

Radio Astronomy and the 25m Nigeria Radio Telescope (NRT) Project

Introduction

Nigeria is one of the few countries in sub-saharan Africa where modern astronomy is taught at both undergraduate and postgraduate levels. The astronomical community has been involved in main stream research activities in modern astronomy and astrophysics. Between 1980 – 2007 Astronomers in Nigeria have made significant progress in the area of theoretical High Energy Astronomy. In observational astronomy, there are astronomers who have been trained in astronomical observations at different observatories including Hartebesthoek Radio Observatory (HartRAO) South Africa, National Astronomical Observatory Japan (NAOJ) among others.

It is important to note that the Nigerian Space policy statement emphasizes that Nigeria will vigorously pursue the attainment of space capabilities as an essential tool for its socio-economic development and enhancement of the quality of life for its people. The National Space Research and Development Agency, (NASRDA) – the Agency responsible for the actualization of this lofty idea hopes to achieve this through research, rigorous education, engineering development, design and manufacture of appropriate hardware and software in space technology and antennas for scientific research and applications. And it is for these reasons that CBSS, an activity centre of the (NASRDA) has embarked on this ambitious project of setting up a 25m Radio Telescope in Nigeria for frontline space research.

The electromagnetic spectrum

The electromagnetic spectrum is made up of light of many different wavelengths. Most wavelengths are invisible to us. In fact, our eyes can only detect the small portion of the spectrum between 400 and 700 nanometres. We call these wavelengths "visible light."

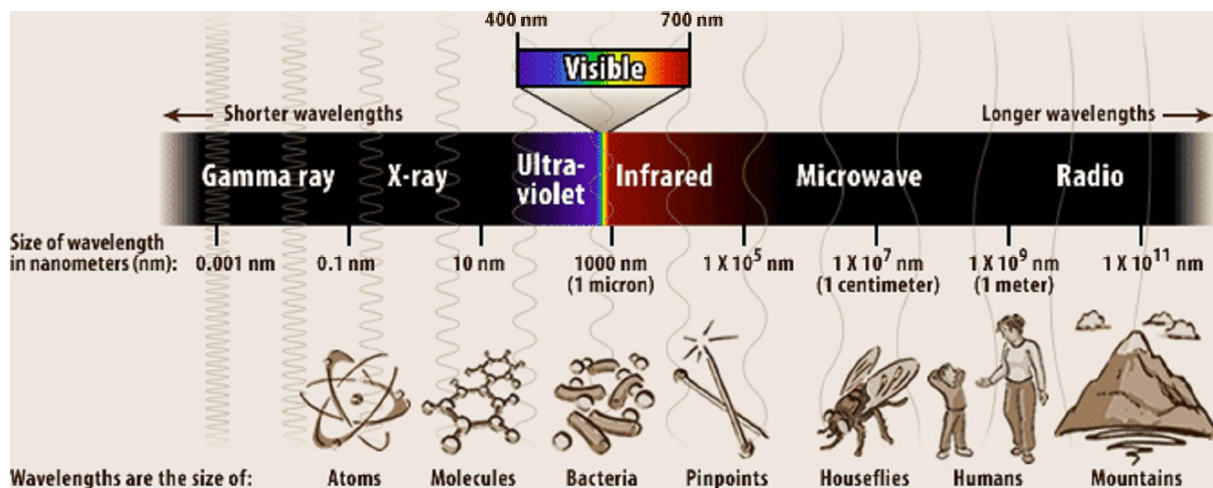


Figure 1: electromagnetic spectrum

Radio Telescope

What is a radio telescope? A radio telescope is a device for measuring radio frequency energy from the cosmos. Radio telescopes come in hundreds of configurations. For illustrative purposes, we first describe a very generalized type called the total power radio telescope shown in diagrammatic form below. It collects radio waves from very distant objects in space such as planets, stars, galaxies, etc. The waves collected by the telescope are then processed and interpreted by means of receivers and computers. It has other wider applications in space science such as tracking and collecting data from satellites and space probes, monitoring our space satellites and satellite communication. Radio telescope has a wider window for observation in electromagnetic spectrum than optical telescope.

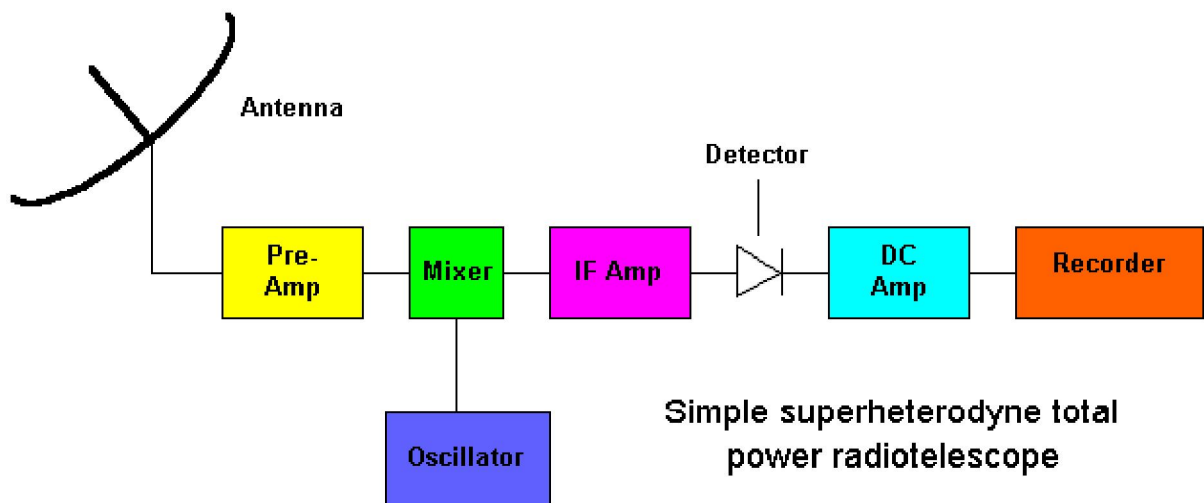


Figure 2: radio telescope components

A professional radio telescope is an astronomical instrument consisting of a radio receiver and an antenna system that is used to detect radio-frequency radiation emitted by extraterrestrial sources.

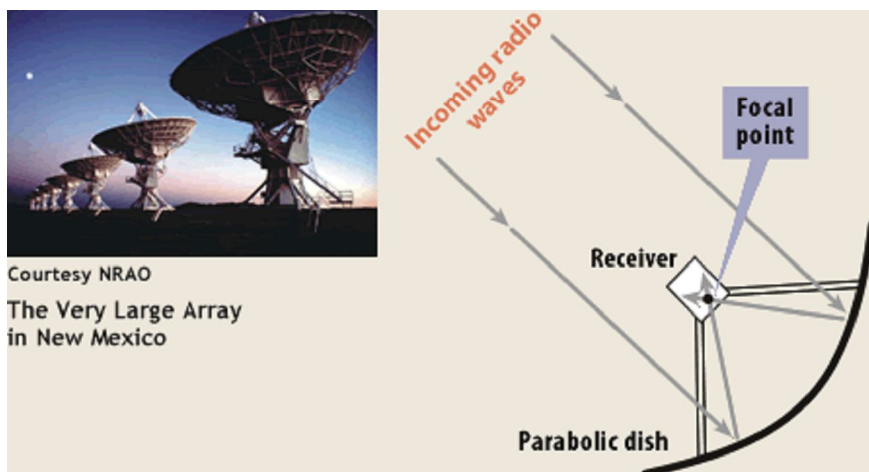


Figure 3: radio telescope showing the parabolic dish

Radio telescopes are generally reflecting telescopes. A huge parabolic dish collects incoming radio waves and focuses them at the receiver, which is mounted at the focal point of the dish. Radio dishes are big, but some radio waves are so long that a single dish is too small to collect them. Astronomers

tackle this problem by building antenna arrays, like the one shown in the picture above in which computers allow many individual dishes to work together as one. Because radio wavelengths are much longer than those of visible light, radio telescopes must be very large in order to attain the resolution of optical telescopes or better.

As indicated above, the most familiar type of radio telescope is the radio reflector consisting of a parabolic antenna -- the so-called dish -- which operates in the same manner as a television-satellite receiving antenna to focus the incoming radiation onto a small antenna referred to as the feed, a term that originated with antennas used for radar transmissions. In a radio telescope the feed is typically a waveguide horn and is connected to a sensitive radio receiver. Cryogenically cooled solid-state amplifiers with very low internal noise are used to obtain the best possible sensitivity.

Observing times up to many hours are expended and sophisticated signal-processing techniques are used to detect astronomical radio signals that are as much as one million times weaker than the noise generated in the receiver. Signal-processing and analysis are usually done in a digital computer. Although some of the computations may be carried out by microcomputers (i.e., those of the personal-computer class), other tasks require large, high-speed machines to translate the raw data into a form useful to the radio astronomer.

The performance of a radio telescope is limited by various factors: the accuracy of a reflecting surface that may depart from the ideal shape because of manufacturing irregularities; the effect of wind load; thermal deformations that cause differential expansion and contraction; and deflections due to changes in gravitational forces as the antenna is pointed to different parts of the sky. Departures from a perfect parabolic surface become important when they are a few percent or more of the wavelength of operation. Since small structures can be built with greater precision than larger ones, radio telescopes designed for operation at millimetre wavelength are typically only a few tens of metres across, whereas those designed for operation at centimetre wavelengths range up to 100 metres in diameter.

Some radio telescopes, particularly those designed for operation at very short wavelengths, are placed in protective radomes that can nearly eliminate the effect of both wind loading and temperature differences throughout the structure. Special materials that exhibit very low absorption and reflection of radio waves have been developed for such structures, but the cost of enclosing a large antenna in a suitable temperature-controlled radome may be almost as much as the cost of the movable antenna itself.

Radio telescopes are used to measure broad-bandwidth continuum radiation as well as spectroscopic features due to atomic and molecular lines found in the radio spectrum of astronomical objects. In early radio telescopes, spectroscopic observations were made by tuning a receiver across a sufficiently large frequency range to cover the various frequencies of interest. This procedure, however, was extremely time-consuming and greatly restricted observations. Modern radio telescopes observe simultaneously at a large number of frequencies by dividing the signals up into as many as several thousand separate frequency channels that may range over a total bandwidth of tens to hundreds of megahertz.

What do radio telescopes do?

Radio telescopes are constantly evolving, but the basic principles remain the same. A telescope collects and concentrates electromagnetic radiation

The bigger the parabolic reflector or dish, the more EM radiation it can collect. The more radiation it collects, the fainter the galactic or extragalactic objects it allows us to see. A radio telescope basically focuses EM radiation and creates a radio image

To create a clear image, radio telescope dishes or mirrors bring EM radiation to meet at a single point, the focal point. If the EM “rays” don’t meet at the same point, the image is blurry. The shape of the dish is designed to make EM radiation meet at a single focal point.

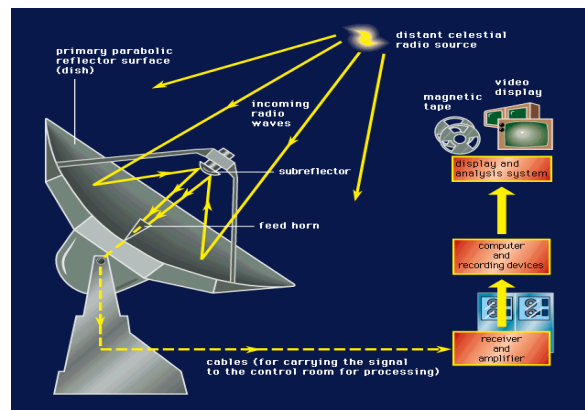
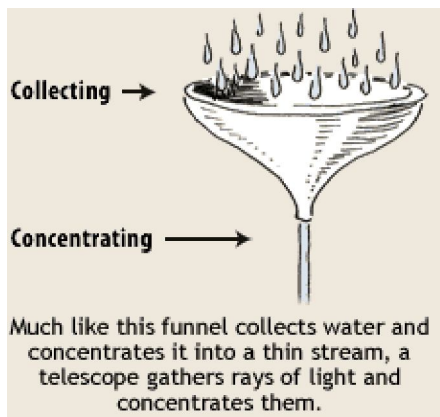


Figure 4: how a radio telescope collects information

The image is recorded

Once an image forms, it must be recorded for research. Originally, people drew the images they saw through optical telescopes. Later, photography allowed people to take pictures of the image on film. Today, astronomers use charge coupled devices (CCDs), electronic light-sensing devices like those in digital cameras, to record images

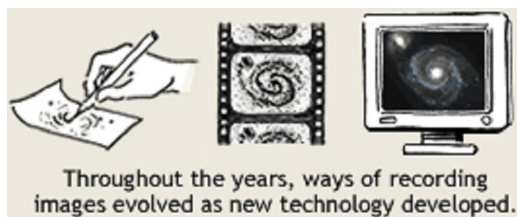
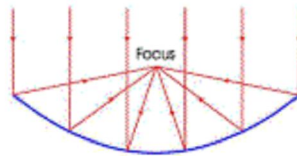


Figure 5: Image recording

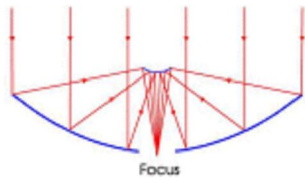
The Anatomy of a Radio Telescope

The reflecting surface

The most fundamental part of a radio telescope is the metal surface which reflects the radio waves to its focus. For example, the Jodrell Bank Lovell, Mark II and Defford telescopes have a single parabolic reflecting surface which brings the radio waves to a "prime focus" as shown below.



The Prime Focus as used on the Jodrell Bank Lovell, Mark II telescope



The Cassegrain System used on the Jodrell Bank 32-metre and E-systems telescopes

The three newer, VLA-type 25-metre telescopes and the Cambridge 32-metre telescope have a secondary reflector which is used at shorter wavelengths to reflect the waves to a "Cassegrain focus" as shown in above. This arrangement is more efficient than a similarly-sized prime focus telescope and allows the receivers to be housed within the main telescope structure. The accuracy with which the surface follows the ideal shape determines the shortest wavelength that may be used. The surface errors, which should not exceed $1/20$ of a wavelength, are determined both by the shape and smoothness of the individual panels and by the precision to which they can be adjusted. A holographic technique now allows radio astronomers to make a map of the surface showing the deviations away from the ideal paraboloid and allows the whole surface to be "set" very precisely at a specific elevation. As the telescope moves to higher or lower elevations gravitational deformation of the surface will reduce the efficiency at the shortest useable wavelengths. In 1987, the Mark II telescope at Jodrell Bank was given a new aluminum surface which now allows it to make observations down to 1 cm wavelength rather than the 4 cm prior to the resurfacing.

What can I do with a radio telescope?

There are few things that come to mind when asked this. Of course, radio astronomy is like so many other fields of knowledge...the more you know and do in the field, the more you find yourself stumbling upon new and intriguing avenues of discovery. But the following are just a few examples taken at random:

- Study Jupiter's noise storms.
- Record flares and predict geomagnetic activity.
- Detect a pulsar using DSP (digital signal processing).
- Detect stronger radio sources.
- Look for HEPs (high energy pulses) from the galactic centre.
- Search for radio correlations to gamma ray bursts.
- Study ionospheric scintillation and refraction.
- Detect meteors invisible to the eye.
- Develop a long base line interferometer.
- Learn radio technology.
- Learn astronomy.

What makes a good radio telescope?

A radio telescope is judged on the following qualities:

Its sensitivity and resolving power

Except in the case of solar telescopes, magnification or gain is the least important element of a research radio telescope. Gain depends on focal length. As the gain increases, the telescope focuses on a smaller piece of the sky. Most research radio telescopes are designed to operate at the smallest gain possible, to examine a larger piece of sky. The distance and details they see depends more on their radiation-collecting ability and resolution than their gain. Solar telescopes, however, can rely on gain because they don't have to look deep into space, see much of the sky, or gather much radiation to clearly view the Sun.

Instrument quality

A modern research radio telescope is only as good as the filters and receivers and other instruments that record and analyze the electromagnetic radiation that it captures.

Its radiation-collecting ability

Faint objects are hard to see. Objects appear faint because they are either far away, and/or because they glow dimly. The more electromagnetic (EM) radiation a telescope can collect, the better it can see faint objects. Large dishes and arrays allow radio telescopes to collect more radiation.

Its resolution

Resolution is the ability to see detail in an object. A telescope with high (good) resolution will be able to see two point radio sources as being separate from one another. A radio telescope with low resolution will blur the two points together into a single point of light.

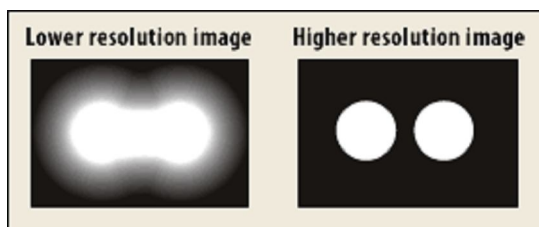


Figure 6: resolution of images

Beam pattern and resolution of a radio telescope

The sensitivity of a telescope is a function of angle from the normal. The full width half maximum resolution angle is the minimum angle projected upon the sky that two sources can be resolved, i.e. if they were any closer together they would appear to be one object. The resolution of a telescope is dependant upon the diameter (D) of the dish and the wavelength at which measurements are being made. Radio waves have a large wavelength and so have poor resolution compared to say optical wavelengths. To improve the resolution radio telescopes are typically made as large as possible, which also allows maximum source radiation collection, or alternatively, used in the form of arrays. In an array, two or more telescopes are used in conjunction and their signals combined. The separation distance can be very large, some arrays have telescopes situated on opposite ends of the earth, if this is the case, D referred to above become the separation distance and the resolvable angle becomes very small.

Telescope Control

Most telescopes operated today are "fully steerable" so that they can track a radio source across the sky to compensate for the rotation of the Earth. The telescope is only sensitive to radio waves coming from a very small part of the sky called the telescope "beam". The control computer calculates the drive rates in azimuth (horizontal rotation) and elevation (vertical) and sends appropriate commands to the drive motors so that the telescope will "track" the radio source to keep it in the centre of the beam. Encoders (i.e. devices used to change a signal such as angular position reading into a computer code) on the telescope structure continuously measure the position of the telescope to a precision of one thousandth of a degree and allow the computer to make fine adjustments to the demanded drive rates to ensure that precise tracking is achieved.

Telescope Control considerations

The purpose of the control task is to provide for an accurate and user-friendly way to position the parabolic mirror or dish. It is important to know the precise position of the dish in the sky so the user can determine where to position the dish using astronomical quantities. From here the control task will be broken down into two main subtasks that are the mechanical subtask and the software subtask.

Mechanical

The parabolic dish antenna is usually mounted on a pedestal called a mount. A telescope mount is the mechanical structure which supports a telescope. Telescope mounts are designed to support the mass of the telescope (which is usually a very heavy structure) and allow for accurate pointing of the instrument. Many sorts of mounts have been developed over the years, with the majority of effort being put into systems that can track the motion of the radio sources as the Earth rotates with a single motion.

The earliest types of mounts are today known as *altitude-azimuth*, or alt-az systems. The name refers to the way the system allows the telescope to be moved in altitude, up and down, or azimuth, side to side, as separate motions. **One negative thing in this mount is that telescopes field-of-view will then rotate at varying speed while the telescope tracks along the sky.** This type of mount, however, is used in practically all modern big telescopes, and has also become popular with inexpensive commercial and hobby constructions.

The introduction of the equatorial mount displaced most alt-az systems for many serious users for several centuries. **By tilting the horizontal base of an alt-az system up until it is parallel to Earth's equatorial plane, the azimuth rotation then swings the telescope in an arc that follows the stars as they move across the sky due to Earth's rotation.** In other words, the equatorial mount is a special case of the altitude-azimuth mount. By attaching a simple clockwork mechanism to this axis, the equatorial system makes long observation easy. Also the telescope's field-of-view does not rotate, which all combined make these simpler tools to use. Equatorial mounts come in different shape, most common forms include German Equatorial Mount (GEM in short), equatorial fork mount, and equatorial platform.

Mechanical Control

An important objective of the control system is to point the antenna at a source at a particular position in the sky and track or follow the source as it moves across the sky with time for a specific amount of time. In order to accomplish this objective, an electronic control system must be designed and built. The design consultants will provide a block diagram of the main components of the control system

possibly, including the motion control card, the motors, motor drivers, and the shaft angle encoders. To develop this block diagram it would have been necessary to determine what needed to be done in order for the antenna to be able to track a source moving across the sky at the latitude and longitude of the telescope position at Nsukka.

An example of a control system is shown in the following diagram except that one must substitute a 25 metre platform for the 8.5 metre platform but the philosophy is the same and one expects our Chinese designers to come up with a similar system. The important features to note are as follows:

1. The connections between the azimuth and altitude motors to the safety circuitry through limit switches and emergency stop switch.
2. The input/output card connection to the altitude feedback circuits for the two motors and the linkage of all of these to the telescope drive computer.

The motion control card can be developed in-house or purchased ready made. The card itself may consist of a specialized chip for on-board computing. After the firmware is loaded and an interrupt is generated, the DSP constantly executes a series of events as follows:

- Read all encoders
- Read analog and parallel input
- Calculate next trajectory point
- Check for event triggers
- Perform event action
- Calculate and set DAC output
- Go to next axis and repeat
- Exit from interrupt

Only going through this loop when an interrupt is generated allows the control card to work in a real time environment.

The card must be interfaced with the control system using an interface module.

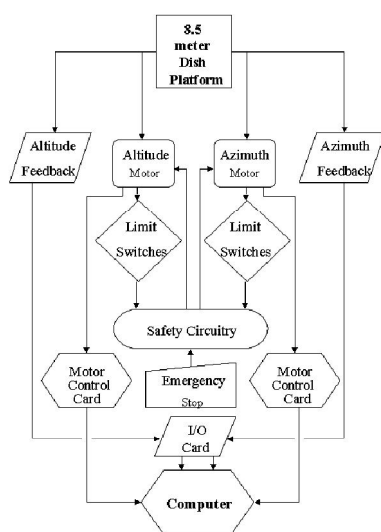


Figure 7: Block diagram of control system

The interface module will consist of a multi-pin interface with screw down terminals to connect wires coming from the encoders and going to the motors. It is possible to control two axes using one of these multi-pin interfaces. The ribbon cable is for example a MEI CBL-100 ribbon cable, and it consists of a 100-pin connector on the controller card end. It then splits into two parallel ribbons with 50 pin connectors at the end of each to interface with two STC-50s. This allows for control of four separate axes simultaneously in one system.

The card can operate in either an open-loop or closed-loop mode.. The mode depends on whether or not there is an encoder present to send feedback to the card. . Since shaft angle encoders will be used for each axis, the closed-loop system will most probably be used. In the closed-loop system, signals from the encoder are sent to the control card. The card then interprets them and signals are sent to the motors telling them exactly what to do. The interpretation of the signals is done through software that will be written and tested. Most of the software would have been developed by our Chinese contractors or with the programs that came with the motion control card.

Shaft Angle Encoders

It is important to note the difference between two types of encoders. Usually, incremental encoders are used for speed and angle of rotation measurements, while absolute encoders are used for exact position recognition (angle position encoder). For this project, absolute encoders and an inclinometer will be found to be the most feasible to use in encoding azimuth and inclination of the antenna dish. In this case there will be need to establish the approximate resolution needed for both inclination and the azimuth encoders as well as how the input and output of the absolute encoder can be interfaced with the controller card.

Assuming for illustration purposes that the approximate calculation of the antenna half power beam width to be around 1° , one can estimate the resolution of the absolute encoder and the inclinometer to be following:

Taking 1/10 of the half power beam width:

Steps needed by Azimuth encoder for $360^\circ = 360/0.1 = 3600$

The resolution of the encoder $= 1/3600 = 0.00028^\circ$

Steps needed by encoder for $90^\circ = 90/0.1 = 900$

The resolution of the inclinometer $= 1/900 = 0.0011^\circ$

These resolutions will give the required accuracy for this control system.

Absolute encoders

With absolute encoders, the angular position is readable as digital information on the rotary disk. The exact position is hereby available as a digital bit-pattern as soon as the equipment is switched on. The exact position is also known after a power failure or when the critical frequency is exceeded. The disk is separated into different tracks that are read by an optical sensor. The values are digitized and can be accessed as coded outputs. The single step Gray Code is most popular. Only one code-information is changed per measurement-step, and it is thereby relatively simple to control for data-transfer errors. The Binary and Binary Coded Decimal (BCD) -Codes are also used.

Limit Switches

To calibrate the encoders and to eliminate the risk of destroying gears, limit switches need to be incorporated to the drive system for the four dish direction limits, elevation minimum, elevation

maximum, azimuth minimum, and azimuth maximum. To calibrate the elevation encoder the dish would have to be moved to the full elevation minimum position. When the dish reaches this position, a limit switch will be opened and the motors will stop. At this point, the limit switch circuitry will send a digital elevation minimum signal to the software so that it knows the elevation minimum position has been reached. The software will take a reading from the encoder as the elevation minimum value and will store the reading. The dish will then be rotated to the elevation maximum position where the elevation maximum limit switch is opened. Again the limit switch circuitry will disable the motor and send a maximum elevation digital signal to the software. The software will take another reading from the encoder and store this value as the elevation maximum position. A similar process will be used to calculate the azimuth minimum and maximum readings.

Limit Switch Circuitry

The limit switch circuitry will be designed by the Chinese contractors to fit our specific needs. It will be used not only for calibration purposes, but also to disable the motors when a particular axis limit is reached to prevent damage to the gears or motors. All four limit switches are wired as a normally closed switch. Using a normally closed configuration helps prevent a malfunction in the event that a wire breaks. When a limit switch is activated, the corresponding motor circuit is opened and the motor is disabled. At the same time, a digital signal is sent to the software alerting it of which limit has been reached. This signal is used to set a flag in the software to warn it that the motor direction for that axis has to be reversed. The circuit also receives input from the software as to which direction the motor is being instructed to move. If the software is still attempting to move the motor in the same direction it was rotating when the limit switch was contacted, the motor will stay disengaged. When the software sends a signal to the motor control card to reverse the motor direction, the motor is again enabled and the dish moves away from the limit switch. Disabling the motors is accomplished using the ENABLE connections on the Motor Control Cards. When these connections have continuity, the motor output is enabled. If the connections lose continuity, the motor output is disabled. The limit switch circuit controls this ENABLE connection through the use of MOS relays, which also provide electrical isolation between the limit switch circuit and the motor control cards.

The Control Room

The centre of telescope operations is the control room which is continuously manned by a team of on-duty controllers who are responsible for the safe operation of the telescope. The duty controller is provided with displays detailing the weather conditions at each time of day as well as the status of the telescope. In normal operation the telescope is controlled by the computers carrying out the observing programme but, should there be any system faults or impending gales or tropical storms, the duty-controller can suspend operations and park the telescopes in a safe position, with their bowls pointing up to the zenith.

The Observatory Clock

The control room also houses the "observatory clock" which derives its time from a hydrogen maser frequency standard (such clocks can be purchased from commercial manufacturers) and synchronizes it to world time to one tenth of a millionth of a second using transmissions from the Global Positioning

Satellite (GPS) network. It provides precise timing signals for the data acquisition hardware and synchronizes the telescope control systems.

Interference and protected bands

Transmitters on earth, TV, AM and FM, military channels etc, produce a myriad of radio signals covering nearly all the radio spectrum. A radio astronomer has the constant challenge of finding an area where transmissions are at a minimum, e.g. away from cities, or finding a frequency where there are no terrestrial signals. Having said this there are certain protected frequencies specifically put aside for radio astronomers, one such being 21 cm.

Motor Control

The mount requires precise controls and very little backlash to maintain the needed accuracy. A typical type of motor would be a 230 VDC, 1.5 HP electric motor. One motor would be for azimuth control and another for elevation control. The motors are usually identical although the gearing is different so the output revolutions are different..

The methods for driving the antenna will vary depending on the precise design. Whatever is the design however, reversible motors would be needed to point the antenna at a specified source in space and track the source for specific amount of time. In doing this, there will be a maximum speed or slew rate measured in fraction of a degree per minute. This occurs mostly in the azimuth direction when the source is at its highest elevation in the sky. The minimum slew rate is many times less than the maximum slew rate.

There are two methods for tracking a source. The first is to continuously track in real time. This would require variable speed DC motors and speed controls. The second is to use a start-stop type of tracking. The latter method could be achieved with AC or DC motors. The antenna position would be updated more often as the source moves faster and less often as it moves slower. The start-stop method is much more viable if the antenna gain is found to have a lower efficiency. Both methods would require geared motors or gear reducers to attain lower rpm values and more torque.

In certain situations, so-called stepper motors may be found to be the most feasible in positioning azimuth and elevation of the antenna because a stepper motor is much easier to control by a PC than is a DC motor. If a stepper motors are to be used, some work will have to be done as to how its input can be interfaced with the motion controller card.

Stepper motors

Stepper motors can be viewed as electric motors without commutators. Typically, all windings in the motor are part of the stator, and the rotor is either a permanent magnet or, in the case of variable reluctance motors, a toothed block of some magnetically soft material. All of the commutation must be handled externally by the motor controller. The motors and controllers are designed so that the motor may be held in any fixed position as well as being rotated one way or the other. Stepper motors translate digital switching sequences into motion. Unlike ordinary DC motors, which spin freely when power is applied, stepper motors require that their power source be continuously pulsed in specific patterns. These patterns, or step sequences, determine the speed and direction of a stepper motor's motion. For each pulse or step input, the stepper motor rotates a fixed angular increment. Typically this step is 1.8 or 7.5 degrees.

Motor controller and driver

A stepping motor controller should provide two bits of output to control the motor, one bit indicating the direction of rotation and another bit that is pulsed every time the motor is to be stepped. The software to operate such a motor controller is simpler than the software to directly control the current through the motor windings. Many microprocessor-based stepper drivers use four output bits to generate the stepping sequence. Each bit drives a power transistor that switches on the appropriate stepper coil. The stepping sequence would be stored in a lookup table and read out to the driver lines as required.

Software

The next subtask to the control is how to make the system work with a user-friendly interface, as well as keeping the complexity of the software programming to a minimum. We discuss some of the control topics that are often considered when preparing to start the software design. One of the main ideas to be considered is that the source appears stationary in the sky while the antenna moves since the earth is constantly moving. **Since standard time does not apply to objects in space, it will be necessary to convert standard time into sidereal time. This is not an easy task because there is no standard conversion method between standard time and sidereal time since the sidereal day varies with the time of year and other factors.** As a result, it will be necessary to purchase a sidereal clock that can be interfaced with the telescope control system, or to maintain a sidereal clock through software. An extensive web search has shown that the best thing to do for this is to go with the software option. This is because sidereal clocks are relatively difficult to find, and the few that are commercially available do not readily interface with custom built control system. There are many software versions of sidereal clocks found on the web that can be used for this purpose. Many of these clocks even have the source code readily available, so it will be a fairly simple task to incorporate this source code into the telescope control system software.

Control System Interface

The first step in implementing a quality control system is to ensure that the component that links all of the other components together will be powerful enough to handle all of the sending and receiving of signals. This leads into two of the most important components of the control system: the computer and the I/O card.

Computer(s)

In choosing a PC, the only real factor to be considered is that the end goal of the project is to do real-time tracking of a source in space. Another PC consideration was that PC costs are at an all time low, so it will be necessary to also consider future projects and their computing needs. The same or another computer may be needed for other observational tasks unconnected with telescope motor control.

I/O Card

The I/O card is probably the single most important component of the control system. It is necessary to have an I/O card that can handle processing all the control signals with some degree of speed and a high degree of precision.

The chosen card must be for a number of good reasons including the following::

1. It can handle all of the signals that need to be input to the computer and output from the computer.

These signals include:

Input

Elevation Position (Analog)

Azimuth Position (Analog)

4 limit switches (Digital)

Output

Elevation Motor (Analog)

Azimuth Motor (Analog)

The card will thus have eight analog input lines, two analog output lines, and twenty-four bi-directional digital lines, so it could easily handle all of the necessary signals for the system.

2. Another major consideration for the I/O card will be the precision of the signals being input to the computer. A resolution of 3600 units is normally necessary for reading the positions from the encoders

3. The final consideration had to do with the software. It will be necessary to choose software that would allow for easy programming in a limited amount of time. The chosen software must be selected because it is designed for automation.

Radio telescope Receiver

The heart of a radio telescope is the receiver. The radio telescope employs the superheterodyne receiver technique to extract the source information from the received unmodulated signal that may be corrupted by noise. This technique consists of both up-converting and down-converting the input radio frequency band signal ($X \text{ GHz} - Y \text{ GHz}$ where X and Y are the max and min frequencies of observation) to an intermediate frequency (IF) band signal (200MHz - 40MHz), and then extracting the signal by using the quadrature product detector.

In converting the radio frequency band into the intermediate frequency band, two similar stages of processing with a tunable voltage controlled oscillator, IF filter, and IF amplifier in each stage are applied. The first stage is for coarse tuning, in which a 1000MHz - 2000MHz tunable voltage controlled oscillator (VCO) is selected to phase shift the signal through the IF filter and IF amplifier, the signal is lowered from 1.4GHz to 200MHz. The second stage is for fine-tuning, in which a 220MHz - 260MHz tunable VCO is selected to process the signal together with another IF filter and IF amplifier, producing a signal with a frequency of 40MHz. Through the two stages, we can effectively filter off the noise and the unwanted image frequency.

The centre frequency selected for the IF amplifier may be chosen based on three considerations:

- The frequency should be such that a stable high-gain amplifier can be economically attained.
- The frequency has to be low enough so that it can provide a steep attenuation characteristic outside the bandwidth of the IF signal. This decreases the noise and minimizes the interference from adjacent channels.
- The frequency needs to be high enough so that the receiver image response can be made acceptably small.

Note: The image response is the reception of an unwanted signal located at the image frequency due to insufficient attenuation of the image signal by the RF amplifier.

A carousel of receivers

There are great advantages in being able to change the receiver in use quickly. For example, at very short wavelengths (high frequencies) the weather affects the observations, so rapid receiver changes allow one to move to high frequency observations when conditions are good. When built, the 25-metre (or 45-metre) telescope should be fitted with a rotating carousel on which are mounted a number of receivers covering different wavebands. The carousel is offset to one side of the axis of the telescope so that, by rotation, any one of the receivers can be quickly brought to the focal point. During the late 1990's the three VLA-type telescopes were fitted with similar carousels, and the Jodrell Bank Mark II telescope was upgraded with a more compact carousel system mounted at its prime focus as illustrated in the diagram below.



Receiver Carousel

Figure 8: A *Typical receiver positioned at the cassegrain focus of one of the VLA-type telescopes*

State-of-the-art receivers

The very-low-noise amplifiers at the heart of the telescope receivers are usually built in the development laboratories of the particular observatory. They are not off-the-shelf equipment that can be purchased from commercial sources. At Jodrell Bank for example, the electronic components are assembled under a microscope into a precision-machined gold-plated chassis produced in their mechanical workshop. The amplifiers with their ancillary equipment are then mounted into a cryostat which is cooled using a compressed-helium refrigeration system. The amplifiers are operated at temperatures less than 15 degrees above absolute zero, reducing their internal noise and so allowing weaker radio sources to be detected. Amplifiers and cryostats built here are also in use with the Parkes 64-metre telescope in Australia, the Very Small Array and other systems at the Mount Teide Observatory in the Canaries, and are being built for use in the European Space Agency spacecraft, Planck Surveyor.

The 25m NRT in Perspective

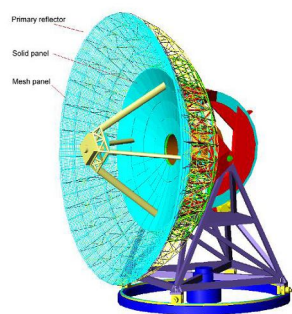


Figure 9a: The NRT structure

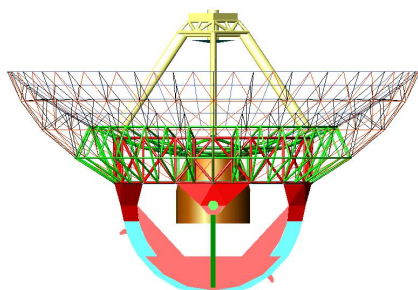


fig. 9b: elevation mount

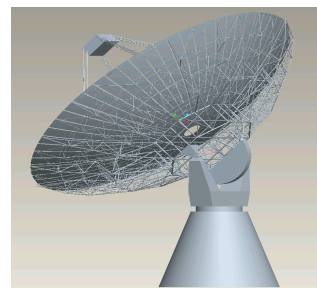


fig. 9c Tower- Type

The Nigerian Radio Telescope will be a 25m fully steerable (alt-az) parabolic cassegrain radio telescope which will allow astronomers to observe waves and microwaves – which have much longer wavelengths than does visible light – coming from space. The mount system will be Tower-Type.

Location

The telescope will be located at Umuakashi 10Km from Nsukka town
Longitude 7.4° E
Latitude 6.9° N,
Altitude (Elevation) 613.44m above sea level.

Aim of the project

The main aim is to build a giant radio telescope for Space and VLBI (Very Long Baseline Interferometry) research which will put Nigerian science on the world stage and boost technological development within the country.

Key Scientific Motivations

A 25-m class radio telescope that approximates the design specification suggested in Table 1, when equipped with the relevant state-of-the-art receiver systems will certainly allow for frontline research in key science projects. Some of the key science projects that would be pursued using NRT include:

Radio pulsar studies: With appropriate modern instrumentation, the proposed 25-m radio telescope will be very useful in precision timing of young and middle-aged radio pulsars. With state-of-the-art instrumentation, one can achieve sensitivity high enough to allow for the monitoring of a good number of millisecond pulsars.

Radio Spectroscopy: several atoms and molecules produce line emissions at specific frequencies in cm wavelength band, which with appropriate instrumentations, are observable with the proposed NRT. The Hydroxyl (OH), Formaldehyde (HCHO) found in molecular clouds in the interstellar medium produce emission lines at 18 and 6 cm wavelength bands, respectively. Spectroscopy can also be used to study masers in star forming regions. While the excited states of Hydroxyl masers produce about 7 emission lines at 6 and 5 cm wavelength bands, strong methanol (CH₃OH) masers have been discovered at 2.5 and 4.5 cm wavelength bands. Recombination lines from HII regions can also be

studied

Planetary science: This telescope when installed, will be used to undertake a wide range of solar system studies such as the study of Jupiter's noise storms and the study of ionospheric scintillation and refraction.

Very Long Baseline Interferometry (VLBI) experiments: The proposed Observatory in Nigeria will certainly play a key role in various VLBI projects, given its strategic location near the equator (Akujor, 1980). NRT will bridge the wide gap between the cluster of observatories in northern and southern hemispheres. Some of the astronomical VLBI in which NRT can operate as part of the network are the European VLBI Network (EVN), Australia Telescope – Long Baseline Array (AT-LBA), North America (Very Long Baseline Array), Global Array, etc.

Space Geodesy Programmes: The proposed NRAO to participate international networks which employs Very Long Baseline Interferometry (VLBI) and the Global Positioning Systems (GPS) to conduct frontline research in Geodesy.

NRT will form a very important ground station for the recently proposed space VLBI network- the Japanese VSOP2 because of its vantage position in Equatorial Africa.

Justification of the Project

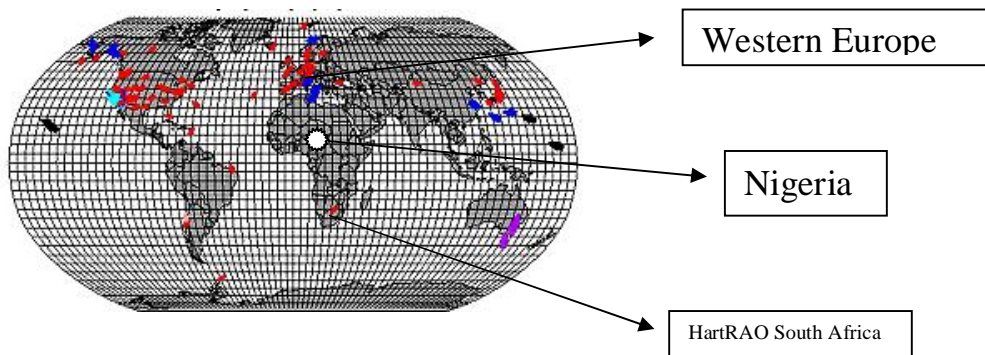


Fig.10: A map showing the strategic location of Nigeria and its interferometry importance

Radio telescopes are particularly important for planetary, solar and stellar system observations, satellite tracking and international geodetic observations. It is a very powerful tool for probing very faint and distant objects, which are needed to understand the origins, and predict the future, of the universe. A radio observation is a must for any nation seriously committed to astronomy and the space sciences. The only operational radio telescope in Africa is the 26m dish in South Africa (though temporary not functional) out of more than 100 radio telescopes that operate across the world today. It has been observed that there a significant gap in the interferometric observation of radio sources about the equator, and a telescope near the equator between Western Europe and the South African telescope at Hartebeesthoek would help solve this problem (fig.10).

Polarization	LCP & RCP	LCP & RCP	LCP & RCP	LCP & RCP	LCP & RCP	LCP & RCP
Amplifier	Cryogenic HEMT	Cryogenic HEMT	Cryogenic HEMT	Cryogenic HEMT	Cryogenic HEMT	Cryogenic HEMT
System Temperature (K)	35	45	50	57	70	80
Lower frequency limit – desired (MHz)	1300	2000	4000	8000	12000	18000
Standard frequency (MHz)	1666.67 OH	2307.69	5000	8500	12178 CH3OH	22235 H2O
Upper frequency limit - desired (MHz)	2000	4000	8000	12000	18000	26000
Receiver bandwidth - desired (MHz)	700	2000	4000	4000	6000	8000
Efficiency (optimal elevation)	≥ 0.60	≥ 0.60	≥ 0.60	≥ 0.55	≥ 0.55	≥ 0.55

- The S/X band (13/3.6 cm) is a dual-feed system to be used for Geodetic VLBI and thus to meet all special requirements for this, e.g. one feed provides both frequency bands, and to have the capability for injecting a calibration comb of frequencies before the first low noise amplifier (LNA).
- All receivers to be equipped with a high stability broadband radio noise source injected before the first LNA, for calibration purposes.
- Feed horn and polarizer design should be optimized to provide desired (at best) / minimum (at worst) bandwidth.
- Feed horns to have Mylar diaphragms over aperture to keep out moisture, insects etc, and to be pressurized with dry air/nitrogen to maintain a positive pressure differential over ambient.
- Helium lines for cryogenic receivers to be connected with computer-controlled valves and pump so that the gas purging and cool down of a cryogenic system can be carried out while the telescope is in normal operation.
- Helium compressors for the cryogenic systems to be mounted on the rotating azimuth base, in a weather-protected shelter.
- Chilled water supply for the helium compressors and air-conditioning systems to be mounted on the rotating azimuth base.
- All electrical equipment to be of a design, which does not produce radio frequency interference (RFI), or shielded / screened such that RFI at a level that could interfere with operation of the receiver systems and backends is suppressed.

The aim of the antenna / feed / receiver design should in general be to maximize the gain / noise temperature (G/T) figure of merit, minimize side lobes (to reduce sensitivity to RFI).

The sub reflector axial position should be motor driven under computer control to permit focus optimization as a function of elevation angle.

Receiver Mount

The telescope should be fitted with a rotating carousel on which are mounted a number of receivers covering different wavebands. The carousel is to be offset to one side of the axis of the telescope so that, by rotation, any one of the receivers can be quickly brought to the focal point.

Carousel aperture is covered by radio transparent diaphragm to exclude rain, insects etc, with an active system for removing water and condensation from dew on the outer surface (e.g. by infrared lamps or a compressed air blower).

Cone protecting the receiver carousel is air-conditioned to keep a constant temperature of $22\pm 1^{\circ}\text{C}$ and to maintain a non-condensing environment.

Present Status

The construction and installation of the project is phased as follows: Designing, Construction and Installation. The project is presently on the designing stage which shall be completed in April 2010. The Company handling this project is ALTECHE Technology Company, China.

Researches have been carried out on the Feasibility of the Site and Radio Quietness of the Site. The results are published in the Nigerian Journal of Space Research (NJSR).

Construction and Installation of the 25m NRT

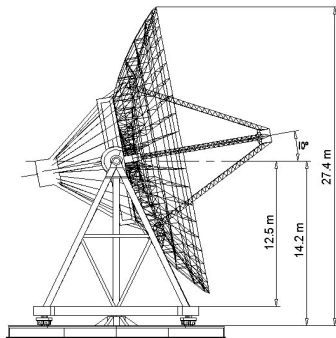


Fig. 11: Sketch description

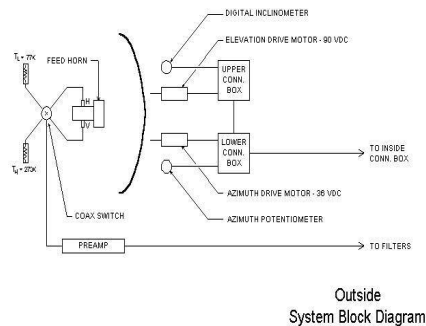


Fig. 12: outside system block diagram

Based on the requirement, the fully steerable exposed design of the 25-m diameter NRT adopts an altitude-azimuth mounting. The parabolic reflector is paneled in the central 15m and wire-meshed in the outer rest annulus. The NRT sketch is referred in Fig. 2 and with dimensions in Fig 3. The reflector elevation angle range covers from 10 to 90 degree above horizon, and the azimuth rotational range spans ± 270 degree from due south.

The reflector back structure is rested in an upside-down “pyramid” supported on the alidade which serves as tracker and pointer to scientific objects. The Quadra-pod legs settle on the four vertexes of the “pyramid” bottom. One of the diagonals of the bottom square of the “pyramid” is mounted with bearings on the top of the alidade yoke to establish the elevation axis. On the bottom of the reflector, radial pipes forming an umbrella-like stabilizer cap on whose extremity counter weight/ballast is set. The alidade yoke is simply a straightforward steel frame with its base centred by a pestle bearing to resist wind turn-over moment. The alidade is supported axially by four groups of rollers running on a track of 15 m diameter to serve azimuthal movement.

The equipment located outside at the antenna site consists of four main systems: the antenna structure, the drive system, the positioning system, and the feed system. These are shown in figure 4.

Schedule of Construction

- | | |
|-----------------------------------|------------|
| ■ Optical system optimization | 15-July-09 |
| ■ Antenna general design | 31-July-09 |
| ■ Backup structure design | 15-Sept-09 |
| ■ Secondary sub-reflector support | 31-08-09 |

■ Panel and adjustor	31-10-09
■ Elevation drive design	31-Aug-09
■ Azimuth drive design	30-Sept-09
■ FEA Finish and report	30-Nov-09
■ Control system design	31-Dec-09
■ CDR	31-Dec-09
■ Detail Design FINISH	22-April-10
■ Manufacture FINISH	22-April-11
■ Integration and test FINISH at NIAOT	22-Oct-11

Future Plans

The 25m NRT will be part of the global VLBI Network such as the EVN.

When the telescope is up and running and finally commissioned, it will be necessary for the following departments/divisions with their complement of staff to be established:

1. Administration

a) CBSS Director

2. Academic Division

a) In-house career astronomers

b) Visiting astronomers from the Department of physics and astronomy, UNN and other Nigerian universities

c) Undergraduate and post-graduate students from the UNN and other Nigerian universities doing project observations for their degrees

3. Telescope Operations and Maintenance Division

a) Chief telescope Engineer

b) Mechanical maintenance engineer/technologist

c) Electrical/electronic maintenance engineer/technologists

d) Information technology Manager/ systems development, support and analysis

e) Telescope systems and components research and development staff

f) Telescope duty-control officers