DEVELOPMENT OF A GROUND STATION (GS) PACKAGE SUITED FOR SPACECRAFT OPERATION CONTROL AND OPTIMIZATION FOR SATELLITE FLYBY OVER THE GROUND STATION

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Dedicated to my Loving Grand-Parents & Parents

with Heartfelt Gratitude and Love...

Development of a GS Package suited for Spacecraft Operation Control and Optimization methods for Satellite flyby over the Ground Station.

Raj Gaurav Mishra

January 12, 2007

Abstract

Development of a Ground Station Package suited for Spacecraft Operation Control and Optimization methods for Satellite flyby over the Ground Station is a Master thesis project done at "Julius Maximilian University of Wuerzburg, Department of Informatics VII- Robotics and Telematics, Germany" from June to Dec 2006.

The CubeSat satellite ground station at the University of Wuerzburg is built with "commercial of the shelf" low cost amateur radio hardware. It opens up opportunities for students to receive and operate CubeSats, including Wuerzburgs UWE-1.

As any other satellite ground station, it is built up on essential hardware, as there are Antenna, Antenna Rotator, Radio, Modem and Computers. Furthermore software is used to afford basic control over the ground station and provide tracking abilities to follow a satellite passing over the ground station.

The main aim of this project is to redesign the ground station system for satellite tracking and to overcome the related problems of the existing system.

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Chapter 1

Introduction

Ground Station at University of Wuerzburg.

Department of Informatics VII is situated at the east of Wuerzburg on a hill, which is approximately 310 meters above the river "Main" level.

The antenna tower is situated on the Department's roof which is infact a most suitable position to operate the Ground Station. The satellite ground station at the University of Wuerzburg is built with "commercial off the shelf" low cost amateur radio hardware. It opens up opportunities for Students to operate CubeSats.

As any other satellite ground station, it is built upon essential hardware, as there are Antenna, Antenna Rotator, Radio, and Modem.

Furthermore software is used to afford basic control over the ground station and provide tracking abilities to follow a satellite passing over the ground station. The basic ground station is composed of 4 main components, an Antenna with antenna rotator, a Radio, a Modem and Computer. Each of these devices fulfils essential operations.

1. *Antenna.*
   An antenna is an arrangement of electrical conductors designed to transmit or receive radio waves which is a class of electromagnetic waves. It is mounted upon a rotator, which provides the possibility to move the antenna to any position by editing its azimuth- and elevation angle. This antenna rotator is further connected with computer to provide the automatic tracking.

2. *Radio.*
   The Radio makes it possible to transmit- and receive-signals from the Antenna.

Ground Station Name	UWE-UWZ
University	University of Wuerzburg, Germany
Latitude	$49^o47'49.20"/49,797 deg.North$
Longitude	$9^o56'56.40"/9,949 deg.East$
City	Wuerzburg
Country	Germany
Altitude	310 meters
Tower	Hummel Teletower Jumbo III
Operating frequencies	2m and 70 cms amateur bands
One 2 meter antenna	M2 2MCP22
One 70 cms antenna	M2 436CP42U/G
Antenna rotator	Yaesu G-5500
Rotator controller	Yaeau G-5500 controller
Rotator-Computer Interface	WinRotor
Rotator-Computer Interface driver	WinRotor XP
Tracking software	NOVA for Windows
Radio	TNC4e
Polarisation switch	WiMO
Preamplifiers	LNA-145, SLN Series
Tranceiver	ICOM IC-910H
Power Supply	Microset 13.5 Volts
Two PCs	Fujitsu Siemens

Table 1.1: New Ground Station Specifications.

3. *Modem.*
   A modem (from **mo**dulate and **dem**odulate) is a device that modulates an analogue carrier signal to encode digital information, and also demodulates such a carrier signal to decode the transmitted information. The goal is to produce a signal that can be transmitted easily and decoded to reproduce the original digital data. Modem is used to transmit or receive analog signals, from radio.

4. *Computer*.
   One or more computers for steering the hardware and for the administration of the sent and received data.

For manual control and automatic tracking purposes, Wuerzburg's satellite ground station is endowed with ground station satellite tracking software.

1.1 Old design of the Ground Station

There were two 70cm antennas and two 2m antennas in the old design of the ground station. The antennas were mounted in an H-construction in a way to provide a uniform distribution of the weight on the rotator. This construction consists of three supporting rods. The central bar was manufactured from aluminium and was 6 meters long.

This H-construction was installed on a metal plate, which served as connecting piece between rotator and antenna construction.

The Rotator used was EGIS EPSR-203 mod, and the rotator controller used was EGIS EPS-103.

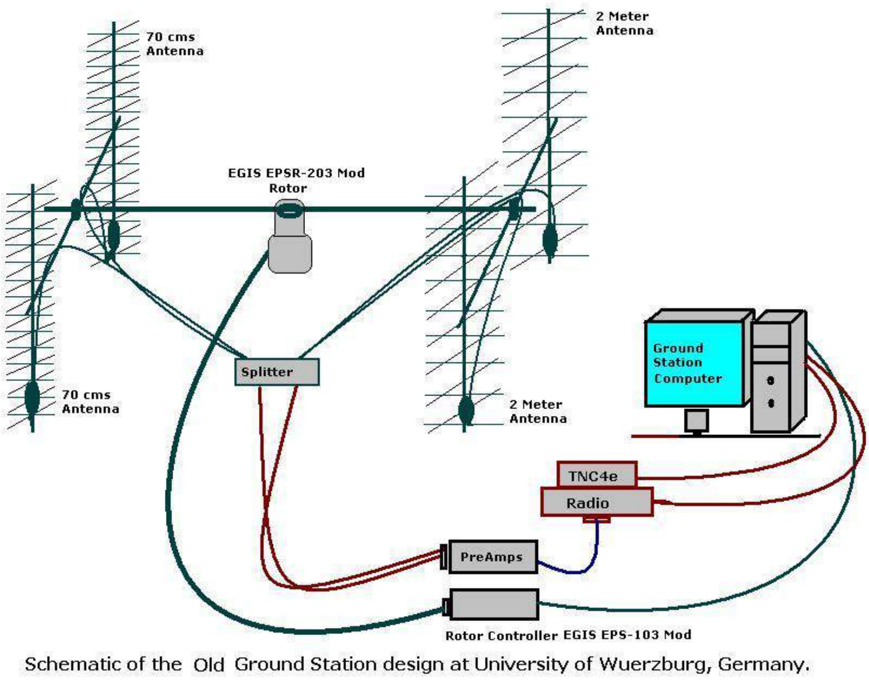


Figure 1.1: Old design of the Ground Station.

Related problems

The University of Wuerzburg's Ground Station was unable to work perfectly with respect of the Satellite flyby time of approx about 12-15 min.

The rotator was weak and was unable to move in speed to track the satellite in a suitable time. The second problem was with the satellite passes with high elevations, the antenna rotator was unable to track them. One of the clear reasons was the weight of the Antenna assembly associated with the malfunctioning of the Antenna Rotor.

Also there were some problems associated with the cabling pattern of the Antenna wires of the ground station system.

The need was to start with a detailed research study of the other CubeSats Ground Stations in order to see what could be the best possible structure so that the new design of the Antenna-Rotator system can auto track satellites, with combination of some satellite tracking software.

1.2 Ground Station Structural Study

The GS structural study survey was made to get an idea about the existing structure of various Ground Stations around the world, made for tracking CubeSat satellites.

The selection of a suitable antenna rotator was one of the important aim for this study. There were two possibilities of using the antenna rotator. The first idea was to use two different rotators for the azimuth and elevation control, and the second was to use a single rotator which can provide the azimuth and elevation movement all together like old antenna rotator "EGIS EPSR-203 mod" used in the Ground Station.

The options were:

1. Creative ERC5A, elevation antenna rotator.
2. Creative RC5A, azimuth antenna rotator.
3. Creative RC5B-3P, azimuth antenna rotator.
4. Yaesu G-550, elevation antenna rotator.
5. Yaesu G-2300DXA, azimuth antenna rotator.
6. Yaesu G-5500, azimuth and elevation rotator.
7. Emotator EV-800D, elevation rotator.

Ground Station structural study

Related CubeSat.	***University.***	***Antenna Rotor.***	***Rotor Computer Controller & Tracking Software.***
Delfi-C3	Delft University of Technology	Yaesu G-5500	NOVA for Windows
AAU Cubesat	Aalborg University of Technology	Yaesu G-5500	Predict
CubeSat	University of Arizona	Yaesu G-5500	NOVA for Windows with Uni_Trac
PolySat	California Polytechnic State University, U.S.	Yaesu G-5500	SatPC32
Cubesat	University of Tokyo, Japan	Elevation Rotator ERC5A (Creative Design) Azimuth Rotator RC5A-3 (Creative Design)	Orbital calculation software (Virtual Ground Station 3)
Cubesat	TU-Berlin	Yaesu G-5500	SatPC32 and ARSWIN
---	Kagawa University, Japan	ERC-5A (El) And RC5B-3P (Az)	Satellite Tracker is RAC825
--- ---	Kyusyu University Ground Station. Kyushu Institute of Technology.	EMOTATOR EV-800D Yaesu G-5500	No avail info GS-232A
---	Nara National College of Tech, Japan	Yaesu G-5500	GS-232A and Nova for Windows.
---	Soka University Ground Station Unit.	Yaesu G-550 (El) And Yaesu G-2300DXA (Az)	GS-232B

Figure 1.2: Ground Station Structural Study.

For the Ground Station at University of Wuerzburg the antenna structure is situated on a tower, for ease in maintenance and installation a single rotator for both elevation and azimuth control is selected. Yaesu G-5500 Azimuth and Elevation rotator is fast, light weight and maintenance free and is available with three possible options of computer interfaces: Yaesu G-232A or GS-232B, Uni-trac computer interface and WinRotor computer interface.

Out of these options, "WinRotor" was easily available and came up with driver software "WinRotor XP" to control antenna rotator.

More about Yaesu G-5500 and WinRotor Interface, specifications are available in chapter two.

1.3 New Planned Structure

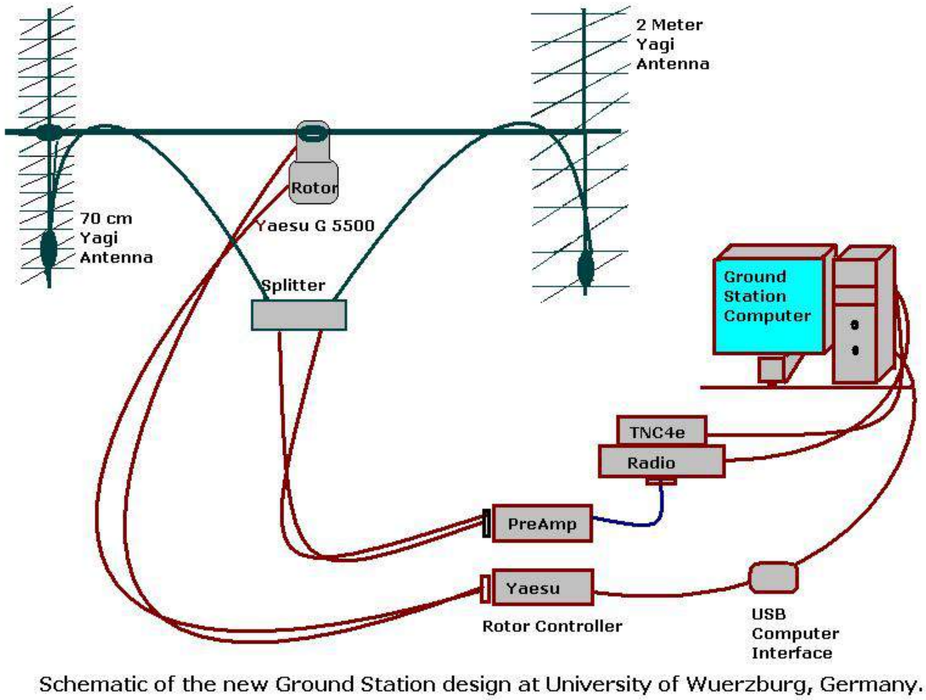


Figure 1.3: New design of the Ground Station.

The new planned structure had many changes as compared to the Old structure. It has **two antennas** in place of four, one 2 meter and one 70 cm antenna to reduce the wait of the antenna assembly on the rotator to increase the rotator efficiency and speed.

After studying the **"Yaesu G-5500"** rotator's specifications and the performance details from the internet, it is selected as a new rotator and controller for the ground station at Department of Informatics VII, University of Wuerzburg.

The next selection was about the computer interface for the *Yaesu G-5500* rotator. The easy availability of the computer interface leads us to go with **"WinRotor computer interface for G-5500/K-5500"**. It comes with the driver software **WinRotor XP**.

"Nova for Windows" was the new selected satellite tracking software. The reason was the compatibility of this software with the WinRotor computer interface for automatic satellite tracking. Also *Nova for Windows* provides live update from Internet and is easy to configure.

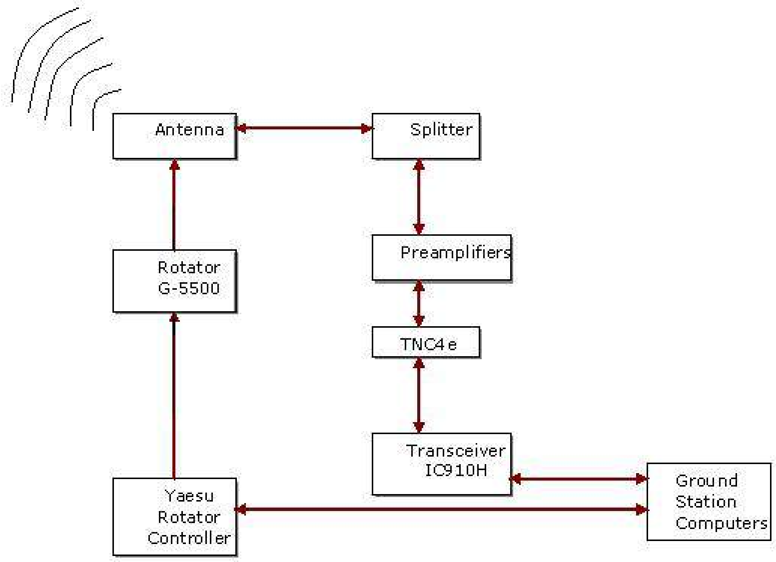


Figure 1.4: Block Diagram of the Ground Station.

Department of Informatics VII- "Robotics and Telematics" at the University of Wuerzburg is the financing body for this Ground Station project.

Chapter 2

Construction

Construction followed in two parts, first one covered the “Hardware and Electronics” and the second covered the “Software” requirements of the GS Package.

2.1 Hardware Specifications

Altitude	310 meters
Tower	Hummel Teletower Jumbo III
Operating frequencies	2m and 70 cms amateur bands
One 2 meter antenna	M2 2MCP22
One 70 cms antenna	M2 436CP42U/G
Antenna rotator and Controller	Yaesu G-5500
Rotator-Computer Interface	WinRotor
Rotator-Computer Interface driver	WinRotor XP
Radio	TNC4e
Polarisation switch	WiMO
Preamplifiers	LNA-145, SLN Series
Tranceiver	ICOM IC-910H
Power Supply	Microset 13.5 Volts
Two PCs	Fujitsu Siemens

Table 2.1: Hardware Specifications Table.

2.1.1 Hummel Teletower Jumbo III

The Hummel Tower is the main base of the Ground Station, which is located on the roof of the Department of Informatics VII- Robotics and Telematics, at University of Wuerzburg, Germany. It provides the platform to the GS to perform the tracking and telemetry operations.

The Hummel Teletower lifts the antennas up to a height of approximately 12 meters above the roof terrace, with which the antenna achieves its own functional height.

A transportation carriage is installed to the Teletower, which carries entire antenna construction including the antenna rotator. On the back of the transportation carriage a switchbox is installed, which can be moved together with the carriage and in which some electronic components necessary for the signal receptions such as Preamplifiers are accommodated.

Manufacturer	Hummel Al-Towers
Model Number	Teletower Jumbo III
Altitude	310 meters

Table 2.2: Hummel Teletower Jumbo III.

The antenna assembly is moved down with the help of transportation carriage when not in use, to a park position, which is on roof height and at which antennas are not exposed to strongly arising storms.

The ***Parking Position*** is:

Azimuth	90 Degrees
Elevation	120 Degrees

Table 2.3: Parking Position.

Parking position is for maintenance and repair work and for the protection of the antennas against strong wind and weather. The software at the Ground

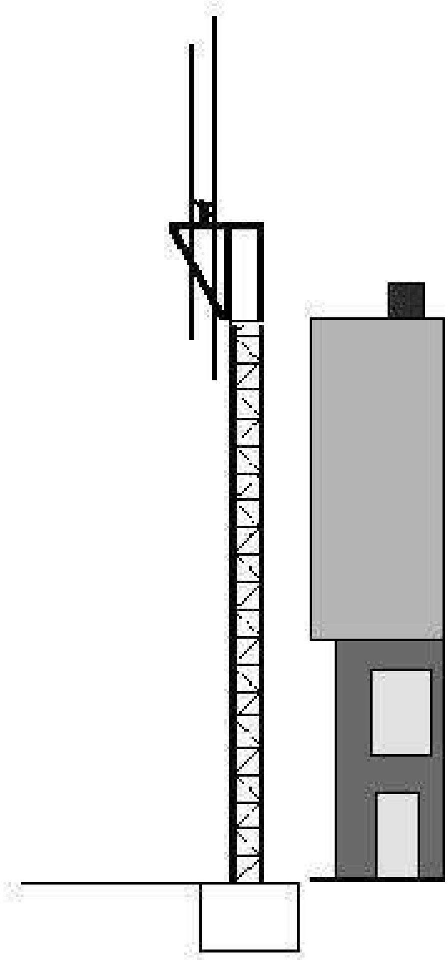


Figure 2.1: Hummel Teletower Jumbo III.

Station is set to bring the antennas to their Parking positions, immediately after quitting the tracking application.

2.1.2 Antennas

The ground station of the Informatics VII, University of Wuerzburg, is equipped with two antennas of the company M2. The two antennas works in the 2m and in the 70cm frequency bands.

M2 Products of this company belong in the range of the amateur radio technology and are the qualitatively best products and permit very good straight receiving powers within the satellite communication service range

The 2 meter antenna is M2 2MCP22.

This cross polarized yagi was computer designed for the serious OSCAR user. The average side and back lobes power have been reduced by approximately 10 dB over any previous design, enhancing signal to noise ratio and putting all your power where it will do the most good. The 2MCP22 is ideal for general use over the entire two meter band. The unique Driven Element Modules are CNC machined and feature O-ring sealed connectors. Internal connections are encapsulated in a space age silicone gel with nearly 4 times the dielectric strength of air. The 2MCP22 is the finest circular polarized antenna.

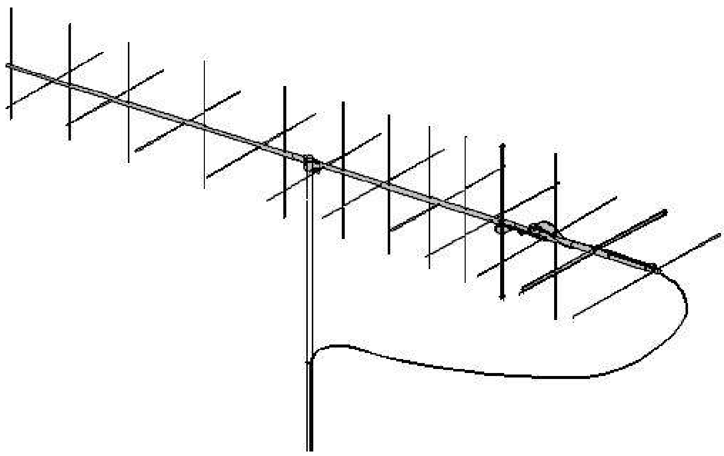


Figure 2.2: 2 m Antenna

The 70 centimetre antenna is M2 436CP42U/G.

The 436-CP42 U/G (Ultra-Gain) sets a new performance standard for UHF circular polarized antennas. Gain and Feedback are excellent. The boom length is matched to the 2MCP22, and together they form an unbeatable satellite communications package. The extremely clean pattern maximizes forward gain and feedback. The pattern is important in order to match the antennas noise temperature with modern low-noise preamps. The driven

2 m Antenna	M2 2MCP22
Manufacturer	M2 Antenna Systems, Inc.
Model	2MCP22
Frequency range	144 TO 148 MHz
Gain @ 145.9 MHz	12.25 dBdc
Front to back	25 dB Typical
Beamwidth	38
Feed impedance	50 Ohms Unbal.
VSWR	1.4: Max
Input Connector	'N' Female
Power Handling	1.5 KW
Stacking Distance	9.5 to 10 feet
Boom length	18'7"
Boom Diameter	1-1/2, Tapering to 1"
Elements/Type	22/3/16" Alum Rod
Turning radius	10 ft.
Wind Area	2.5 sq.ft
Weight/ShipWt.	12.5 lbs 14 lbs UPS

Table 2.4: 2 meter Antenna Specifications.

element and 'T' blocks are CNC machined, with connectors O-ring sealed for low maintenance and long-term peak performance.

For further specifications refer Table 2.4 and 2.5.

The minimum distance between the antennas should be 1 meter for distortion free transmission and reception of the signals, but to keep the movement of the antennas flexible enough up to 360 degrees in azimuth, both of the antennas are mounted on a six meters long aluminium rod keeping the antennas four meters apart.

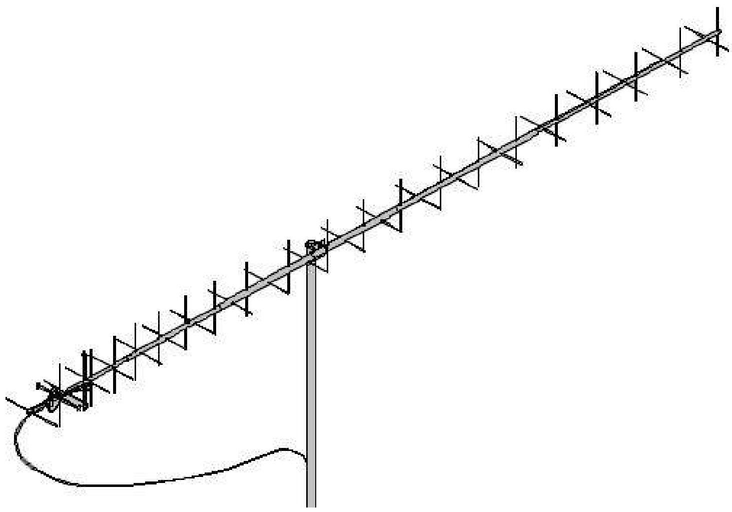


Figure 2.3: 70 cms Antenna

2.1.3 Yaesu G-5500- Azimuth-Elevation Rotator and Controller

The Yaesu G-5500 provides 450 degrees azimuth and 180 degrees elevation control of medium and large sized unidirectional satellite antenna arrays under remote control from the station operating position.

The two factory-lubricated rotator units are housed in weatherproof melamine resin coated die-cast aluminium, to provide maintenance-free operation under all climatic conditions.

The rotators may be mounted together on a mast, or independently with the azimuth rotator inside a tower and the elevation rotator on the must.

The controller unit is a desktop unit with dual meters and direction controls for azimuth, in compass direction and degrees and elevation, from 0 to 180 degrees. An external control jack is provided on the rear of the controller for interfacing via D-to-A converters to an external microcomputer or other display/controller.

The Yaesu G5500 requires two six conductor control cables. The rear panel of the control box has six screw terminals for azimuth and six terminals for elevation. Two 7 conductor metal plugs with weather-boots are included. These two plugs will require careful soldering. It is important to test the

70 cm Antenna	M2 436CP42U/G
Manufacturer	M2 Antenna Systems, Inc.
Model	2MCP22
Frequency range	430 - 438 MHz
Gain @ 145.9 MHz	16.8 dBdc
Front to back	25 dB Typical
Beamwidth	21 circular
Polarity	Circular, RHC or LHC
Ellipticity	1.5 dB Typical
Feed impedance	50 W, Unbalanced
VSWR	1.5:1 and better
Input Connector	'N' Female
Power Handling	1.0 KW
Turning radius	88" El, 138" Az
Wind Area	2 sq.ft.
Mast Size	1.5 to 2 Inches
Weight/ShipWt.	7.8 lbs /10 lbs UPS

Table 2.5: 70 cms Antenna Specifications.

rotator and wirings on the ground, before installing it on the tower.

Please refer Appendix B for the connection documentation.

2.1.4 Rotator Plate

The antenna rotator Yaesu G-5500 is installed onto a metal plate, which serves as connecting piece between rotator and Hummel Teletower. This metal plate guarantees a fixed connection between the antenna rotator and the Hummel Teletower. Thus will at the same time structurally separate the antenna construction from the Hummel Teletower.

The old rotator's plate is redesigned for the new rotator with few modifications as per requirement.
Figures 2.5 and 2.6 can more illustrate it.

Figure 2.4: Yaesu G-5500 Rotator and Controller.

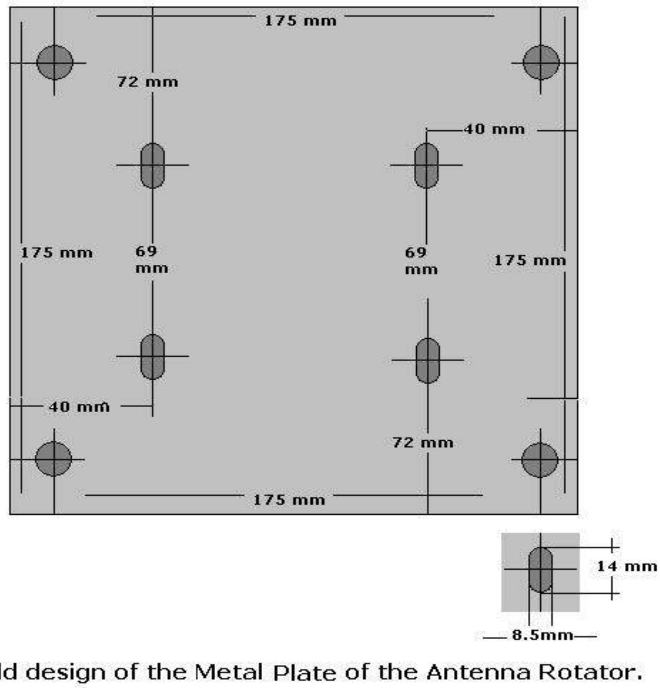


Figure 2.5: Rotator Plate - Old design.

This plate is fixed on the tower using M10 screws which provides it stability to hold the rotator and antenna while the tracking movement.

Power Supply Voltage	117 VAC, 50-60 Hz
Power Supply Current Consumption	120 VA
Rotor Voltage	24 VAC
Cable Conductors Required	6 and 6
Rotation Time (Non Loaded)	Elevation (180): 67 sec at 60 Hz
Rotation Time (Non Loaded)	Azimuth (360): 58 sec at 60 Hz
Rotation Range	Elevation: 180, Azimuth: 450
Rotation Torque	Elevation: 101 foot-pounds (14 kg-m)
Rotation Torque	Azimuth: 44 foot-pounds (6 kg-m)
Braking Torque	Elevation : 289 foot-pounds (4 kg-m)
Braking Torque	Azimuth: 289 foot-pounds (4 kg-m)
Maximum Vertical Load	Elevation: 30 kg or less
Maximum Vertical Load	Azimuth: 440 Lbs. (200 kg) or less
Mast Outside Diameter	1.5-2.5 inches (38 to 63mm)
Boom Outside Diameter	1.24-1.675 inches (32 to 43mm)
Braking Type	Mechanical and Electrical stoppers
Wind Loading Area	1.0 square meter or less
Maximum Continuous Duty	5 minutes
Operating Temperature Range	0 deg C to +40 deg C (Controller)
Operating Temperature Range	-20 deg C to +40 deg C (Rotator)
Rotator Dimension	10x13.75x7.5 inches
Rotator Weight	20 Lbs (9 kg)
Controller Dimension (WHD)	200 x 130 x 193 mm
Controller Weight	6.6 Lbs (3 kg)

Table 2.6: Yaesu G-5500 Rotator and Controller's Specifications.

The Yaesu G-5500 is attached on the top of the rotator plate using M8 screws.

2.1.5 Rotator-Computer Interface

The computer Interface for the Yaesu G-5500 rotator controller is "Die Funkbox - WinRotor". It provides an USB connection to the computer. Yaesu G-5500

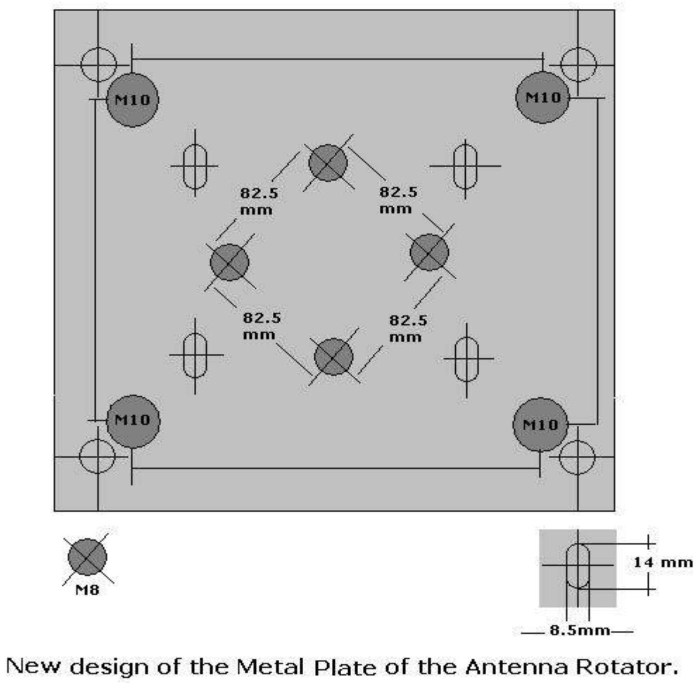


Figure 2.6: Rotator Plate - New design.

controller and WinRotor Interface is shown in figure 2.7.

Figure 2.7: WinRotor Computer Interface.

2.1.6 Cabling

Cabling pattern is another basic requirement of the Ground Station. This is important to bind the Antenna and Rotator cables in a pattern, so that it will not stuck at any time during the tracking operation of 0-360 degrees azimuth and 0-180 degrees elevation movements all together.

2.1.7 Preamplifiers

The LNA series for 2 m and 70 cm has a silver plated brass housing and a tuneable nand pass filter with air coils and high Q trimmers at the output. The amplifiers are not used only for amateur radio but on different frequencies also for professional applications, for example in radio astronomy, as preamplifiers in company radio networks and for increasing the sensitivity of repeaters.

In addition to the extremely low noise figure also the good electrical stability (no self-excitation) should be emphasised as well as the very large signal behaviour.

Preamplifier Specifications:

LNA 145 MK II	
Frequency Range	144 - 148 MHz
Noise Figure, typical @ 20 deg.C	0.2 dB
Gain, typical	23 dB
Socket	N-Female
Operating Voltage	15 V DC
Current Drain	25 mAmp
Dimensions	74 x 56 x 30 mm
Weight	150 gms

Table 2.7: Specification Table - Preamplifier LNA 145 MK II.

Figure 2.8: Preamplifiers.

LNA 435 MK II	
Frequency Range	430 - 440 MHz
Noise Figure, typical @ 20 deg.C	0.25 dB
Gain, typical	22 dB
Socket	N-Female
Operating Voltage	15 V DC
Current Drain	25 mAmp
Dimensions	74 x 56 x 30 mm
Weight	150 gms

Table 2.8: Specification Table - Preamplifier LNA 435 MK II.

2.1.8 Transceiver - IC-910H and TNC4e

The IC-910H is an all mode satellite radio. It is compact and lightweight for field operation. The IC-910H features a powerful 100 W of output on 2 meter band, and 75 W on 430/440 band provided by the newly designed power amplifier circuit, which employs bipolar transistors in parallel. The combination of the aluminium die-cast chassis and effective cooling fan ensures stable output for continuous operation.

In the satellite mode, the downlink and uplink frequencies are displayed simultaneously on the main and sub bands respectively. Doppler shift compensation is also available. Up to ten satellites memory channels are there to store uplink downlink frequencies and operating mode. Also the Transceiver IC-910H can also be connected with a PC using a RS-232 cable.

TNC is Terminal Node Controller, In 1983 the TAPR (Tucson amateur packed radio) developed a computer map TNC1 which could send and receive the data in the AX.25 minutes. With the TNC2 the mode of operation packing radio is introduced in 1985. Different advancements of the TNC2 followed and in 1993 the TNC3S, and in 1997 TNC4e were developed in Germany.

The TNC4e is attached with a serial cable to the ground station PC. The use of a MC68EN302 integrated with Ethernet interface is available in the version TNC4e which provides coupling of several TNCs and the PC all together.

Dimensions	218 x 67 x 124 mm
Input voltage	8-16 V DC
Input Power excluding modems	130 mA
Max Input Power	300 mA
Radio Ports	max. 3 x 1.2 MBauds
Ethernet-Port	Twisted Pair (RJ45) 10 MBaud
Asynchronous Transmission	max. 115.2 kBaud
Real-Time Clock	Epson RTC 64613
Memory	1 MByte 5V-Flash
RAM	1 MByte intern + 3 MByte optional

Table 2.9: Specifications Table - TNC4e.

SPECIFICATIONS

• General

• Frequency coverage : (Unit: MHz)

Version	144 MHz	430(440) MHz	1200 MHz*1
U.S.A.	Tx: 144.0–148.0 Rx: 136.0–174.0*2	Tx: 430.0–450.0 Rx: 420.0–480.0*3	Tx: 1240.0–1300.0 Rx: 1240.0–1320.0*4
Europe	144.0–146.0	430.0–440.0	1240.0–1300.0
Australia	144.0–148.0	430.0–450.0	1240.0–1300.0
Sweden	144.0–146.0	432.0–438.0	1240.0–1300.0
Italy	144.0–146.0	430.0–434.0 435.0–438.0	1240.0–1245.0 1270.0–1298.0

*1 Optional UX-910
*2 Guaranteed range is 144.0–148.0 MHz.
*3 Guaranteed range is 430.0–450.0 MHz.
*4 Guaranteed range is 1240.0–1300.0 MHz.

• Mode : USB, LSB, CW, FM, FM-N*
*Not available in 1200 MHz
• No. of memory Ch. : 212 (99 regular, 6 scan edges, 1 calls for each band) plus 10 satellite memories)
• Antenna connector : SO-239 (50 Ω; VHF)
Type-N (50 Ω; UHF)
• Usable temp. range : –10°C to +60°C; +14°F to +140°F
• Frequency stability : Less than ±3 ppm (–10 to 60°C; +14 to +140°F)
• Frequency resolution : 1 Hz minimum
• Power supply : 13.8 V DC ±15% (negative ground)
• Current drain (at 13.8 V DC; approx.):
Transmit Max. power 23.0 A
Receive Standby 2.0 A (3.0 A; UX-910)
Max. audio 2.5 A (3.5 A; UX-910)
• Dimensions : 241(W)×94(H)×239(D) mm
(projections not included) 9½(W)×3¹¹⁄₁₆(H)×9¹³⁄₃₂(D) in
• Weight (approx.) : 4.5 kg; 10 lb
(5.35 kg; 11 lb 13 oz w/UX-910)
• ACC 1 connector : 8-pin DIN connector
• CI-V connector : 2-conductor 3.5(d) mm (⅛″)
• DATA connectors : 6-pin mini DIN × 2 (for MAIN and SUB)

• Transmitter

• Output power (continuously adjustable):
144 MHz 5–100 W
430(440) MHz 5–75 W
1200 MHz 1–10 W (optional UX-910)
• Modulation system :
SSB Balanced modulation
FM Variable reactance modulation
• Spurious emission :
144/430(440) MHz More than 60 dB
1200 MHz More than 50 dB
• Carrier suppression : More than 40 dB
• Unwanted sideband suppression : More than 40 dB
• Microphone connector : 8-pin connector (600 Ω)
• KEY connector : 3-conductor 3.5(d) mm (¼″)

• Receiver

• Receive system :
VHF SSB, CW Single conversion superheterodyne
FM Double conversion superheterodyne
UHF SSB, CW Double conversion superheterodyne
FM Triple conversion superheterodyne
• Intermediate frequencies: (Unit: MHz)

		MAIN BAND			SUB BAND		
		1st	2nd	3rd	1st	2nd	3rd
144 MHz	SSB	10.8500	—	—	10.9500	—	—
	CW	10.8491	—	—	10.9491	—	—
	FM	10.8500	0.455	—	10.9500	0.455	—
430(440) MHz	SSB	71.2500	10.8500	—	71.3500	10.9500	—
	CW	71.2491	10.8491	—	71.3491	10.9491	—
	FM	71.2500	10.8500	0.455	71.3500	10.9500	0.455
1200 MHz	SSB	243.8500	10.8500	—	243.9500	10.9500	—
	CW	243.8491	10.8491	—	243.9491	10.9491	—
	FM	243.8500	10.8500	0.455	243.9500	10.9500	0.455

• Sensitivity :
SSB, CW (10 dB S/N) Less than 0.11 μV
FM (12 dB SINAD) Less than 0.18 μV
• Squelch sensitivity (threshold):
SSB, CW Less than 1.0 μV
FM Less than 0.18 μV
• Selectivity :
SSB, CW More than 2.3 kHz/–6 dB
Less than 4.2 kHz/–60 dB*
FM More than 15.0 kHz/–6 dB
Less than 30.0 kHz/–60 dB*
FM-N More than 6.0 kHz/–6 dB
Less than 18.0 kHz/–36 dB
CW-N More than 0.5 kHz/–6 dB
(w/FL-132 or FL-133) Less than 1.34 kHz/–60 dB*
*Except 1200 MHz band
• Spurious and image rejection ratio:
144/430(440) MHz More than 60 dB
1200 MHz More than 50 dB
• AF output power (at 13.8 V DC) : More than 2.0 W at 10% distortion with an 8 Ω load
• RIT variable range :
144/430(440) MHz ±1.0 kHz (SSB, CW)
±5.0 kHz (FM)
1200 MHz ±2.0 kHz (SSB, CW)
±10.0 kHz (FM)
• IF SHIFT variable range : More than ±1.2 kHz
• PHONES connector : 3-conductor 6.35(d) mm (¼″)
• Ext. SP connectors : 2-conductor 3.5 (d) mm (⅛″) /8 Ω × 2 (for MAIN and SUB)

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

Figure 2.9: Specifications of Transceiver - IC910H.

2.2 Software Specifications

Satellite Tracking Programme	Nova for Windows
Rotator-Computer Interfacing software	WinRotor XP
Operating System	Windows XP

Table 2.10: Software Specifications Table.

2.2.1 Nova for Windows

"Nova for Windows" is owned by Northern Lights Software Associates (NLSA) and is an innovative map-based satellite tracking system. It features over 150 realistic 256-color and 16-bit colour maps, unlimited numbers of satellites, observers, and views, as well as real-time control of antennas through several popular hardware interfaces.

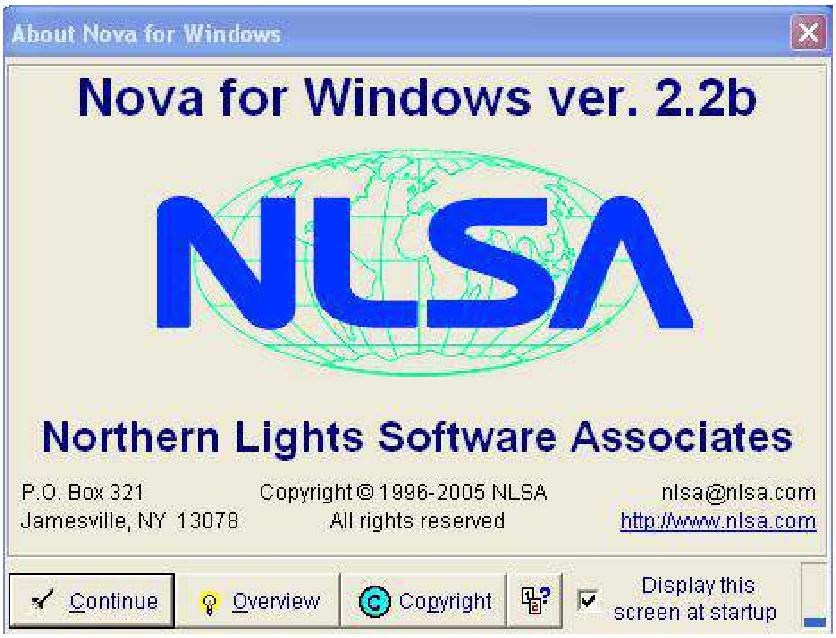


Figure 2.10: Nova for Windows

Some Useful features:

1. Visually stunning maps, multiple sizes.
2. Unlimited numbers of satellites, observers, and views simultaneously.
3. Tracks all artificial satellites, Moon, Sun, planets, and celestial noise sources.
4. Fast, accurate, clear satellite positions.
5. Built-in Auto-Tracking support for all popular antenna control interfaces.
6. Floating/docking toolbar for easy access to common functions.
7. Context-sensitive online help.
8. Multi-level configuration setup screens.
9. Text listings to screen, printer, or disk file.
10. Configurable Satellite Script for priority tracking.
11. Two-satellite mutual visibility, including 1 and 2-observer 2-satellite mutual windows
12. Satellite eclipse predictions.
13. Full Moon data for EME.
14. 2,000-city, DXCC, and EME databases included.
15. Fully Year 2000 (Y2K) compliant.
16. Sound alarms for AOS and LOS.
17. Built-in FTP for download of Keplerian elements.
18. 1,600 stars and constellations included.

System requirements:

1. Pentium or similar fast processor (a 386 or 486 will work, but slowly).
2. Microsoft Windows '95, 98, ME, NT, 2000 or Windows XP.
3. Video: 640x480, 256 colours required; 1024x768, 16-bit colour preferred.
4. At least 12 MB hard disk drive storage for full installation.

2.2.2 Die Funkbox - WinRotor XP

WinRotor XP is a software driver for the WinRotor computer Interface manufactured by "Die Funkbox" in Germany. WinRotor XP provides the control to the antenna rotator movements with the help of WinRotor computer interface and also works under DDE (Dynamic Data Exchange) mode with "Nova for Windows" to provide complete automatic script tracking.

Software Installations.

Insert "WinRotor XP" CD-ROM and click once on **setup**, which will install the software. One can install the icon "WinRotor" on the system on the screen from which it will be possible to start it.

For **General** rotator settings, the path is "Options" and then "General". Refer figure 2.23. Settings for the Ground Station at Informatics VII, University of Wuerzburg are as follows:

1. "USB IF 1" is the type of Interface connection used.
2. Azimuth rotator (horizontal) is enabled and stops at North 0 degrees with a tolerance of +/- 2 degrees. Limit is from 0 to 360 degrees.
3. Elevation rotator (vertical) is enabled with tolerance of +/- 1 degrees. Limit is from 0 to 180 degrees.
4. Then click on "Save settings" to keep the adjustments chosen and quit the window.

Software **Calibration** is the most important part of this Interface software in order to get the precise and accurate antenna position.
It is necessary to calibrate WinRotor XP in case of a new software installation and in case of a new rotor, it is also recommended to check the calibration from time to time. Make sure all connections are correct, Interface on USB port and the cable between the interface and the command box of the rotor.

Switch on the rotor command box and start WinRotor XP. Go to the menu "Options" and open the window "calibration".
Follow these steps:-

1. Using the manual settings of the rotor command box set, the azimuth value to the full left (0 degrees) and elevation to 0 degrees. Now click on the box "New Value", a set of new values of azimuth and elevation

Figure 2.11: WinRotorXP - General Configuration.

are displayed next to the box "new value". Inscribe these values on the line "left border".

2. Set azimuth to 180 degrees and elevation to 90 degrees, click on the box "new value" and inscribe the values thus obtained on the line "middle value".

3. Carry out the same operation for azimuth at full right (360 degrees) and elevation 180 degrees, inscribe the values on the line "right border". Click on the box "save values" which will put the measured values in the memory and quit the window "Calibration".

Important:

The WinRotor interface must be connected to the USB port of the computer before running WinRotor XP software. The connection must be done when the computer is off.

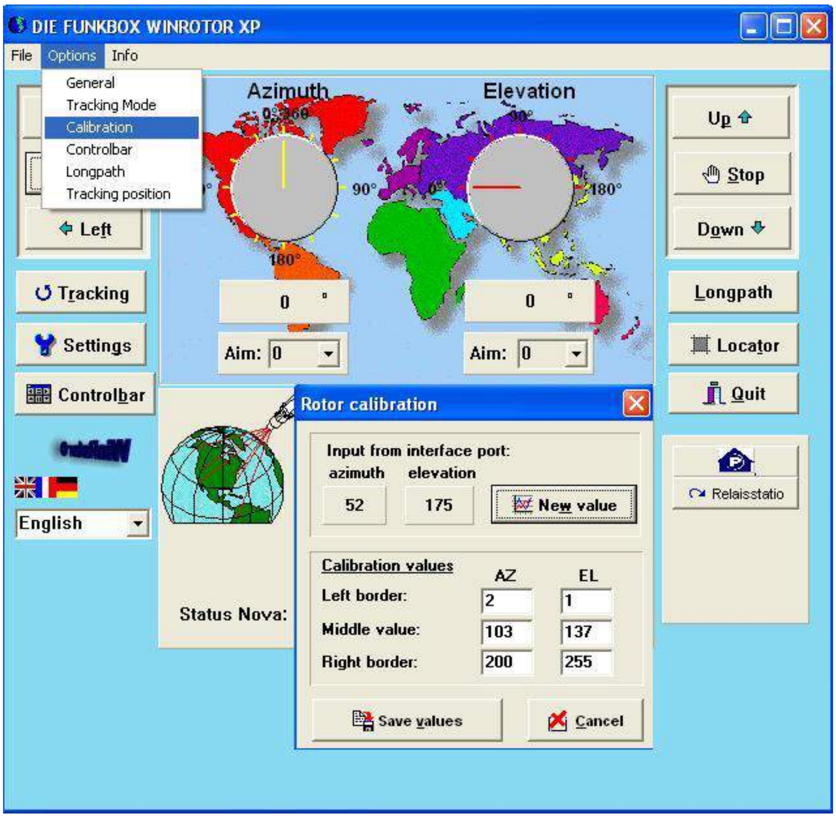


Figure 2.12: WinRotorXP - Rotator Calibration.

For computer Interface WinRotor and antenna rotator Yaesu G-5500 calibrated values for the Ground Station at Informatics VII, University of Wuerzburg is shown in the Figure 2.24.

Automatic tracking with "Nova for Windows"

WinRotor XP provides a feature of using "Nova for Windows" as a Satellite tracking tool under DDE (Dynamic Data Exchange) mode.

After selecting the satellite tracking tool and saving the new settings the screen will look like the Figure 2.25.

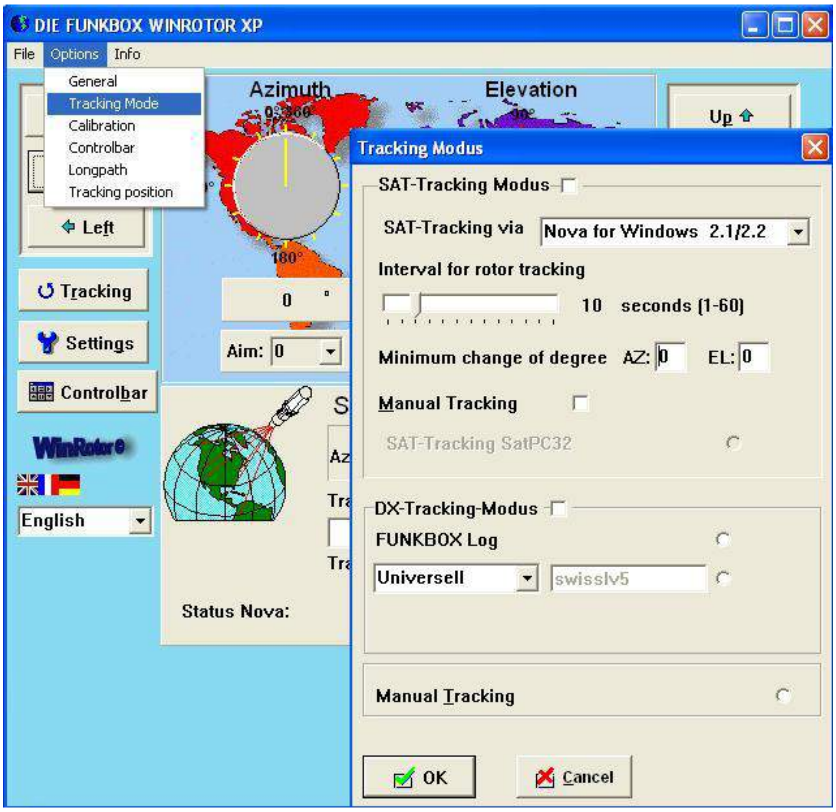


Figure 2.13: WinRotorXP - Tracking Modus.

Tracking position can be defined by going on menu “Options” and then “Tracking position”.

Parking position is said to be a final position of antennas at parking and while quitting the application. For the Ground Station at Informatics VII, University of Wuerzburg *Parking position* is set at 90 degrees Azimuth and 120 degrees Elevation. Refer figure 2.26.

And when the tracking command is **ON**, It can be stopped at any point of time by clicking on the **cancel** button. Also current azimuth and elevation positions of antennas can also be seen manually on the rotator controller screen, during the tracking process.

Figure 2.14: WinRotorXP - Tracking and Parking Positions.

2.2.3 Why Windows XP..??

1. As it matched with the "WinRotor XP" and "Nova for Windows" system's requirements.
2. Reinstallations of the software are easy.
3. Easy to maintain.

Figure 2.15: WinRotorXP - Satellite Tracking with NOVA.

Chapter 3

Testing and Optimization of Ground Station

Testing of the Ground Station is done with a CubeSat Satellite "QuakeSat". QuakeSat is a small satellite, 4"x4"x12", launched on June 30, 2003, and provides a "proof-of-concept" for collecting ULF earthquake precursor signals from space. The design was based on the CubeSat concept where each CubeSat is 4"x4"x4". QuakeSat is in fact a triple CubeSat to provide a large enough size to include a one-foot long magnetometer that extends on a telescoping boom.

The satellite was built by the Space Systems Development Laboratory at Stanford University, under the direction of Professor Robert Twiggs, with the receiver unit provided by QuakeFinder.

QUAKESAT
NORAD ID: **27845**
Int'l Code: **2003-031F**
Perigee: **818 km**
Apogee: **832 km**
Inclination: **98.7 Degrees**
Period: **101.4 min**
Launch date: **2003-06-30**
Source: **United States (US)**
Comments: Nanosatellite; research on early warning for earthquakes.
Beacons Frequency: 436.675 MHz, AX.25 packets at a baudrate of 9600bps.

While testing the first problem resolved was the matching values of the actual elevation and azimuth positions with the software values.

Calibrated the software for rotator movement to work exactly from 0 to 180 degrees in elevation and 0 to 360 degrees in azimuth.

Resolved was related to the cabling pattern. Cables are binded in a way that it will never stuck during an automatic tracking movement of 0 to 180 degrees in elevation and 0 to 360 degrees in azimuth.

The problem was Yaesu G-5500 rotator has a maximum continous duty of 5 minutes, and the satelite flyby time is about 15 mins. To optimize it while testing WinRotor XP software is optimized to track for the satellite position in every 10 seconds, only if the change in Azimuth is more than +/- 2 degress and in Elevation +/-1 degrees. These values are tested and worked with all satellite passes. Thus the current supply to the rotator is limited for a small period of time and thus it never exceeds the maximum continous duty level.

3.1 Testing Summary

While testing the Ground Station, several conclusions are made. The evaluation is as follows:

1. The testing of the Ground Station is done without installing preamplifiers and is working well in almost all weather conditions and can said to be completely operational. But it is recommanded **not** to use Ground Station in high winds. This is for the safety reasons. Also high winds effets antenna's pointing towards the satellite, resulting in low signal strength.

2. Ground Station can start sensing satellite from a low elevation of about (less than) 10 degrees, but to decode the beacons the minimum signal strength required is more than 4 dB. This signal strength is available at an elevation of about 15 degrees or higher. So this is recommanded to always go with the passes having maximum elevation of 15 degrees or more.

Chapter 4

Conclusion

(a) New deign of the Ground Station is implemented sucessfully, which removed some of its old pitfalls.

(b) Automatic satellite tracking is now possible.

(c) Satellite Tracking with hign elevations are now possible.

(d) Problems related to cabling pattern is also resolved.

(e) Ground Station is again operational.

Appendix A

Hardware Documentation

Connections at Yaesu G-5500 Antenna rotator and controller: To follow reusability, the old Rotors cable of 18 wires is used, and out of its 18 wires six wires are connected to azimuth control and six wires to elevation control, of the Yaesu G-5500 Controller.

For the Ground Station at the University of Wuerzburg, connections are documented in Tables A.1, A.2, A.3 and A.4.

Azimuth Control	
Pin 1	Wire 1
Pin 2	Wire 2
Pin 3	Wire 3
Pin 4	Wire 4
Pin 5	Wire 5
Pin 6	Wire 6

Table A.1: Connections at Rotator Controller.

Elevation Control	
Pin 1	Wire 9
Pin 2	Wire 10
Pin 3	Wire 7
Pin 4	Wire 12
Pin 5	Wire 13
Pin 6	Wire 14

Table A.2: Connections at Rotator Controller.

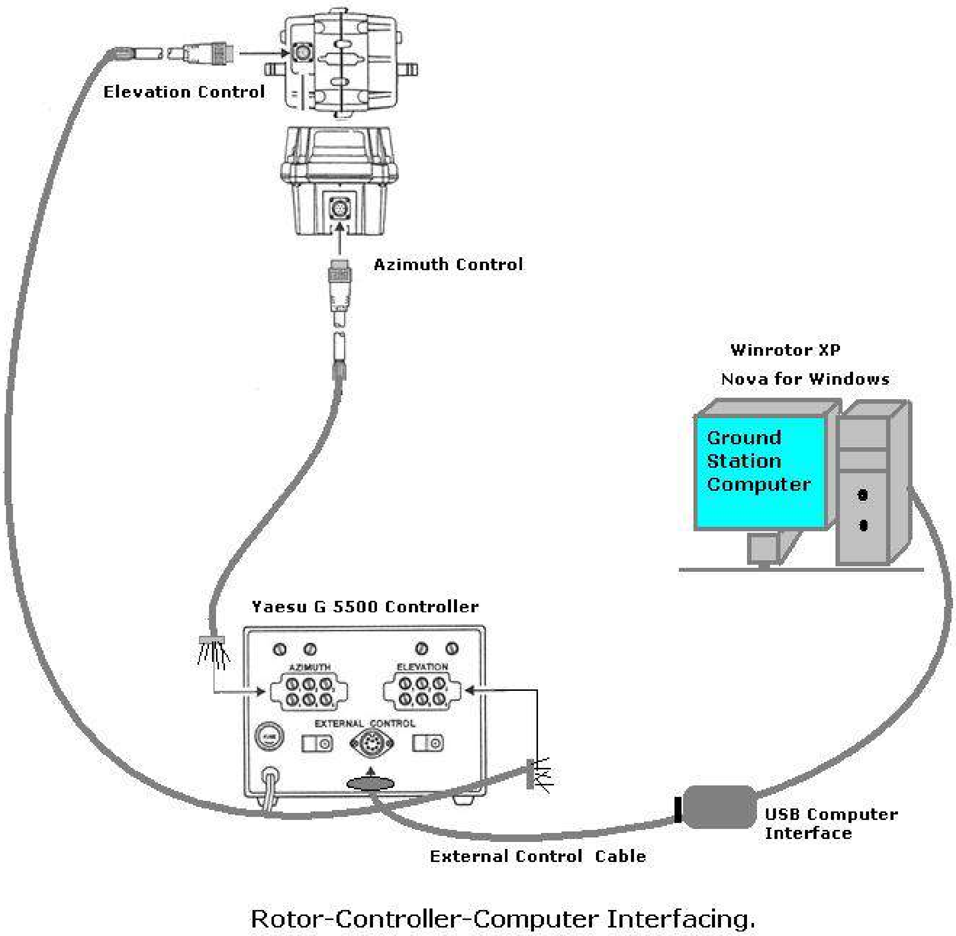


Figure A.1: Connections at Yaesu Rotator and Controller.

Azimuth Control	
Pin 1	Wire 1
Pin 2	Wire 2
Pin 3	Wire 3
Pin 4	Wire 4
Pin 5	Wire 5
Pin 6	Wire 6
Pin 7	Unused

Table A.3: Connections at Rotator's Metal Plug.

Elevation Control	
Pin 1	Wire 9
Pin 2	Wire 10
Pin 3	Wire 7
Pin 4	Wire 12
Pin 5	Wire 13
Pin 6	Wire 14
Pin 7	Unused

Table A.4: Connections at Rotator's Metal Plug.

Appendix B

Configurations for "Nova for Windows".

Installing Nova for Windows

(a) Insert the Nova for Windows CD into the CD-ROM drive of your computer.

(b) If the setup program doesnt start automatically, click on the Start button (lower left corner of the desktop).

(c) Click on Run.

(d) In the file name box, type **Setup.EXE**.

(e) Follow the directions in the Nova for Windows Setup.

Important:

Be sure to enter the serial number carefully. Serial number must include the NLD- prefix.

First step is to set the type of Map. In the screenshots shown below "Large Rectangular Map" is selected for convenience.

To choose the new map setting the path is-
"Views" then "Configure current view" and then Choose "Map display" and "Map Size".
Refer figure 2.11.

Second step is to set the position of the Ground Station in "Nova for Windows". The path is- "Setup" and then "Observers".

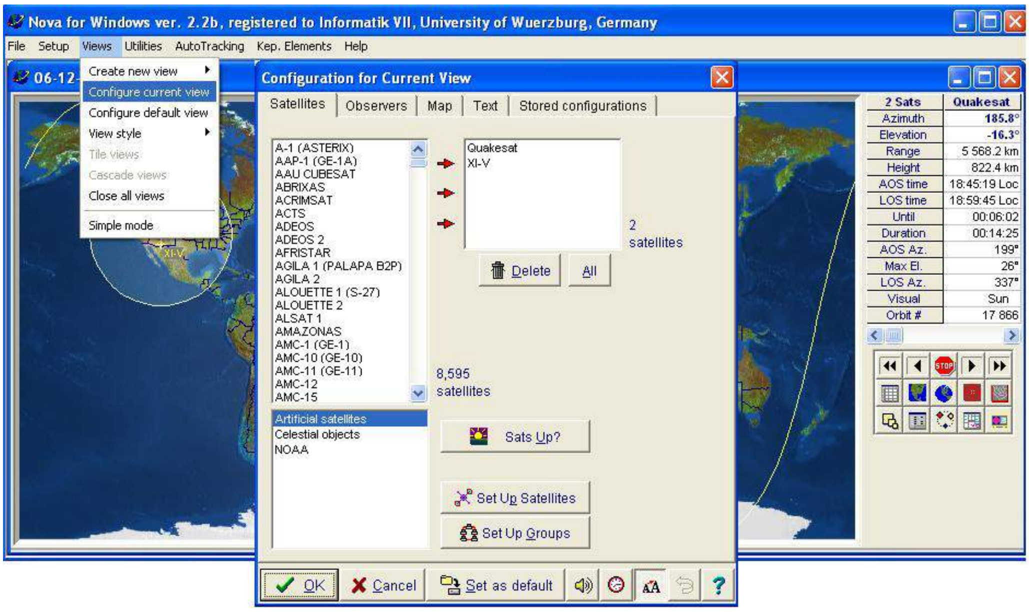


Figure B.1: Nova for Windwos - Configuring View.

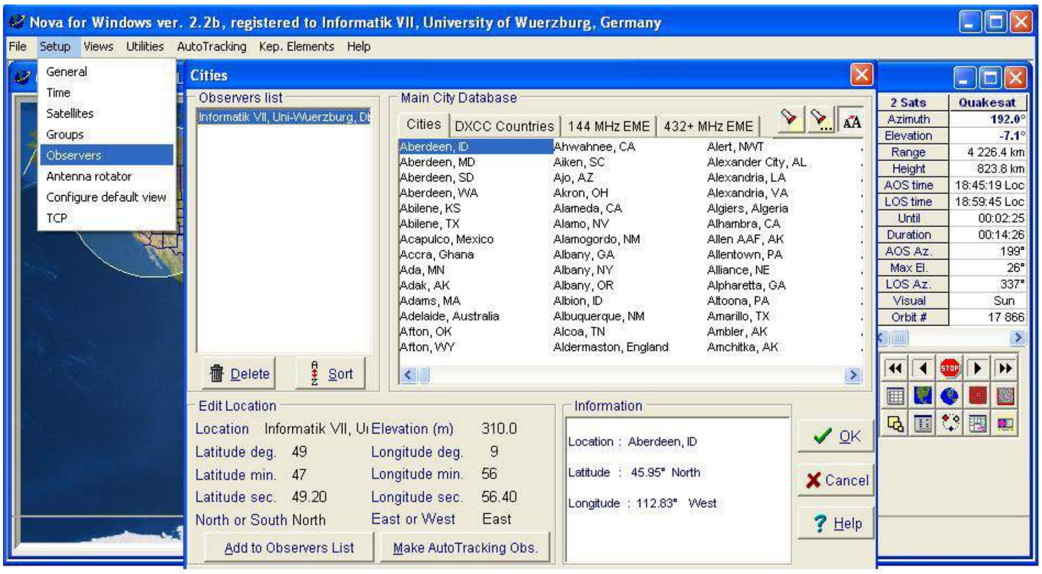


Figure B.2: Nova for Windows - Configuring Observer.

In our case it is:
Location: "*Informatics VII, Uni-Wuerzburg, Germany.*"
Elevation is of *310 meters*.
Latitude is *49 degrees 47 minutes 49.20 seconds North*.

Longitude is *9 degrees 56 minutes 56.40 seconds East.*
Refer figure 2.12.

Third step is to check the availability of the specific satellite from the Satellite Editor in the database of "Nova for Windows".
In this editor, new satellite names and its Keplerian elements can also be added. Also "Update Keplerian Elements" button provides the online update.
The path is "Setup" and then "Satellites".
Refer figure 2.13.

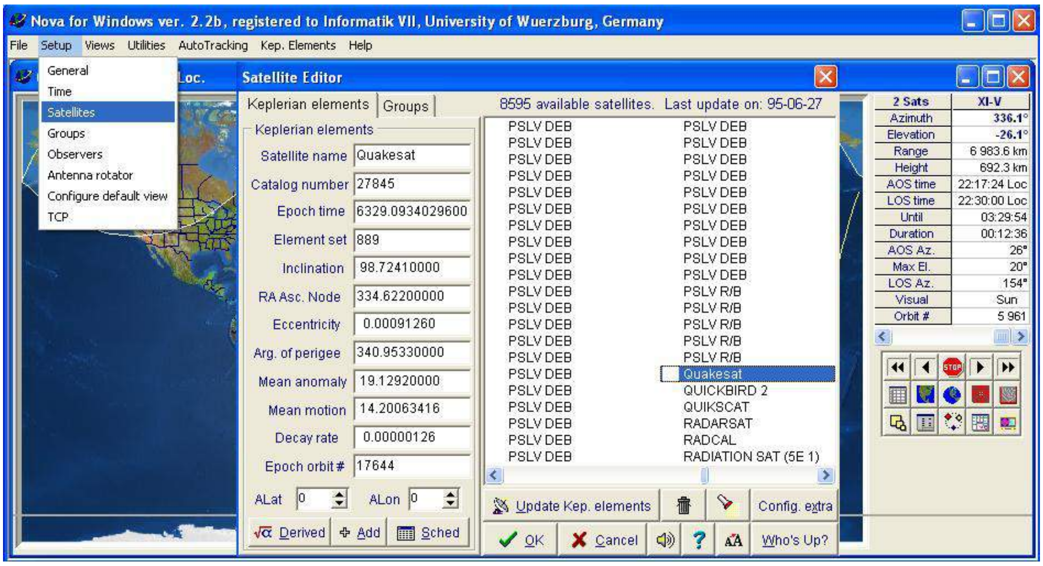


Figure B.3: Nova for Windows - Configuring Satellites.

To update Keplerian elements or to get related help click on "Kep Elements". Refer figure 2.14.

Fourth step is to choose the "Current View" in order to see Satellite and Observer (Ground Station position) all together.
This provides a feature of selecting multiple Satellites and Observation points on the map at the same time.
The path is "Views" and then "Configure current view" and then "Satellites" or "Observes" or "Map" or "Text". Refer figures 2.15 and 2.16.

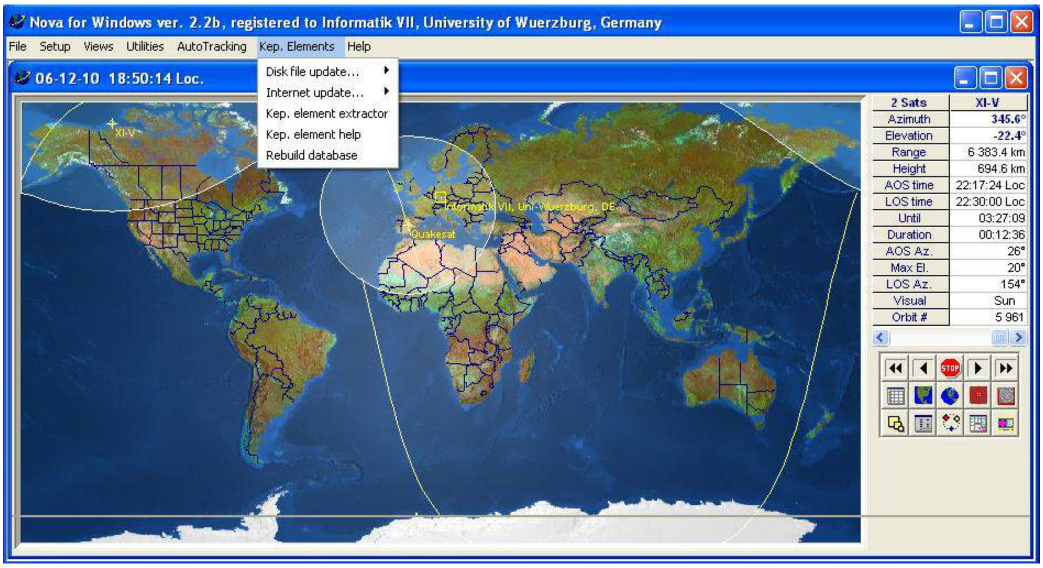


Figure B.4: Nova for Windows - TLE Updation

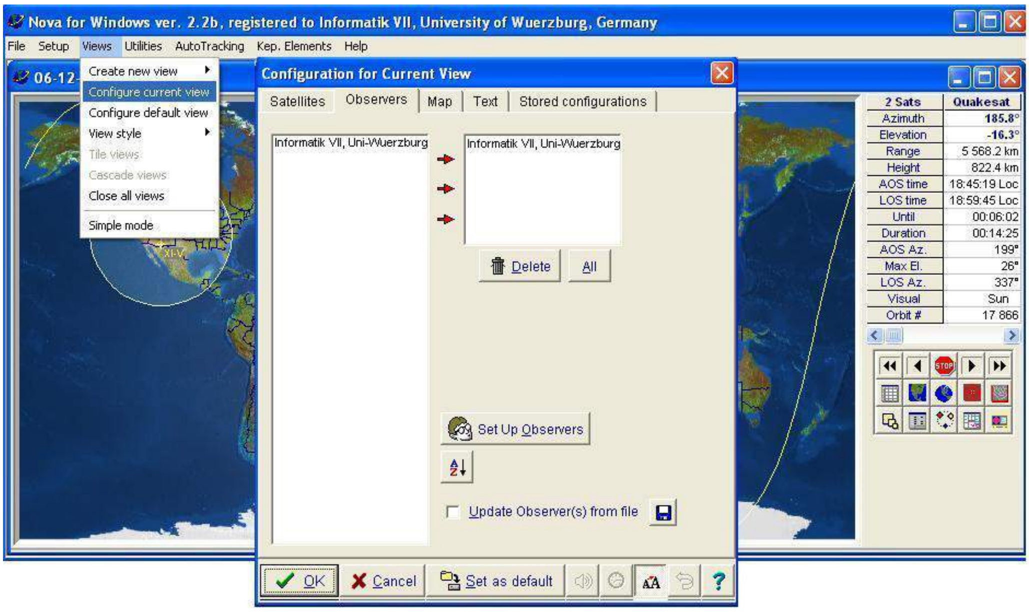


Figure B.5: Nova for Windows - Current View Observer.

On the Map, Footprint of the satellite/s and the Ground Station's position/s can be easily found. Refer figure 2.17.
On the Right hand side of the screen, Real-time text data of the con-

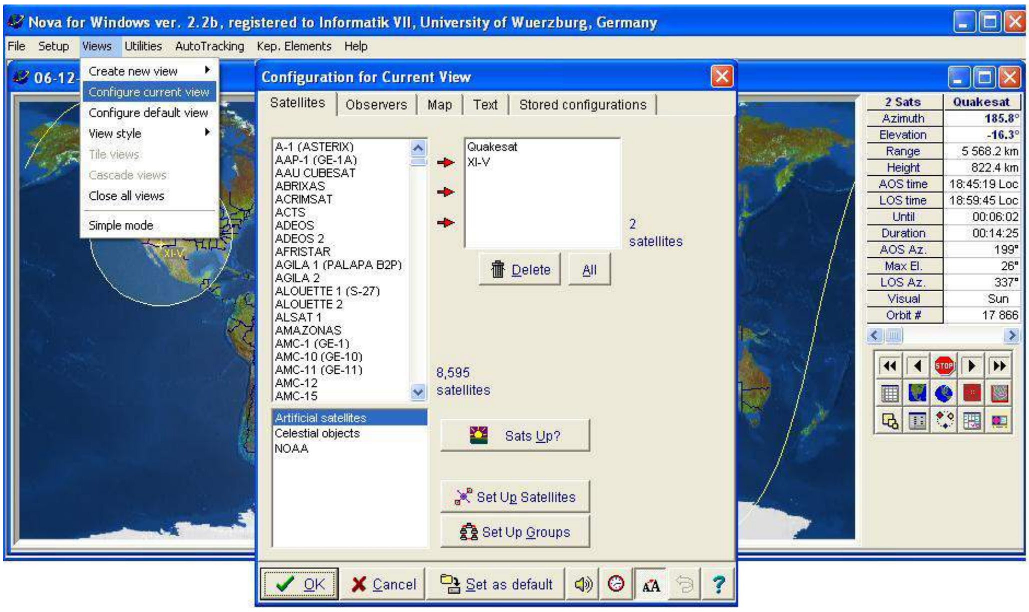


Figure B.6: Nova for Windows - Current View Satellite.

cerning satellite is available. The number of columns in the real-time text window depends on the number of satellites in the view.

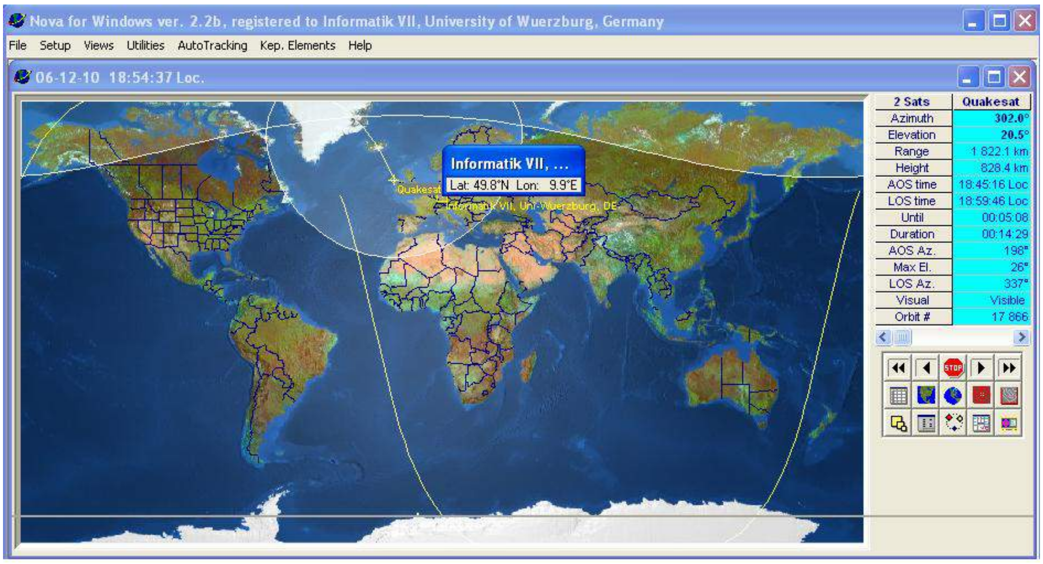
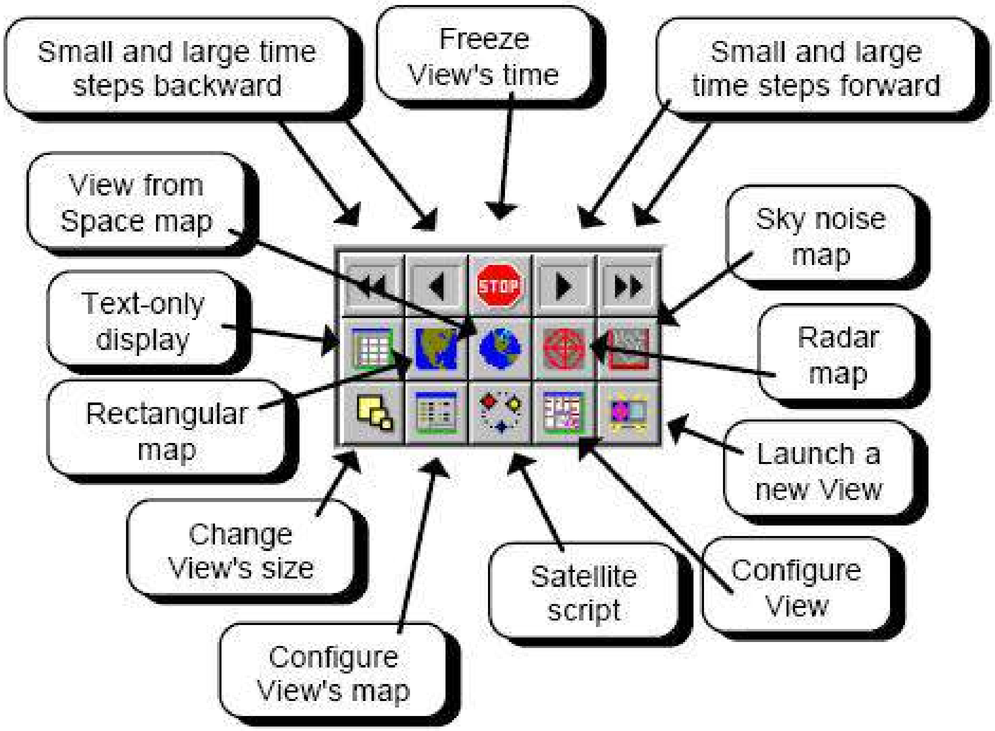


Figure B.7: Nova for Windows - Satellite Footprints.

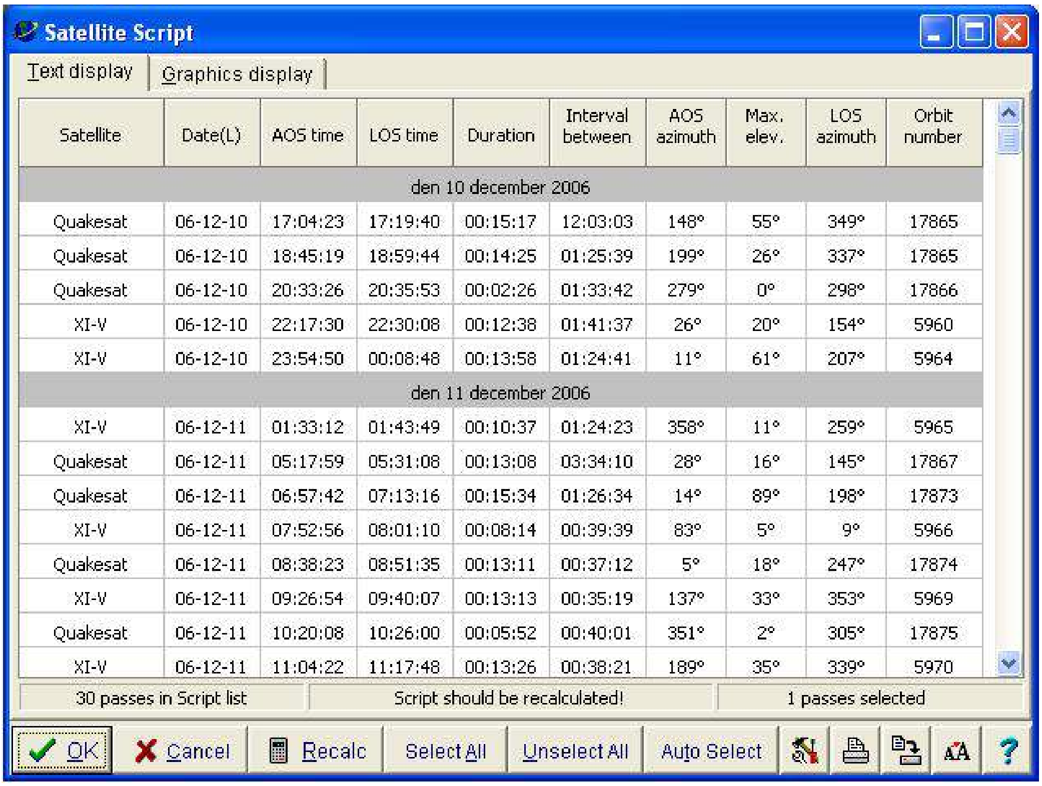
Satellite Script.

“Satellite Script” features the prediction of the flyby time of the satellite or satellites over a particular Observer (Ground Station) up to 48 hours in advance.
This also enables “automatic script tracking”. Refer figure 2.19.



*Nova for Windows' floating **ToolBar** provides access to the most frequently-used functions.*

Figure B.8: Nova for Windows - Floating Toolbar.



Satellite Script

Text display | Graphics display

Satellite	Date(L)	AOS time	LOS time	Duration	Interval between	AOS azimuth	Max. elev.	LOS azimuth	Orbit number
den 10 december 2006									
Quakesat	06-12-10	17:04:23	17:19:40	00:15:17	12:03:03	148°	55°	349°	17865
Quakesat	06-12-10	18:45:19	18:59:44	00:14:25	01:25:39	199°	26°	337°	17865
Quakesat	06-12-10	20:33:26	20:35:53	00:02:26	01:33:42	279°	0°	298°	17866
XI-V	06-12-10	22:17:30	22:30:08	00:12:38	01:41:37	26°	20°	154°	5960
XI-V	06-12-10	23:54:50	00:08:48	00:13:58	01:24:41	11°	61°	207°	5964
den 11 december 2006									
XI-V	06-12-11	01:33:12	01:43:49	00:10:37	01:24:23	358°	11°	259°	5965
Quakesat	06-12-11	05:17:59	05:31:08	00:13:08	03:34:10	28°	16°	145°	17867
Quakesat	06-12-11	06:57:42	07:13:16	00:15:34	01:26:34	14°	89°	198°	17873
XI-V	06-12-11	07:52:56	08:01:10	00:08:14	00:39:39	83°	5°	9°	5966
Quakesat	06-12-11	08:38:23	08:51:35	00:13:11	00:37:12	5°	18°	247°	17874
XI-V	06-12-11	09:26:54	09:40:07	00:13:13	00:35:19	137°	33°	353°	5969
Quakesat	06-12-11	10:20:08	10:26:00	00:05:52	00:40:01	351°	2°	305°	17875
XI-V	06-12-11	11:04:22	11:17:48	00:13:26	00:38:21	189°	35°	339°	5970

30 passes in Script list | Script should be recalculated! | 1 passes selected

OK | Cancel | Recalc | Select All | Unselect All | Auto Select

Figure B.9: Nova for Windows - Satellite Script.

Frequency display.

It also displays the Uplink and Downlink Frequencies, with the Doppler value for the particular selected satellite.
To check this, the path is “Utilities” and then “Frequency display”.
Refer figure 2.20.

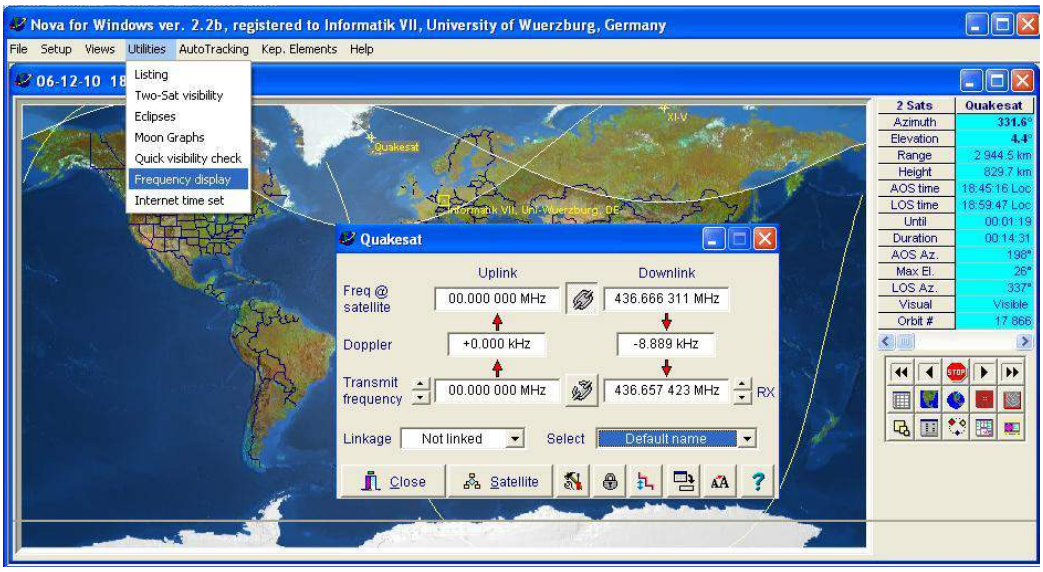


Figure B.10: Nova for Windows - Frequency Display.

To enable **Auto-Tracking** with "Nova for Windows", the first step is to select the type of Antenna Rotator from the Rotator Interface list. The path is "AutoTracking" and then "Antenna Rotator Setup" and then "Interface".
Select the Rotator Interface from the available list.
For the Ground Station at Informatics VII, University of Wuerzburg, "WinRotor" is the Rotator Interface.

For **Yaesu G-5500** azimuth rotator range is 0 to 360 degrees and elevation rotator range is 0 to 180 degrees. Refer figure 2.21.

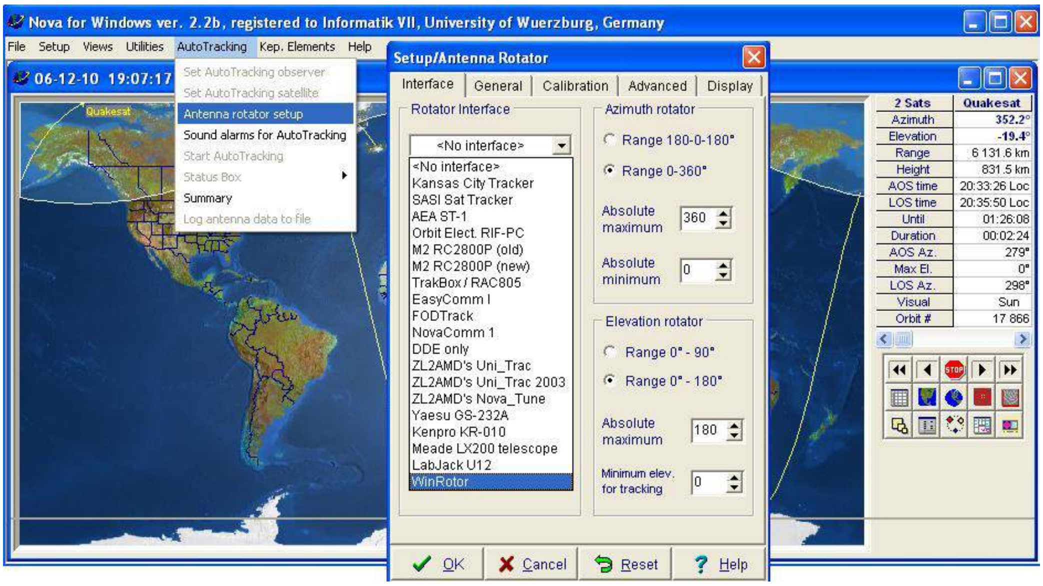


Figure B.11: Nova for Windows - Antenna-Rotator Setup.

More ***help*** regarding "Nova for Windows" can be available from "help" of the display window or please refer its detailed brochure. Refer figure 2.22.

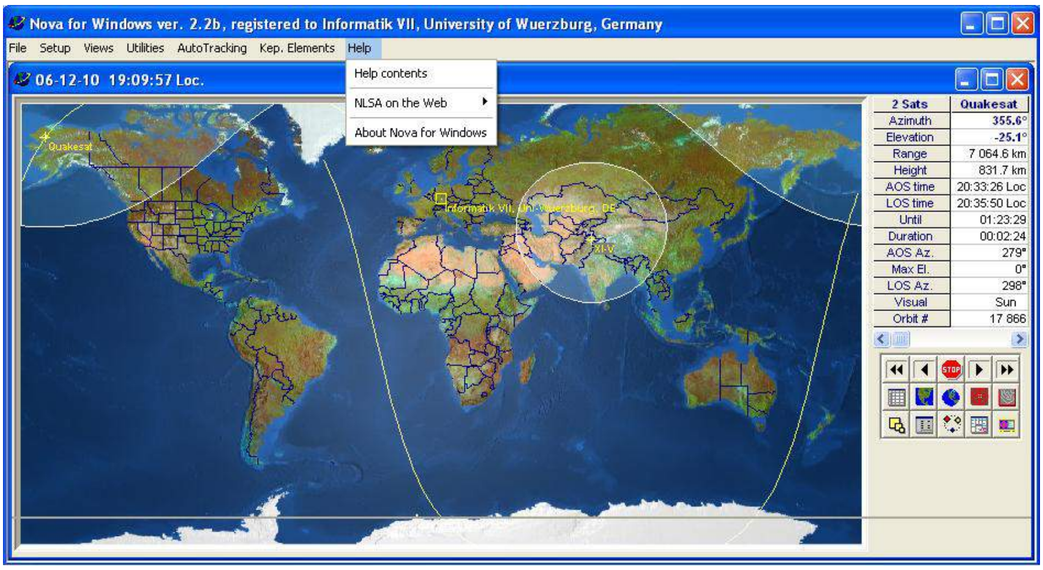


Figure B.12: Nova for Windows - Further Help.

Appendix C

Test Results

Eleven tests are documented in a duration of 10 days from 08 Dec 2006 to 18 Dec 2006. Testing summary is as follows:

08 December 2006	
AOS Time	16:04:08 Local Time
LOS Time	16:17:42 Local Time
Duration	00:13:33 hrs
AOS Azimuth	118 degrees
Maximum Elevation	21 degress
LOS Azimuth	355 degress

Table C.1: Testing - Satellite Script 08Dec2006.

Number of Beacons received : 3.

tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 16:10:18
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 16:10:28
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 16:10:57

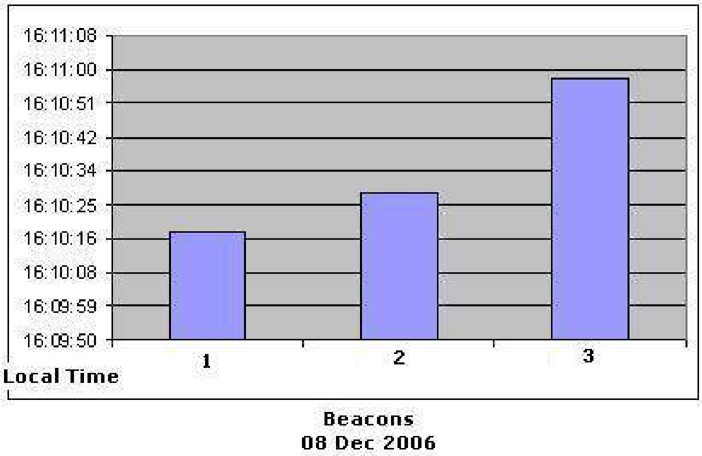


Figure C.1: Test Beacons on 08Dec2006.

11 December 2006	
AOS Time	15:08:46 Local Time
LOS Time	15:19:13 Local Time
Duration	00:10:26 hrs
AOS Azimuth	87 degrees
Maximum Elevation	8 degress
LOS Azimuth	1 degress

Table C.2: Testing - Satellite Script 11Dec2006.

11 December 2006	
AOS Time	16:45:23 Local Time
LOS Time	17:00:18 Local Time
Duration	00:14:55 hrs
AOS Azimuth	139 degrees
Maximum Elevation	40 degress
LOS Azimuth	351 degress

Table C.3: Testing - Satellite Script 11Dec2006.

Number of Beacons received : 1.

tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 15:13:45

Number of Beacons received : 14.

tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 16:50:41
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 16:50:51
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 16:51:01
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 16:51:11
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 16:51:20
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 16:51:31
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 16:51:40
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 16:51:51
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 16:52:01
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 16:52:12
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 16:52:20
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 16:52:31
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 16:52:41
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 16:53:31

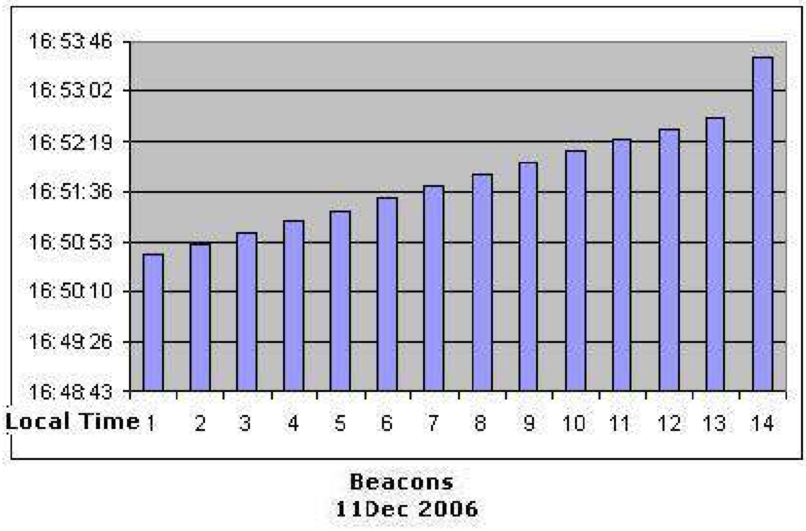


Figure C.2: Test Beacons on 11Dec2006.

Number of Beacons received : 13.

12 December 2006	
AOS Time	18:05:56 Local Time
LOS Time	18:21:18 Local Time
Duration	00:15:22 hrs
AOS Azimuth	178 degrees
Maximum Elevation	52 degress
LOS Azimuth	342 degress

Table C.4: Testing - Satellite Script 12Dec2006.

tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 18:10:52
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 18:11:23
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 18:11:32
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 18:11:43
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 18:11:52
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 18:12:02
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 18:12:13
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 18:12:24
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 18:12:42
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 18:12:53
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 18:13:02
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 18:13:12
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 18:13:22

13 December 2006	
AOS Time	16:07:43 Local Time
LOS Time	16:21:26 Local Time
Duration	00:13:43 hrs
AOS Azimuth	120 degrees
Maximum Elevation	22 degress
LOS Azimuth	354 degress

Table C.5: Testing - Satellite Script 13Dec2006.

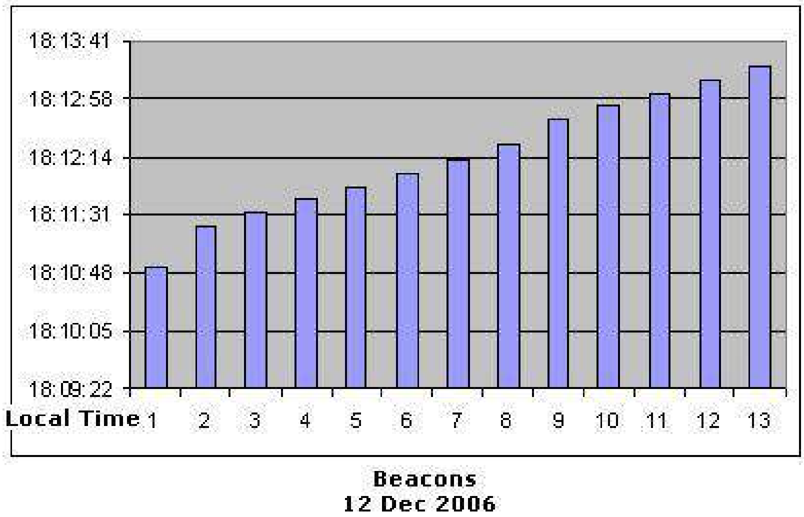


Figure C.3: Test Beacons 12Dec2006.

Number of Beacons received : 14.

tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 16:11:42
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 16:11:53
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 16:12:12
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 16:12:23
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 16:12:43
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 16:13:12
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 16:13:22
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 16:13:32
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 16:13:42
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 16:13:52
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 16:14:02
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 16:14:13
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 16:14:23
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 16:14:42

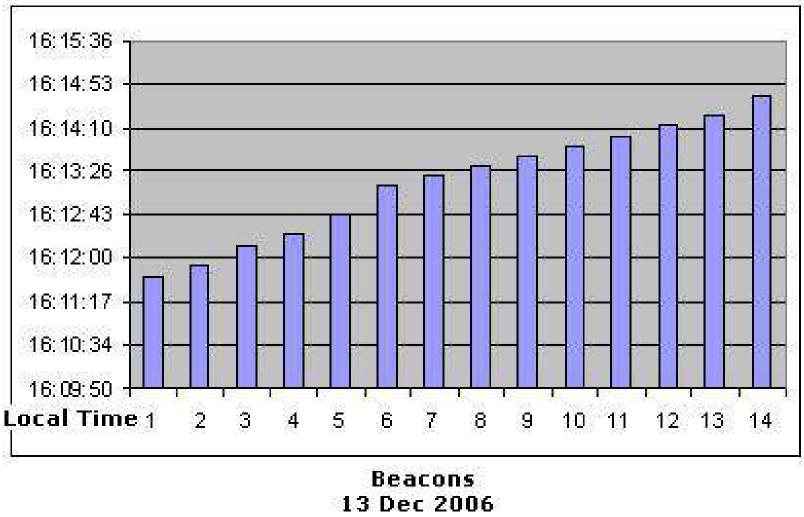


Figure C.4: Test Beacons on 13Dec2006.

13 December 2006	
AOS Time	17:46:29 Local Time
LOS Time	18:02:01 Local Time
Duration	00:15:32 hrs
AOS Azimuth	169 degrees
Maximum Elevation	73 degress
LOS Azimuth	344 degress

Table C.6: Testing - Satellite Script 13Dec2006.

Number of Beacons received : 12.

tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 17:51:48
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 17:51:58
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 17:52:08
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 17:52:18
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 17:52:28
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 17:52:38
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 17:52:49
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 17:52:58
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 17:53:08
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 17:53:18

tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 17:53:30
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 17:53:38

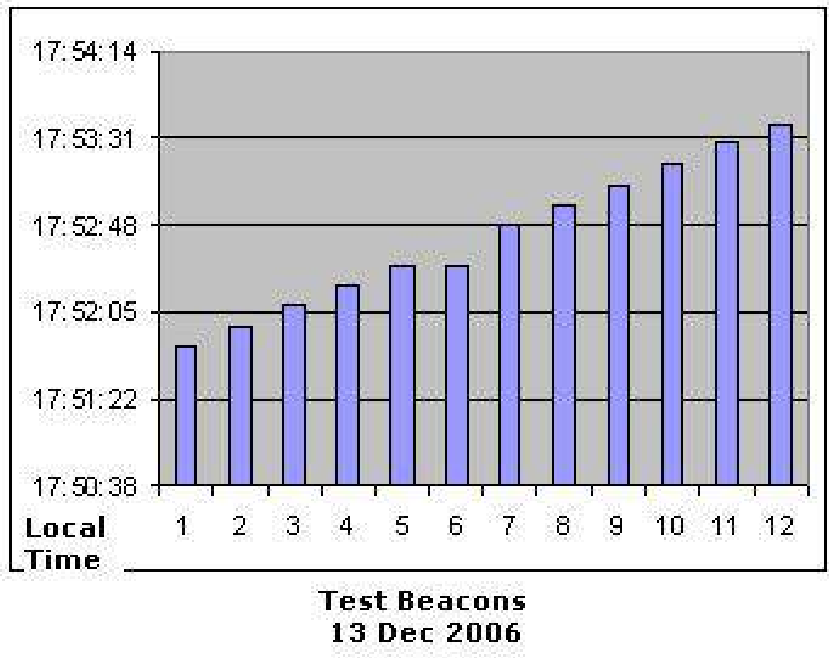


Figure C.5: Test Beacons on 13Dec2006.

14 December 2006	
AOS Time	15:49:05 Local Time
LOS Time	16:01:58 Local Time
Duration	00:12:53 hrs
AOS Azimuth	110 degrees
Maximum Elevation	17 degress
LOS Azimuth	356 degress

Table C.7: Testing - Satellite Script 14Dec2006.

Number of Beacons received : 4.

tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 15:49:39
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 15:54:58
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 15:55:09
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 15:55:29

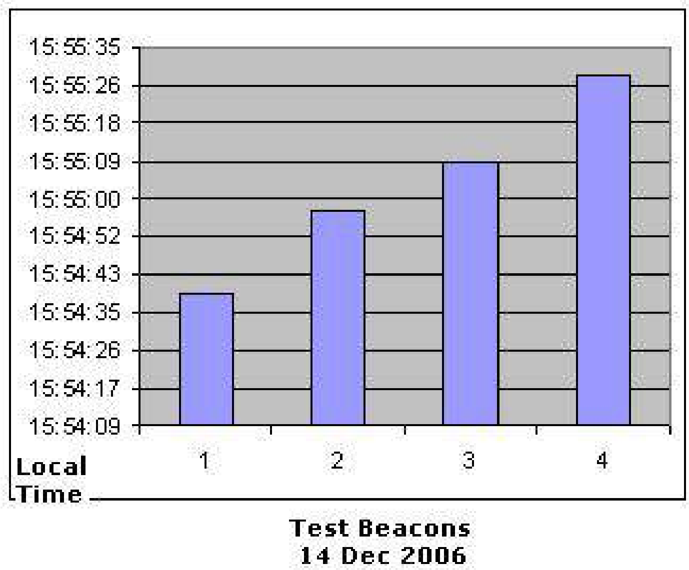


Figure C.6: Test Beacons on 14Dec2006.

14 December 2006	
AOS Time	17:27:10 Local Time
LOS Time	17:42:42 Local Time
Duration	00:15:31 hrs
AOS Azimuth	159 degrees
Maximum Elevation	81 degress
LOS Azimuth	346 degress

Table C.8: Testing - Satellite Script 14Dec2006.

Number of Beacons received : 12.

tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 17:32:33
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 17:32:44
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 17:32:55
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 17:33:03
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 17:33:14
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 17:33:23
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 17:33:34
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 17:33:54
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 17:34:04
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 17:34:13
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 17:34:24
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 17:34:34

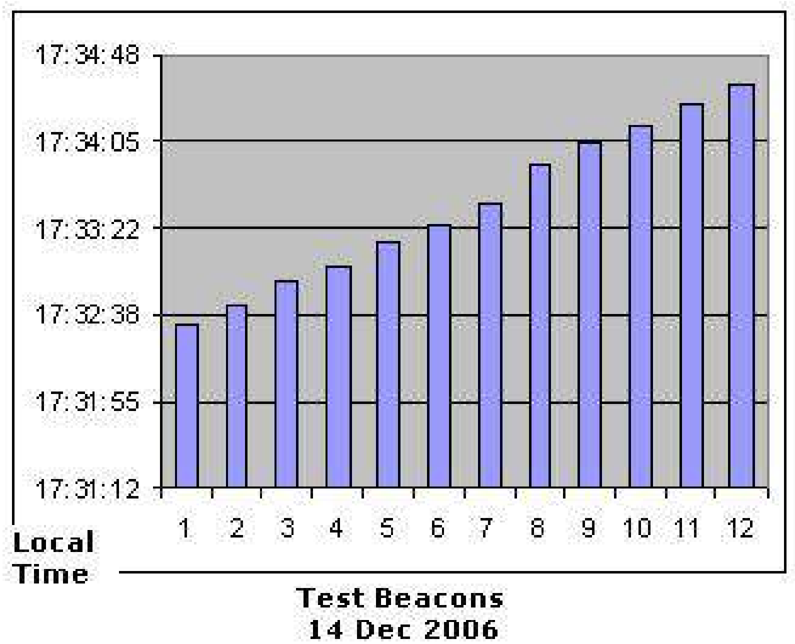


Figure C.7: Test Beacons on 14Dec2006.

15 December 2006	
AOS Time	17:08:00 Local Time
LOS Time	17:23:21 Local Time
Duration	00:15:21 hrs
AOS Azimuth	150 degrees
Maximum Elevation	58 degress
LOS Azimuth	348 degress

Table C.9: Testing - Satellite Script 15Dec2006.

Number of Beacons received : 13.

tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 17:13:10
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 17:13:19
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 17:13:29
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 17:13:41
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 17:13:51
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 17:14:01
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 17:14:10
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 17:14:20
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 17:14:30
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 17:14:40
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 17:14:50
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 17:14:59
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 17:15:10

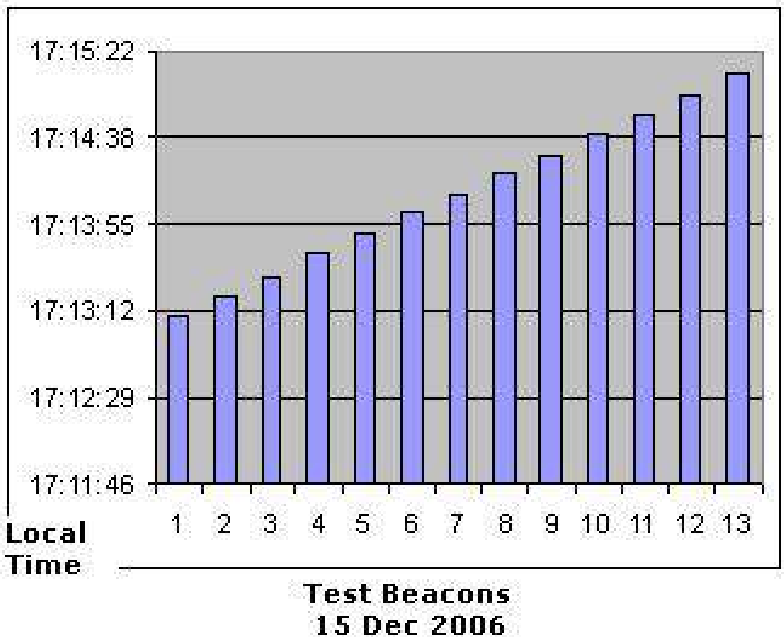


Figure C.8: Test Beacons on 15Dec2006.

18 December 2006	
AOS Time	17:27:10 Local Time
LOS Time	17:42:42 Local Time
Duration	00:15:31 hrs
AOS Azimuth	159 degrees
Maximum Elevation	81 degress
LOS Azimuth	346 degress

Table C.10: Testing - Satellite Script 18Dec2006.

Number of Beacons received : 6.

tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 16:16:07
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 16:16:57
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 16:17:08
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 16:17:17
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 16:17:27
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 16:17:47

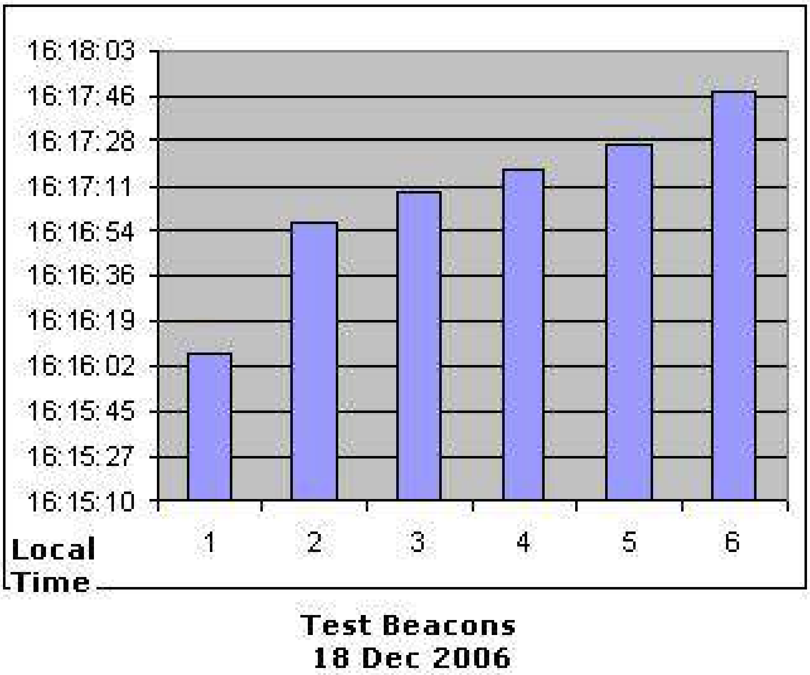


Figure C.9: Test Beacons on 18Dec2006.

18 December 2006	
AOS Time	17:27:10 Local Time
LOS Time	17:42:42 Local Time
Duration	00:15:31 hrs
AOS Azimuth	159 degrees
Maximum Elevation	81 degress
LOS Azimuth	346 degress

Table C.11: Testing - Satellite Script 18Dec2006.

Number of Beacons received : 12.

tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 16:50:41
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 16:50:51
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 16:51:01
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 16:51:11
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 16:51:20
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 16:51:31
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 16:51:40
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 16:51:51
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 16:52:01
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 16:52:12
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 16:52:20
tnc4e2: fm KD7OVB to QST ctl UI pid=BB len 255 16:52:31

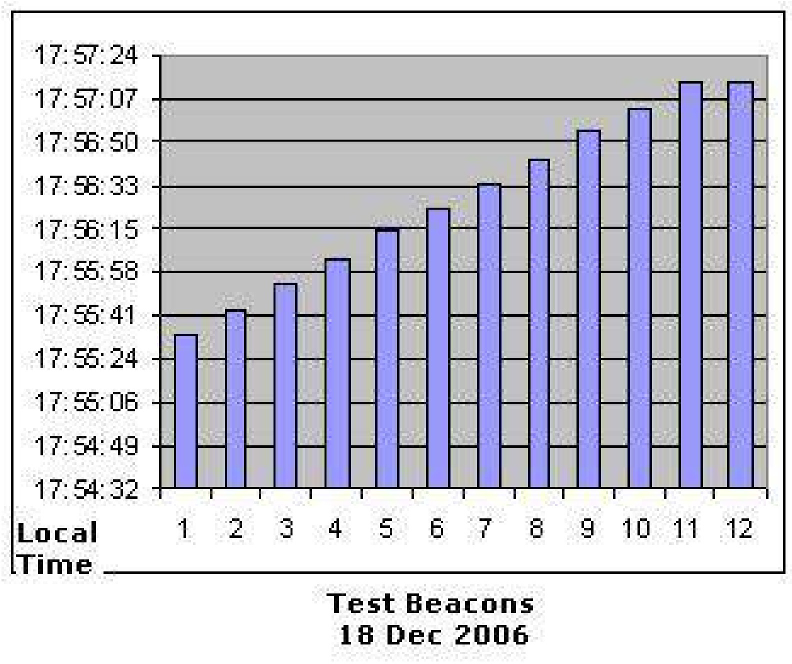


Figure C.10: Test Beacons on 18Dec2006.

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