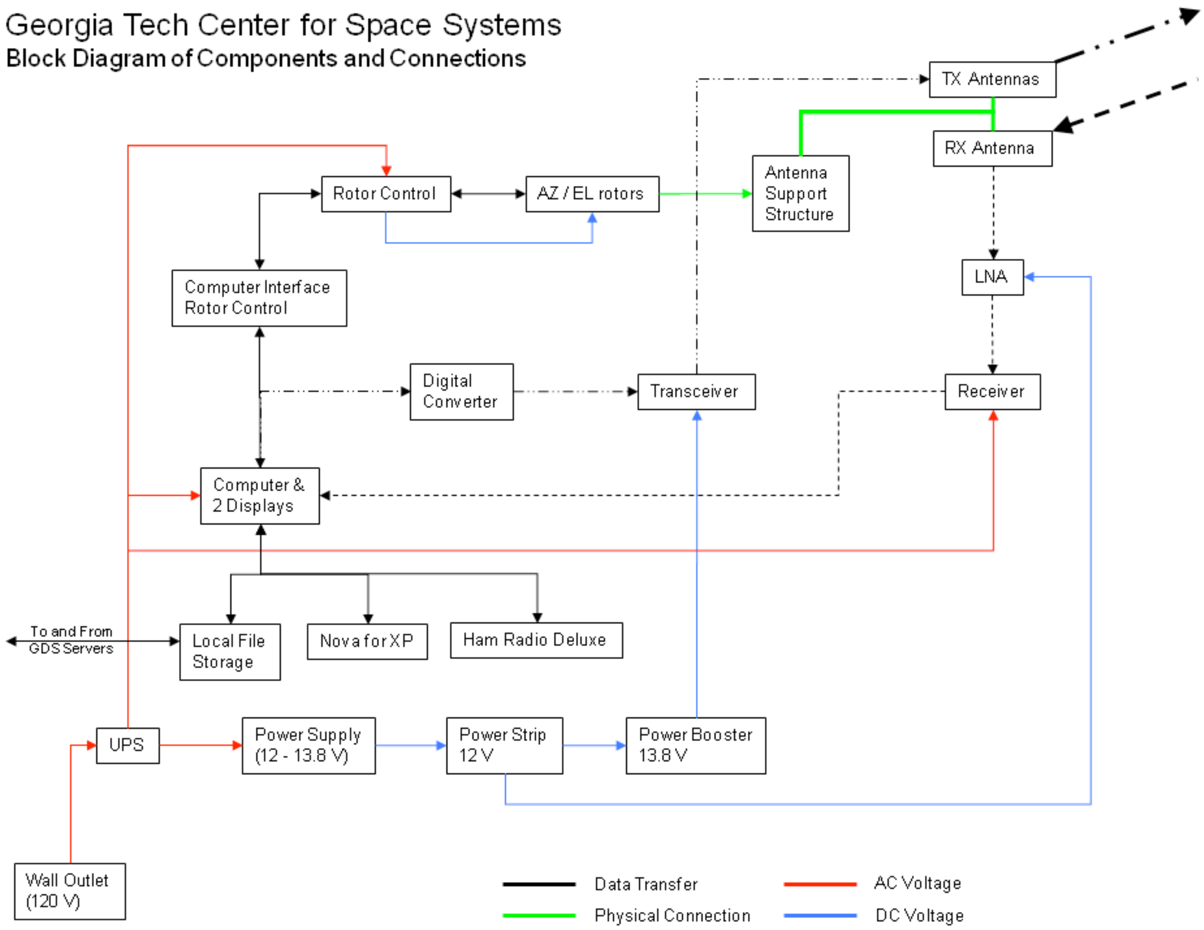


Figure 1: Block Diagram of Tracking Station Components

Design of Downlink Subsystem

Key components to the functioning of the downlink subsystem are highlighted in red boxes in the figure below. Explanation and key parameters of these components are detailed in the following section.

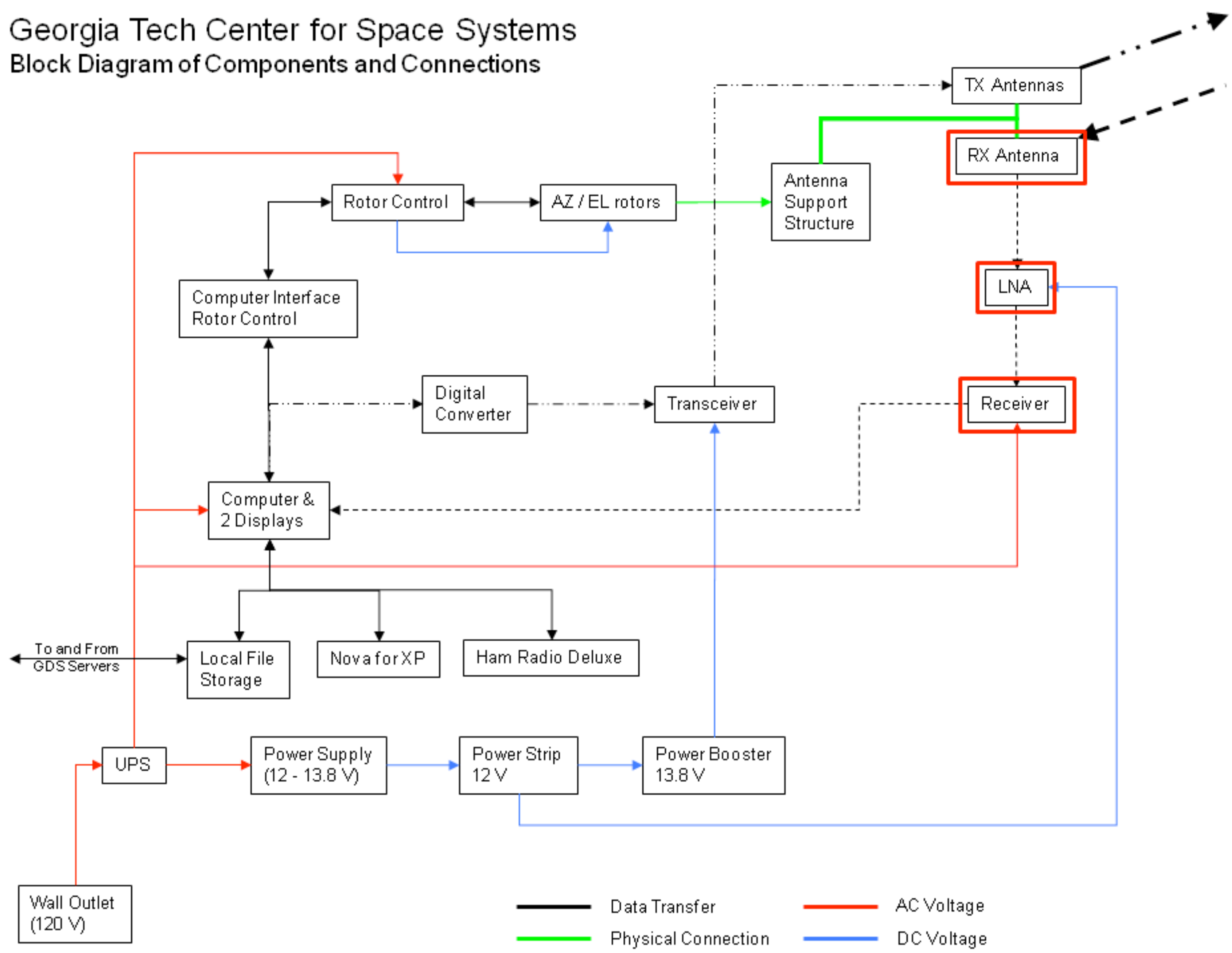


Figure 2: Highlighted Selection of Key Downlink Subsystem Components

Key Components for the Downlink System are the RX Antenna, the LNA, the Transmission Cables (dashed line between the LNA and receiver), and the Receiver.

Key Components for the Downlink Subsystem

RX Antenna

The main receive antenna for the tracking station is composed of two key components: 1. the mesh dish reflector, and 2. the septum antenna feed. Design and explanation of these two components are detailed below respectively.

1. Mesh Dish Reflector. The mesh dish reflector was directed to be 10 foot in diameter (3.048 meter). M2 Antennas Incorporated (www.m2inc.com) provided the 10 foot mesh dish reflector, which has an f/D ratio of 0.38. The f/D ratio is the focal distance of the dish (f), divided by the diameter (D). The mesh dish reflector is 3.048m in diameter, with an f/D ratio of 0.38, which results in a focal distance of 1.158m. This measure indicates where to place the septum antenna feed for optimum signal reception from the mesh dish reflector.

$$0.38 = \frac{f}{D} = \frac{f}{3.048} \Rightarrow 0.38 \cdot 3.048\, m = 1.158\, m$$

The figure below visually shows a cross section of the dish parameters.

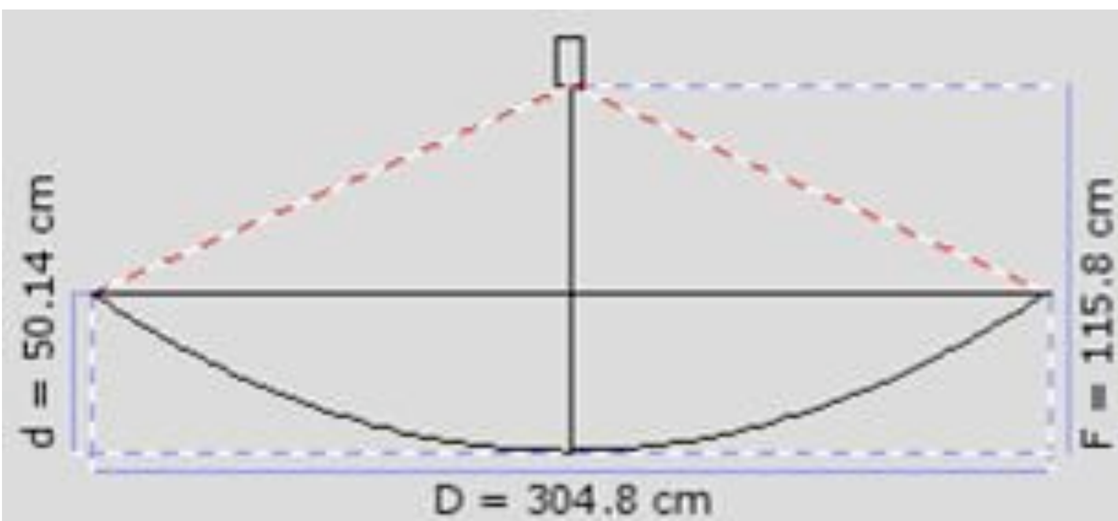


Figure 3: Mesh Dish Reflector cross section.

An accepted determination for the gain of a parabolic type reflector is:

$$G = \frac{4 \cdot \pi \cdot A_e}{\lambda^2}$$

Where

G: is gain, typically represented in decibel (dB) format

π: is Pi, 3.14159265…

A_e: is Effective Aperture

λ: is wavelength

The translation of the physical area of the dish antenna to its electromagnetic area is through Effective Aperture. Effective Aperture is calculated as:

$$A_e = \eta_A \cdot A_r$$

Where:

A_e: is Effective Aperture

η_A: is Aperture Efficiency (Typically accepted range is 0.5 to 0.75, or 50% to 75%)

A_r: is physical aperture area

The physical aperture area for the Receiving dish is:

$$A_r = \pi \cdot r^2 = \pi \cdot (1.524m)^2 \cong 7.296m^2$$

This results in an Effective Aperture range for 50% to 75% of:

$$A_{50\%} = 0.5 \cdot A_r = 0.5 \cdot 7.296m^2 \cong 3.648m^2$$

$$A_{75\%} = 0.75 \cdot A_r = 0.75 \cdot 7.296m^2 \cong 5.472m^2$$

Using these Effective Aperture values, the expected Gain for the Receiving dish in decibels is shown in the graph below:

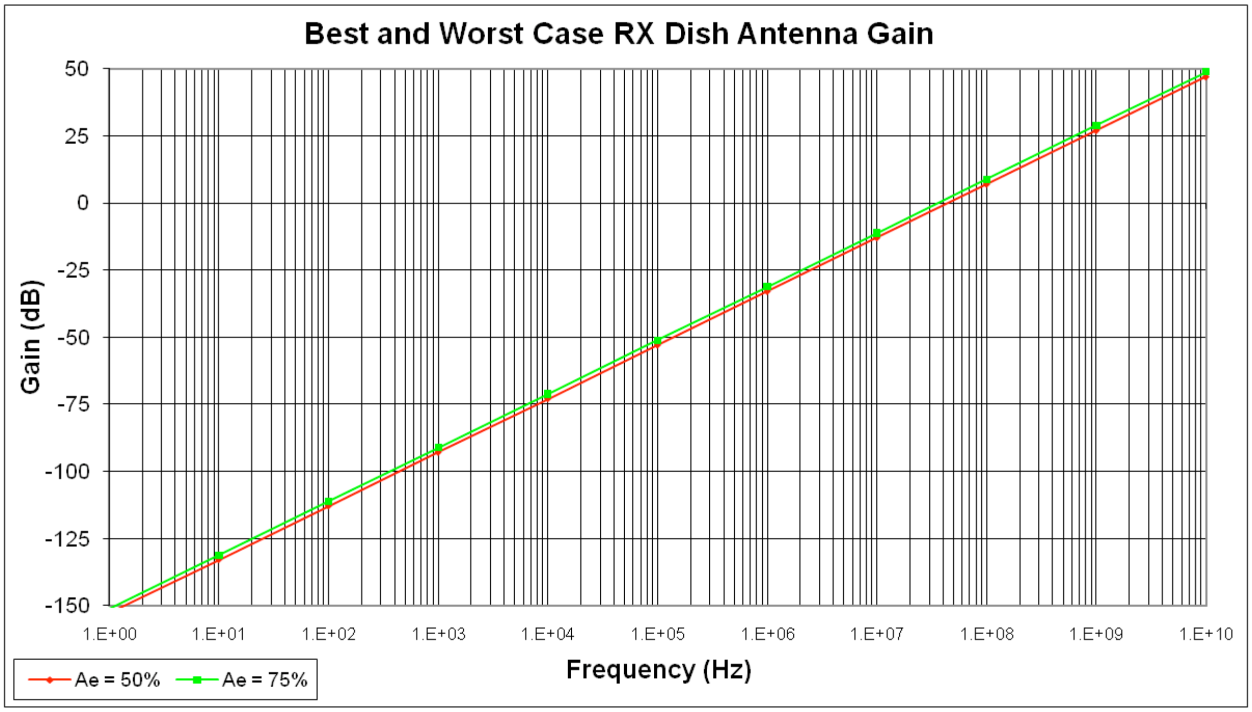


Figure 4: Best and Worst Case Receive Gain for a 10 foot diameter dish.

The septum antenna is designed to operate at 2405 MHz frequency, or 0.1246 m wavelength, therefore the expected gain from the mesh dish for the septum antenna when based on the range of Effective Aperture is reasonably expected to be between:

Worst Case: $G_{Ae50\%} = 34.69$ dB

Best Case: $G_{Ae75\%} = 36.46$ dB

The graph below shows the expected best and worst case gain for a 10 foot diameter mesh dish reflector operating in the Amateur radio S-band, which is where the septum antenna is designed to operate, specifically at 2405 MHz.

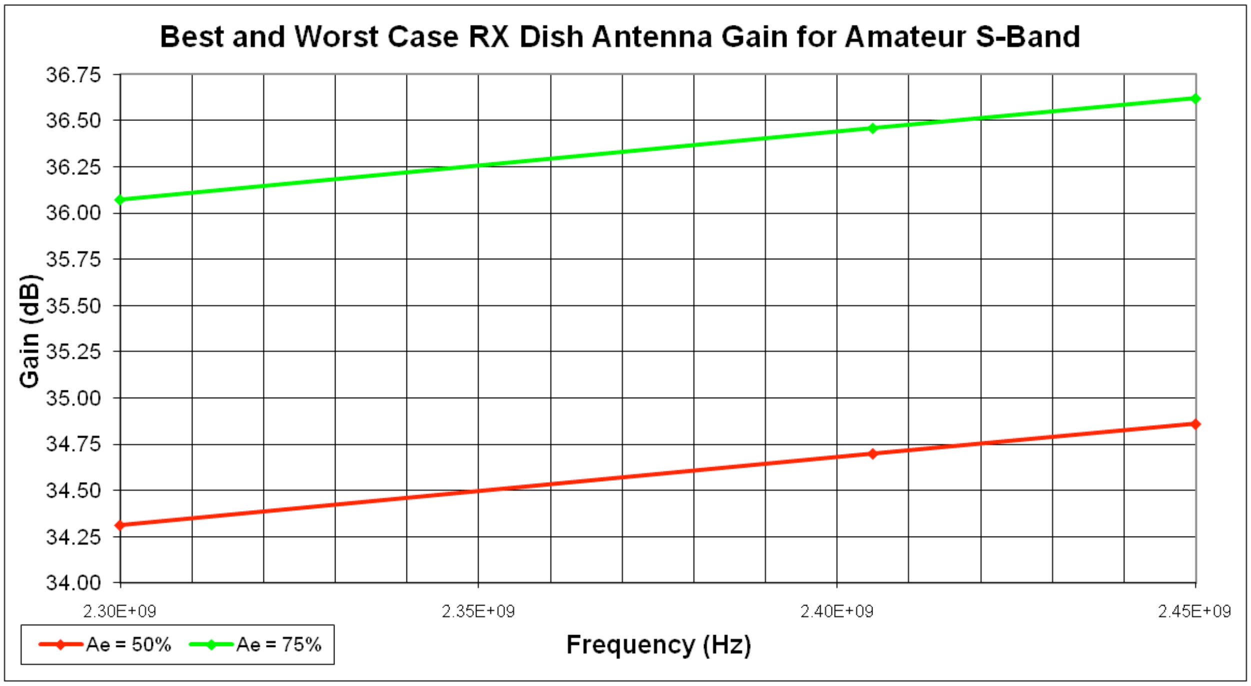


Figure 5: Best and Worst Case Receive Gain for a 10 foot diameter dish in Amateur S-band.

It is interesting to note that even if the Effective Aperture was only 16.95%, this would still result in a gain of 30 dB at 2.405 GHz. So it is reasonable to assume that the mesh dish reflector will provide at a minimum of 30 dB of gain for receiving signals from satellites in the amateur S-band region of the spectrum.

2. Septum Antenna Feed. The septum antenna feed is based on an Amateur radio design and built by the GT Aerospace Shop. The tracking station RX antenna uses a square septum antenna which is based on a design originally developed by Chen and Tsandoulas, then later modified for amateur radio applications by Czech amateur radio operator Zdenek Samek, OK1DFC, and then

improved by Russian amateur radio operator Dmitry Dmitriev, RA3AQ. The septum antenna offers the ability to access both left hand and right hand circular polarized (LHCP, RHCP) electromagnetic radiation based on which side of the septum transformer plate the feed element is positioned, which is connected to a female N-type four hole flange connector. The septum antenna can be used for either receiving or transmitting or both, in either left or right hand circular polarization, however, for the tracking station it is used exclusively for receiving circular polarized electromagnetic radiation.

Figure 6: Pictures of square septum antenna feed, courtesy Zdenek Samek, OK1DFC.

The selection of 2405 MHz as the operating frequency for the septum feed is based on the Amateur Radio Relay League (ARRL) recommended band plan for the 2390 – 2450 MHz spectrum and expert opinion given by Dr. Paul G. Steffes, GT School of Electrical and Computer Engineering. This is a frequency commonly used among amateur satellite developers, and follows common practices for band plan compliance.

An operating frequency of 2405 MHz is in the Satellite high-rate data segment of the band plan, and is also the middle frequency value for Satellite operations, as noted in the table below. See Appendix A for the entire ARRL Band Plan for 2300 – 2310 and 2390 – 2450 MHz (12 Centimeters).

Table 2: Segment of ARRL 12 Centimeter Band Plan

2400.0 - 2403.0 MHz	Satellite
2403.0 - 2408.0 MHz	Satellite high-rate data
2408.0 - 2410.0 MHz	Satellite

Zdenek provides a simple Microsoft Excel spreadsheet (available on www.ok1dfc.com) for calculating the key dimensions required for construction of the septum antenna. The spreadsheet linearly scales the dimensions for the septum feed based on the input operating frequency. Given that the dimensions scale with frequency, the spreadsheet was altered to provide the same results as the dimensions developed by Dmitry for his improved septum antenna operating at 2320 MHz (see Appendix B for his septum antenna dimensions) by changing the various fraction values of lambda. The only non uniform change made was to overall length, which is based on Dmitry's HL0 value combined with the HL1, which are 215mm + 32.2mm = 247.2mm for overall length of the septum antenna. The longer the septum antenna length is the more narrow a beam it creates, which results in higher gain. However, for our purposes, we are limited in total overall length of about 300mm due to the shape of the weather cap on the mesh dish reflector cover in order to fit all the required components underneath the weather cap. Also, keeping the overall length of the septum antenna short, the operating bandwidth of the antenna is larger, allowing for more received frequencies from various other satellites. The trade off for a shorter septum antenna is a wider beam angle, which translates to some loss of gain, and lower side lobe signal rejection, which results in some received noise. However, the loss of gain due to septum antenna length is negligible compared to the gain that the mesh dish reflector provides, and the noise value received due to lower side lobe rejection is below the nominal level of ambient noise already received by the antenna system, so it does not contribute any significant noise to the overall system noise.

Shown below is a side by side comparison for the recommended key dimensions for Zdenek and Dmitry's septum antennas operating at 2320 MHz. This shows the difference in lambda values for comparison and before using the altered spreadsheet results for the recommended key dimensions for an operating frequency of 2405 MHz.

Zdenek Samek's Recommended Dimensions					Dmitry Dmitriev's Recommended Dimensions		
Frequency:	2320	MHz			Frequency:	2320	MHz
Wave length:	129.310	mm	Lambda	Lambda	Wave length:	129.310	mm
Measurement	Value in mm				Measurement	Value in mm	
L1	43.7	Length of tooth	0.338	0.326	L1	42.2	Length of tooth
L2	77.2		0.597	0.6435	L2	83.2	
L3	112.2		0.86	0.953	L3	123.2	
L4	124.3		0.961	1.047	L4	135.4	
SL	206.9		1.6	1.469	SL	190.0	
S1	10.3	Width of tooth	0.08	0.092	S1	11.9	Width of tooth
S2	23.0		0.178	0.2025	S2	26.2	
S3	38.9		0.301	0.306	S3	39.6	
S4	63.5		0.491	0.459	S4	59.4	
A	80.9		0.626	0.6162	A	79.7	
Values in mm					Values in mm		
Distance between opening and transformer	129		1	0.442	Distance between opening and transformer	57.2	
Distance between Probe and rear wall	25		0.19	0.187	Distance between Probe and rear wall	24.2	
Overall Probe Length	24		0.185	0.186	Overall Probe Length	24.1	
Recommended thickness of septum transformer sheet	1.034	Not a critical parameter			Recommended thickness of septum transformer sheet	1.034	Not a critical parameter
Total of feed length	336	Total			Total of feed length	247	Total

Figure 7: Comparison of key dimensions for a septum antenna feed.

Below is the reference picture for the dimensions specified in the above comparison.

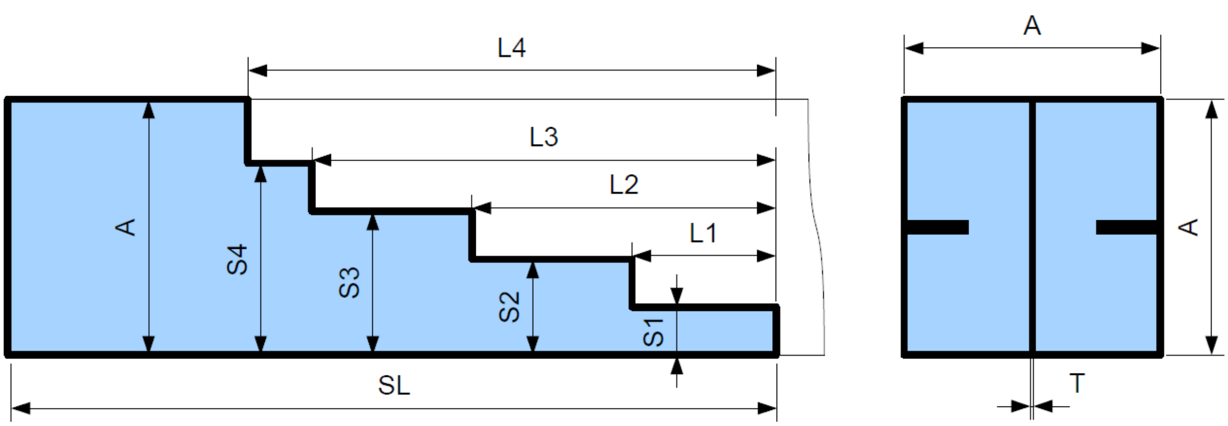


Figure 8: Septum antenna feed transformer, picture courtesy Dmitry Dmitriev, RA3AQ.

Based on the updated and altered spreadsheet, the dimensions for a septum antenna operating at 2405 MHz are shown in the figure below (see Appendix C for the detailed septum antenna design layout).

	Frequency:	2405	MHz
Lambda	Wave length:	124.740	mm
	Measurement	**Value in mm**	
0.326	L1	40.7	Length of tooth
0.6435	L2	80.3	
0.953	L3	118.9	
1.047	L4	130.6	
1.469	SL	183.2	
0.092	S1	11.5	Width of tooth
0.2025	S2	25.3	
0.306	S3	38.2	
0.459	S4	57.3	
0.6162	A	76.9	
	Values in mm		
0.442	Distance between opening and transformer	55.1	
0.187	Distance between Probe and rear wall	23.3	
0.186	Overall Probe Length	23.2	
	Recommended thickness of septum transformer sheet	0.998	Not a critical parameter
	Total of feed length	238	Total

Figure 9: Dimensions for a 2405 MHz septum antenna feed.

The 2405 MHz septum antenna is constructed from aluminum alloy, specifically Al 6061 aluminum alloy, that is 0.04 inches thick (approximately 1.016mm). This is close to the recommended thickness of 0.998mm specified by the spreadsheet and as shown in the figure above. Note that the thickness of the material used for the septum is not a critical parameter according to Zdenek.

The septum antenna has two feed elements which are constructed from female N-type four hole flange connectors with a copper probe soldered to the inner exposed conducting element. The flange connectors are bolted, one to each half of the septum antenna, through mounting plates which are tack welded to the exterior left and right side components of the septum antenna feed, as shown in the picture below.

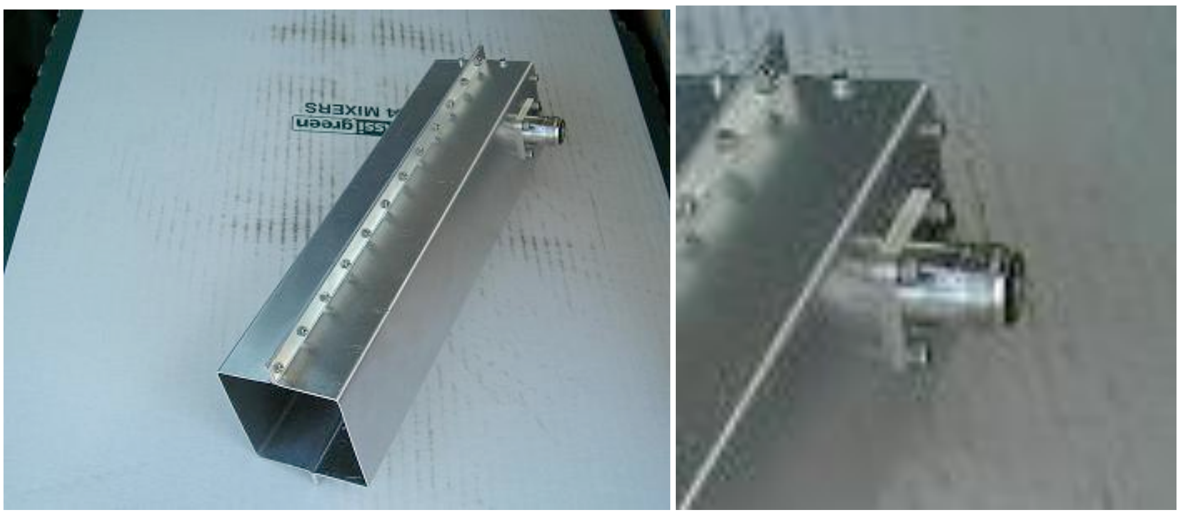


Figure 10: Completed septum antenna feed, pictures courtesy Zdenek Samek, OK1DFC.

The probes which are soldered to the female N-type 4 hole flange inner exposed conducting elements are made of copper metal rods which are approximately 6mm in diameter (OD) by 23.2mm long, as specified by the spreadsheet, and show in the figure above.

Low Noise Amplifier (LNA)

The low noise amplifier is an electronic amplifier used to amplify weak signals captured by an antenna. The tracking station RX antenna uses an ultra low noise amplifier (ULNA) designed for use in the amateur S-band. The ULNA was developed and manufactured by Down East Microwave (www.downeastmicrowave.com) and the complete ULNA specifications can be found in Appendix D: DEM 13ULNA Specifications.

The ULNA operates in a frequency range of 2300 to 2450 MHz, which covers the entire portion of the Amateur S-band, and specifically the operating frequency of the septum antenna feed at 2405 MHz. The ULNA has the specifications as listed in the table below.

Table 3: DEM 13ULNA Specifications.

Gain:	16dB minimum
Noise Figure:	<0.7dB maximum
P1dB:	+5dBm output
Input VSWR:	>6dB @ design frequency
Output VSWR:	>10dB DC - 3 GHz.
Voltage:	+7 - +16 VDC

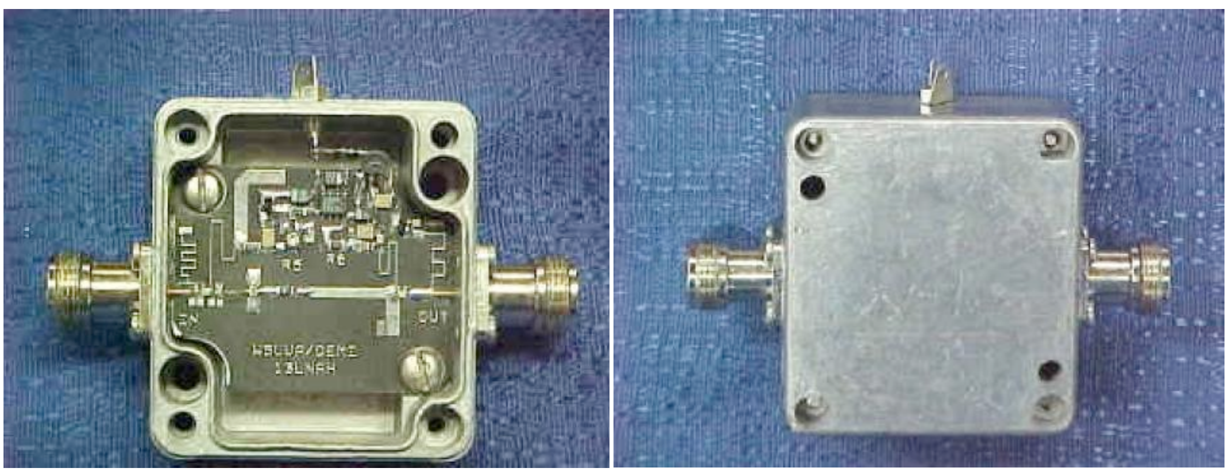


Figure 11: Interior and Exterior pictures of the Ultra Low Noise Amplifier, courtesy Down East Microwave.

The LNA requires a direct current power source which comes from the West Mountain Radio 4010S power strip. The power strip will provide 12 to 13.8 volts of direct current for the LNA to operate, therefore allowing the gain to reach its minimum 16 dB of gain. Refer to the user's manual for proper power hookup connection to the LNA.

TRANSMISSION CABLES

The transmission cables carry the signal received by the RX antenna, through the LNA, to the Icom IC-R9500 receiver. They were fabricated by the company Cable X-perts, and they are available online at www.cablexperts.com.

There are two cables, one for each side of the septum antenna feed, which are connected through the LNAs and carry the signal from the LNA to an antenna switch which then routes the signal to the receiver. The two position antenna switch allows for selection and switching between either left or right side of the septum antenna feed, which allows for reception of either left or right hand circular polarization. The two position antenna switch is a MFJ Enterprises MFJ-2702N, and is capable of handling signals up to 3GHz in frequency, and a power capability rating of 2kW. The cables are constructed of 119 feet of LMR-600 UltraFlex (also known as Cinta CNT-600) with male N-type connectors on both ends. The LMR cables are UV resistant thermoplastic elastomer polyethylene jacketed cable designed for 20 years of outdoor service use.

The LMR-600 UltraFlex experiences signal loss, or attenuation, according to the chart below.

Frequency MHz	Attenuation dB/100 ft	dB/100 m	Avg. Power kW
30 MHz	0.42	1.4	5.5
50 MHz	0.55	1.8	4.2
150 MHz	1.0	3.2	2.4
220 MHz	1.2	3.9	2.0
450 MHz	1.7	5.6	1.35
900 MHz	2.5	8.2	0.93
1500 MHz	3.3	10.9	0.70
1800 MHz	3.7	12.1	0.63
2000 MHz	3.9	12.8	0.59
2500 MHz	4.4	14.5	0.52
5800 MHz	7.3	23.8	0.32

Add 15% to tabulated attenuation for LMR-UltraFlex

Calculate Attenuation = $(0.07555) \bullet \sqrt{FMHz} + (0.00026) \bullet FMHz$

(interactive calculator available at http://www.timesmicrowave.com)

Attenuation: VSWR=1.0 ; Ambient = +25°C (77°F)

Power: VSWR=1.0; Ambient = +40°C; Inner Conductor = 100°C (212°F); Sea Level; dry air; atmospheric pressure; no solar loading

Figure 12: Times Microwave Systems company specifications for LMR-600 UltraFlex.

Based on the data provided by Times Microwave Systems, the graph below shows the corrected values for attenuation to include the +15% attenuation factor for UltraFlex cable.

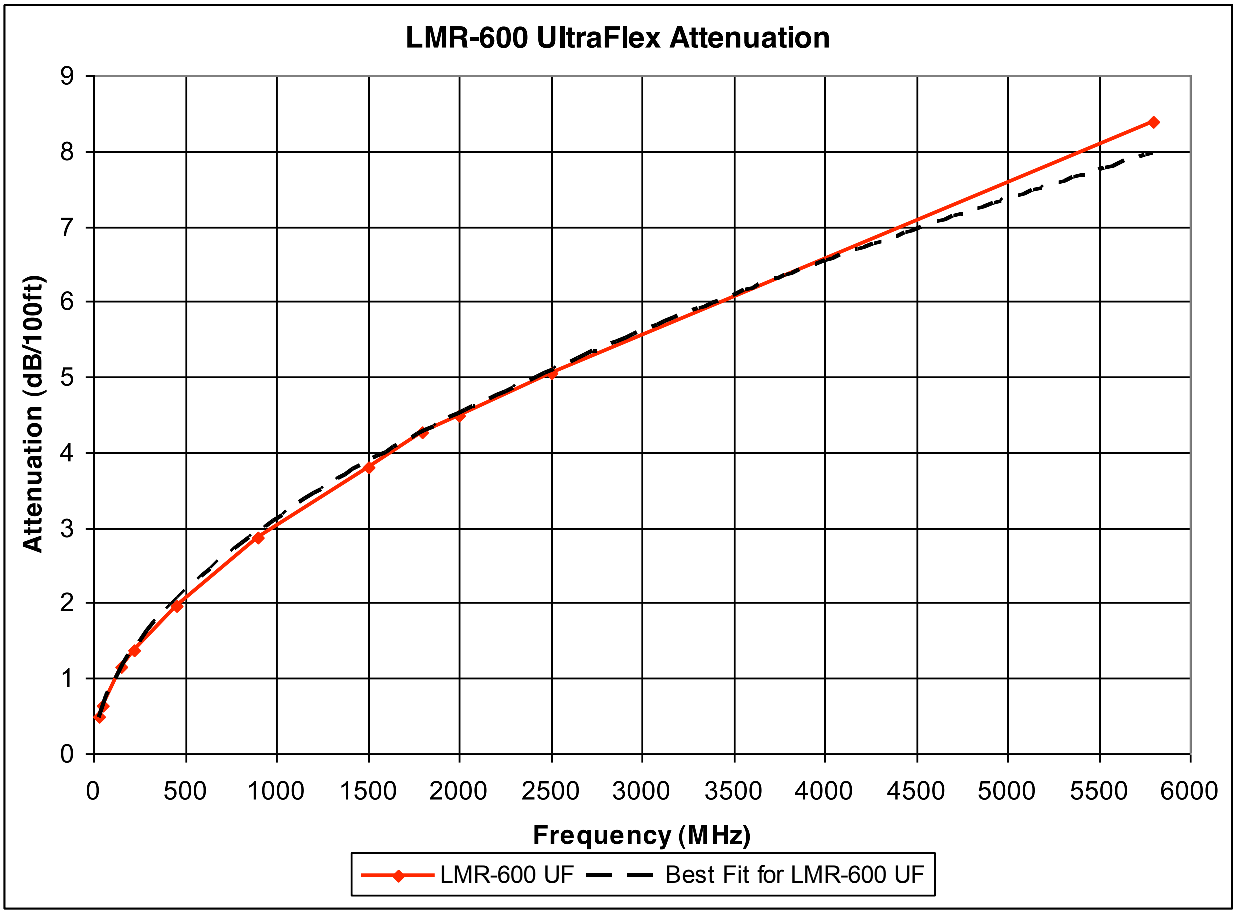


Figure 13: Graph of the corrected attenuation values for LMR-600 UltraFlex.

The red line depicts the corrected attenuation factor, while the black dashed line depicts the Best Fit line with an equation of:

$$y = 0.0772 \cdot x^{0.5351}$$

The Best Fit line has a coefficient of determination of $R^2 = 0.9993$, which means the Best Fit line approximates the data set very well and it is suitable to use the Best Fit equation to approximate other values between the data set points.

Based on being able to reasonably use the Best Fit equation and knowing the operating frequency of the septum antenna is designed for 2405 MHz, it is possible to approximate the attenuation for the cable to be 4.98 dB per 100 feet of cable. Since the cables are 119 feet long each, this translates in to an overall total cable attenuation of approximately 5.92 dB for each cable.

RECEIVER

The receiver is an Icom IC-R9500 which was developed for professional communications use with laboratory grade functions incorporated in the design. It provides frequency coverage of 0.005 to 3335 MHz and a high performance spectrum scope. It was purchased through Ham Radio Outlet, which is available online at www.hamradio.com. For a brief overview of specifications for the receiver see Appendix E: Brief Specifications for the Icom IC-R9500 and for more in-depth detail on the specifications refer to the user manual. This receiver was selected because of the frequency range of coverage in addition to the spectrum scope view, along with several of the lab grade features offered with the model.

Figure 14: Front and Rear view of the Icom IC-R9500 Receiver.

Design of Uplink Subsystem

Key components to the functioning of the uplink subsystem are highlighted in red boxes in the figure below. Explanation and key parameters of these components are detailed in the following section.

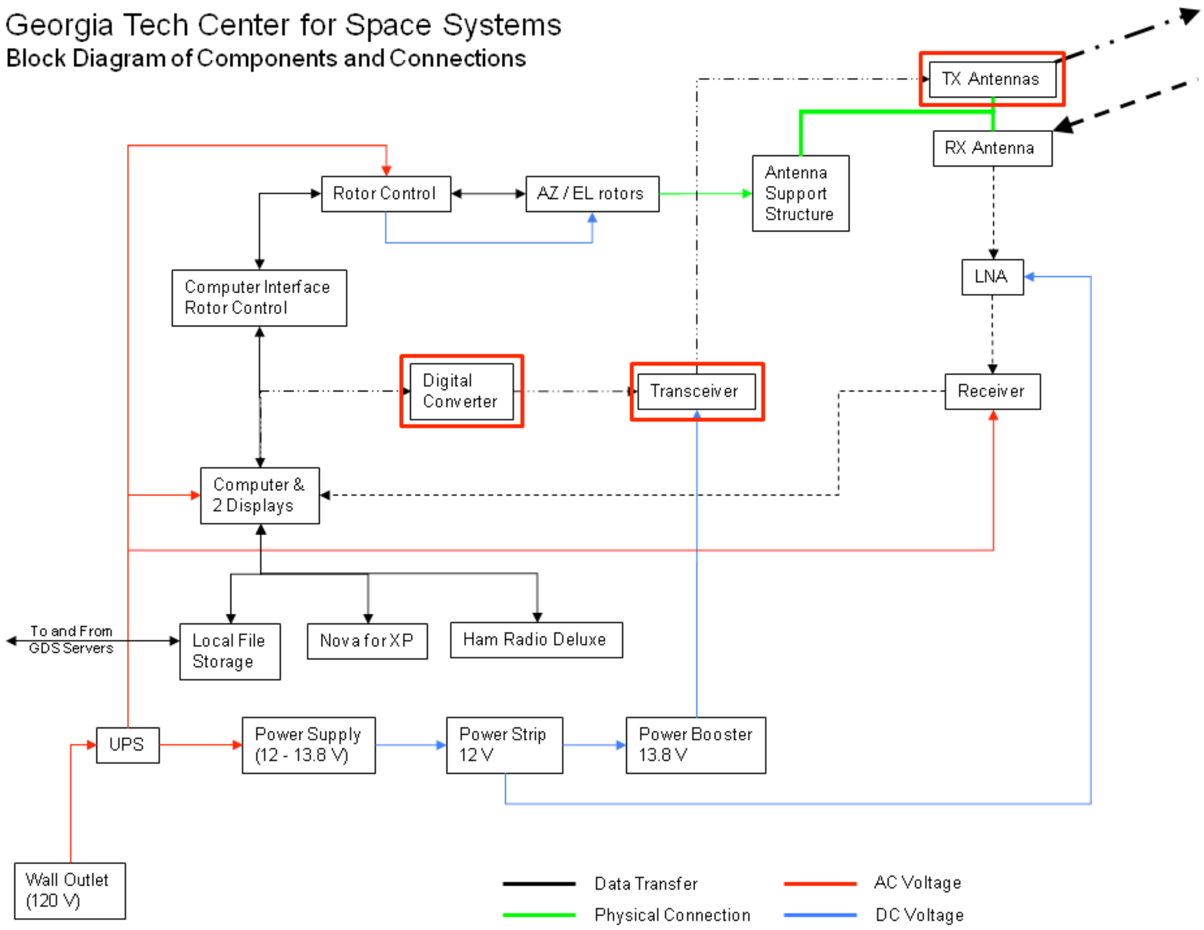


Figure 15: Highlighted Selection of Key Uplink Subsystem Components

Key Components for the Uplink System are the TX Antenna, the Transceiver, the Transmission Cables, and the Transceiver, and Digital Converter.

TX ANTENNA

The main transmitting antenna for the tracking station is designed to operate in the UHF range, specifically between 432 and 440 MHz. It is circularly polarized yagi antenna with a switching option to allow for selection between left and right hand circular polarization, and with some modification can be made to transmit with either vertical or horizontal polarization. The antenna was designed and manufactured by M2 Antennas Incorporated (www.m2inc.com), who also supplied the receiving dish reflector and rotor system, and was purchased through them. The antenna provides 14.15 dB of gain while being able to handle 600 watt power loads for transmitting and the whole antenna with the switching kit weights a mere 7 lbs. In order for the antenna to operate at the specified 14.15 dB of gain, it cannot be placed to closely to the mesh dish reflector, or the antenna beam patterns will interfere with each other, degrading performance of the entire antenna cluster. However, the yagi antenna needs to be mounted as close as possible to the mesh dish reflector in order to reduce the overall amount of torque placed on the rotors during wind loading, which the adjustment of the counter balance weights cannot correct. The manufacture recommends a stacking distance of 51 inches, which is equivalent to 4.25 feet, and the radius of the mesh dish reflector is 5 feet, so a boom arm of 9.25 feet or 111 inches is need to ensure the antenna beam patterns do not interfere.

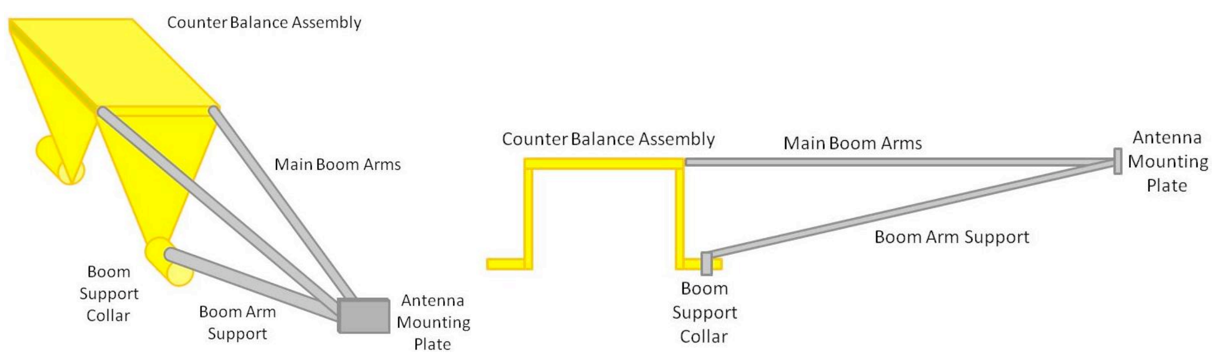


Figure 16: Diagram of Yagi Antenna Boom Arm

All elements of the Boom Arm assembly are constructed from aluminum 6061 material, either in 1 inch tubing or blocks which are milled to specification. The main boom arms are 111 inches in length of 1 inch aluminum tubing and are angled from the counter balance assembly to the antenna mounting plate. The main boom arms each have angled L brackets welded to the ends with a vertical hole drilled through them and are mounted to the counter balance assembly by the same bolts that secure the mesh dish reflector to the counter balance assembly. The main boom arms terminate together at an angle with the antenna mounting plate. The antenna mounting plate, which is supplied in the yagi antenna construction materials from M2 Antennas, is welded vertically perpendicular to the angled main boom arms, with additional triangle flanges welded between the two for more support. The boom arm support is constructed of two sections of 1 inch aluminum tubing with a threaded section milled or inserted into each end between the two sections. Between these sections will go a long headless bolt or rod with matching thread count and pitch to the aluminum tubing. This rod will serve to adjust the length of the boom arm support in order to keep the main boom arms and antenna mounting plate parallel to the counter balance assembly. The boom are support section terminating at the antenna mounting plate will have a hinged joint welded to the antenna mount plate which will allow for adjustment of the boom arm support. The other section of the boom arm support will terminate on the boom support collar, which is located on the counter balance weight support arm. The boom support collar is placed between the counter balance weights and the locking collar. The boom support collar is similar in dimensions to the counter balance locking collar which secures the counter balance weights to the counter balance arm. Similar to the antenna mount plate boom arm support hinge, the boom support collar has a hinged joint welded to it in order to allow for the adjustment of the boom arm support sections thought the adjustment rod between the boom arm support sections. With the addition of the yagi antenna to one side of the antenna cluster, the overall weight distribution on the rotor gears is un-balanced. Based on approximately 7 pounds of antenna at about 9.25 feet distance, this is 64.74 foot pounds of torque that needs to be balanced on the opposite side of the counter balance assembly. Assuming a counter balance weight arm is about 1.5 foot long, it would require transferring approximately 40 pounds of counter balance weights from the yagi antenna side to the opposite counter balance weight arm in order to offset the torque difference. Once this is complete, it will require two operators to confirm that the balance of weights is correct and the rotor motors and gears are not over stressed. This is done by one operator using the rotor control box to slew the antenna cluster back and forth as the other operator is listening to the rotor motor and gear housing boxes for and sounds of stress or strain. If sounds are heard other than typical motor operation, further balancing of the counter balance weights is required.

TRANSCEIVER

The transceiver is a Kenwood TS-2000X and is a common amateur radio for base station operations. It has a built-in TNC and several output jacks for the various amateur radio bands and provides transmit and receive capabilities for the HF, VHF, UHF, and L-bands. It was purchased through Ham Radio Outlet, which is available online at www.hamradio.com. For a brief overview of specifications of the transceiver see Appendix F: Brief Specifications for the Kenwood TS-2000X, and for more in-depth detail on the specifications refer to the user manual. This model was selected because it offered access to the L-band frequencies in additional to all the typical amateur HF, VHF, and UHF frequencies. It also has a built in TNC for packet data.

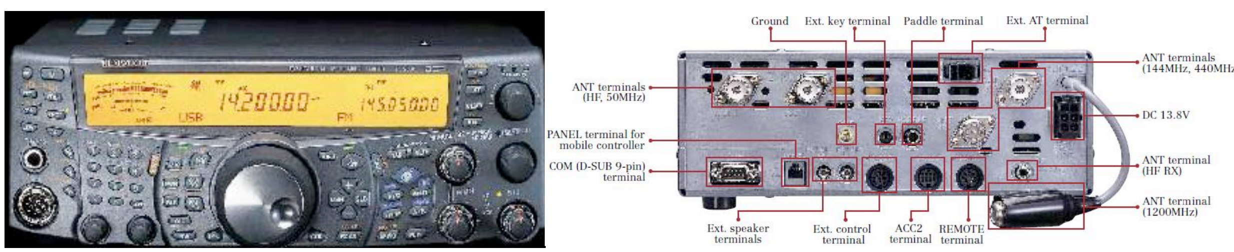


Figure 17: Front and Rear view of the Kenwood TS-2000X Transceiver.

DIGITAL CONVERTER

The digital convert is the RIGblaster PRO, which was designed, developed, and manufactured by West Mountain Radio (www.westmountainradio.com). The RIGblaster PRO provides an easy way to connect the Transceiver to the Tracking Station Main Computer through the onboard sound card and allows for the operation of various amateur modes of transmission, such as Frequency Shift Keying and Phase Shift Keying. It must be configured specifically for Frequency Shift Keying operation according to the user's manual instructions. The figure below gives a general idea of the setup of the RIGblaster PRO; however for setup with the Tracking Station, the details are in the user's manual.

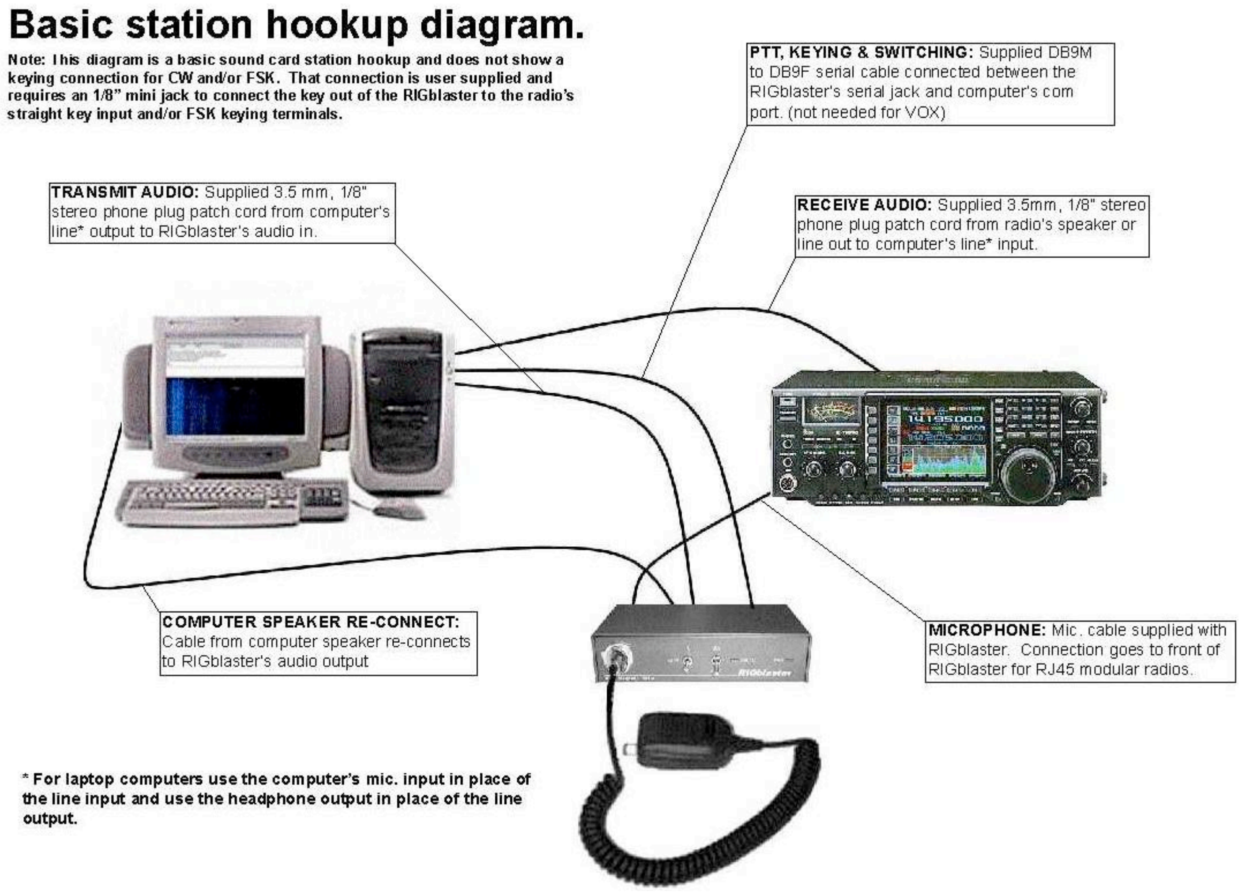


Figure 18: General diagram of RIGblaster hookup connections for a radio station

TRANSMISSION CABLE

The transmission cable between the transceiver and transmitting yagi antenna, if constructed of LMR-600 similar to the receiving transmission cables but with 129 foot length to account for the additional boom arm length, would result in a loss of 2.57 dB based on the Best Fit line developed under the Transmission Cable in the Downlink section. This is calculated at the upper limit of the specified frequency range for the yagi antenna, which is 440 MHz. The cable would be constructed of 128 feet of LRM-600 UltraFlex (also known as Cinta CNT-600) with a male N-type connector on one end, to interface with the yagi antenna, and the other end should have an UHF connector (also known as a PL-259 connector) to interface with the Kenwood transceiver. The LMR cable is UV resistant thermoplastic elastomer polyethylene jacketed cable designed for

20 years of outdoor service use. As with the transmission cables for the receiver, this cable should be procured through the company Cable X-perts, available online at www.cablexperts.com.

Design of Common Components

Common components to the functioning of the Tracking Station system can be divided into two subsystems. 1. The Tracking Station Main Computer and control software programs. 2. Rotor Subsystem and the Antenna Support Structure. Explanation of these two subsystems and their respective components are detailed in the following sections.

1. The Tracking Station Main Computer

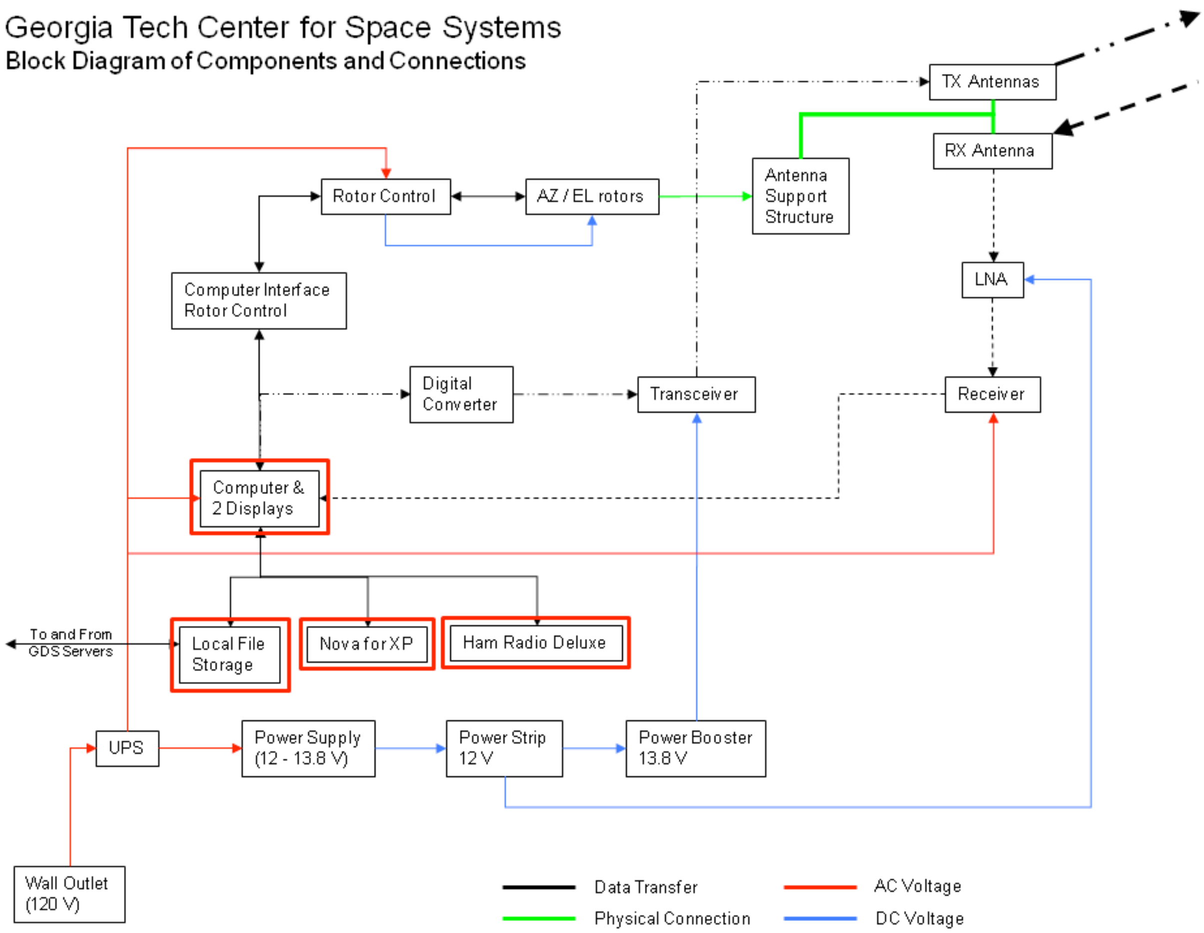


Figure 19: Highlighted Selection of Key Tracking Station Main Computer Components

Key Components for the Tracking Station Main computer are the Computer and two displays, Local File Storage, NOVA for Windows, and Ham Radio Deluxe.

Computer and Two Displays

This is the Tracking Station Main Computer. It was student conceived and student built with commercial off the shelf parts and able to handle multiple tasks at one time with constant operation for long periods of time while offering safe storage of files though redundant drives in RAID 1 format. The table below lists the components used to build the computer and the parts were purchased from Newegg, which is available online at www.newegg.com.

Table 4: List of Parts for the Tracking Station Main Computer

Part	Manufacture	Model	QTY	Price	Total Price
Power Supply	Cooler Master	UCP RS700-AAAAA3 700W	1	$189.00	$189.00
Motherboard	ASUS	ASUS P6T LGA 1366 Intel X58 ATX Intel 3-Way SLI & Quad-GPU CrossFireX Support	1	$234.00	$234.00
CPU	Intel	Intel Core i7 940 Nehalem 2.93GHz 4 x 256KB L2 Cache 8MB L3 Cache LGA 1366 130W	1	$559.99	$559.99
CPU Cooler	Zalman	ZALMAN CNPS9900LED 120mm 2 Ball CPU Cooler	1	$74.99	$74.99
RAM	Kingston	Kingston HyperX 3GB (3 x 1GB) 240-Pin DDR3 SDRAM DDR3 2000 (PC3 16000) Triple Channel Kit	1	$169.99	$169.99
Main Drive	WD	Western Digital VelociRaptor WD3000GLFS 300GB 10000 RPM 16MB Cache SATA 3.0Gb/s Hard Drive	2	$229.99	$459.98
Operating System	Microsoft	Microsoft Windows XP Professional SP3 for System Builders	1	$139.99	$139.99

Dual Boot	Microsoft	Microsoft Windows Vista Ultimate SP1 64-bit for System Builders	1	$179.99	$179.99
GPU	Sapphire	SAPPHIRE 100260SR Radeon HD 4850 X2 1GB 512-bit (2 x 256-bit) GDDR3 PCI Express 2.0 x16 HDCP Video Card	1	$259.99	$259.99
Case	Antec	Antec Nine Hundred Two Black Steel ATX Mid Tower Computer Case	1	$159.99	$159.99
Disk Drive	Samsung	SAMSUNG 22X DVD±R DVD Burner with LightScribe Black SATA Model SH-S223Q	1	$26.99	$26.99
Monitor	Acer	Acer P243WAid Black-Silver 24" 2ms(GTG) HDMI Widescreen LCD Monitor with HDCP Support 400 cd/m2 3000:1 ACM	2	$259.99	$519.98
Case Fans	Sony	Scythe S-FLEX SFF21E 120mm Case Fan	2	$14.99	$29.98
				Total	$3,004.86

LOCAL FILE STORAGE

This aspect of the key components is accomplished within the Tracking Station Main Computer by the two Western Digital VelociRaptor hard disk drives (HDD). These two drives are arrayed in a RAID 1 format. The RAID 1 format is known as a Mirrored set without parity, and provides fault tolerance from disk errors and failure. There is increased read performance when using a multi-threaded operating system that supports split seeks, as well as a very small performance reduction when writing. The array continues to operate so long as at least one drive is functioning. This allows for the failure of one of the drives while still enabling the tracking station to operate until the bad drive is replaced.

NOVA FOR WINDOWS

This is a software program that enables the Tracking Station Main Computer to command the rotor subsystem in order to track selected satellites from the database which can down load the

TLEs for various selected satellites. This is a product developed by amateur radio operators and is available commercially for purchase from www.nlsa.com, and was purchased through the website. The Tracking Station currently uses a purchased and registered copy of the NOVA for Windows, and the registration key for this product is NLD-7180427 which enables all the functions while it removes the demonstration limited copy of the program. The setup and operation of this program is further explained in the Operability Chapter.

HAM RADIO DELUXE

This is a software program that enables the Tracking Station Main Computer to command the receiver and transceiver in order to account for Doppler shift as the satellite conducts an over flight pass of the ground station. HRD is a free program developed by members of the world wide amateur radio community to facilitate the use of multiple radios using different kinds of modulation schemes and is available for download at www.ham-radio-deluxe.com. The Tracking Station is currently using the beta copy of HRD version 5, which offers many capabilities for satellite operation. The setup and operation of this program is further explained in the Operability Chapter.

2. Rotor Subsystem and Antenna Support Structure

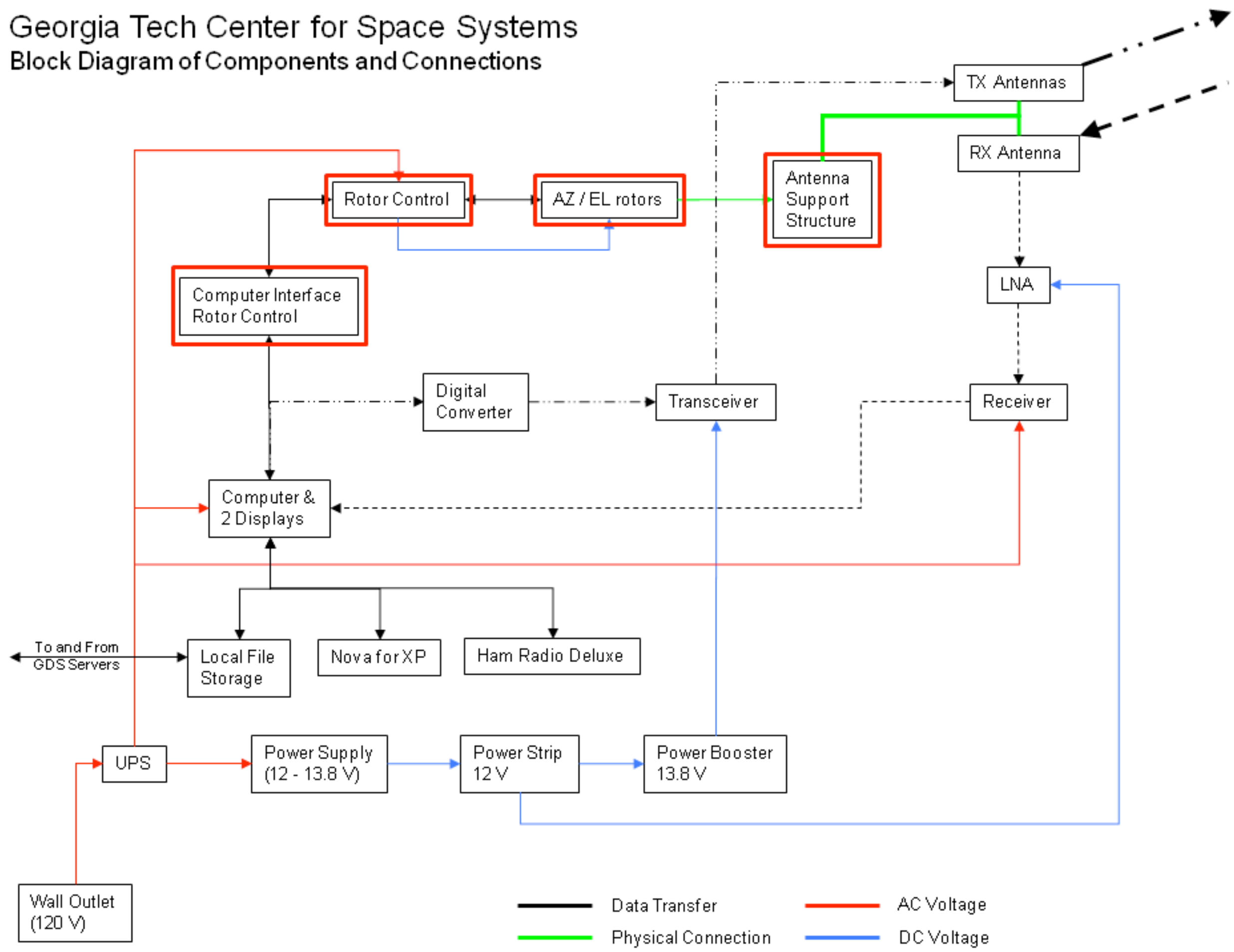


Figure 20: Highlighted Selection of Key Rotor Subsystem and Antenna Support Structure Components

Key Components for the Rotor Subsystem and Antenna Support Structure are the Computer Interface Rotor Control, the Rotor Control, Azimuth and Elevation Rotors, and the Antenna Support Structure.

Computer Interface Rotor Control

This is the Serial to USB cables that connect the Tracking Station Main Computer to the Rotor Control box, and were purchased locally at Fry's Electronics. They provide the means of transferring commands from the computer USB port to the rotor control box RS-232 (Serial) port.

These cables require the installation of support drivers on the computer in order to operate properly. The position location of the USB socket on the computer rear face plate determines for which COM port the cable is designated, which also affects the proper selection of set requirements in NOVA for Windows and HRD. Physical setup of these cables requires attention to detail to the numerically labeled cables. The setup and operation of these software drivers are further explained in the Operability Chapter.

ROTOR CONTROL

This is the M2 Antenna Systems RC2800PRKX2SU Rotor Control Unit, often referred to as the rotor control box. It was purchased though M2 Antenna. It is rack mounted along with the Icom IC-R9500 and Astron power supply. This unit provides the conversion of computer commands to the commands that control the direction and rate of the rotors.

Figure 21: Picture of the rotor control unit RC2800PRKX2SU

AZIMUTH AND ELEVATION ROTORS

These are the AZ-1000A w/LSK-1000 and EL-1000A w/LSK-1000 rotors with rotate and move the antenna cluster assembly from commands received by the rotor control box. They were supplied by M2 Antenna as a kit that was put together and mounted to the mast extension with three clamping collars. The LSK stands for Limit Switch Kit and provides the feature of preventing either the AZ or EL rotors from rotating beyond certain user defined limits or mechanical capabilities of the structure and rotors. The rotors are robust enough to support the antenna cluster and move it while in breezes, and its wind loading capabilities are aided by the selection of a mesh dish reflector with provides less mass and less wind loading area.

ANTENNA SUPPORT STRUCTURE

This consists of a custom fabricated mast extension mounted on top of a pre-existing antenna structure. The mast is constructed of a 6 inch diameter steel pipe with a collar to adapt the mast to the pre-existing antenna structure and secured with multiple bolts. The mast itself is undercoated with several layers rust inhibiting primer spray paint with an over coating of several layers of weather resistant silver gray spray paint in order to allow the mast to withstand the local Atlanta, GA, climate. The antenna support structure is mounted on top of the pre-existing structure shown in the figure below on the left, while the mast extension, AZ and EL rotors, and counter balance arms are shown in the figure below on the right.

Figure 22: Pictures of the pre-existing structure and the mounting of the rotor system.

Design of Other Components Not Previously Listed

UNIVERSAL POWER SUPPLY

This is an APC 3000 W model universal power supply (UPS) which is the main power supply for the Tracking Station components, and was purchased though the GT Aerospace Finance office. The UPS provides 3000 watts of power should the power in the building fail, which would allow the Tracking Station to continue operation uninterrupted for several minutes until regular building power returned. It also provides power conditioning to the majority of the electronic components in the tracking station, which will help extend the useful life of the components. Replacement batteries for the UPS are available for purchase online at www.apc.com as well as for potential future upgrades.

Power Supply

The power supply is an Astron RM-50M, that is available online at www.astroncorp.com, and is rack mounted with the other tracking station equipment, and was purchased through the GT Aerospace Finance office. The power supply provides the means of converting the typical 120 volt alternating current from the universal power supply to the typically used 13.8 volt direct current utilized by radio equipment. It is capable of providing 37 amperes of current for continuous duty activity which is plenty of current for operation of the transceiver and LNAs.

Figure 23: Picture of the Astron RM-50M power supply

Power Strip

The power strip is manufactured by West Mountain Radio and is the model RIGrunner 4010S, which provides multiple outlets for the 12 to 13.8 volt direct current convert by the power supply. It was purchased from West Mountain Radio directly. It offers easily recognized positive and negative terminals with one way plugs to prevent accidental crossing of polarities. Currently the power strip is slotted to provide power to the transceiver and the LNAs; however, it has multiple plugs to offer future expansion for the tracking station.

Figure 24: Picture of the West Mountain Radio RIGrunner 4010S

Power Booster

This is the TGE Electronics N8XJK Super Booster, available online at www.tgelectronics.org and was purchased through the website. This item is not required for the tracking station to operate properly, but is a precautionary piece of equipment. It provides a steady voltage of 13.8 volts at various current draws when powering equipment, namely the transceiver, to allow the equipment to operate specifically at its designed input voltage, which results in steadier signals produced during transmitting activities.

Figure 25: Picture of the TGE Super Booster

The figure below shows all the components of the Tracking Station block diagram with the specified part for each component. It is a useful diagram for depicting all the key components and parts of the tracking station for easy reference.

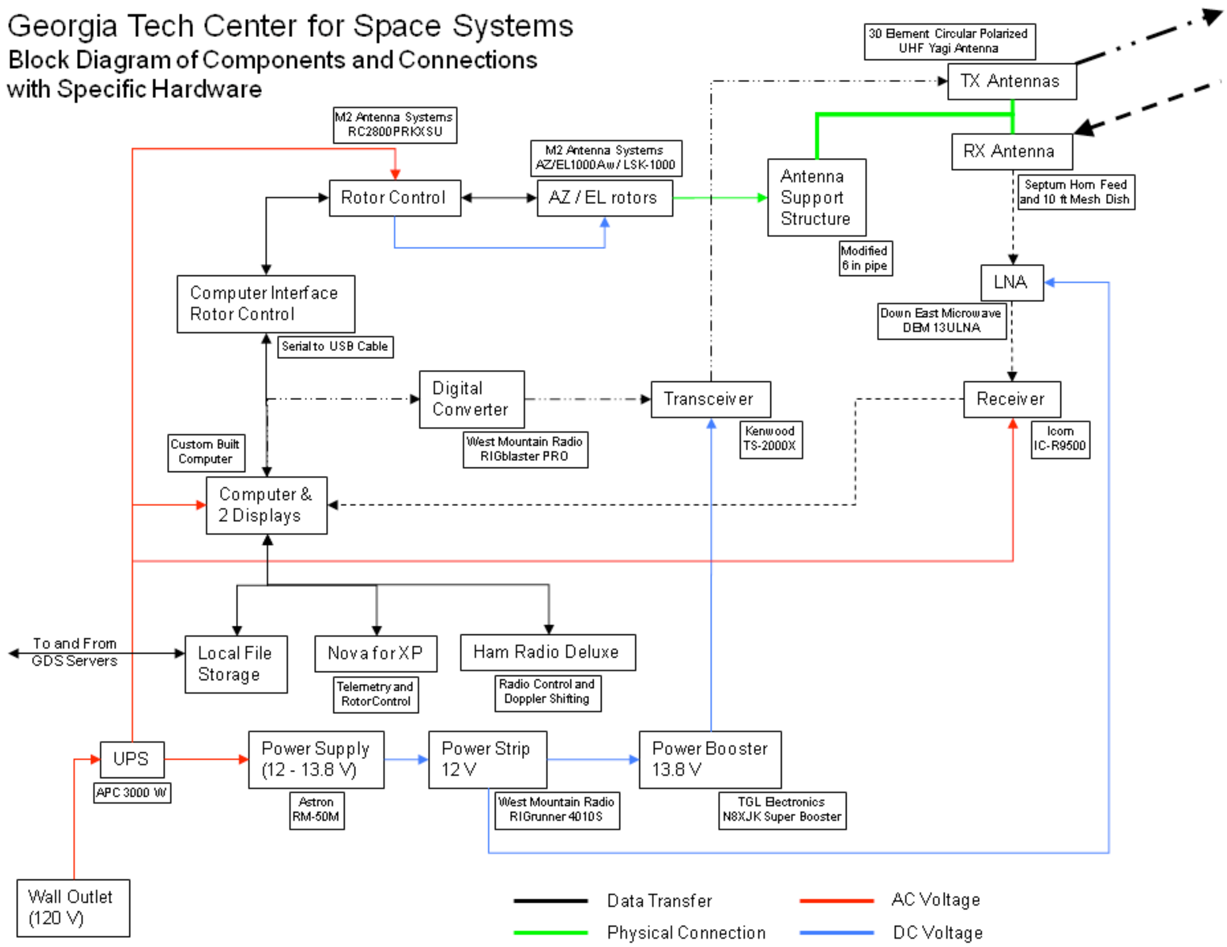


Figure 26: Block Diagram of Tracking Station Components with specific part identified

CHAPTER 3: TRAINING PROGRAM FOR THE TRACKING STATION

The Ground Station may operate in the receiving mode with no FCC certification, so any individual that has proper training on the operation of the receiving equipment may operate the station in the receive mode only. The FCC requires that amateur stations have a certified individual operating the station when conducting transmissions. Therefore any operator who wishes to uplink commands to the R^3 satellite must be a certified amateur radio operator. The licensing body for amateur radio in the United States is the Amateur Radio Relay League (ARRL) and more information is available at www.arrl.org. They are responsible for testing and licensing individuals, which is typically done through local clubs of the ARRL. On campus there is the Georgia Tech Amateur Radio Club (call sign W4AQL) at http://cyberbuzz.gatech.edu/w4aql/. They regularly schedule training and testing for licensing. It is recommended to contact the Club and coordinate for licensing activities prior to any unlicensed user using the Ground Station system, even in receive mode, and is definitely required for transmit mode. Also visit the ARRL website for other useful information on amateur radio operations. While the operation of the Ground Station system only requires a Technician class license, it is recommended that the operator(s) earn their General class license, as this requires more in depth knowledge of general radio operations and procedures. This will help the operator(s) understand the Ground Station system and subsystems in more detail, which should translate to better operating efficiency.

The next section discusses key equipment familiarization for the operator from a downlink and uplink perspective and recommended equipment instruction manual sections or chapters to review prior to operation of the equipment.

Key Downlink Equipment

ICOM IC-R9500

The IC-R9500 is the primary receiver for satellites operating near the 2405 MHz frequency. It is a professional communications receiver with laboratory grade functions incorporated in the design and provides a 10 MHz wide spectrum view. Prior to operating the IC-R9500 is it recommended that the operator read the following chapters in the instruction manual.

Section i – iii: Foreword, explicit definitions, and precautions.

Section 1: Panel Description

- Front Panel
- Rear Panel
- LCD Screen
- Screen menu arrangement
-

Section 3: Basic Operations

- Initial Settings
- Frequency Settings
- Operating mode selection
- Volume setting
- RF gain adjustment
- Squelch level adjustment
- Meter indication selection

Section 4: Receive Modes

- Operating FM
- Operating WFM
- Operating AM
- Operating SSB
- Operating CW
- Operating FSK

Section 5: Receive Functions

- Spectrum scope screen
- Preamplifier
- Attenuator
- Twin PBT operation
- IF filter selection
- Notch function

Section 12: Maintenance

- Troubleshooting
- Screen type selection
- Main dial break adjustment
- Frequency calibration

- Fuse replacement

Section 13: Control Command

- Remote interface information

M2 ANTENNA ROTOR CONTROLLER UNIT RC2800PRKX2SU

The rotor controller is responsible for moving and positioning the antenna cluster to follow the satellite through its over flight pass of the ground station. Prior to operating the RC2800PRK2SU is it recommended that the operator read the entire instruction manual for the rotor controller.

Key Uplink Equipment

KENWOOD TS-2000X

The TS-2000X is an amateur base station transceiver used primarily for transmitting commands to the R^3 satellite through the built in TNC. It also has secondary receive capabilities for the 70cm band. Prior to operating the TS-2000X is it recommended that the operator read the following chapters in the instruction manual.

Section i –iii: Precautions

Chapter 1: Installation

- Antenna Connection
- Ground Connection
- DC Power Supply Connection
- Replacing Fuses
- Accessory Connections

Chapter 4: Getting Acquainted

- Front Panel
- Rear Panel
- Display

Chapter 5: Operating Basics

- Switching power On/Off
- Adjusting Volume
- Selecting A band
- Selecting A mode
- Adjusting Squelch

- Selecting a Frequency
- Transmitting

Chapter 6: Menu Setup

- Menu A / Menu B
- Menu Access
- Menu Configuration

Chapter 7: Basic Communications

- SSB Transmission
- FM Transmission
- AM Transmission
- CW transmission

Chapter 10: Sub-Receiver

- Sub-Receiver
- TX Band and Control Band
- Receiving
- Transmitting

Chapter 11: Specialized Communications

- Packet radio
- Built In TNC
- Preparation
- AMTOR/PacTOR/CLOVER/G-TOR/PSK31

Chapter 15: Operator Conveniences

- Antennas
- Automatic Antenna Tuner
- Attenuator
- Display
- TNC
- Transverter
- TX Monitor
- TX Power
- Computer Control

Chapter 16: Connecting Peripheral Equipment

- Computer
- MCP and TNC

Chapter 18: Troubleshooting

West Mountain Radio RIGblaster PRO

The RIGblaster provides the interface between the Tracking Station Main Computer sound card and the TS-2000X. Prior to operating the RIGblaster PRO is it recommended that the operator read the entire instruction manual for the sound card interface.

Key Software Programs

Ham Radio Deluxe

Familiarity with the use of Ham Radio Deluxe and its capability to mirror the functions available on the receiver and transceiver is important to learn firsthand. The online user's manual is beneficial to review, however, systematically going through the various menu tabs and exploring their listed functions is a more useful way to learn how to use HRD and discovering its capabilities. HRD requires proper setup as discussed in the Operability chapter below to connect to the transceiver and receiver

NOVA for Windows

Familiarity with NOVA for Windows is straight forward as it is a basic program with few menu tab options to explore. The biggest requirement is to learn to properly configure the program for the rotor control unit though the correct COM port using the Serial to USB cable. Aside from that, NOVA for Windows does not need much practice in its use.

Practice Recommended

It is recommended that all selected operators thoroughly practice the use of the equipment prior to any scheduled down linking or uplinking activity. Familiarity with the functions on both the actual piece of equipment and its counterpart in HRD are required prior to the successful operation of the tracking station for capturing and transmitting data. The use of other amateur ground base stations in the Atlanta region is a good way for operators to learn to use HRD when practicing it use. The 2 meter amateur band usually has FM activity on it at all hours during the day or night, and amateur operators will offer RST reports on request. An RST report is a report from a receiving station on the quality and strength of the transmitted signal. The report uses numbers to represent the tone of a voice transmission of a transmitting station's signal at the receiving station's location.

Readability (R): This is transmission understanding what is said and how well; on a scale of 1 to 5, with a signal readability of 5 being perfect with no difficulty in understanding. In other words readability is the ability of the other operator to understand what you are saying, where a 1 is unreadable and a 5 is perfectly readable.
Strength (S): On a scale of 1 to 9, strength indicates how strong the station's signal is received. A 1 is a very faint signal while a 9 is an extremely strong signal.
Tone (T): On a scale of 1 to 9 this is the quality of the tone of the transmission, from a "60 cycle harsh tone" as 1 to a very pure tone at 9.

CHAPTER 4: OPERABILITY

TRACKING STATION SETUP

This section covers the setup of the tracking station for preparation of operation. It covers the setup of the key software drivers and programs.

Serial to USB Cable Setup

These cables are responsible for connecting the Tracking Station Main Computer to the various peripheral devices that control the functioning of the tracking station. The Serial to USB cables used in the tracking station are made by i.Connect and are Model # 3312. The drivers for these cables are available for download at www.ppa-usa.com/drivers.htm. Select the Windows Vista download on that website under the link 3312 | 7796D: Windows Vista Download as the selected device driver for these cables. Verify that the drivers are installed correctly by checking under the computer properties in the Device Manager section. Each Serial to USB cable is labeled for specific hardware to computer connection and each specific USB socket port determines which COM port is enabled.

Table 5: Communication Port (COM #) Allocation

Communications Port COM #	Peripheral Device Connected
COM 3	Icom IC-R9500
COM 4	Kenwood TS-2000X
COM 5	Azimuth rotor control
COM 6	Elevation rotor control

Ham Radio Deluxe Setup

The primary software used to control the receiver and transmitter in the tracking station is Ham Radio Deluxe (HRD) 5.0(Beta). The program is downloadable from http://www.ham-radio-deluxe.com/HRDv5.aspx and the website should be checked regularly for updates to the software since the current version is a Beta test. Ensure that HRD is installed by powering up the computer and turning on all the rack mounted hardware. Ensure all the Serial to USB cables are connected correctly and execute HRD. When HRD is started, the program will offer a set of preset devices. Ensure the devices have the correct preferences set as indicated in the figure below.

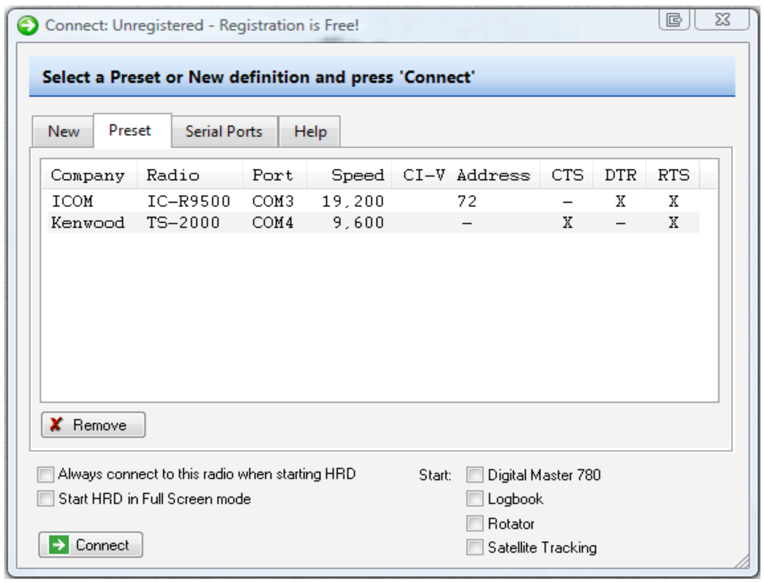


Figure 27: Ham Radio Deluxe Preset Preferences

It is possible to open two instances in one running version of HRD by clicking the connect button again and selecting the other device, or execute a completely new instance of HRD and connecting to the other device. The first method mentioned is the preferred method. Note, on occasion the Kenwood transceiver will fail to connect. This requires closing HRD and turning the TS-2000X off, checking to ensure the cable is properly seated, then turning on the transceiver, waiting a moment, the executing HRD and following the above described connection procedure. To install a new device with a new connection when the “Select a Preset” box pops up is to click on the “New” tab. Once that is done select the company and radio type of the specific piece of hardware being added. Enter the COM port number and speed and check off the proper Flow Control and Interface preferences as shown in the figure above, or determine a new setting.

Once the receiver and transceiver are connected and operating properly, initiate the built in satellite program under HRD by clicking on the "Satellites" button on the toolbar at the top of the HRD window. Select the preferred satellite from the drop down menu and check mark the TX and RX boxes, this gives the satellite program control over the receiver and transceiver though HRD. Confirm that both the receiver and transceiver are properly connected by the tab files on the left hand side of the screen. The map will show the ground trace path of the selected satellite and on the bottom will display radar images of several of the next overhead passes for the satellite.

Shown under the "Satellite Definitions" tab will be all the satellites that are available for selection under the drop down menu, and can limit the available selections by checking only those desired. In general, keep this limit on "All Definitions" just so any satellite can be chosen for tracking. Note, DO NOT choose satellites GOES 10 through GOES 14 as the software program will freeze and reboot of the software must occur to fix the problem. To get rid of all the old TLE information click on "Purge Old Entries" button. Following that, get the new information by clicking on the "Kepler Data" tab and check each box except for the one that ends in "goes", as seen in the figure below, and the press the "Download Now" button.

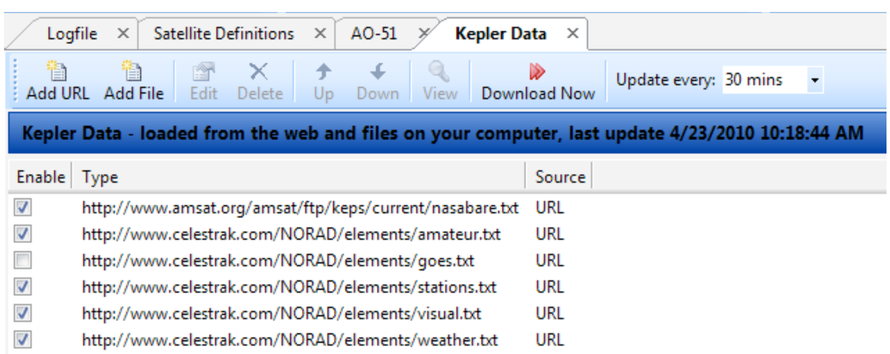


Figure 28: Kepler Data selection tab in Ham Radio Deluxe

This will ensure that the latest information on satellite trajectories is available for HRD to use in the tracking of satellites. Another important step in setting up the Satellite tab under HRD is the Options button. It is important for the software program to know where it is located so it can properly track satellites. In order to have correct coordinates for tracking station latitude and longitude click on “Options” button and fill out the latitude, longitude, and height boxes as shown in the figure below.

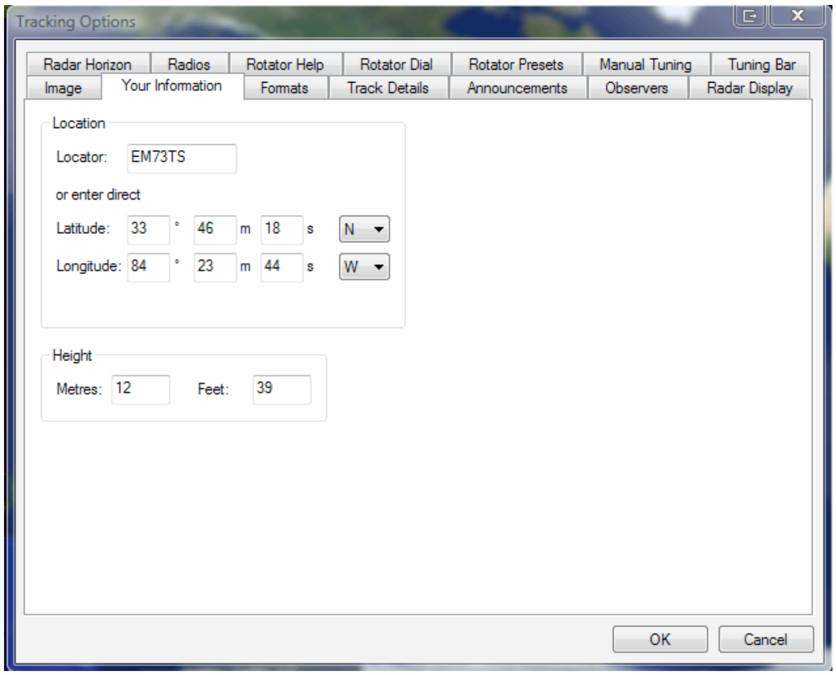


Figure 29: Tracking Station latitude, longitude, and height input for location option

NOVA for Windows Setup

This is an alternate program that is responsible for sending commands to the rotor control box which translates the commands into the actual movement of rotors to move the antenna cluster. Until HRD fully supports the selection of the rotor control box, NOVA for Windows is the alternative. The program installs easily and setup for the COM port connection is straight forward. The registration key for NOVA for Windows is NLD-7180427 which allows for the full version of the program, not just the demonstration version. Unfortunately at this time, it has not been possible to connect the program to both azimuth and elevation rotor controls. M2 is investigating the problem, and it might be they sent an upgraded version of the rotor control box that does not work directly with NOVA for Windows or HRD. This is still an ongoing issue to be resolved potentially through a replacement unit rotor control box.

CHAPTER 5: INTEGRATION AND TESTING

REQUIREMENT VERIFICATION

Requirement 1

All communication shall abide by ITU and FCC regulations. Georgia Tech Center for Space Systems shall obtain the necessary spectrum licenses for operating its space segment radio communication equipment prior to FCR. This requirement verification will be done by inspection of the license document that will be on hand at the Ground Station and Mission Operations Center prior to FCR.

Requirement 2

Ground transceivers and antennas shall operate in the UHF and S-Band frequencies. This requirement verification will be done by testing through the use of other ground based radio stations transmitting in the UHF and S-Band frequencies. The test procedure will require a secondary transceiver that can operate in the UHF and S-Band frequencies, in order to send test transmission at the start and end segments of the designed bandwidths for the two antennas. Coordinate with the GT Amateur Radio Club for available radio frequency sources to conduct the testing. Send and receive test messages between the two stations.

Requirement 2.1

The Ground Receiving antenna shall operate in the amateur S-band for downlink. This requirement verification will be done by analysis as indicated in the design section of this report. Confirmation of the analysis and design can be accomplished by testing with an S-Band transmission source, such as satellite AO-51, or another similar type source. Consult with the GT Amateur Radio Club for potential sources.

Requirement 2.2

The Ground Transmitting antenna shall operate in the amateur UHF band for uplink. This requirement verification will be done by analysis as indicated in the design section of this report. Confirmation of the analysis and design can be accomplished by testing with another UHF transceiver, such as those available through the GT Amateur Radio Club. Coordinate with that organization for use of their UHF transceiver equipment in order to test the UHF antenna system.

Requirement 3

The Tracking Station shall use computer controlled rotors to direct the antenna system. This requirement verification will be done by testing the rotor system through input control on the Tracking Station Main Computer. The testing done is to confirm that the rotors do in fact follow the commands issued by the computer to properly track satellites as they pass over the ground station and point the dish assembly in the correct direction to receiver satellite S-Band transmissions. This requires proper setup of the limit switch kit which is installed on the rotor gears and prevents the rotor from traversing to far beyond its design limits. Then the rotor system must be oriented correctly so that the rotor witness marks line up with the displayed direction on the control box. The system should then be set for proper tracking. Visual confirmation can be accomplished by selecting and loading TLEs for Iridium satellites and coordinating day time flares for observation.

Requirement Number 3.1

The Tracking Station Main Computer will control the automated tracking functions for the antenna cluster system. This requirement verification will be done by testing to ensure that the program controls the antenna cluster through the rotor system correctly by selecting and tracking an amateur satellite such as AO-51 to test expected signal strength versus actual received signal strength.

Requirement Number 3.2

A designated computer in the Mission Operation Center shall be used to pass command signals to the antenna rotor system. This requirement verification will be done by testing the commands passed from the MOC to the Tracking Station Main Computer through the use of remote desktop control of the programs that control the radios and rotor systems, mainly Ham Radio Deluxe and NOVA for Windows.

FUNCTIONAL TESTS

The Ground Station is designed primarily to be a computer operated station. In order to achieve this goal, the station is tested, first by independent major component groups (listed below), and then as a collective whole group. Within major component groups, testing generally consists of, first, manually configuring and confirming correct operation with fixed stations; secondly, configuring software control of components then confirming correct operation with fixed stations; thirdly, confirming software control of components then correct operation with moving stations.

Major Component Groups

1. Rotor/Dish Control
2. Receiver Operation
3. Transmitter Operation
4. Computer Software Configuration

1. Rotor/Dish Control

This is testing for the operation of the rotor control which is responsible for moving and pointing the antenna cluster toward the satellite during its over flight pass of the ground station.

1. Direct connection of the hardware (AZ/EL1000A w/LSK1000) to the rotor control assembly box (RC2800PRKXSU) to confirm operation of mechanisms to rotate the antenna assembly. COMPLETED

2. Direct connection of the computer and software control program (NOVA for Windows) to the rotor control assembly box (RC2800PRKXSU) and software operation of the rotor system. INCOMPLETE

3. Indirect connection to the computer and software control program software through the use of Window's Remote Desktop feature. INCOMPLETE

Notes: Currently working with M2 Antenna staff to find a solution for computer control and tracking. The supplied M2 software works properly; however, NOVA for Windows does not currently work, though it should.

2. Receiver Operation

This is testing for the operation of the Icom receiver which is responsible for receiving signals through the mesh dish reflector septum feed antenna from S-band satellites.

1. Manually configure and manually control Receiver (IC-R9500) and receive fixed station contact (Amateur or ISM). COMPLETED

2. Configure computer software control (Ham Radio Deluxe) and receive fixed station contact (Amateur or ISM). COMPLETED

3. Configure computer software control (Ham Radio Deluxe) and receive moving station contact (NOAA satellite or AMSAT). INCOMPLETE

Notes: The IC-R9500 has received many ground fixed stations, both amateur and commercial, through manual control and computer software control. On occasion the software can put the receiver into a "locked" mode, where front faceplate input commands on the receiver to do not work. To remove the lock, press the "Local" button located just under the power button on the front faceplate.

3. Transmitter Operation

This is testing for the operation of the Kenwood transceiver which is responsible for transmitting signals through the Yagi antenna to the UHF receiver on the satellite.

1. Manually configure and manually control Transmitter (TS-2000X) and transmit voice to a fixed station (Amateur). COMPLETED

2. Configure computer software control (Ham Radio Deluxe) and transmit data to a fixed station (Amateur). INCOMPLETE

3. Configure computer software control (Ham Radio Deluxe) and transmit data to a moving station (AMSAT). INCOMPLETE

Notes: In order to get data from the computer through the Kenwood transceiver requires setup of the West Mountain Radio RIGblaster and the selection of the communication mode to be used for the transmission.

4. Computer Software Configuration

This is testing for the operation of the Tracking Station Main Computer which is responsible for computer control of the receiver and transmitter.

1. Configure rotor control assembly box (RC2800PRKXSU) computer program (NOVA for Windows) for remote desktop operation. INCOMPLETE

2. Configure Receiver (IC-R9500) computer program (Ham Radio Deluxe) for remote desktop operation. INCOMPLETE

3. Configure Transmitter (TS-2000X) computer program (Ham Radio Deluxe) for remote desktop operation. INCOMPLETE

4. Operate NOVA for Windows and Ham Radio Deluxe concurrently. COMPLETED

5. Configure and operate NOVA for Windows and Ham Radio Deluxe simultaneously using Windows remote desktop feature. INCOMPLETE

Note: Most of these operations are for remote operation of the ground station software programs and requires setup of the remote desktop feature available in Windows.

INTRAGRATED TESTS

End-To-End Test

End to End testing of the Ground Station consists of locally and remotely operating the station for receiving and transmitting data.

1. Complete the above listed Functional Tests and Integration of individual systems.

2. Confirm that the rotor, receiver, and transmitter controls are set properly and that software is appropriately configured, both locally and for remote desktop operation.

3. Successful conclusion of the Ground Station setup is determined by successfully receiving an image from an orbiting NOAA satellite and displaying it on the computer and posting the image to the server for the Ground Data System.

CHAPTER 6: RISK AREAS AND OPEN ITEMS

RISK AREAS

The largest risk to the operation of the Tracking Station is currently the inability of either HRD or NOVA for Windows to connect properly to the rotor control unit. This could be because the initial quote was listed as model number RC2800PRKXSU while the unit that was shipped was model number RC2800PRKX2SU. Note the difference between PRKXSU and PRKX-2-SU. Current solution in progress involves a discussion with M2 Antenna for an exchange of rotor control units. This still needs to be resolved.

OPEN ITEMS

The following items require completion for the Tracking Station to become fully operational.

1. Construction of the UHF yagi antenna.
2. Construction and mounting of the UHF yagi antenna boom arm support structure.
3. The septum antenna feed needs a mounting bracket designed and fabricated.
4. The universal power supply needs to be setup and components connected to it.
5. A power cable needs to be fabricated to go from the power strip to the power connection on the low noise amplifiers.
6. The three transmission cables need to be routed from the receiver and transceiver to the appropriate antennas, either with a cutout under the door and through the existing wall hole, or create a new wall hole.
7. The West Mountain Radio RIGblaster needs to be connected properly between the Tracking Station Main Computer and Kenwood transceiver. The internal jumpers in the RIGblaster have already been configured according to the manual for a Kenwood transceiver.
8. Rotor control through either HRD or NOVA for Windows needs to be established. See the Risk Area above for current problems with configuration.
9. A short cable run, about 2 to 3 feet, needs to be ordered with LMR-600 and N-type female connectors on both ends in order to connect the antenna switch to the receiver.
10. Recommend the purchase of 12 to 15 foot tall folding ladder, long enough to reach the weather cap, in order to perform maintenance on the antenna cluster and attach other components.

APPENDIX LIST

Appendix A: Amateur Radio Relay League Band Plans for 12 Centimeters and 70 Centimeters

The entire ARRL Band Plan is available at www.arrl.org or http://www.arrl.org/band-plan-1

12 Centimeters (2300-2310 and 2390-2450 MHz):

2300.0 - 2303.0	High-rate data
2303.0 - 2303.5	Packet
2303.5 - 2303.8	TTY packet
2303.9 - 2303.9	Packet, TTY, CW, EME
2303.9 - 2304.1	CW, EME
2304.1	Calling frequency
2304.1 - 2304.2	CW, EME, SSB
2304.2 - 2304.3	SSB, SSTV, FAX, Packet AM, Amtor
2304.30 - 2304.32	Propagation beacon network
2304.32 - 2304.40	General propagation beacons
2304.4 - 2304.5	SSB, SSTV, ACSSB, FAX, Packet AM, Amtor experimental
2304.5 - 2304.7	Crossband linear translator input
2304.7 - 2304.9	Crossband linear translator output
2304.9 - 2305.0	Experimental beacons
2305.0 - 2305.2	FM simplex (25 kHz spacing)
2305.20	FM simplex calling frequency
2305.2 - 2306.0	FM simplex (25 kHz spacing)
2306.0 - 2309.0	FM Repeaters (25 kHz) input
2309.0 - 2310.0	Control and auxiliary links
2390.0 - 2396.0	Fast-scan TV
2396.0 - 2399.0	High-rate data
2399.0 - 2399.5	Packet
2399.5 - 2400.0	Control and auxiliary links
2400.0 - 2403.0	Satellite

2403.0 - 2408.0	Satellite high-rate data
2408.0 - 2410.0	Satellite
2410.0 - 2413.0	FM repeaters (25 kHz) output
2413.0 - 2418.0	High-rate data
2418.0 - 2430.0	Fast-scan TV
2430.0 - 2433.0	Satellite
2433.0 - 2438.0	Satellite high-rate data
2438.0 - 2450.0	WB FM, FSTV, FMTV, SS experimental

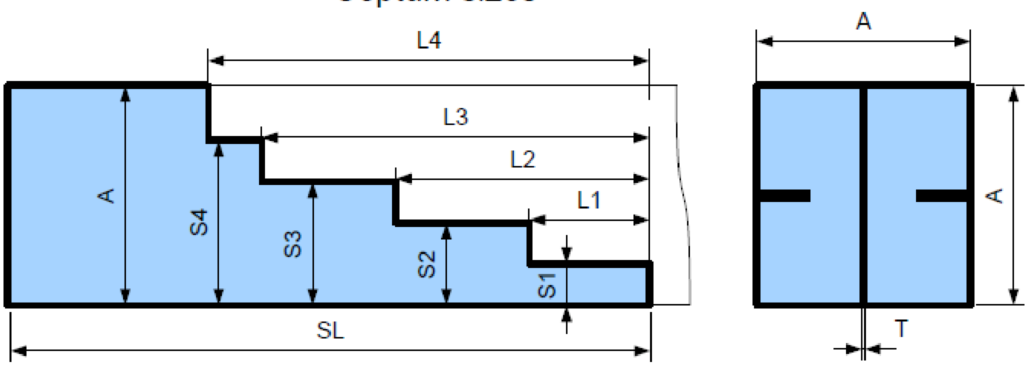
70 Centimeters (420-450 MHz):

420.00 - 426.00	ATV repeater or simplex with 421.25 MHz video carrier control links and experimental
426.00 - 432.00	ATV simplex with 427.250-MHz video carrier frequency
432.00 - 432.07	EME (Earth-Moon-Earth)
432.07 - 432.10	Weak-signal CW
432.10	70-cm calling frequency
432.10 - 432.30	Mixed-mode and weak-signal work
432.30 - 432.40	Propagation beacons
432.40 - 433.00	Mixed-mode and weak-signal work
433.00 - 435.00	Auxiliary/repeater links
435.00 - 438.00	Satellite only (internationally)
438.00 - 444.00	ATV repeater input with 439.250-MHz video carrier frequency and repeater links
442.00 - 445.00	Repeater inputs and outputs (local option)
445.00 - 447.00	Shared by auxiliary and control links, repeaters and simplex (local option)
446.00	National simplex frequency
447.00 - 450.00	Repeater inputs and outputs (local option)

Appendix B: Dimensions for Improved Septum with Dual Mode Horn, by Dmitry Dmitriev, RA3AQ.

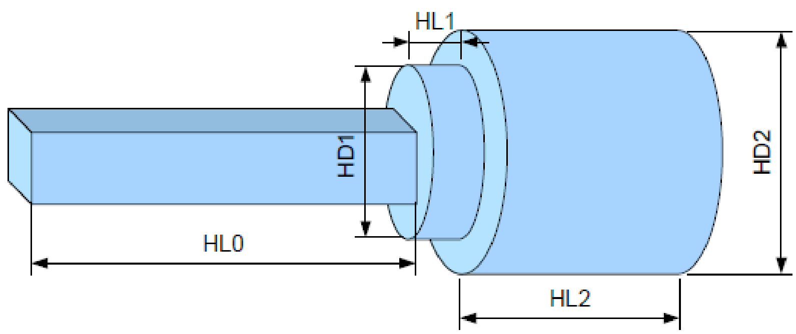
IMPROVED SEPTUM WITH DUAL MODE HORN

Septum sizes

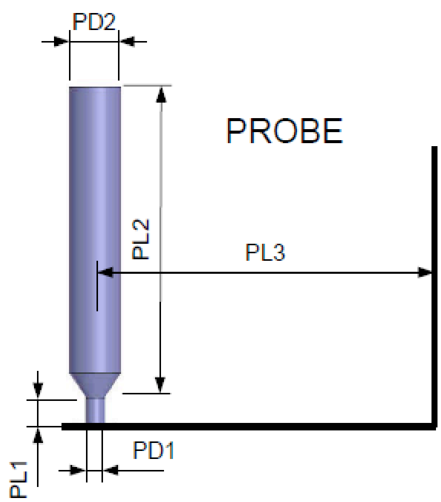


Sizes [mm]	A	T	SL		S1	S2	S3	S4	L1	L2	L3	L4
1296MHz	142,6	0,5	340,0		21,3	46,9	70,9	106,3	75,6	148,9	220,5	242,3
2320MHz	79,7	0,5	190,0		11,9	26,2	39,6	59,4	42,2	83,2	123,2	135,4

Horn sizes



Sizes [mm]	HL0	HL1	HD1	HL2	HD2
1296MHz	420,0	57,7	254,6	332,0	304,0
2320MHz	215,0	32,2	142,2	186,0	170,0

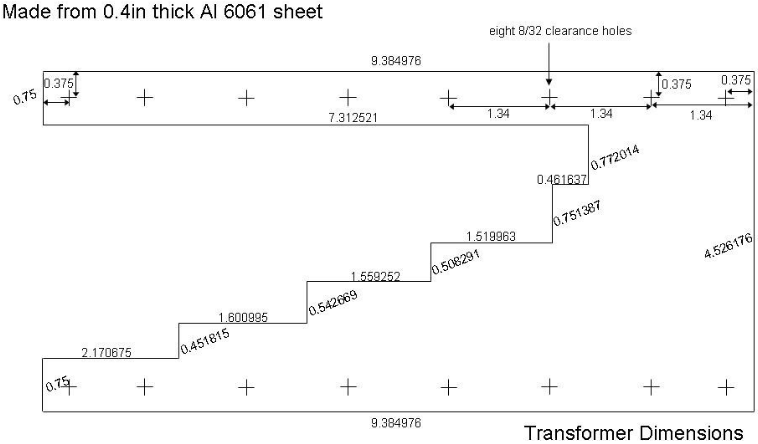


Sizes [mm]	PD1	PL1	PD2	PL2	PL3
1296MHz	1,3	2,0	3,5	44,0	41,1
2320MHz	1,3	2,0	3,5	22,1	24,2

RA3AQ Aug 2006

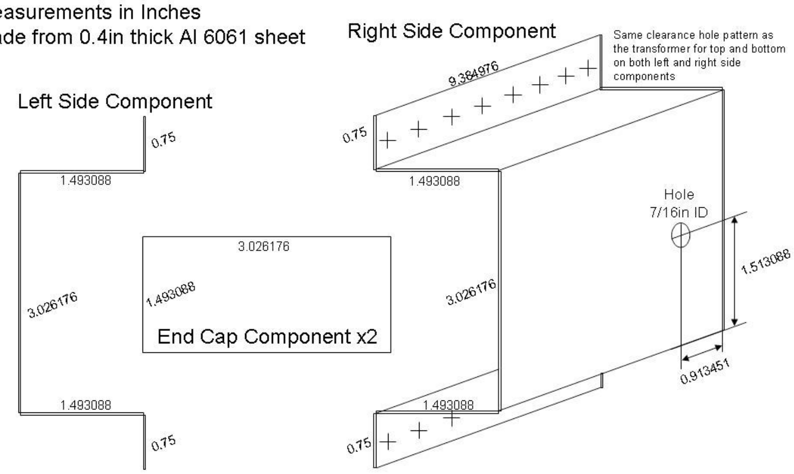
Appendix C: 2405 MHz Septum Antenna Design Layout.

2405 MHz Improved Septum Antenna
Measurements in Inches
Made from 0.4in thick Al 6061 sheet



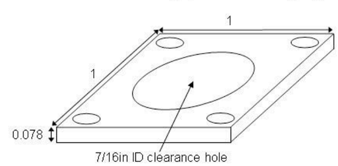
Transformer Dimensions

2405 MHz Improved Septum Antenna
Measurements in Inches
Made from 0.4in thick Al 6061 sheet

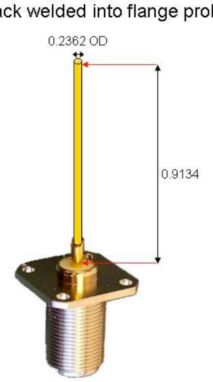


2405 MHz Improved Septum Antenna
Measurements in Inches
Made from 0.4in thick Al 6061 sheet

N type 4 hole flange plug standoff
Tack welded to both side components
Provides mounting point for flange plug



Copper Probe Dimensions
0.2362 OD x 0.9134
Tack welded into flange probe



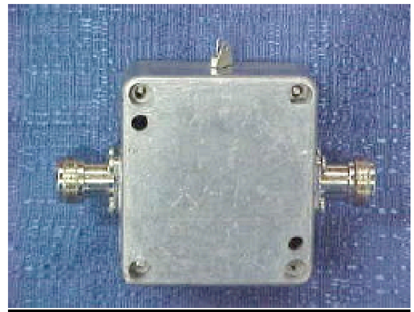
Envisioned final product

Not To Scale

Appendix D: DEM 13ULNA Specifications.

DEMI **Down East Microwave Inc. 954 Route 519, Frenchtown NJ 08825** DEMI
Phone: 908-996-3584 (Voice) 908-996-3702 (Fax) http://www.downeastmicrowave.com

DEM 13ULNA - *2.3 - 2.45 GHz. Ultra Low Noise Amplifier*

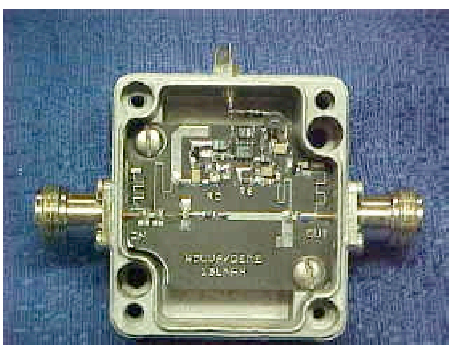


Specifications:

Gain:	16dB minimum
Noise Figure:	<0.7dB maximum
P1dB:	+5dBm output
Input VSWR:	>6dB @ design frequency
Output VSWR:	>10dB DC - 3 GHz.
Voltage:	+7 - +16 VDC

Product Description:

The DEM 13ULNA is one of a series of Ultra Low Noise Amplifiers that was designed by W5LUA and produced by Down East Microwave Inc. The ULNA series utilizes the latest in PHEMT technology and is designed for receive systems such as EME stations and satellite reception that requires the lowest noise figure possible. All of the ULNAs do not provide any RF bypass switching circuitry. Standard gain of the 13ULNA may range from 16 to 18 dB. The noise figure is FET dependant and may vary from an minimum of 0.4 dB to a maximum of 0.7 dB. The ULNAs are adjusted on an individual basis for the best performance possible. Each ULNA may be biased through the coax or from the external DC feed through. The internal power supply provides external power supply isolation for the FET DC supply.

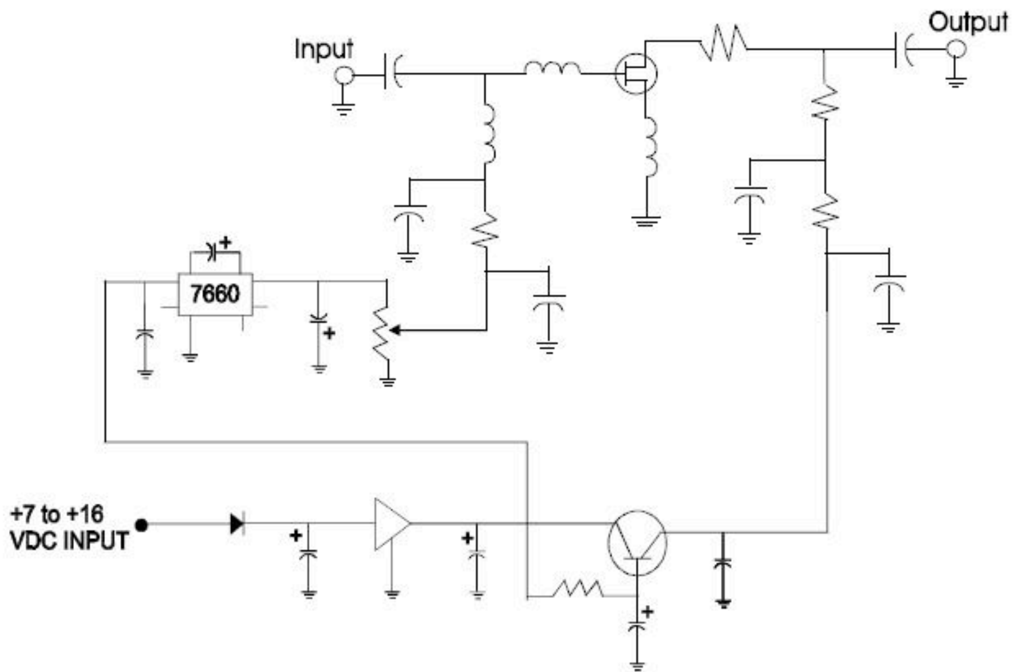


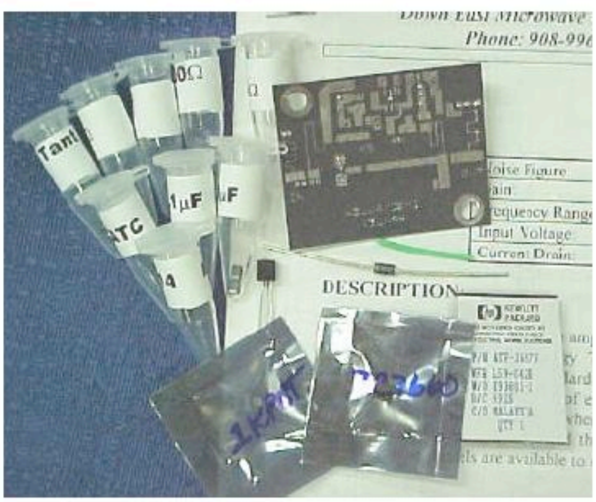
Our ULNA design incorporates low loss microstrip circuitry and resistive loading to accomplish all RF matching. During testing, the input circuit is optimized for gain and noise figure. The resistive loaded output circuit, is adjusted to control the gain and is tested for a constant wide bandwidth output impedance. This resistive load impedance absorbs products caused by reflections from band pass filters or high Q receiver front ends. We do not use tuned output circuits or baluns in our ULNA designs. Tuned output circuits and baluns do not offer constant output impedances over wide bandwidths and may cause out of band instabilities from reflected signals. Tuned circuits may also require returning if a cable length or the tuning of a filter that is connected to the output of a tuned circuit LNA is changed.

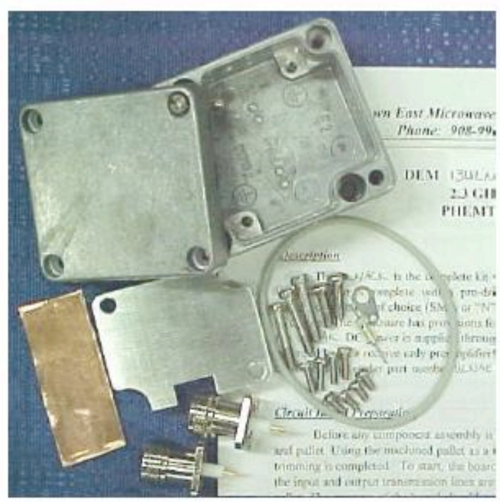
This ULNA design is provided with type "N" or SMA connectors that are mounted on a weather proof die cast aluminum enclosure that measures 2.5" L x 2.25" W x 1.375" H. This enclosures enhances RF insusceptibility and protects against stray external EMI. DC power is either applied through a Pi-circuit feed through filter connector which is a simple solder connection that attenuates frequencies through 18 GHz. or it may be applied through the coax depending on the model ordered. Specify preference at the time of order. The ULNA design is also offered in kit form as a PCB kit or complete kit depending on you requirements.

ULNAs with operating frequencies, configurations, gains and noise figures not found on our price list or product descriptions can be designed by Down East Microwave Inc. and produced with relatively short delivery times. Please contact us with your specifications and/or requirements.

Schematic Diagram of ULNA Design:







13ULNAK-PC Board Parts Kit

13ULNACK-Contains Parts Kit and Hardware

Appendix E: Brief Specifications for the Icom IC-R9500.

GENERAL

Frequency coverage (Unit: MHz)	0.005–3335.000000* * Cellular bands are blocked in the U.S.A. version.
France version	0.005 – 29.999999 50.200 – 51.200000 87.500 – 108.000000 144.000 – 146.000000 430.000 – 440.000000 1240.000 – 1300.000000
Mode	USB, LSB, CW, FSK, AM, FM, WFM, P25* * Optional UT-122 required.
Number of memory channels	1220 (1000 regular, 100 auto memory write channels, 100 memory scan skip and 20 scan edges)
Antenna connectors	SO-239 (50Ω for HF), Phono [RCA] (500Ω for HF), Type-N × 2 (50Ω one each for 30–1149.99999MHz, 1150–3335MHz)
Temperature range	0˚C to +50˚C; +32˚F to +122˚F
Frequency stability	Less than ±0.05ppm (at 25˚C) after warm up (5 minutes)
Temperature fluctuation	Less than ±0.05ppm (0˚C to +50˚C)
Frequency resolution	1Hz
Power supply requirement	100V/120V/230V/240V AC
Power consumption (Representative value)	Stand-by Less than 100VA Max. audio Less than 100VA
Dimensions (WxHxD) (projections not included)	424 × 149 × 340 mm; 16 11/16 × 5 7/8 × 13 3/8 in
Weight	20kg; 44.1lb (approx.)

Supplied accessories

- AC power cable
- Carrying handles
- Spare fuses
- ACC plugs
- RCA plugs
- DC power plug
- Speaker plugs

RECEIVER

Intermediate frequencies	
HF	58.7MHz (1st)/10.7MHz (2nd)/48kHz (3rd)
VHF/UHF	278.7MHz or 778.7MHz (1st)/ 58.7MHz (2nd)/10.7MHz (3rd)/48kHz (4th)

Sensitivity

	SSB, CW, FSK	AM	FM	FM50k	WFM
0.100 – 1.799MHz*1	0.5μV	6.3μV	–	–	–
1.800 – 29.999MHz*1	0.2μV	2.5μV	0.5μV*3	0.71μV*3	–
30.0–2499.999MHz*2	0.32μV	3.5μV	0.5μV	0.71μV	1.4μV
2500–2999.999MHz*2	0.32μV	3.5μV	0.5μV	0.71μV	1.4μV
3000–3335.000MHz*2	1.0μV	11μV	1.6μV	2.2μV	4.5μV

*1 Preamp1 ON *2 Preamp ON *3 28–29.999MHz
SSB, FSK BW=2.4kHz, CW BW=0.5kHz, AM BW=6.0kHz at 10dB S/N,
FM BW=15kHz, FM50k BW=50kHz, WFM BW=180kHz at 12dB SINAD

3rd order IMD dynamic range	109dB (typ.) at 14.1MHz, 100kHz separation, preamp OFF
Selectivity (Representative value)	
USB, LSB, FSK (BW= 2.4kHz)	More than 2.4kHz/ –3dB Less than 3.6kHz/–60dB
CW (BW= 500Hz)	More than 500Hz/ –3dB Less than 700Hz/–60dB
AM (BW= 6kHz)	More than 6.0kHz/ –3dB Less than 15.0kHz/–60dB
FM (BW= 15kHz)	More than 12.0kHz/ –3dB Less than 25.0kHz/–60dB
WFM	More than 180kHz/ –6dB
Spurious and image rejection ratio	
0.1 – 30.0MHz	More than 70dB
30.0 – 2500MHz	More than 50dB
2500 – 3000MHz	More than 40dB
AF output power	More than 2.6W with an 8Ω load

All stated specifications are subject to change without notice or obligation.

Full specifications for the receiver are in the user manual which is available for download from the Icom website.

www.icomamerica.com

http://www.icomamerica.com/en/products/receivers/tabletop/r9500/default.aspx

Appendix F: Brief Specifications for the Kenwood TS-2000X.

	TS-2000/TS-2000X/TS-B2000
GENERAL	
Transmitter Frequency Range	Main: 160, 80, 40, 30, 20, 17, 15, 12, 10, 6, 2 meter bands, 70, 23 (TS-2000X only) cm bands Sub: 2 meter band, 70cm band
Receiver Frequency Range	Main: (0.03) 0.5 ~ 30 MHz, (30) 50 ~ 54 (60) MHz, (142) 144 ~ 148 (152) , (420) 430 ~ 450 MHz, 1240 ~ 1300 MHz (TS-2000X only), Sub: (118) 144 ~ 148(174) MHz, (220) 438 ~ 450 (512) MHz ** Figures in parenthesis ( ) indicate VFO coverage range*
Mode	A1A (CW), J3E (SSB), A3E (AM), F3E (FM), F1D (FSK), F2D
Power Requirement	13.8 V DC ±15%
Current Drain (Less than)	Transmit: 20.5 A (HF, 6m, 2m), 18 A (70cm), 9 A (23cm) Standby: 2.6 A
Operating Temperature	14° F ~ +122° F (-10° C ~ +50° C)
Frequency Stability	Main: Other mode within ±0.5 x 10^{-6} (±0.5 ppm) FM TX mode within ±0.5 x 10^{-6} ± 2 kHz Sub: Within ±0.5 x 10^{-6} ± 600 Hz
Antenna Impedance	50Ω
Microphone Impedance	600 Ω
Dimensions, projections not included (W x H x D)	TS-2000/X: 10-5/8 x 3-3/4 x 12-1/2 inch (270 x 96 x 317 mm) TS-B2000: 10-5/8 x 3-3/4 x 12-1/2 inch (270 x 96 x 317 mm)
Weight (approx.)	TS-2000: 17.19 lbs. (7.8 kg) TS-2000X: 18.07 lbs. (8.2 kg) TS-B2000: 16.53 lbs. (7.5 kg)
TRANSMITTER	
RF Output Power	SSB/CW/FM/FSK=100W, AM=25W (HF, 6m, 2m), SSB/CW/FM/FSK=50W, AM=12.5W (70cm) SSB/CW/FM/FSK=10W, AM=2.5W (23cm)
Modulation SSB FM AM	 Balanced modulation Reactance modulation Low-level modulation
Maximum Frequency Deviation (FM)	Less than ±5 kHz (wide) Less than ±2.5 kHz (narrow)
Spurious Radiation	1.8 ~ 28MHz: Less than −50dB 50 ~ 430MHz: Less than −60dB 1200MHz: Less than −50dB
Carrier Suppression	More than 50 dB
Unwanted Sideband Suppression	More than 50 dB
Transmit Frequency Response (SSB)	400 ~ 2600 Hz (within -6 dB)
XIT Variable Range	±20.00 kHz
Antenna Tunable Range	16.7Ω ~ 150Ω (160 ~ 6m Band)
RECEIVER	
Circuitry Main: SSB/CW/AM/FSK FM Sub: AM/FM	 Quadruple superheterodyne Triple conversion superheterodyne Double conversion superheterodyne
Intermediate Frequency Main: 1st IF 2nd IF 3rd IF 4th IF Sub: 1st IF 2nd IF	 69.085 MHz or 75.925 MHz (HF ~ 50 MHz) 41.895 MHz (144/440MHz), 135.495 MHz (1200MHz) 10.695 MHz 455 kHz 12.0 kHz 58.525 MHz 455 kHz

KENWOOD CORPORATION

	TS-2000/TS-2000X/TS-B2000
RECEIVER (Continued)	
Sensitivity Main: SSB/CW/FSK (S/N 10 dB) AM (S/N 10 dB) FM (12 dB SINAD) Sub: AM (S/N 10 dB) FM (12 dB SINAD)	 Less than 4 µV (500 kHz ~ 1.705 MHz), Less than 0.2 µV (1.705 ~ 24.5 MHz), Less than 0.13 µV (24.5 ~ 30 MHz), Less than 0.13 µV (50 ~ 54 MHz), Less than 0.16 µV (144 ~ 148 MHz), Less than 0.11 µV (430 ~ 450 MHz), Less than 0.11 µV (1240 ~ 1300MHz), Less than 31.6 µV (500 kHz ~ 1.705 MHz), Less than 2 µV (1.705 ~ 24.5 MHz), Less than 1.3 µV (24.5 ~ 30 MHz), Less than 1.3 µV (50 ~ 54 MHz), Less than 1.4 µV (144 ~ 148 MHz), Less than 1.0 µV (430 ~ 450 MHz), Less than 1.0 µV (1240 ~ 1300MHz) Less than 0.22 µV (28 ~ 30 MHz), Less than 0.22 µV (50 ~ 54 MHz), Less than 0.25 µV (144 ~ 148 MHz), Less than 0.18 µV (430 ~ 450 MHz), Less than 0.18 µV (1240 ~ 1300MHz) Less than 2.25 µV (144 ~ 148 MHz), Less than 1.55 µV (438 ~ 450 MHz) Less than 0.40 µV (144 ~ 148 MHz), Less than 0.28 µV (438 ~ 450 MHz)
Squelch Sensitivity Main: SSB/CW/AM/FSK FM Sub: AM FM	 Less than 18 µV (500 kHz ~ 1.705 MHz), Less than 1.8 µV (1.8 ~ 28.7 MHz), Less than 1.1 µV (50 ~ 54 MHz), Less than 1.1 µV (144 ~ 148 MHz), Less than 1.1 µV (440 ~ 450 MHz), Less than 1.1 µV (1240 ~ 1300MHz) Less than 0.2 µV (28 ~ 30 MHz), Less than 0.2 µV (50 ~ 54 MHz), Less than 0.16 µV (144 ~ 148 MHz), Less than 0.1 µV (430 ~ 450 MHz), Less than 0.1 µV (1240 ~ 1300MHz) Less than 1.1 µV (144 ~ 148 MHz), Less than 1.1 µV (438 ~ 450 MHz) Less than 0.23 µV (144 ~ 148 MHz), Less than 0.18 µV (438 ~ 450 MHz)
Image Rejection Ratio Main / Sub	 More than 70 dB / More than 60 dB
IF Rejection Ratio Main / Sub	 More than 70 dB / More than 60 dB
Selectivity Main: SSB (Low: 300MHz, Hi: 2600MHz) AM (Low:100MHz, Hi:3000MHz) FM FM (Narrow) Sub: AM FM	 More than 2.2 kHz (-6 dB), Less than 4.4 kHz (-60 dB) More than 6.0 kHz (-6 dB), Less than 12.0 kHz (-50 dB) More than 12.0 kHz (-6 dB), Less than 25.0 kHz (-50 dB) More than 8.0 kHz (-6 dB), Less than 20.0 kHz (-50 dB) More than 12.0 kHz (-6 dB), Less than 25.0 kHz (-50 dB) More than 12.0 kHz (-6 dB), Less than 25.0 kHz (-50 dB)
RIT Variable Range	±20.00 kHz
Notch Filter Reduction	More than 30 dB (1 kHz)
Beat Elimination	More than 40 dB (1 kHz)
Low Frequency Output	More than 1.5 W 8 Ω at 10% distortion

Full specifications for the receiver are in the user manual which is available for download from the Kenwood website.

www.kenwoodusa.com

http://www.kenwoodusa.com/Communications/Amateur_Radio/

http://inform3.kenwoodusa.com/Manuals/TS-2000.pdf

Appendix G: Contact Information for various vendors.

M2 Antenna Systems, Inc. (Provided rotors, rotor control unit, mesh dish, and cables)
http://www.m2inc.com/
4402 North Selland Avenue, Fresno, CA 93722
Tel: (559) 432-8873 Fax:(559) 432-3059
Hours: Weekdays 7:30AM - 4:00PM PST

Down East Microwave (Provided low noise amplifiers (LNAs))
http://www.downeastmicrowave.com/
19519 78th Terrace, Live Oak, FL 32060
Tel: (386) 364-5529
Monday thru Thursday from 9:00am to 6:00pm EST (we close for lunch 12noon to 1pm)

Cable X-perts, Inc. (Provided transmission cables)
http://www.cablexperts.com/
540 Zenith Drive, Glenview, IL 60025
Tel: (800) 828-3340 Fax: (847) 391-9103
Normal business hours are M-F 9:00AM to 5:00PM CST

Ack Electronics Atlanta (Provided transmission cable connectors and adapters)
http://www.acksupply.com/
554 Deering Road North West, Atlanta, GA 30309
Tel: (404) 351-6340 or (800) 282-7954 Fax: (404) 351-1879
Open 8AM-5PM EST

Ham Radio Outlet Atlanta (Provided the transceiver and receiver)
http://www.hamradio.com/
6071 Buford Highway, Atlanta GA 30340
Tel: (800) 444-7927 or (770) 263-0700
Telephone hours 9:30AM-5:30PM Monday-Saturday
HRO stores open 10AM-5:30PM

West Mountain Radio (Provided the RIGblaster PRO and RIGrunner 4010S)
http://www.westmountainradio.com/
34 Smith Street, Norwalk, CT 06851
Tel: (203) 853-8080 Fax: (203) 299-0232

Fry's Electronics (Provided the Serial to USB cables)
http://www.frys.com/
3296 Commerce Avenue North West, Duluth, GA
Tel: (678) 405-6800 Fax: (678)405-6818

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