L-shaped array for multi-frequency interferometry telescope

Abstract

An array of eight antennas with different configuration, more precisely an L-shaped array has been built for the Multi-frequency Interferometry Telescope for Radio Astronomy (MITRA) project. It consists of quite newly designed Dual Polarised Log Periodic Dipole Antennas (DPLPDA).

The first stage of the project was to test the existing array of DPLPDA antennas in a parallelconfiguration in the North South direction and to bring forward different improvements. Also, comparision of data was done with the Durban University of Technology (DUT) at Durban RSA where a similar array was constructed.

Next, UV coverage of different arrays were simulated. After that, the DPLPDA were constructed. After setting up the array, the antenna response of each antenna was tested and the results obtained was interpreted. The final test was to test the complete array after combining all the antennas.

CHAPTER 1

Introduction and Overview

1. 1Introduction

1. 1. 1Radio Astronomy

Radio astronomy is the study of celestial objects that emit radio waves. In the 1930’s, Karl Jansky (1905-1950), working for the Bell Laboratories, was trying to determine the origin of the source of noise interfering with radio voice transmissions. He built a steerable antenna designed to receive radio waves at a frequency of 20. 5 MHz. From the observations, he found that the period of the earth's rotation relative to the radio source was 23 hours and 56 minutes instead of 24 hours. Hence, he concluded that the source was follwing sidereal time. He also observed that the strongest radiation was coming from the centre of our Milky Way galaxy. Inspired by Jansky's work, Grote Reber (1911-2002) built a parabolic radio telescope of diameter 9m in his back yard, in 1937. After several trials, Reber successfully detected radio emission from the Milky Way, in 1938, confirming Jansky's discovery. This led to the discovery of a range of celestial objects, such as radio galaxies, quasars, and pulsars with radio emission with various types of antennas. [1]

1. 1. 2. 1 Radio Interferometry

R adio interferometr y are arrays of radio antennas that are used in astronomical observations simultaneously to simulate single telescope sof very large aperture s and are used to make measurements of fine angular detail in the radio emission. Radio interferometry enable measurement of the position of radio sources with accuracy to allow identification of other objects detected in the electromagnetic spectrum. Michelson and Pease made the discovery of the interferometric techniques in 1921. They were able to obtain sufficiently fine angular resolution to measure the diameters of some of the nearer stars such as Arcturus and Betelgeuse. [2]

1. 1. 2. 2 Aperture Synthesis

Aperture Synthesis or Synthesis Imaging is a type of interferometry that correlates radio signals obtained from a collection of telescopes or antennas to produce images. These images have the same angular resolution as that of the size of a single and a much larger telescope or antenna. Aperture synthesis was first discovered by Sir Martin Ryle (27 September 1918 – 14 October 1984) and coworkers from the Radio Astronomy Group at Cambridge University at radio wavelengths. In 1974, Martin Ryle was the first astronomer awarded a Nobel Prize. [3]

Very Long Baseline Interferometry (VLBI) also makes use of radio interferometric techniques. TypicallyVLBIrefers to experiments that do not process their data in real time, but record it for latercorrelation to produce the resulting image. It achieves ultra-high angular resolution and is a multi-disciplinary technique. VLBIis used in measuring pulsar parallaxes andproper motion, resolving the cores of radio galaxies and fets from supermassive black holes, among others. [14]

Some of the commonly used radio interferometers are:

1. the Very Large Array (VLA) in Socorro, New Mexico, USA;

- It consists of 27 radio antennas, each of diameter 25 metres, along three arms of a Y-shaped configuration spread over three 21 kilometres tracks providing 351 baselines. [4]

2. the Multi-Element Radio Linked Interferometer Network (MERLIN) , operated by Jordrell Bank Observatory;

- It is an array of 7 radio telescopes spread across Britain with separation up to 217 kilometres operating at frequencies between 151 MHz and 24 GHz. [5]

3. the Australia Telescope Compact Array (ATCA) in Narrabri, NSW, Australia.

- The telescope is an array of six identical 22 metres diameter dishes with five movable dishes along a 3 kilometres railway track and the sixth one is 3 kilometres west at the end of the main track. The maximum baseline length is 2. 7 kilometres and the observing frequencies are from 300 MHz to 8 GHz.[6]

4. the Giant Metrewave Radio Telescope (GMR T) in Narayangaon, Pune, India.

- It consists of 30 steerable parabolic dish each of diameter 45 metres opertaing at six different frequency bands and where 14 dishes are arranged in a central square and remaining 6 in a three arm Y-shaped array giving a baseline of about 25 Kilometres . [7]

Some of the new radio interferometers are:

1. Low Frequency Array (LoFAR) in north of Exloo, the Netherlands (core) and neighbouring countries

- It is a phased-array of radio telescopes of about 25, 000 small antennas in at 48 larger stations where 40 of these stations are distributed across the north of Netherlands, five stations in Germany , and one each in Great Britain , France and Sweden and has a low requency range from 10-240 MHz. [8]

Figure 1: The LoFAR Array

2. Atacama Large Millimeter Array (ALMA) in llano de Chajnantar Observatory, Atacama Desert , Chile

- It consists of sixty six 12 metres and 7 metres diameter radio telescopes observing at wavelengths of 0. 3 to 9. 6 millimetres . [9]

3. Murchison Widefield Array (MWA) in Murchison Radio Astronomy Observatory, Western Australia

- It consists of 2048 dual-polarization dipole antennas, each a 4×4 array of dipoles and operates at low radio frequencies, 80-300 MHz, with a processed bandwidth of 30. 72 MHz for both linear polarisations, and consists of 128 aperture arrays (known as tiles) distributed over approximately 3- kilometres diameter area. [10]

Figure 2: MWA Antenna tiles

4. KAT7 & MeerKAT in Northern Cape, South Africa

Figure 3: Aerial View of KAT7

KAT-7 consist of 7 dishes of 12 metres in diameter each a Prime Focus Reflecting Telescopes having a minimum baseline of 26 meters and maximum baseline of 185 metres and have a frequency range of 1200 MHz – 1950 MHz. KAT-7 is an engineering prototype for the MeerKAT. KAT-7 is the world's first radio telescope array with fiberglass dishes. . MeerKAT, which is still under construction and is slated for completion in 2016 , will consist of 64 dishes of 13. 5 meters in diameter having a minimum baseline of 29 metres and maximum baseline of 20 kilometres and it will operate at frequency ranging from 580MHz – 1. 75 GHz and 8 – 15 Ghz.[11, 12]

5. e- MERLIN is an enhanced and upgraded array of the old MERLIN array. The e- MERLIN instrument is a high resolution radio interferometer connected by a new optical fibre network to Jodrell Bank Observatory. This new system gives rise to a massive increase in sensitivity and observational capabilities.[13]

Figure 4: e-MERLIN array

European VLBI Netwok (EVN) is an interferometric array of radio telescopes spread across Europe which also includes stations in far-East Asia , South Africa and Puerto Rico that conducts high resolution radio astronomical observations of radio sources. It is the most sensitive VLBI array in the world. It was formed in 1980 and the administering body now comprises 14 institutes[15]. TheEVNalso routinely joins other networks, such as the Very Long Baseline Array (VLBA) and the Multi-Element Radio Linked Interferometer Network (MERLIN) , to become a globalVLBIarray. The VLBA is spread throughout Mauna Kea , Hawaii and St Croix. It typically consists of 10 VLA radio antennas and as result it has a maximum baseline exceeding 8000 Km[16].

Some of the future African based new radio interferometers are:

1. African VLBI Network (AVN)
2. Multi-Frequency Interferometry Telescope for Radio Astronomy (MITRA)

1. 1. 3 MITRA (Multi-frequency Interferometry Telescope for Radio Astronomy)

1. 1

The MITRA is an international radio astronomy project which aims to do extremly wide field of imaging with heterogenius non coplanar arrays. The acronym of MITRA means “ friend” in Sanskrit. It is a low frequency array telescope jointly started by Girish Kumar Beeharry from University of Mauritius (UOM) nd Stuart David Macpherson and Gary Peter Janse Van Vuuren from the Durban University of Technolagy (DUT) in South Africa.

The project is being simultaneously implemented at the Mauritius Radio Telescope (MRT), located at Bras D’Eau Mauritius, site and at the DUT campus site. The projects will then be expanded to the different SKA Africa partner countries and eventually to other African countries. Data from each country will be combined to form an international aperture synthesis telescope using the techniques of Very Large Baseline Interferometry (VLBI). It is a sensitive high resolution multifrequency dual polarity instrument in the range of 200 to 800 MHz. The instrument chosen for this purpose are Dual Polarized Log Periodic Dipole Antennas (DPLPDA)[17].

1. 1. 4 African Long Baseline Interferometry Network (AVN)

The African Very Long Baseline Interferometry Network (AVN) is an array of radio telescopes throughout Africa. It is planned to form part of the existing global VLBI networks . It will be associated with the European VLBI Network (EVN). The latteris a consortium of major radio astronomy institutes in Europe and China (Schilizzi). It has member and associated radio telescopes in Europe, China, South Africa (Hartebeesthoek0, Japan(Kashima) and Puerto Rico (Arecibo). The EVN is capable of providing an excellent angular resolution(from 5 to 0. 15 milliarc seconds depending on observing frequency) and high sensitivity for VLBI observations. One of the main technological drivers has been the availability of telecommunication antennas all over Africa. Part of the scheme is to modify the existing dishes, of about at least 30 m in diameter, into radio telescopes. All these telescopes will be linked together, and to radio telescopes in South Africa, forming the African VLBI Network. This, in turn, would be connected to radio telescopes and arrays in Europe and elsewhere in the world, including North and South America, Asia and Australia. The conversion of a Ghana located dish into a radio telescopes has already been begun. The AVN's plans to convert three more dishes in Kenya, Zambia and Madagascar. It also aims to build four new radio telescopes in Namibia, Botswana, Mauritius and Mozambique. [19]

1. 1. 5 Electronic Multi Beam Radio Astronomy ConcEpt(EMBRACE) and African European Radio Astronomy Aperture Array (AERA [3])

The EMBRACE demonstrates the technical and scientific potential of the aperture array concept using a phased array station with the essential SKA. There are two stations, one in NanÒ« ay, France and the other one at the Westerbork Synthesis Radio Telescope (WSRT) in the Netherlands. These two stations are prototype arrays for the SKA MFAA. It consists of an antenna array organized in tiles of dual polarization antennas. A large number of antenna tiles forms the collecting area. The signals from the radiating elements of the antenna from each tile are amplified and the initial analogue RF beam forming is applied. Generally, an EMBRACE is designed for a frequency range of 400-1500 MHz of single polarization, a collecting area of 100 m^2 , system temperature of 100 K and has two fields of view with 8 digital beams . The idea of having multiple independent beams gives rise to the AERA3 because EMBRACE considers only two beams. AERA3 is similar to EMBRACE but this new aperture array will have a greater collecting area with will be approximately 2000 m^2 varying with a frequency range of 400-1500 MHz with full polarization, two fields of view with 64 digital beams, system temperature of 50 K and bandwidth of less than 500 MHz. AERA3 will be used for intensity mapping, surveys of the whole sky and search for pulsars. [20, 21]

Figure 5: Embrace at Nancay, Paris

1. 1. 6 The Square Kilometre array (SKA)

The SKA will be a revolutionary radio telescope made of hundred of thousands of receptors. They will be linked together, forming a total collecting area of approximately one square kilometre. It will be the largest and most sensitive radio telescope ever built. It will be able to survey the sky faster than present instruments.

In 2006, the African consortium and Australia were both shortlisted as potential sites fot building the SKA. In the 25 th May 2012, the SKA organisation announced that SKA would be shared between the African consortium and Australia on a 2: 1 ratio basis. The African consortium would be undertaking the construction of the high and mid frequency arrays. The Australian would be in charge of the low frequency aperture array.

The SKA consists of two phases where

- Phase 1 is the construction of about 10% of the SKA. It will make use of the existing infrastructure and telescopes already being built by the two countries. That is, the South Africa's precursor array the 64-dish MeerKAT telescope and the Australia's 36-dish SKA Pathfinder (ASKAP). Additionally, there will be 50low-frequency 1. 5 metre high antenna stations, 60mid-frequency 15 metre dishes built in Australia. Finally, 190mid-frequency 15 metres dishes will be built in South Africa.
- Phase 2 is the extension to a baseline of 3, 000 Km or more in South Arica and African partners countries. These are namely, Botswana, Ghana, Kenya, Madagascar, Mauritius, Mozambique, Namibia, and Zambia. Also, a total of about three thousand dishes, with the highest concentration in the Northern Cape, South Africa, and some dishes in the other consortium countries will be built.

In Australia, the telescope will extend over a baseline of200 km.

It will operate with a frequency coverage from 70 MHz to 30 GHz. The SKA will use aperture synthesis, over a distance of more than 3000km to simulate a single giant radio telescope capable of extremely high sensitivity and angular resolution.

The SKA will be able to observe the black holes, stars, galaxies and detect black holes[11, 22, 23, 24].

Figure 6: SKA overview

1. 1. 7 The Log Periodic Dipole Antenna

A log periodic antenna, also referred to as a log periodic array, is an antenna that can operate on a wide frequency band. It was ï¬ rst built in 1958 by Dwight Isbell at the University of Illinois, United States of America. LPDA is a directional antenna which possesses constant electrical characteristics such as gain, impedance and front-to-back ratio over the wide range of frequencies. It varies periodically with the logarithmic. The antenna consists of a series of linear elements also known as dipoles and the individual elements connect with a transmission or feed line such as coaxial cable. Each element is placed in an alternating configuration leading to a phase shift of 180 ^{o} (π radians). [25]

1. 2 Aim

The aim of this project is to construct a front-end system for radio astronomical observations in the frequency range 200 MHz to 800 MHz using the Dual Polarised Log Periodic Dipole Antenna model with bandwidth 200 MHz to 800 MHz. The front end system will consist of an L-shaped array of antennas. This L shaped array is the start of a matrix of an eight by eight antennas. It will be used as a prototype for Intensity mapping for large scale neutral hydrogen (HI) mapping. Several improvements to the existing antennas will be made and applied to new array configuration. Also along with the array, a shielded box will be constructed for electronic purposes. This work focuses on the longer baseline sparse mid frequency aperture array (MFAA), in contrast to the dense aperture arrays like EMBRACE and the future AERA3.