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Calibration of Radio Telescope using a Satellite dish

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ABSTRACT
Telescopes in general, as an astronomical instrument could not be completely defined as a word. A radio telescope, which measures in the radio part of the electromagnetic spectrum (EM) is a directional antenna used in radio astronomy to detect radio waves. Higher angular resolution is achieved by using the principle of interferometer. In radio telescope array; the complex gain, the system temperature and the beam width are usually unknown and have to be calibrated. In this paper, I assembled and calibrated a radio telescope to determine these unknown parameters.

Key words: *Beam width, Gain, Signal to noise ratio*

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I. INTRODUCTION

Developments in the technology [1] of electronics and radar provided means for the establishment of radio astronomy. The discovery that energy in the form of radio waves was arriving from space was made by Karl Jansky: other discoveries of importance to astronomers were made by chance during the World War II but it was not until its end that the new techniques could be applied to Astronomy research for its own sake.

Telescope as an astronomical instrument could not be completely defined as a word because it has no simple definition. For instance, a telescope [2] used to observer gamma ray can be a pack of electronic sensors launched above the atmosphere while a radio telescope can be a large number of aerials or antennas. There are different types of telescopes such as optical telescope, radio telescope, infrared telescope, ultra violet telescope, x-ray telescope and gamma rays telescope. Telescopes are used to magnify, resolve and gather light. Its magnifying power tells us how many times a telescopic image is larger than a naked eye viewed image. Another property of a telescope is it's resolving power i.e. its ability to give a clearer image and gather light.

Radio telescope on its own is a form of directional antenna [3] used in radio astronomy and in tracking and collecting data from satellites and space probes. In their astronomical role, they differ from optical telescope in that they operate in the radio frequency portion of the electromagnetic spectrum where they can detect and collect data on radio sources. Radio telescopes are typically large parabolic [3] dishes used singularly or as an array. The range of frequency in the electromagnetic spectrum that makes up the radio spectrum is vary large. This means that varieties and types of antennas that are used in radio telescope vary in design, size and configuration. The angular resolution of a dish style antenna is a function of the diameter of the dish in proportion to the wavelength of the electromagnetic radiation being observed. This dictates the size of the dish a radio telescope needs to have for useful resolution.

A radio telescope is used primarily in astronomy to locate objects that don't emit or reflect enough light to be seen by usual optical methods. It can also pick radio waves that are sent from another source, hit an object and bounce back to the receiver. This is actually the same technology that was developed in World War II [1], and became known as radar. Today, we see a form of radio telescope everywhere around us; the satellite dish is a modified version of the radio telescope that picks up waves sent on purpose from satellite in orbit around the earth.

Satellites are found in the synchronous orbit which means that its position in the orbit is fixed with respect to the earth's rotation. This is accomplished when the satellite is positioned approximately 35888km above the earth's surface. The satellite dish has a radiometer, which is a device that measures the strength of the radio signals coming from the receiver on the dish. It also has a detector whose output is proportional to the input radio power called "square- law'' detector. The output from the detector is displayed on a meter, which has an arbitrary scale. The dish has two functions [4], to gather in as much signal energy as possible and focus that energy on the feed horn, which is mounted at the focal point of the dish. Its function (feed horn) is to channel and collect signal (reflected by the dish) to the low noise amplifier or low noise block down-converter (LNB's). The LNB's [4] is a pre-amplifier that further amplifies the signal that is reflected by the dish into the feed horn.

In radio telescope arrays, the complex receiver gain and signal noise are initially unknown and have to be calibrated: gain calibration can enhance the quality of astronomical sky image and moreover, improve the effectiveness of array signal processing techniques for interference mitigation and spatial filtering. The calibration method considered here consists of observing a single point and extracting the gain parameters from the estimated covariance.

II. LITERATURE REVIEW

TELESCOPES IN GENERAL

The invention of telescope allows objects to be seen at a distance. Its application to astronomy has become an essential part of the array of equipment, which is applied to make the basic measurement. Telescope [5] is a device that permits distance and faint objects to be viewed as if they were much closer and brighter to the observer. Most telescopes [3] work by collecting and magnifying visible light that is given off by stars or reflected from the surface of planets, some detects radiations that has wavelength longer than the light human can see, some detects radiation that has shorter wavelength than visible light, while some equally detects and gather x-rays. Such telescope includes optical telescope, radio telescope, infrared telescope ultra violet telescope, x-ray telescope and grammar- ray telescope.

Many telescopes [5] are earth based, located in astronomical observatories around the world: but only radio waves, visible light and some infrared radiations can penetrate earth's atmosphere and reach the surface of our planet which is prone to distortion and pollution. To overcome this problem, scientist have launched telescope in space which can collect waves from other regions of the electromagnetic spectrum, offer much clearer view of astronomical objects and cover the entire celestial sphere.

RADIO TELESCOPES

A radio telescope is a directional antenna that collects radiation in an aperture or antenna and transforms it to electrical signals by a receiver called the radiometer. The purpose of the antenna [1] is to collect waves arriving from a particular direction and provide at its terminal, a disturbance, which can be detected by a radio receiver. This disturbance set up by the antenna is fed into the receiver which is tuned to the frequency of interest and which amplifies them before rectification to provide the final output signal. The output is registered on some recording device such as the magnetic tape or computer disc, which provides the radio astronomer with measurement of the strength of radio radiation and its polarization over the celestial sphere.

When a telescope is directed to a particular source, a signal appears at the output of the receiver, if the telescope is allow to drift (move slowly) relative to the source's direction, the output signal does not fall to zero as soon as the telescope is just off the source's position; the signal may only fall to zero when the telescope is directed away from the source by several degrees. The rates at which the signals fall with angle describe the directional quality of the telescope.

One of the aims of the radio telescope is to collect energy from well-defined point on the celestial sphere. Its resolution [2] can be deduced from the same formula as optical telescope i.e.λ/D where . λ is the wavelength used and D is the diameter of the antenna. Only having large antenna complexes and collecting areas extending over many hundreds of square meters rather than using single dish type collector can achieve high angular resolution. It is only with special techniques of long-based line interferometer [1] in which telescopes are used thousands of kilometer apart, that the angular precision of measurement is beginning to look reasonable in relation to the order of one thousandth of a second. By connecting antenna in the form of an array, high absolute power gain can be obtained with values, which are sufficient for radio astronomical purpose. There are two basic form of array [1].

- Collinear array and
- Broadside array.

In collinear array, the dipoles are arranged to be in line and connected together so that their individual contribution are brought in phase. In broad side arrays, the dipoles are arranged to be in parallel formation such that a distance equal to a half wavelength separates each dipole. They are again connected so that their contribution arrives in phase at the receiver.

RADIO TELESCOPE MOUNTING

Large constructions are required for mounting radio telescopes and consequently, every telescope is given an adjustment to allow all points of the sky to be monitored. In some cases, it has been found possible to design the telescope so that it can be mounted equatorially and some in alt-azimuth position. The mechanical problem of the equatorial mounted telescope is more severe than that of alt-azimuth mounting. Thus, larger telescopes with dish collectors are more often mounted by the later method.

A few radio telescopes [1] dish have been designed so that they remain in a fixed position and the skies are scanned by allowing the diurnal motion to carry a strip of the celestial sphere through the focus of the telescope. By titling the antenna supports so that the sensor is set at the exact focus of the dish, a range of strips can be scanned. However, the area of the sky that is available for observation is greatly reduced by using this type of fixed system. Nevertheless, extremely large collecting areas are to be used.

III. REASEARCH METHODOLOGY

ASSEMBLING OF A RADIO TELESCOPE

MATERIALS FOR MAKING A RADIO TELESCOPE

The material/electrical parts and equipment needed for this design includes the following

1 MATERIALS

- 30x30 composite board of similar material for the base
- A lazy Susan
- 8-1/4 metal sheet or wood screws
- Wood glue
- Nylon washer
- Electrical tape
- A compass

2 ELECTRICAL PARTS

A terminating resistor

- 4’’ coax cable
- 2’’ coax cable
- 1- 0.1 MHz RF choke
- 12volt batteries.

3 EQUIPMENT NEEDED

- 1-18 inch satellite dish with LNB and mount
- A satellite finder or channel master.

MAKING THE BASE FOR THE RADIO TELESCOPE

The satellite dish has a mounting bracket used to attach the dish to a house; I attached this bracket to a base that can turn, which makes pointing the dish easier. The base will need to be strong so as to prevent the dish from topping over, and then, I followed the following steps. I

- Cut the composite board to 30 by 30inch
- Attached the bottom of the lazy Susan to the center of the composite board
- Attached the top of the lazy Susan to the base. Pre-drill a hole through the board and then use a bolt and a washer to attach the top of the lazy Susan. This allows the tightening of the lazy Susan as needed.

PROCEDURES FOR ASSEMBLING THE DISH

- The satellite dish also has the following items; a multi-satellite dish reflector, a mounting bracket used to attach the dish to the house, an arm that attaches the LNB to the dish and the receiver plus various screws and washer.
- I installed the terminating resistor on the LNB output, which will help to reduce signal loss.
- I inserted the 4’coax cable through the LNB before attaching it to the LNB.
- I attached the LNB to the LNB’s arm.
- To reduce the height of the dish, I shortened the mounting bracket thus, only the lower portion was used.
- I attached the lower portion of the mast to the mounting bracket, and used the nylon or Teflon washer to help make the mast and the dish glide against each other easily.

PROCEDURE FOR ASSEMBLING THE POWER SUPPLY

I used a 12-volt of Dc power to operate the satellite finder; this provided the power through a battery holder. Then, I followed these steps

- Cut off the two end of the 2’ coax cable.
- Strip off about 2inch of the black covering.
- Comb and pigtail the silver braid shielding and remove the foil shield exposing the white insulation.
- Solder the RF choke to the coax center wire
- Solder the other end of the RF choke to the red lead of the 9volt battery connector.

- Using electrical tape, wrap from the insulation of the coax cable to the red and black leads of the 9-volt connector.
- Attach the coax from the LNB to the LNB terminal of the satellite finder.
- Attach the coax from the battery pack to the SAT RX terminal on the satellite finder
- Figure 1 shows the assembled radio telescope.

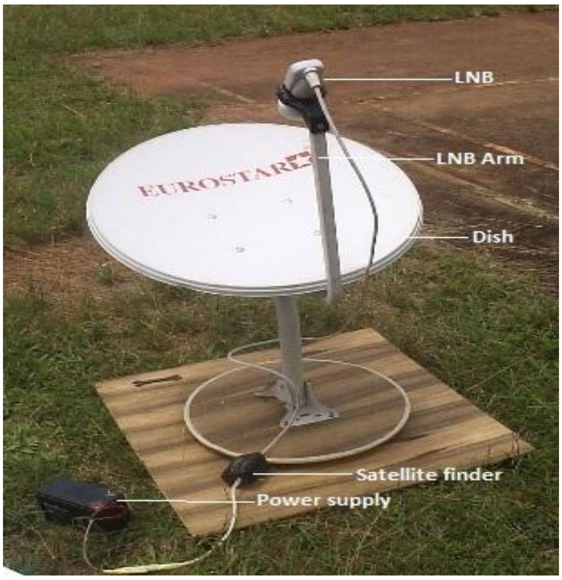


Fig 1: Diagram of a radio telescope

RESULT AND DISCUSSION

CALIBRATION OF RADIO TELESCOPE USING A SATELLITE DISH

In radio telescope arrays, system temperature (T_{sys}) receiver gain, and sensor noises are initially unknown and have to be calibration, apriority. Calibration can enhance the quality of astronomical sky image and determines the error associated with a measurement. However, in this experiment, the individual components are assured to operate at the manufacture's specification. Thus, I calibrated the telescope to determine the system temperature, the beam width, and the gain of the antenna.

ANTENNA THEORY

A common type of radio telescope and the one I used in this experiment has a parabolic reflector as shown in fig 1 above. Once the waves bounce on the dish, they are reflected towards the LNB, which sits at the focus of the dish. The LNB converts a whole band or block of frequency, called the intermediate frequency (IF). This is done by means of a local oscillator and a mixer; the incoming signal frequency oscillator is combined with a signal frequency from the oscillator (w_{lo}) and sent to a mixer, which outputs it at the intermediate frequency $W_{IF.}$

NOISE AND ITS SOURCES

Noise [9] is an inherent part of all electrical and electronics system. Not only does the IF frequency get amplified, any noise from the mixer and local oscillator will also be sent through the IF amplifier. It is important to understand the sources of noise when working with any type of receiving system since noise that is recovered can either be desirable or undesirable. Thus, we must understand more about and how radiation is spread across its surface area.

The antenna picks up signals (or noise) from different sources even when it is pointed directly upwards at the sky, the antenna receives signals from the atmosphere, the ground and any other type of radio interference such as automobile. These sources all create noise and the total noise temperature of the system is measured in unit of system temperature (T_{sys}). Thus,

$T_{sys} = CV_1 – T_{sky}$ ………………………………… Equation 1

$T_{sys} = CV_2 – T_{ground}$ ………………………….Equation 2

Where C = constant of proportionality

V_1 = meter reading when aimed as the sky

V_2 = meter reading when aimed at the ground.

ANTENNA PARAMETERS

From the previous section, we know that that everything that has temperature emits radiation and thus introduce noise into our receiving system. The amount of noise that enters depends on many factors; the antenna design, the direction the antenna is pointing, the antenna beam width, the effective aperture and gain.

When a radio telescope is aimed directly at a radio source, it gives a maximum signal, as it is moved away from the radio source; it still receives some of the signal. A good telescope will show a signal strength drop to zero as it moves away from the radio source called its narrow beam width. By definition, the beam width of a radio telescope is the angle between the directions corresponding to half the maximum power called the half power beam width (HPBW). For instance, the circular aperture antenna beam width is given by [3] θ where

$\theta = 58.4\lambda/D$……………………………..Equation 3

Where λ= wavelength of the incoming radiation and D =the diameter of the dish.

Gain of an antenna is a measure of how it can increase the power of a radio signal as compared to some standard. Gain calibration can be calculated in different ways depending on what specific information is known about the system. One way of doing this is to take the logarithm of the ratio of output power (P_{out}) to input power (P_{in}) of the signal and multiply by 10.

I.e. $G = 10\text{Log } P_{out}/P_{in}$ ………………………………………………… Equation 4

Another useful formula relates the gain of the antenna to the effective aperture [10] is

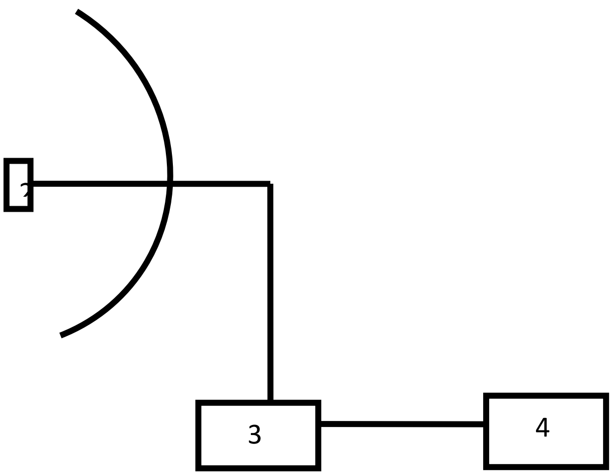
$G = 4\pi A_e/\lambda^2$ …………………………………………. Equation 5

.

Where A_e = effective aperture

Thus from equation 5, bigger dish gives more gain; also the smaller the wavelength of the incoming radiation (narrow beam width) the higher the gain. Thus for achieving higher gain and narrow beam width, larger radio telescopes are better than smaller ones. Hence vary lager arrays (VLA) are used in radio astronomy interferometer.

EXPERIMENTAL SETUP AND PROCEDURE.



1. Dish
2. LNB
3. Satellite finder
4. 12 volt battery

LNB is a commercial C-band low noise block converter. It takes an incoming signal, mixes it with local oscillator frequency and produces an intermediate frequency between 950-1450MHz, which is then amplified. The IF signal then travel through the coaxial cable to a satellite finder, which is a detector used in the experiment. The satellite finder has a signal meter and a sensitive adjustment on the front panel; its purpose is simply to let us know when the antenna is pointed at a radiating source. Because it has an in-built amplifier, it acts as the second stage of amplification.

PROCEDURE AND DATA AND ANALYSIS

Sky temperature. [9] (T_{sky}) 3K.
Ground temperature. [9] (T_{ground}) ~ 300K
Sky pointing V_1 2dB
Ground pointing V_2 4.9dB

ANALYSIS

Translating these numbers into temperature, we recalled equation 1 and 2.

$T_{sys} = cV1 - T_{sky}$ Equation 1
$T_{sys} = cV2 - T_{ground}$ Equation 2

Rewriting these equation gives.

$cV_1 = T_{sys} + T_{sky}$ Equation 6
$cV_2 = T_{sys} + T_{ground}$ Equation 7

We can solve for c and T_{sys} as follows:
Substituting the vales from our data to equation 6 and 7

$2c = T_{sys} + 3$ Equation 8
$4.9c = T_{sys} + 300$ Equation 9
$-2.9c = -297$
$c = 102.4k.$

Thus, each division on the meter (satellite finder) equals 102.4 Kelvin. Hence, putting back this valve into equation 8 or 9. We now have

$102.4(2) = T_{sys} + 3$
$204.8 = T_{sys} + 3.$
$T_{sys} = 204.8 – 3 = 201.8$ Kelvin
Thus system temperature = 201.8 Kelvin

THE BEAM WIDTH

We recalled equation 3, i.e. $\theta = 58.4 \lambda /D$,
Where λ wavelength = c/f = 3.0x10^8/950x10^6
λ = 3.2x10^-1m
D = 1.5 ft. = 46cm = 0.46m
Thus,
Beam width θ = 58.4(λ/D)
= 58.4 x 3.2x10^-1/0.46
= 58.4 (6.9x10^-1)
= 40.3
= 40 deg (approximately)

THE GAIN.

We equally recalled equation 5 i.e.

$G = 4\pi A_e /\lambda^2$ Equation 5.

Where A_e = effective aperture of the dish.
But A_e = efficiency x geometric aperture (A_g)
Where (Ag) = $\pi d^3/4$ Equation 10
Thus, A_g = 3.142 $(0.46)^3$ / 4
=3.142 (0.097)/4
=0304774/4 =0.076

If the dish is 50% efficient, then the effective aperture $A_e = 50 \times A_g$
I.e. 50/100x0.076 = 0.038
Where λ= 3.2x10^-1
Therefore, gain $G = 4\pi A_e /\lambda^2$ = 4 x 3.142 x 0.038/ (3.2x10^-1)^2
= 0.477584/0.1024
= 4.9dB

IV. SUMMARY/ CONCLUTION

A radio telescope is simply a telescope that is designed to receive radio waves from space. Unlike the optical telescope that is used to view or study distant objects in visible light, radio telescope is used to study naturally occurring radio emission from stars, galaxies, quasars and other astronomical objects. It equally detects microwaves emitted by human body and that emitted by other objects of sufficiently high temperature. Its simplest form consists of a parabolic reflector, a receiver and a detector.

The angular resolution or the ability of a radio telescope to distinguish fine detail in the sky depends on the wavelength of observations divided by the size of the instrument. Higher angular resolution is achieved by using the principle of interferometer to synthesis vary large effective aperture.

In radio telescope array, the complex receiver gain, the sensor noise power and the system temperature are usually unknown and have to be calibrated. However, the calibration method considered here consists of observing a single point source and extracting the gain and noise parameter from that source.

The experiment I carried out in this project was the calibration of a radio telescope using a satellite dish. The results shows that this dish has these characteristics; system temperature of 201.8kelvin, beam width of 40 and gain of 4.9dB.

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