Beam Pattern Simulation of Nkutunse Antenna

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Abstract - The African VLBI Network (AVN) is an initiative by SKA-SA to establish VLBI stations on the African Continent through conversion of existing telecommunications facilities or building new facilities. The immediate focus is on converting an existing 32m satellite communication antenna at Nkutunse, Ghana as a joint venture between SKA-SA and Ghana Atomic Energy Commission (GAEC). Phase one of these conversions would include the application of pointing direction of these antennas. OSKAR simulator is therefore used to simulate Ghana's antenna to determine the beam patterns at different intensities of Stokes *I*, *Q*, *U* and *V*. This would help research scientists and engineers to know the amount of field strength being received by these antennas. OSKAR presented the beam pattern in a form of geometric dipole showing clearly the field strength at different intensities.

Keyword - *Beam Pattern, OSKAR Simulator, Very Long Baseline Interferometry (VLBI), Stokes Parameters.*

1. Introduction

The 32 m diameter telecommunications antenna situated at Nkutunse, off Nsawam road, 25 km north-west of Accra, Ghana was part of the Ghana Satellite Earth Station that was commissioned in 1981. The antenna which is no longer being used as telecommunications has been donated by Vodafone Ghana to Ghana Atomic Energy Commission (GAEC) for Science Research. Currently, it is jointly being managed by Ghana Space Science and Technology Institute under GAEC and Square Kilometer Array – South Africa (SKA-SA) team in conversion of its present state into a Very Long Baseline Interferometry (VLBI) Radio Astronomy Facility. The present state of the antenna is shown in Fig. 1 and it is mounted on a concrete base.

The first phase in the conversion of this antenna would be in the application of pointing directions. Beam-forming can therefore be applied to steer the antenna to determine the direction of a signal source. The paper therefore uses OSKAR [1] simulator to determine the beam patterns of this antenna at different intensities.

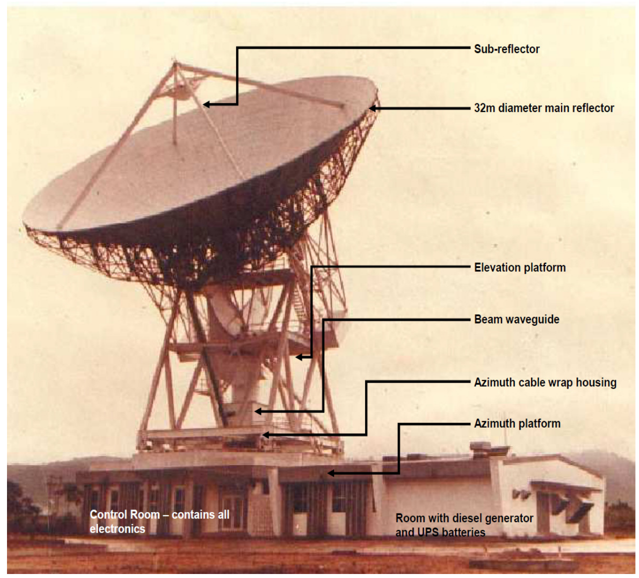


Fig. 1: The 32 m satellite communications antenna at the Ghana Earth Station at Nkutunse (as built in 1981)
Source: AVN, SKA – SA, 2011. [2]

Beam-forming is a general signal processing technique that is used in radio astronomy to observe radio signals from a defined area of the sky. This technique comes from the fact that early spatial filters were designed to form pencil beams [3] in order to receive a signal radiating from a specific location and attenuate signals from other locations. The technique is applicable to either radiation or reception of energy. In this paper we discuss formation of beam patterns for reception.

1.1 Very Long Baseline Interferometry (VLBI)

VLBI is part of radio interferometry that uses radio telescopes that have no direct link for data and real-time between the stations for the received signals. Its resolution is of order a milliarcsecond with baselines only limited by the size of the Earth [4]. For detailed discussions on how science is performed with VLBI, refer to [5, 6 and 7]. Fig. 2 shows the collaborators who form the African VLBI Network currently.

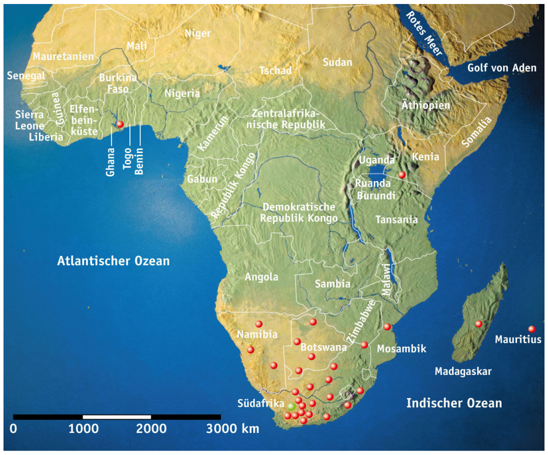


Fig. 2: African VLBI Network (AVN) Collaborators

2. Methodology

The simulation of the beam pattern graphically depicts the relative field strength received by the antenna. The patterns are usually presented in polar form as shown in Fig. 3 and also, taken at specific frequency and polarization. Mathematically, we can express the beam pattern as the power radiated per unit solid angle or its intensity. That is,

$$U = r^2 W_{rad} \quad \textbf{(1)}$$

where, $U =$ beam intensity $\left(W / unit\ solid\ angle\right)$ and $W_{rad} =$ power density $\left(W / m^2\right)$

The beam intensity has a direct relationship with the far-zone electric field of an antenna and can be expressed as

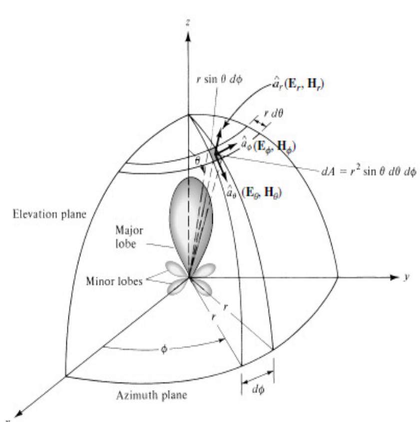


Fig. 3: Antenna Beam Pattern in a Spherical Coordinate System

$$U(\tau,\upsilon) = \frac{r^2}{2\xi}\left|E(r,\tau,\upsilon)\right|^2 \approx \frac{r^2}{2\xi}\left[\left|E_\tau(r,\tau,\upsilon)\right|^2 + \left|E_\upsilon(r,\tau,\upsilon)\right|^2\right]$$
$$\approx \frac{1}{2\xi}\left[\left|E_\tau^\circ(\tau,\upsilon)\right|^2 + \left|E_\upsilon^\circ(\tau,\upsilon)\right|^2\right] \quad \textbf{(2)}$$

where, $E(r,\tau,\upsilon) = E^\circ(\tau,\upsilon)\dfrac{e^{-jkr}}{r} =$ far-zone electric field intensity of the antenna with spherical coordinate (τ,υ) and radius r, $E_\tau, E_\upsilon =$ Far-zone electric field component of the antenna, $\xi =$ intrinsic impedance of the medium. The phase factor is expressed as kr.

Therefore, its total power density is defined as,

$$P_{beam} = \oiint_\omega U d\omega = \int_0^{2\pi}\int_0^{\pi} U \sin\tau\, d\tau\, d\upsilon \quad \textbf{(3)}$$

where, $d\omega = \sin\tau\, d\tau\, d\upsilon =$ element of solid angle. More detailed explanations can be obtained from [8, 9].

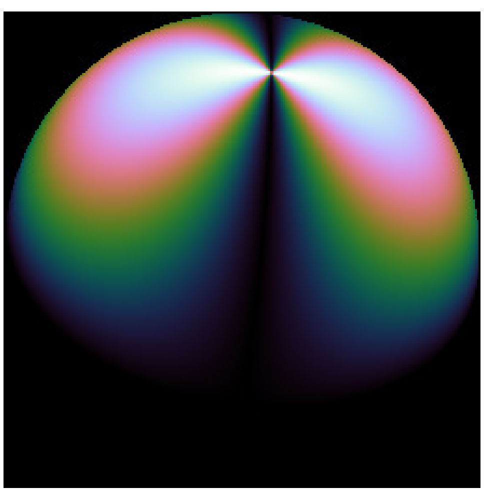
In this study, an OSKAR simulator was used to model the beam pattern by studying the response of the beam to object outside its line of direction. This is very significant for the phase 1 conversion of this antenna. The following was the setup used to simulate the antenna beam pattern in OSKAR:

[General]
version=2.4.0
[simulator]
double_precision=true
keep_log_file=true
max_sources_per_chunk=10000
[observation]
num_channels=1
start_frequency_hz=1400000000
frequency_inc_hz=125000
phase_centre_ra_deg=0
num_time_steps=500
start_time_utc=02-09-2000 00:21:40.000
length=12:00:00.000
phase_centre_dec_deg=-49
[telescope]
longitude_deg=5.750405
latitude_deg=-0.305112
aperture_array\element_pattern\enable_numerical=true
input_directory=$HOME/Nkutunse_ANTENNA/telescope
station_type=Aperture array

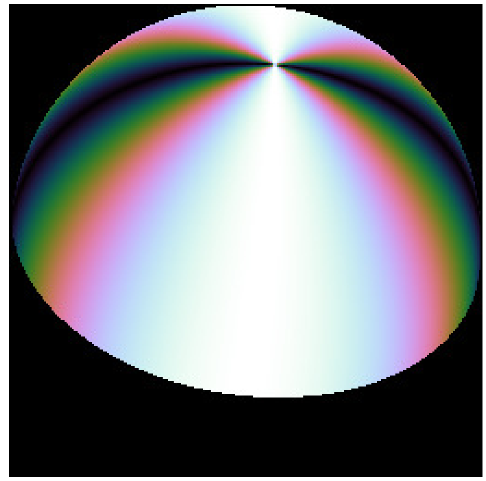
altitude_m=70
[beam_pattern]
root_path=Nkutunse_beam_pattern1
fits_file\save_voltage=true
beam_image\size=256
beam_image\fov_deg=180.0
oskar_image_file\save_voltage=true
station_id=1
oskar_image_file\save_total_intensity=false
oskar_image_file\save_phase=false
fits_file\save_total_intensity=false
fits_file\save_phase=false
coordinate_type=Beam image

3. Results and Discussions

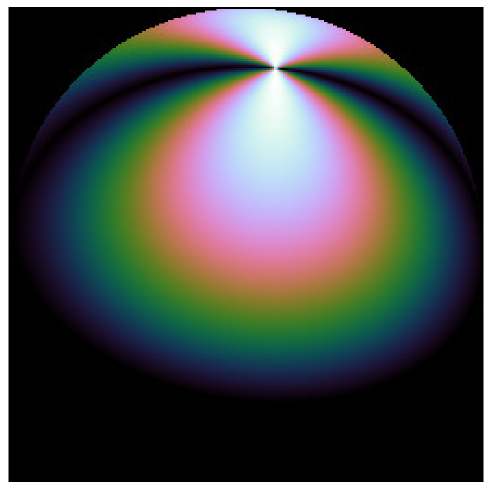
The outputs in Fig. 4 show the simulated beam patterns of Nkutunse antenna at different intensities of Stokes parameters (I,Q,U,V) . This is due to the polarized emissions of the observing signal. The simulated observations were made at the phase centre with right ascension and declination at 0 hr 0 mins 0 secs and - 49^{o} 00 arcmin 00 arcsec respectively. These observation parameters were chosen since the Nkutunse antenna would track the same object as those in the southern hemisphere. The antenna location was considered in modeling the beam patterns with -0.305112 being the latitute, 5.750405^{o} the longitude and 70 m being the altitute above Mean Sea Level (MSL). Geometric dipole was used to describe the antenna patterns. These patterns of Stokes *I*, *Q*, *U* and *V* in Fig. 4 describes the filed strength received by the antenna. The field-of-view (FoV) of the beam patterns were considered at 180^{o} with pixel dimensions of 256 by 256.



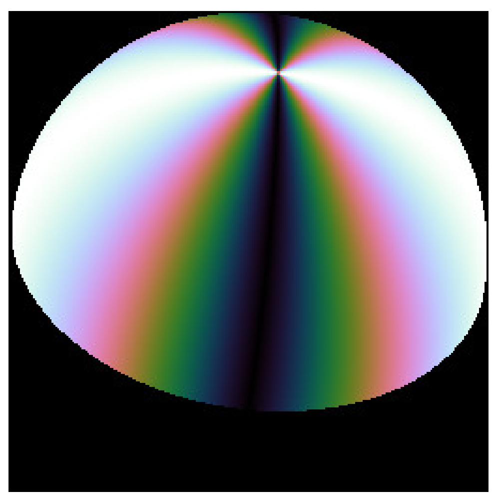
(a) Stokes I



(b) Stokes Q



(c) Stokes U



(d) Stokes V

Fig. 4: Beam Patterns at Various Intensities

4. Conclusion and Future Works

In conclusion, signals with different intensities can be expressed in Stokes parameters *I*, *Q*, *U* and *V* with *I* being the total intensity which is formed as a result of autocorrelation likewise *V*. These intensities generate different beam patterns during observations in the sky.

A continuation of this research is to simulate the correlation between the Nkutunse antenna (in Ghana) and MeerKAT (in South Africa) to effectively evaluate how much resolution the new set of baselines bring with the combine instruments.

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Bibliography

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