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Radio Astronomy at Schools

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Abstract

The document outlines the development of a small radio telescope that shall be installed at schools to interest students in science and technology. It is based on existing commercially available satellite TV equipment. Safe assembly and operation of the telescope were primary drivers in the design of the system, along with the need to keep the cost down to ~6,000 Euros. The telescope uses a 1.2 metre diameter dish and a receiver operating at Ku band (10-12 GHz). The system has a basic tracking capability, and is remotely commanded through a computer interface. Detailed manuals were written to enable students to assemble, calibrate and operate the telescope themselves, under the guidance of a teacher. The performance of the prototype telescope was evaluated, and Sun and Moon observations were executed. These results were discussed with teachers and an astronomer. It is concluded that although the low cost of the system leads to limitations in sensitivity and pointing accuracy, there are nonetheless significant pedagogical benefits from this project in a variety of educational subjects. A field trial is proposed of a number of these telescopes in ESA member states.

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Terms and Abbreviations

A/D	Analogue to digital
API	Application Programming interface
AZ	Azimuth
C-Band	Frequencies from ~ 4 – 6 GHz
Cyg	Cygnus
DVB	Digital Video Broadcast
EL	Elevation
GUI	Graphical User Interface
MFC	Microsoft Foundation Class Library
Ku-Band	Frequencies from ~ 10 – 12 GHz
L-Band	Frequencies from ~ 1 – 2 GHz
LNB	Low Noise Block
PC	Personal Computer
Sat	Satellite
SDK	Windows Software Development Kit
TV	Television

1 Aims of the project

The goal of the project "Radio Astronomy at Schools" was the design and assembly of a radio telescope kit that can be used for the education of students. This in turn would inspire the students to pursue further activities in science and technology. Radio astronomy is an interesting and modern science that complements the more common optical astronomy that schools commonly perform. Radioastronomy encompasses different disciplines such as physics, astronomy, and computer science. One major advantage is the feasibility of daytime observations, thereby allowing for its integration into regular school lessons.

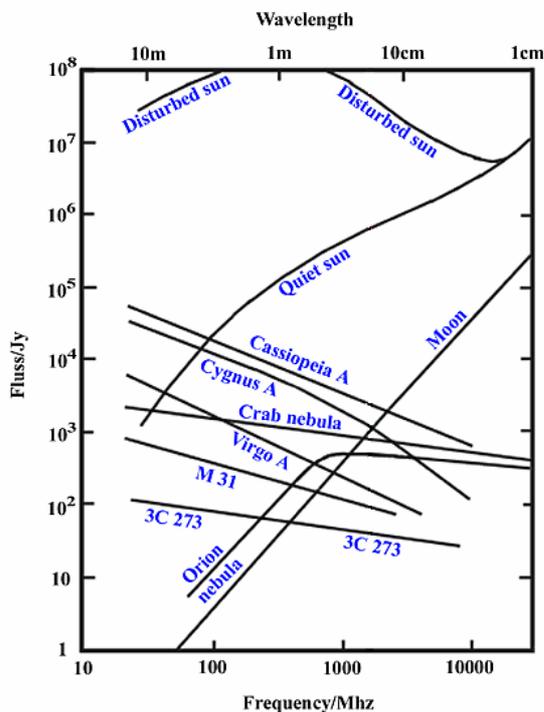


Figure 1 The strongest radio sources (taken from [2])

A prototype of a radio telescope kit was developed which contains all of the required subassemblies. Key design drivers were the safe installation and operation of the telescope by students, and costs that could be reasonable for schools. For example, the radio telescope contains a surge protection system. The telescope can be installed by the students with guidance of a teacher and the provided manuals. The hard- and software is well documented to allow the development of future improvements.

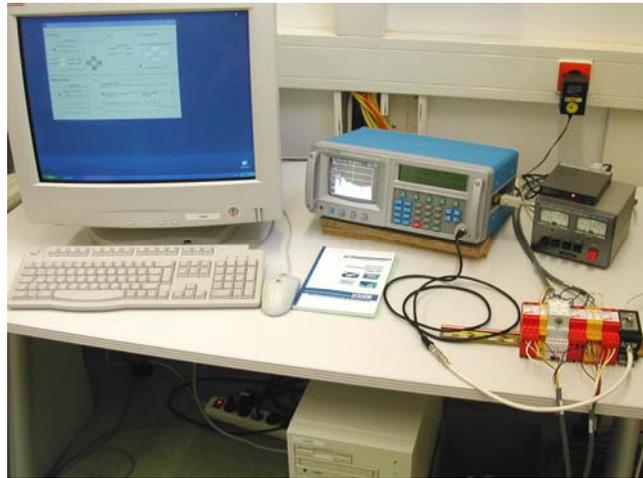


Figure 2 Outdoor and Indoor unit of the school radio telescope

This project provides multi-disciplinary, interactive, exciting learning opportunities for the students who can cooperate by working together in teams to build and operate the telescope. Students for example with interests in astronomy and physics might plan, execute and analyse observations. Students with interests in computer science might develop software for data reduction, visualisation and analysis.

In the future, the internet could be used to initiate communication between student teams in different ESA Member States to exchange their experiences of radio astronomy and possibly to make joint observations.

2 Survey on existing school radio astronomy projects

A survey on the web and in publications [1],[2] has shown that school and amateur radio telescopes already exist. Basically, radio astronomy projects can be classified into two groups:

- Absolutely low cost projects
- Semi-professional telescopes

The equipment used and the observations made are summarised in the next sections.

Low Cost School Projects

The telescope architecture is typically characterised by the following parameters:

- A dish with a diameter from 0.6m up to 1.5m is used, usually installed on a fixed mount without the antenna rotator
- As front-end unit, a commercial LNB is used, typically in Ku-Band for Europe

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- Signal measurement is made with a simple receiver, often using a modified satellite-finder
- Data recording is performed on request, often with a computer by using home-made A/D-converters
- The system is not well calibrated

Documented observations:

- All of these telescopes were used to detect the radiation of the quiet Sun
- In some cases, Moon observations are documented
- The observation of galactic point sources was not realised due to the restricted sensitivity, with exception of the SRT that uses a 2.3m antenna as described below.
- Long term observations were not realised due to the lack of adequate tracking capabilities

Despite of the restricted capabilities of this school telescopes, the students learn a lot about radio astronomy and how to measure signals from the sky. In addition, they learn how to use A/D converters and how to record the data with a PC.

Semi Professional Telescopes

Universities typically operate these educational telescopes. They use professional antennas of larger size and in most cases special receivers. The technical capabilities can be characterised as follows:

- Dishes with diameters from 3m up to 10m are used, installed on a fixed mount, movable in 2 axes
- As front-end units, commercial LNBs and special antennas are used in several frequency bands starting from 1.4 GHz via C-Band up to Ku-Band
- Special back-end receivers are used
- Data recording is performed automatically by computer, and raw data are partly published by Internet
- The systems are well calibrated

Common documented observations

- Sun, also long term Sun activity observations
- Hydrogen spectral line
- Galactic point sources (e.g. Cygnus A, Taurus A, Sagittarius A)

Unlike low cost telescopes, these university telescopes are operated in the same manner as professional ones. They are usually controlled by specialised software on a PC located in a "control room". The systems are calibrated to achieve a more accurate measurement of the received signals. Since these telescopes use larger antennas and better receivers, a better sensitivity is achieved that makes it easier to detect galactic point sources. Nevertheless they are used more for education purposes than for science.

Two kits were found in the survey of existing radio astronomy kits, both of which were developed in the United States and are available for purchase.

The Small Radio Telescope (SRT) from the MIT Haystack Observatory

The SRT is a 2.3m radio telescope operated in L- or C-Band. The design and functionality look similar to professional telescopes, but dish size and sensitivity is more restricted. The kit costs about \$6000 and can be now ordered from Europe. A summary on the main parts of the kit is given below:

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Satellite Dish:

- Diameter 2.3m, shipped in segments, beam width 7.0 Degrees (L-band)
- Weight with mount 72.5 kg
- Azimuth and Elevation positioning

Receiver:

- Analogue and digital receiver is available, frequency range 1.3 -1.8 GHz
- Typical system temperature 150K
- Square law detector
- Electronic noise-source is provided for calibration

Assembly:

- Instructions available on project home page
- The system must be installed with care due to the large antenna

Software:

- JAVA program for telescope control is available on the Internet. The look and feel is like a professional telescope and may be difficult to use for students at schools.

The NASA Radio Jove

The NASA Radio Jove Kit is very different from the SRT. It is dedicated to Sun and Jupiter observations at 20.1MHz, which is well suited for the observation of noise storms. Due to the low observation frequency, a dipole antenna is used instead of a satellite dish. The kit contains specific components for the receiver device and the antenna. Additional material is needed to complete the telescope. The kit itself costs \$125, and for the other equipment about \$130 is necessary. So it is very a low-cost system. Some skills in electronics are required for the assembly of receiver and antenna, e.g. soldering. A well-illustrated assembling manual is available on the web, as well as video sequences for some work steps. The data are recorded and post processed. Data samples can be found on the Radio Jove Homepage. For schools without their own Radio Jove, observation data are published on the Internet.

Conclusion from Survey

A number of school activities were identified in the survey. Low-cost hardware is used in the majority of these projects to discover the basics of radio astronomy. Few schools cooperate with universities to install more powerful telescopes. The focus of all projects is education rather than on publishable-quality scientific work. Two radio telescope kits are available in the USA. Radio Jove is specialised for observations of Jupiter. The Small Radio Telescope (SRT) is a radio telescope kit for L- and C-Band observations, including an antenna positioning system. The SRT is now also available in Europe. Currently there is no radio telescope kit provided and supported from within a Member State of ESA.

3 Survey on European providers of satellite TV components

The aim of the market survey was the collection of up-to-date information about vendors and distributors of satellite TV equipment, technical parameters of individual products and prices. The following system parts were included in the survey:

- Satellite dishes
- LNB
- Positioning equipment (rotators)
- Amplifiers
- Cables
- Dish mounts
- Measurement equipment

The individual data sheets are provided on CD-ROM in PDF or HTML format. The results of the survey on the main parts are summarised below. Information related to other equipment is included in the report *Survey on European Satellite Television Systems* [4].

3.1 Satellite Antennas

The satellite dish focuses all incoming electromagnetic waves in direction towards the LNB and provides signal amplification. Satellite dishes for the frequency range from 10.7 GHz to 12.75 GHz were focused on in the survey. The essential parameter of a satellite dish is the effective collecting area. The larger the effective collecting area, the higher is the gain or the amplification of the antenna.

European TV satellites, like Astra and Eutelsat satellites, transmit with high power. Therefore small and less expensive antennas are widely used in the consumer market, in conjunction with sensitive satellite receivers. Antennas with diameters up to 120 cm are commonly in use. However, larger antennas are available if needed for special purposes.

Two types of antenna constructions will be distinguished; offset antennas and prime focus antennas. Offset antennas with diameters from 0.6 m to 1.2 m are typically used by the consumer market. Larger antennas (1.5 m and larger) are generally constructed as prime focus antennas.

Besides the antenna collecting area, the gain of the antenna depends on the operating frequency. The antenna gain comprises the range from 40 dBi (100 cm diameter) to 48 dBi (240 cm diameter). The differences in gain between 100 cm, 120 cm and 150 cm diameter dishes are about 1.5 dB respectively. However, with increasing antenna diameter the antenna weight and wind load also increase. This must be considered in the design of the dish support unit and positioning system, and it would possibly have an impact on the allowable location of the telescope. In addition, the price of satellite dishes increases rapidly with increasing dish size.

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It was proposed to use an offset antenna with a diameter of 1.2m. This is the largest antenna in the consumer area that provides a good price-performance ratio. This size also keeps the requirements for transport, location and footprint to a manageable level.

3.2 Rotator Units

Different kinds of positioning devices exist. Low-cost dish movers are used for the reception of geostationary TV satellites. Radio amateurs use more powerful devices for Earth-Moon-Earth and satellite communication which can move in azimuth and elevation direction. Beside these, there are special units for the positioning of optical telescopes.

Consumer Positioners for Multi-Satellite Reception

These units are designed for the reception of multiple geo-stationary TV satellites. Therefore, azimuth positioning is provided only in a range of several degrees. They are available for about 100€. The restricted positioning capability is not appropriate for astronomy applications.

AZ-EL Positioners

YEASU G-5500:

The YEASU G-5500 is an azimuth-elevation rotator combination for a satellite Earth station or other systems with one common control unit. This rotator is used by radio amateurs, e.g. for Earth-Moon-Earth-connections. The price for the rotor unit and the related PC interface is about 1190 €.

EGIS AZ/EL Mount:

A professional solution for antenna rotors is the AZ/EL mounts by EGIS, used by satellite operators and TV stations. The rotor can handle antennas with a diameter of up to 2.5 m. EGIS makes available the additional accessories needed for proper radio astronomical applications. These units assure an excellent quality but are expensive. The EGIS kit "PROFI-TRACKER" and the required options cost about 5300 € excl. VAT.

Positioners for optical telescopes

Optical telescopes may also be mounted on a positioning unit. Controller devices and step motors with high precision are typically used in this area. They provide interfaces to astronomy software. With respect to functionality and precision, these units are ideal for astronomy. The main disadvantage for using such devices with a radio telescope is the limited force of the actuators, which cannot hold a satellite dish with the dedicated wind load. These units are not designed for permanent outdoor installation. The devices cost about 1000 to 1500€ (mount not included).

With respect to the budget of the telescopes it was proposed to use the YAESU G5500 antenna rotor.

3.3 Measurement Receiver

The selection of the most suitable receiver device was the most important and difficult task, because the datasheets of the device candidates found during the survey only contained information about parameters related to processing of DVB satellite signals. Therefore, the survey was completed by actual testing of candidate devices.

Requirements

Beside the positioning system, the receiver plays a central role in the telescope concept. The device shall provide the features noted below:

- signal power measurement of noise signals
- computer interface with access to the measurement results and receiver control
- power supply and control for the Low-Noise-Block

Sat-Finder

Sat-Finders are tools for adjustment of satellite dishes that provide a value of signal strength on an analogue or digital display. The small devices are available at prices from about 40 € to 140 €, but additional equipment would be necessary for the radio astronomy application. An additional power supply is needed to power the LNB and the device itself. More complicated is the access to the measured values. A PC interface must be developed that may also contain an analogue to digital converter. The access to the signal strength values inside the receiver is a critical task, which cannot be easily executed by students.

Experiments with the sat-finder DIGISAT PRO showed a poor sensitivity and accuracy of the measurements, resulting from the low-cost architecture of these devices. Together with the missing PC interface this is the reason why it is not proposed to use such devices in the radio telescope.

DVB Receiver

Other potential measurement devices are satellite TV receivers. Analogue receivers are replaced on the market by digital satellite receivers for DVB broadcasts. Some DVB receivers (for example DIGIT 4 S by Technisat) provides a serial PC interface (RS232). In addition, DVB-S PC cards are available. These consumer devices cost about 100 to 500€.

Even though a PC interface is available, no access to the received signal or to the signal strength is provided at the interface. It could probably be made available through a firmware modification executed by the device vendor. An official request for tender in July 2004 for implementation of these modifications was unfortunately rejected from TechniSat for commercial reasons. Due to the relatively small number of radio telescopes it must be assumed that other vendors would decide similar. Therefore this simple and cost effective solution drops out.

Commercial measuring devices

For commissioning and service of TV stations, TV distribution and cable TV systems measuring devices with a wide functional range are offered. They provide accurate signal level measurement. However, few devices enable access to the measured signal values via PC interface, for reporting and monitoring in cable TV networks.

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More advanced measurement receivers with a PC interface are available at prices of 3000 to 6000€. These commercial devices comprise further various functionalities that are not required for the radio telescope.

Bearing in mind the accuracy of measurement and the possibility of data access via the PC-interface, it was proposed to use the commercial measurement receiver AMA 301 by KWS Electronics.

3.4 Conclusion on survey

With respect to technical requirements and costs, the following main parts were used for the radio telescope:

- 1.20m offset dish antenna with LNB by Golden Interstar
- YAESU G5500 AZ/EL positioner with PC interface
- Professional Measurement receiver KWS AMA 301
- Balcony stand by Technisat

4 Design of the telescope

The design of the radio telescope is based on commercially available components. Safe installation and operation by students is absolutely mandatory. The telescope must be robust enough to withstand errors in operation. Due to the restricted budget of most schools, the purchase cost must be carefully considered.

The radio telescope consists of the main parts noted below:

- outdoor unit (antenna and rotator)
- indoor unit (measurement receiver and controller for positioning)
- standard PC with RadioAstro software applications
- surge protection

The outdoor and indoor unit are connected by cables with a maximum allowable length of 50 m. In addition to the antenna cable, two shielded cables are used for the positioning system. Each cable between the outdoor and indoor unit is protected against over voltage. The following sections contain a summary of the telescope parts, with detailed information given in the *Design Description* [5].

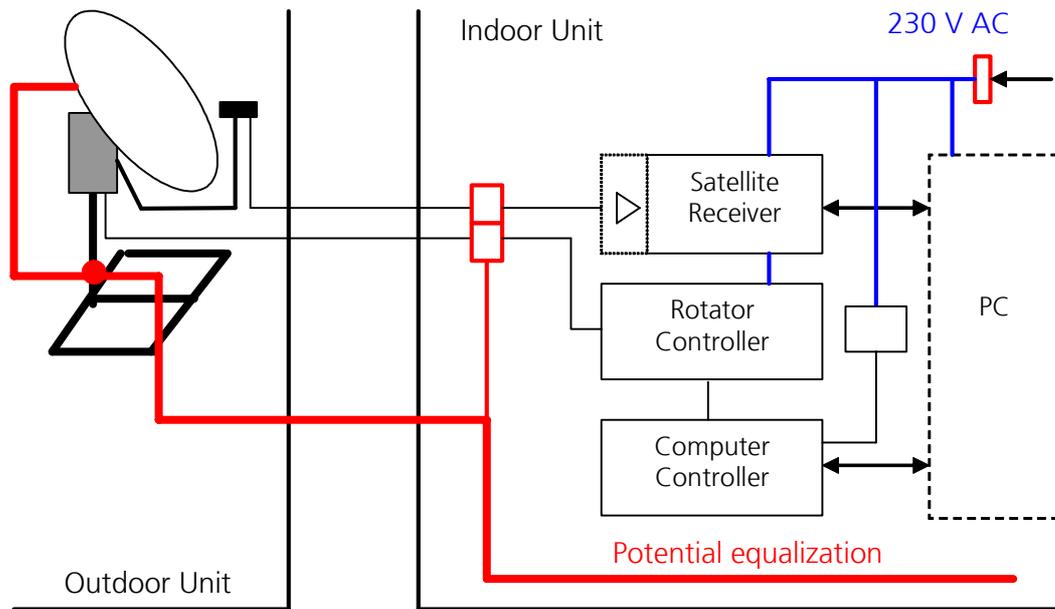


Figure 3 Main components of the radio telescope kit with surge protection

4.1 Outdoor Unit

The outdoor unit is mounted on a Technisat balcony stand (Figure 2, left-hand side). The unit is fixed with four concrete slabs commonly available in do-it-yourself hardware stores. The telescope can be installed at a flat area, for example at balconies, gardens or flat roofs. The prototype has been implemented with a 1.20 m offset antenna from TechniSat.

The antenna can be moved by the YEASU G-5500 Antenna Azimuth-Elevation Rotator. This rotator consists of a double-motor unit (outdoors), a controller device (indoors) and a computer control interface module (indoors). The red elastic band as shown in Figure 2 was added after commissioning to reduce the impact of the slack in the gear of the azimuth rotor. A special dish support frame was designed to provide a stable connection between antenna and rotator.

An LNB unit by vendor Golden Interstar was used. The noise figure is listed as 0.3dB in the datasheet. The LNB consists of mixer and amplifier units, and transforms frequencies from the Ku-Band to the SAT-IF (L-Band). For this conversion, the LNB includes two internal oscillators. The switching between the both oscillators for selection of Low- or High-Band is controlled with a 22 kHz signal, which is generated from the receiver and transmitted via the receiver cable.

4.2 Indoor Unit

The indoor unit comprises the measurement receiver, the controllers of the positioning system, the PC and the surge protection. The signal amplifier is optional. The right-hand part of Figure 2 shows a photo of the indoor unit of the prototype.

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The SAT measurement receiver AMA 301 by KWS is used to measure the signal strength. It provides the following features useful for radio telescope applications:

- Signal level measurement of L-Band (950 – 2150 MHz) signals
- Tuneable measurement frequency with 4.3 MHz bandwidth
- Signal level indication in dB μ V or dBm with 0.1 dB resolution
- High input sensitivity (-60 dBm or better)
- Signal level indication and transfer via RS232 interface in real-time
- Power supply 11.5 to 19 V and 22 kHz signal provision for the LNB

Additionally it allows:

- Display of the frequency spectrum (helpful to verify the LNB quality and to determine disturbing radiation sources)
- Configuration of the measurement receiver by the PC, via the RS232 interface

The Motor Controller (back right-hand unit in the figure) of the rotator G-5500 controls both motors for the adjustment of elevation and azimuth. Manual control of position is performed with different switches on the front of the controller. The antenna position may be observed on two analogue indicators. The Computer Control Interface is placed on top of the Motor Controller. It allows the positioner to be controlled by a computer.

The PC is not included in the kit, but a standard commercially available PC is suitable for use in the radio telescope kit. Software must be installed for the telescope operation and for additional tools (e.g. the free astronomy software “Les Cartes du Ciel”), but no hardware changes are needed.

The surge protection devices are mounted on the top-hat-rail shown on the right-handed side of Figure 2. The rail contains also a speed control switch for improvement of the positioning accuracy.

4.3 Surge protection

Lightning strikes close to the radio telescope can cause danger to telescope operators and equipment. The surge protection concept helps to arrest disturbing energy in as safe a manner as possible. Lightning protection of the building shall be implemented and operational prior to installation of the radio telescope system.

Protection devices are inserted into all cables that connect indoor and outdoor unit. All disturbing energy, which is injected on cables going to system, shall be arrested to ground by the surge protection. Dedicated devices by Dehn & Söhne are used as appropriate for the antenna or motor control cable.

Figure 4 shows the connection scheme for the protection devices, Speed Control Switch, Motor Controller and outdoor unit. The protection modules must be mounted on a top hat rail. The *Design Description* [5] contains a detailed description of the protection concept.

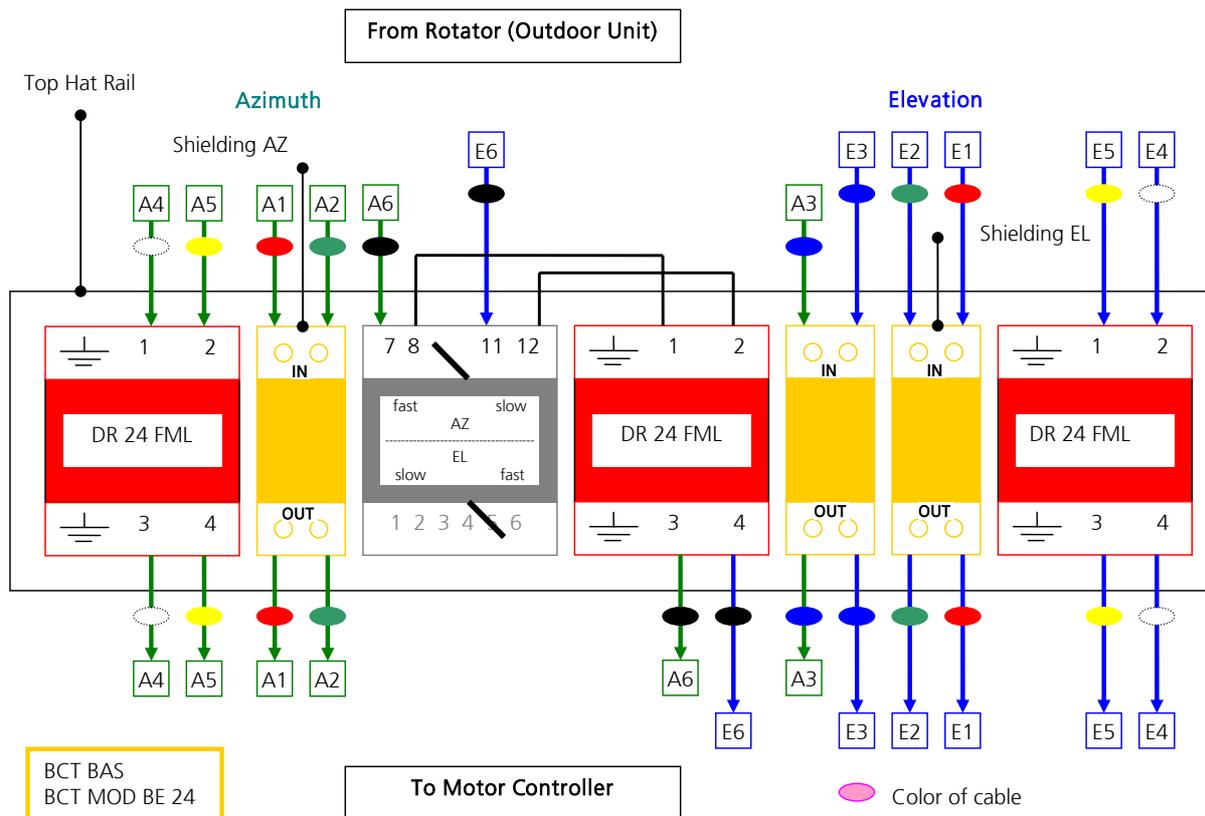


Figure 4: Connection of Rotator Control Cables to Surge Protection

4.4 RadioAstro Software

The RadioAstro Software allows control of the receiver and positioning unit, and recording of the measured values. A graphical user interface (GUI) is provided for easy operation of the telescope as shown in Figure 6. The software will run on a standard PC with Windows2000 or WindowsXP operating system.

Software Architecture

The architecture of the RadioAstro is shown in Figure 5. The operating system at the lowest layer provides access to all system resources such as serial ports, hard disks, system time and Windows management via the Windows Software Development Kit (SDK). Using this Windows SDK, the RadioAstro software comprises two libraries (DLLs) at the next layer, one for the positioning system and one applicable to the measurement receiver. Both libraries feature an easy-to-use application-programming interface (RadioAstroPos API and RadioAstroMeas API respectively) for the user application. The user application at the highest layer is the Graphical User Interface (GUI), which allows the user to control and observe all tasks for the Radio Telescope Kit. The report *Design Description* [5] contains a description of API and user application.

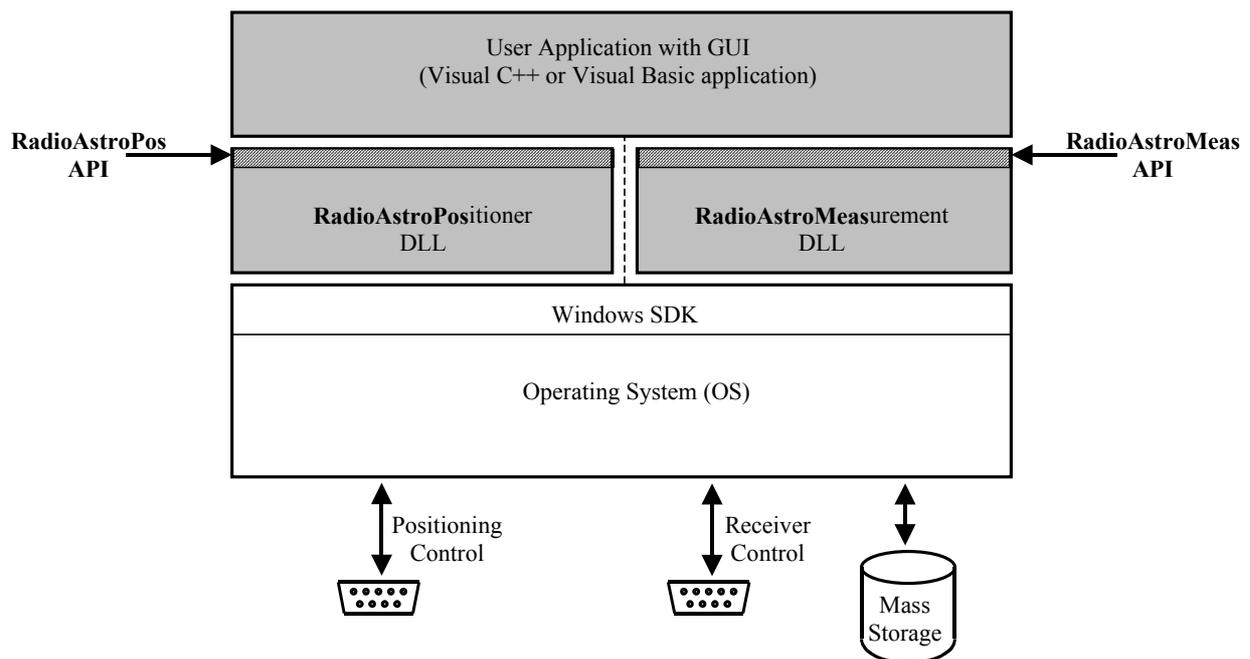


Figure 5: Architecture of RadioAstro software

Graphical User Interface

Figure 6 shows the Graphical User Interface (GUI) of the RadioAstro software, which allows the user to control and observe all tasks for the Radio Telescope Kit. The upper part of the main window corresponds to the positioning system, and the lower part to the measurement receiver. Both controller parts work independently of each other. The user interface is implemented in parallel in two programming languages; Visual C++ and Visual Basic. It can be modified as needed by students.

Beginners should favour programming with Visual Basic. The handling is more intuitional, the programme architecture is quite simple and the language is easier to learn. Visual C++ is the more professional solution, but it takes more effort to deal with the complex programme structure (MFC application framework) and the object-oriented C++ programming language.

Visualisation of Results

Gnuplot provides a first graphical evaluation of measurement result. This freeware programme can be started with proper input data and settings directly from the RadioAstro software with one single push of a button. Post processing and graphical visualisation can be performed with Microsoft Excel. The measurement data file may be imported directly from RadioAstro software into Excel upon completion of the measurement. More complex post processing could be managed best with Visual Basic scripting inside Excel.

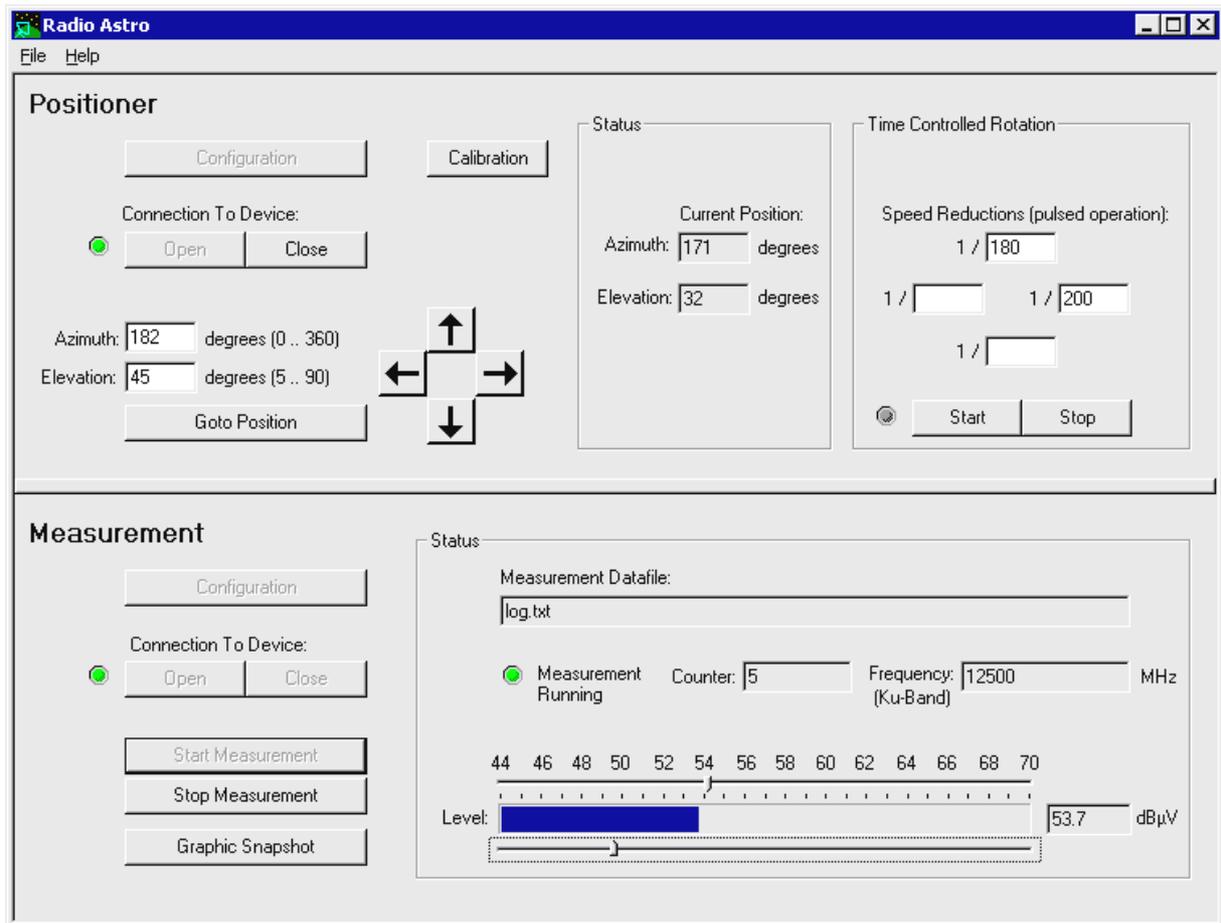


Figure 6: Graphical User Interface of RadioAstro software (Main window)

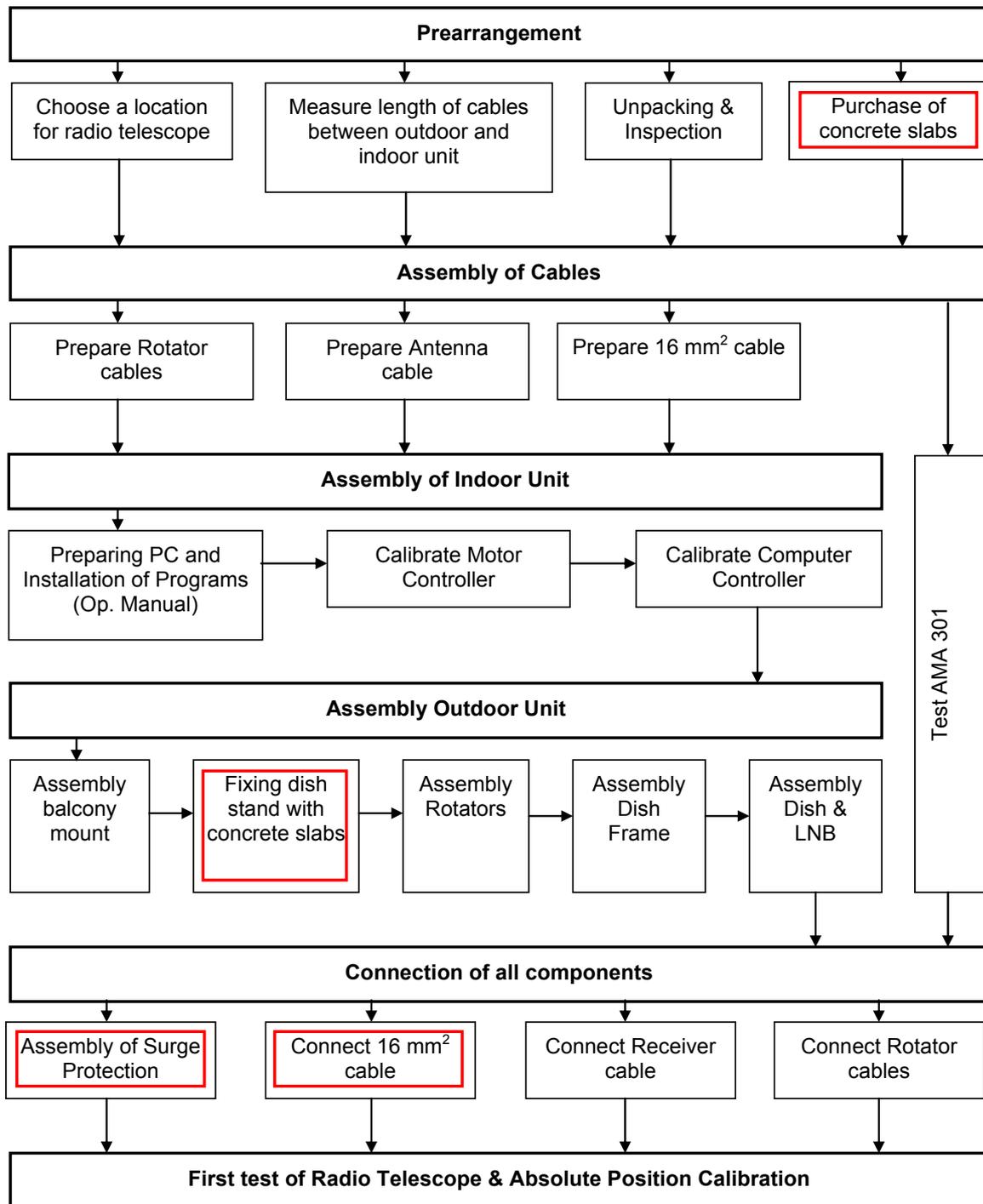
The public domain astronomy software *Les Cartes du Ciel* is used to plan observations. It is provided on the CD-ROM of the radio telescope or can be downloaded from Internet.

5 Assembly and Commissioning

The telescope assembly can be executed by students with guidance by a teacher. A detailed *Assembly Manual* [6] has been prepared that contains:

- safety instructions
- parts and tool list
- a work plan
- detailed assembly instructions, illustrated with figures and photos

The work plan is shown in Figure 7. The majority of the tasks can be performed by students. Only the handling of the heavy concrete slabs and the installation of the surge protection must be executed by qualified personnel. A small number of assembly operations require special care and are marked with warning signs accordingly.



- Task must be executed by adults /qualified persons
- Task can be executed by students

Figure 7 Work Flow for Telescope Assembly

6 Evaluation of Prototype

The prototype was installed at a balcony of the Fraunhofer Institute. The balcony permits observation of the sky in the south and south-west directions. First tests showed a slack in the gear of the positioners. Its impact to the observation results could be reduced by slight modifications of the prototype. The telescope allows the observation of Sun, Moon and satellites. Additionally, the AMA receiver provides a spectrum view of satellite signals. Several sample observations were executed and a basic calibration procedure was developed.

6.1 Enhancements to the prototype

Experiments with the telescope showed the limited accuracy of the low-cost positioning system YAESU G5500 rotator. The following problems could be detected:

- A slack in the gear of the motors made the telescope sensitive to wind forces.
- The movement speed is too fast to point exactly to the desired objects.
- The returned value of the current position of the antenna has a low resolution and accuracy (+/- 1 degree with 1 degree resolution).

The rotor unit was inspected. Inside the device there are no opportunities to improve the performance. Two less-expensive modifications were developed which significantly improve the positioning behaviour and which are now part of the telescope kit.

The rotator speed was reduced by diodes inserted into the motor ground wire. The diodes can be short-circuited with a switch to allow for manual selection of normal and slow operation mode. The slow motion enables objects to be tracked. The tracking speed is specified by the on-time of the motor and a period which can be controlled from the telescope software. The cost for the additional diodes, switch and box is about 15€.

Additionally, an elastic band was mounted to pre-stress the azimuth rotator. Such elastic bands are available for few Euros and can be easily mounted. In such a way, the impact of wind and slack could be reduced.

6.2 Sample Observations

At the location of the prototype telescope, the sky can be observed in south and south-west directions only. Several test observations were executed repeatedly, to evaluate a stable operation of the telescope. The *Operating Manual* [7] contains instructions how to execute the sample observations.

Sun Observation

The Sun can be easily detected even if the sky is covered with clouds. "Cartes du Ciel" was used to compute the position of the Sun at the observation time. After the positioning system has moved the antenna to this position, the power level increases. In slow positioning mode, the position of the antenna can be optimised. If the maximum radiation power is detected,

data recording is started. Due to the rotation of Earth, the Sun leaves the antenna beam as shown in Figure 8. The power level of Sun is ~ 10dB above the level of the surrounding sky, depending on the observation frequency.

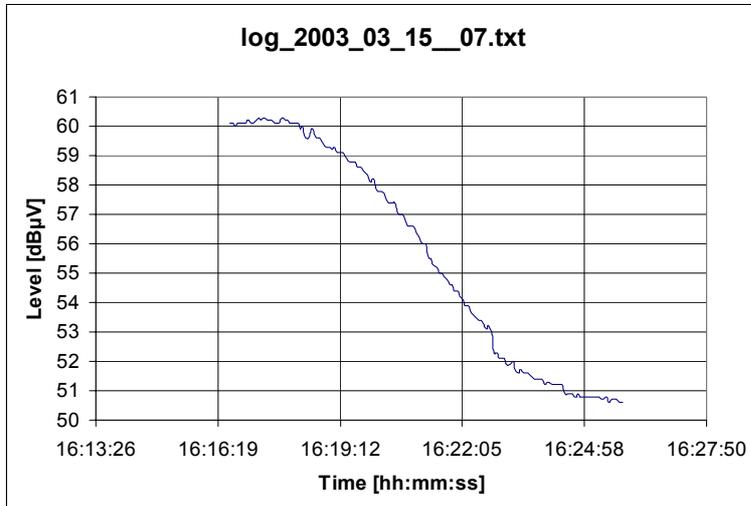


Figure 8 Sun: Frequency = 12600 MHz, Horizontal Polarization

Sun Tracking

The slow-speed mode of the positioning system allowed for the implementation of a basic tracking functionality, which was tested with a Sun observation. The dish tracked the Sun for about one hour. After this time, the antenna was still pointed to the maximum of Sun radiation.

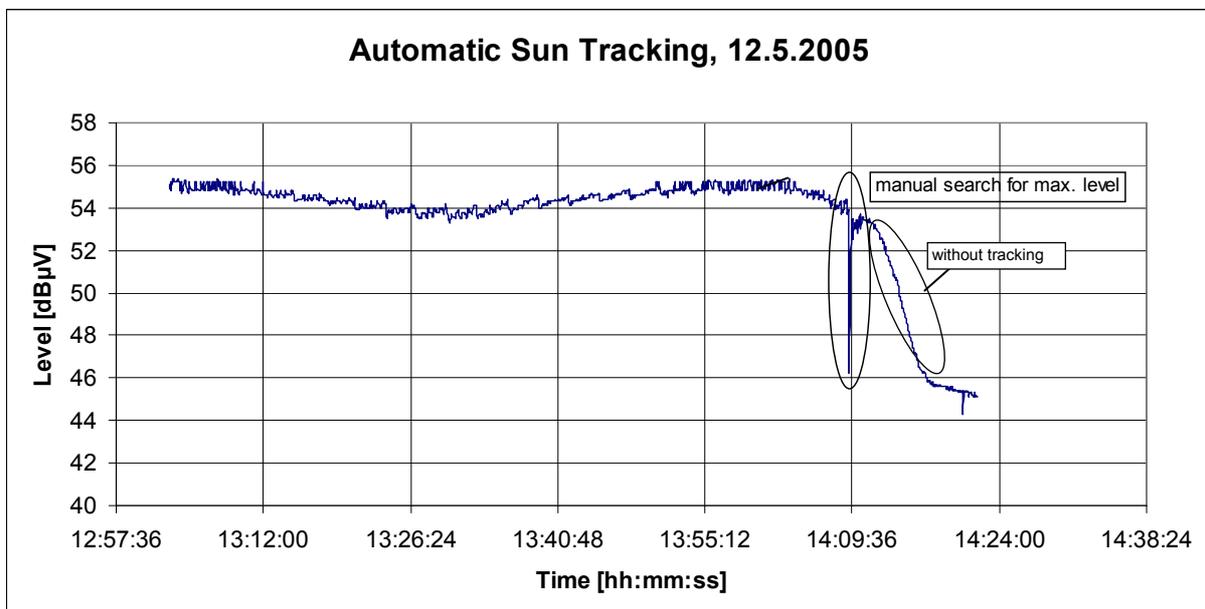


Figure 9 Sun Tracking

Moon Observation

The observation of the Moon at daytime is also possible, when it is often invisible for optical instruments. "Cartes du Ciel" is needed to determine a suitable observation time and coordinates. The radiation level of the Moon is 10 times lower than the level of Sun. It lies about 1dB above the surrounding sky. The Moon is the weakest source that can be easily detected with the prototype.

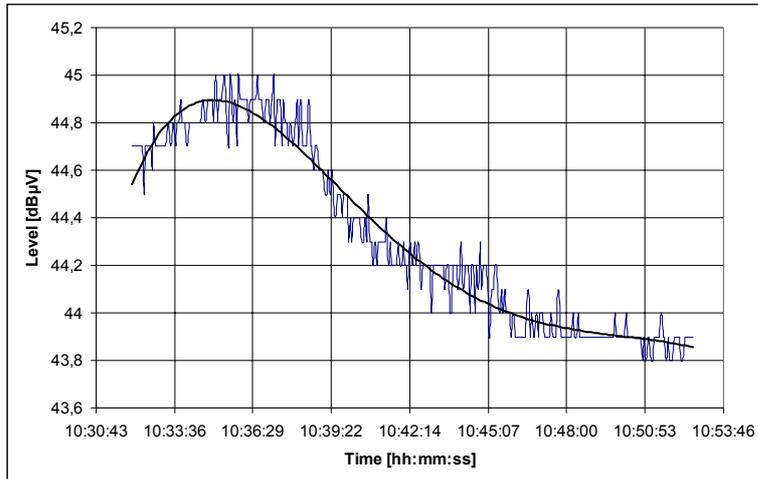


Figure 10 Moon: Frequency = 12600 MHz, Horizontal Polarization

6.3 Calibration

For cost reasons the telescope was calibrated without a local noise reference source. Due to the restricted sensitivity of the telescope, the Sun was used as reference source. The daily radiation level of Sun is published on the Internet. The *Calibration Report* [8] contains more information.

Effective Antenna Size

The geometric size of a 1.20m antenna is about 1.13m^2 . As expected, the effective antenna size A_{eff} is smaller [12]. Therefore, the efficiency factor of the antenna is 0.745. This value is in the expected range.

System Temperature T_{sys}

With the knowledge of A_{eff} and the observation of a radio source with known flux S , the system temperature can be calculated. Well known point sources like Cassiopeia are often used as calibration sources, since their flux is very stable. However, due to the limited sensitivity, we use the Sun as a calibration source. In contrast to A_{eff} , T_{sys} will change over time. Therefore the calculated value is valid for a short period only.

If the telescope is pointed to a radiation source, a power P is measured. Pointed away from any source a base power level P_0 is measured, mainly caused by the noise of the telescope parts. The ratio between the power on source and off source is referred to as Y-factor. It can be computed from the on source (U_{dB}) and off source ($U_{0\text{dB}}$) signal level values expressed in dBµV as follows:

$$(1) \quad Y = \frac{P}{P_0} = 10^{\frac{UdB-U_0dB}{10}}$$

T_{sys} can be computed with (2), whereas K is the Boltzmann constant:

$$(2) \quad T_{sys} = \frac{S \cdot A_{eff}}{\frac{P}{P_0} - 1} \cdot K$$

Calibration of Tsys with Sun observation

The results of a Sun observation and reference values for the radio flux of the Sun published on the Internet [14] are used with equation (2) to determine the current value of T_{sys} :

Parameter	Value	Comment
S	402.1 sfu	1sfu = 10000J = 10^{-22} W/m ² /Hz
Aeff	0.8425m ²	
K	1.38^{-23} J/K	Boltzmann constant
P	53.5 dBuV	Observation at 2005-08-05 – 16:20
P ₀	44.0 dBuV	Observation at 2005-08-05 – 16:20

With this data a system temperature T_{sys} of 310.0 K was computed.

Discussion on resolution and integration time

The resolution (3) or minimum measurable temperature increase (4) of a radio telescope can be calculated by the "Dicke" expression [13].

$$(3) \quad \frac{\Delta P}{P} = \frac{1}{\sqrt{B \cdot \tau}}$$

$$(4) \quad T_{min} = \frac{T_{sys}}{\sqrt{B \cdot \tau}}$$

where B is the bandwidth and τ is the measurement integration time. The expressions (3) and (4) show that the sensitivity can be improved by increasing bandwidth and integration time.

However, because this school radio telescope is based on the AMA 301 receiver, there is no option to change the bandwidth and integration time. The receiver bandwidth is about 4.3MHz in the used Sat-TV mode. This bandwidth is high compared with ham radio receivers used in other radio astronomy projects. In the datasheets of the receiver there is unfortunately no information about integration time and measurement of the signal strength. After warm-up, the absolute accuracy of the measurement is specified with +/- 1 dB μ V, the values are provided with 0.1 dB μ V resolution.

The accuracy of the power measurement can be increased by computing the mean value of a number of single measurements. It requires an accurate tracking of the object position on the sky, which can be realised by using the tracking feature. To observe a weak radio source, a high absolute pointing accuracy of the telescope is additionally needed. However, an appropriate level of accuracy is not provided by any rotator unit in a price range suitable for this introductory project.

6.4 Datasheet and limitations

Unit	Parameter	Value
System Performance	Frequency Range	Ku-Band 10.7 – 12.75 GHz
	Bandwidth	4.3 MHz
	Effective antenna aperture	0.84 m ²
	System temperature	310-350 K (determined by Sun observation)
	Observed Objects	Sun, Moon, Satellites
	Total hardware costs	Ca. 6000 € (excl. VAT)
	<hr/>	
Outdoor Unit	Parts	Portable stand, AZ/EL rotator, dish, LNB
	Antenna diameter	1.20m (offset antenna)
	Azimuth motor	0 to 360 degrees
	Elevation motor	0 to 90 degrees
	Pointing accuracy	+/- 1 degree
	Pointing resolution	1 degree
	Antenna mount	Portable balcony stand
<hr/>		
Indoor Unit	Parts	PC, receiver, positioner controller with interface, surge protection
	Receiver sensitivity	40 – 120 dB μ V
	Receiver accuracy	+/- 1.5 dB @ 20°C after warm-up
	Receiver resolution	0.1 dB μ V

Table 1 Datasheet of telescope prototype

Experiments with the developed prototype showed the performance of the components used. The telescope can detect emissions from Sun, Moon and satellites. The detection of weak sources such as Cassiopeia is limited by three properties:

- the system temperature of the LNB, cables and receiver
- the low measurement rate of the AMA receiver
- the total pointing accuracy inferior to +/- 1 degree with low resolution of the returned coordinates

Future enhancements of the telescope could be investigated within a field test project:

- investigation of other receivers (e.g. HAM radio receiver) or development of a special receiver
- improvement of the sensitivity through cooling of the LNB
- an additional position sensor to improve the pointing accuracy
- experiments with an operating frequency in C-Band (other LNB available?)

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7 Feedback from astronomers and teachers

The prototype of the telescopes was presented at the local university, and to teachers in the Saxony region. The potential application of the project to schools and other institutions was discussed.

7.1 Feedback of a professional astronomer

The telescope was presented to Prof. Soffel and two of his colleagues. He is Professor of Astronomy and Director of the Lohrmann Observatory of the Dresden University of Science and Technology. He concluded that:

With respect to the requirements (limited costs, use of commercial available parts for satellite TV) the prototype reaches the optimal performance. The observation of further objects would be desirable, but it would probably require the implementation of other (and more expensive) devices.

7.2 Feedback of teachers from high-school

Three teachers of the high-school Martin-Andersen-Nexö-Gymnasium reviewed the prototype of the radio telescope. Their school specialises in the natural sciences. Their feedback was that the telescope would be a useful tool for the education at their school. It is related to the curriculum in Saxony in three disciplines:

- Electromagnetic waves (physics), e.g. visualisation of spectrum
- Applied computer sciences (measurement, controlling, data handling)
- Astronomy (Daytime observations are very important. Optical observations at night or late evening are impractical, because some students that live outside from Dresden cannot reach the school safely at this time).

The telescope is an example for cooperation between different disciplines, particularly because multidisciplinary work is an important element of contemporary education programmes. The observation of other objects beside Sun and Moon would have been preferred, but is not mandatory for educational purposes.

The teachers were interested in a future participation, and some points needed to be clarified:

- Is a suitable location available at this school?
- What are the annual costs for the maintenance of telescope?

An initial cooperation between the school and the Fraunhofer Institute was agreed. The students attended a project week. One student will start in November 2005 with the preparation of experiments with the telescope. At the end of February 2006 he will work for one week with the prototype at the Fraunhofer Institute.

7.3 Feedback of a teacher from secondary school

The integration of the radio telescope into the curriculum of secondary schools in Germany would be critical. Reasons are:

- Too little time is available in the related subjects to discuss such specialised topics.
- Astronomy is not a separate subject at secondary schools in Saxony (only few lessons in physics covers astronomy).
- These schools have an extremely low budget for teaching materials.

At secondary schools or general high schools, the radio telescope would preferably be used after school. This provides more time to work with the telescope than available in the lessons, and ensures that genuinely interested teachers and students participate. The teacher assumed that high schools, specialised in science and technology, would have better opportunities to use the radio telescope.

7.4 Conclusions on feedback

Multi-disciplinary education in physics, astronomy and computer sciences is the main advantage of the radio telescope. In Germany this might be well-integrated into the curriculum of high schools that are specialised in natural sciences. At German secondary schools, too little time exists in the curriculum to teach basics of radio astronomy. Therefore it could be used in after school activities by interested teachers and students. The prototype is well suited for education purposes. It is less applicable for science due to the limited sensitivity and pointing accuracy.

8 Strategic plan for field trial

Before the telescope kit is made available to schools in all member states, it is proposed to perform a field trial at few schools in two countries [9]. It would allow the evaluation of the telescope, and to enhance the design and manuals and to test new applications.

8.1 Goals of the field test

About five schools in two ESA Member States could be involved in the field test of the telescopes. This will allow exploration of different education systems in the countries. The field trial shall answer the questions below:

- Is the assembly and commissioning of the telescope easy to realise by students under the guidance of their teacher? Is the assembly manual clear? Which problems occur?

- How difficult is the operation of the telescope? Is the operating manual easy to understand?
- How is the radio telescope integrated into the educational curriculum?
- What is the feedback from the students of their interest and enjoyment of the project?
- Which enhancements or additional applications are desired by students and teachers?
- How can students of different schools communicate and cooperate most effectively?

As a result of the field test, the telescope kit and the related documents will be improved and the implementation in other ESA Member States prepared.

8.2 Partners in the field test

ESA is a well suited organisation to introduce the school radio telescope project at schools and institutions. ESA has a high expertise in the area of space sciences. The partners in the field test could be:

- ESA as initiator of the project
- A technical support team consisting of:
 - a kit vendor, responsible for the completion and shipment of the telescope kits
 - a technical consultant, to provide technical support and enhancements of the kit
 - a consultant on astronomy, to answer astronomical questions
- schools and institutions, where the telescopes are installed and evaluated
- sponsors, which fund the purchase of the telescopes by schools

8.3 Implementation Scenarios

There are two main scenarios for the implementation of telescopes. Telescopes may be installed at schools, or at institutions outside schools that provides access to students of one or more schools in a region. Both variants should be evaluated in the field trial.

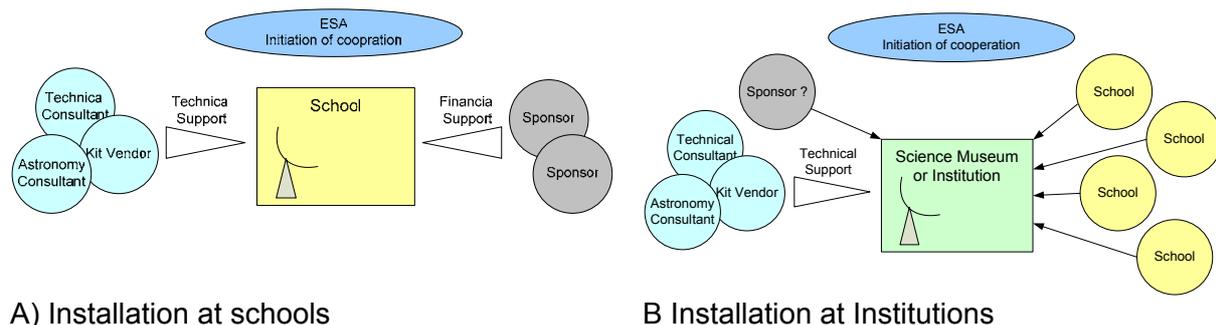


Figure 11 Implementation scenarios

The telescope was principally developed for the installation in ESA member states. It should be investigated if telescopes could be installed in lesser-developed countries. A potential partner could be UNESCO. Beside observation of Sun and Moon, the telescope can be used to receive broadcasts from various satellites. Using the telescope in an African country would probably require the reception of signals in C-Band. This should be analysed in the follow-up project.

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8.4 Work package structure for field trial

The work can be organised in the following work packages:

WP1 Initialization of partnership

The task of this work package is the selection of partners of the field trial in the country of the technical partner and a second ESA Member State. Technical and financial tasks have to be discussed. It must be clarified if the potential partners have a suitable location for the installation of the telescopes. If necessary, sponsors must be found.

WP2 Preparation and shipment of telescope kits

It is proposed to order collectively the components for all telescopes in the field trial. Possibly this might allow for getting a discount price from the manufacturers. The completed telescope kits will be shipped to the telescope locations. The user documentation of the telescope is currently available in English only. It must be discussed with schools and institutions if a translation into other languages is required.

WP3 Support of assembly, commissioning and operation

The technical partner shall provide telephone and email support for installation and operation of the telescope. Questions by the users are a valuable input to identify which problems may occur at user side, and which parts of the documentation may be described more detailed. It is proposed to use an Internet site to track questions and answers. It should be used to initiate communication between the teams.

WP4 Enhancement of telescope kit and documentation

Based on the feedback of the users, enhancements to the telescope and the documentation are defined and realised. It will include the investigation of performance enhancements, for example the evaluation of other receivers or the development of a special receiver. In parallel it is evaluated how the telescope kit can be extended to enable new applications, as outlined below.

WP5 Preparation of implementation in member states

At the end of the field trial the availability of telescopes for schools and institutions in all ESA member states will be promoted. Activities include standardisation of the improved telescope kit, international publication and establishing a provider.

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8.5 Potential applications of the radio telescope

It is planned to evaluate potential new applications of the radio telescope during the field trial period.

Generation of Sky Maps at Ku-Band

For a map the sky is scanned line by line. The measured power level is encoded in colours to show regions with strong emissions. Emission from the interstellar gases hydrogen and hydroxyl are not located at the Ku-Band. Nevertheless there are also emissions at higher frequencies. Sky maps at 8.35GHz and 14.35GHz are published by the professional radio telescope NRAO Green Bank (US) [10]. Modifications of the software of the school radio telescope are required to enable sky mapping. This concerns the controlling of the positioners and extensions to the data recording.

Reception of weather satellites

Receiving images von weather satellites is a very interesting task with direct relation to the work of ESA. To enable weather satellite reception with the school radio telescope, additional parts are necessary. The hardware costs are in the range from about 300€ to 500€, depending on the selected satellites and devices. It should be discussed if weather satellite reception is a useful add-on to the telescope.

9 Acknowledgement

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