Section A: Overview of the Research Project Proposal

1. Academic level of research project

Doctoral

2. Broad field of research

Engineering

3. Title of the research project

Planar Sparse Regular Array Antenna Demonstrator

4. Research project abstract/summary

Antenna arrays with elements arranged on a regular lattice, but spaced more than a wavelength apart, are an interesting option for large scale radio astronomy applications. The main advantage here is the high resolution obtained by the larger aperture size of the system, while requiring fewer elements than a dense system which brings down the cost. However, grating lobes due to the sub-Nyquist spacing degrades the performance of such a system in terms of sensitivity as well as the fundamental difficulty in dealing with the inherent angular ambiguity of the receiving system. However, a recent breakthrough in exponential analysis by researchers at Antwerp University in Belgium allows for the fast and systematic resolution of the grating lobe ambiguity when using sparse, regularly spaced arrays in a so-called co-prime configuration.

Currently the first full wave simulation version of simpler linear arrays show that the idea is practically tractable for the direction-of-arrival estimation problem. The goal of this research is to expand the idea to the 2D planar case, and demonstrate the beamforming and imaging problems with a practical array antenna system. The system must be carefully characterised for radio astronomy applications, with specific attention given to the 500 – 1500 MHz band. Noise, bandwidth and back-end processing requirements must be defined, and comparisons drew with classic dense regular and sparse random array systems.

Section B: Supervisor(s) Details

1. Primary supervisor's details

a. Title and full name

Prof. Dirk de Villiers

b. Name of South African university

Stellenbosch University

c. Email address and/or contact telephone

ddv@sun.ac.za

0218084011

d. Supervision of postgraduate students.

i. Doctoral Students:

Name of student	Nationality	Date started	Date completed	Title of Research Project / Thesis	Co-Supervisor (if relevant)
Ryno Beyers	South African	Jan 2013	Dec 2015	Circuit Model Design of Conical Transmission Line Power Combiners and Isolation of Reactive Combiners	N/A
Ngoy Mutonkole	DRC	Jan 2014	Dec 2016	Modelling of Antenna Responses	N/A
Brandt Klopper	South African	Jan 2016	Dec 2018	Antenna elements for sparse-regular aperture arrays	N/A
Fahmi Mokhupuki	Botswana	Jan 2017	Dec 2019	Surrogate-based Design and Optimisation of Wideband Feeds for the SKA	N/A

ii. Masters students:

Name of student	**Nationality**	**Date started**	**Date completed**	**Title of Research Project / Thesis**	**Co-Supervisor (if relevant)**
Sunelle Otto	South African	Jan 2009	Dec 2010	A study of radio astronomy principles and SKA pathfinder system designs with pulsar science	Prof. Petrie Meyer
Karla Schoeman	South African	Jan 2009	Dec 2010	Waveguide Antenna Feed for the Square Kilometre Array	Prof. Petrie Meyer
Phillip Terblanche	South African	Jan 2010	Dec 2011	Electronically Adjustable Bandpass Filter	Prof. Petrie Meyer
David VdM. Prinsloo	South African	Jan 2010	Dec 2011	Characterisation of L-band Differential Low Noise Amplifiers	Prof. Petrie Meyer
Shamim O. Nassar	Kenya	Jan 2010	Dec 2011	An Investigation of the Equivalence Between Combline and Evanescent-Mode Waveguide Filters & of Aspects Related to Reduction of Manufacturing Costs for Combline Filters	Prof. Petrie Meyer
Stephanie Alphonse	Madagascan	Jan 2010	Mar 2012	Fast Analysis of a Compound Large Reflector Antenna	Prof. Keith Palmer
Alex Ibbotson	South African	Jan 2011	Dec 2012	The Design and Analysis of a Rotman Lens with Reduced Conjugate Port Coupling	Prof. Keith Palmer
Dewald Schoeman	South African	Jan 2011	Mar 2013	Full Scale Low-Cost Ultra Wide Band Antenna for SKA Low Frequency Array	N/A
Ngoy Mutonkole	DRC	Jan 2012	Dec 2013	Study of a Wideband Sinuous Feed for Reflector Antenna Applications	N/A
Lukas M. van Vuuren	South African	Jan 2013	Dec 2014	Design of a Receiver System for Use in Radio Astronomy’	N/A
Brandt Klopper	South African	Jan 2014	Dec 2015	Fast Design and Optimisation of One-Dimensional Microstrip Patch Antenna Arrays	N/A
Alex A. Vermeulen	South African	Jan 2014	Dec 2015	The design of a dual reflector feed using surrogate modeling techniques	N/A
Nicol Steenkamp	South African	Jan 2015	Dec 2017	Design of a Wideband Sinuous Antenna for Radio Telescope Applications	N/A
Malan A.X. Ruppert	South African	Jan 2016	Dec 2017	A Study on Phased Array Feeds for Paraboloidal Reflector Antennas	Dr. Ryno Beyers
Ridalise Louw	South African	Jan 2016	Dec 2017	Surrogate Modelling of Performance Metrics of a Wideband Feed for the SKA Reflector Antenna	N/A

Clifford Sibanda	Zimbabwe	Jan 2016	Mar 2018	Design and Optimization of Gap Waveguide Components through Space Mapping	N/A
David Wolsky	South African	Jan 2015	Dec 2018 (Part time student)	A space Mapping Code for Microwave Optimization	N/A
Jako du Toit	South African	Jan 2016	Dec 2018	Partially Filled Radial Power Combiner	Dr. Ryno Beyers
Chanel Hannah	South African	Jan 2016	Dec 2018	Antenna Noise Temperature Measurements and Modelling	N/A
William J. Cerfonteyn	South African	Jan 2017	Dec 2018	A Multi-beam Reflector Antenna for Water Vapour Radiometry	N/A
Shane Moyce	South African	Jan 2017	Dec 2018	Practical Implementation Issues of Null-steering Anti-jamming GPS Arrays	N/A
Hein Swart	South African	Jan 2017	Dec 2019 (Part time student)	A Short-step Axially Symmetric Power Combiner	N/A
Michael Johnston	South African	Jan 2017	Dec 2018	Wideband Marchend Baluns for Radio Astronomy Antennas	Dr. Carlo van Niekerk
Scott Kriel	South African	Jan 2018	Dec 2019	Antenna Array Calibration using a UAV	N/A
Zain de Toit	South African	Jan 2018	Dec 2019	Manufacturing wideband sinuous antenna reflector feeds	Dr. Carlo van Niekerk
Jackline Koech	Kenya	Jan 2018	Dec 2019	Hyperband directional EMC antenna design	`Dr. Gideon Wiid
Ben van der Merwe	South African	Jun 2018	Dec 2020 (Part time student)	H1 Galactic Drift Scan Using a 4.5m Reflector	N/A

Section C: Full Research Project Proposal

1. Scientific merit:

One of the ongoing questions in the development of aperture array antennas for radio astronomy applications is the trade-off between regular dense and random sparse arrays. Sparse systems cover large apertures with fewer elements, while dense arrays can be analogue beam steered or allow for FFT based processing in the fully digital beamformed case. Some recent studies have been performed on the compromise case – regular sparse arrays. These systems cover larger apertures than dense arrays using the same number of elements, and therefore provide higher resolution for extended sources, and higher sensitivity for point sources. Due to the fundamental requirement for sub-Nyquist spacing to ensure a single array beam, regular sparse systems suffer from grating lobes and the subsequent loss in sensitivity and ambiguous/spurious direction of arrival and imaging results. Grating lobes can be partially removed by using station and polarisation rotation techniques – this technique is currently being investigated in another PhD by Jan Geralt Bij de Vaate of ASTRON and Stellenbosch University.

Co-prime arrays are a class of sparse arrays which, similar to random sparse arrays, can be designed to have the grating lobes add destructively and thus removed from the beam. These systems have been investigated theoretically, but traditionally the processing is very expensive since it requires full enumerated searches to identify matching roots in noisy data. The idea is actually very straight forward – the total array is configured to contain two regularly spaced versions – the one a shifted

version of the other. Each of the sub-arrays are handled separately to produce main beams in the direction of interest, while the co-prime spacing forces the grating lobes to be non-overlapping. Recently, researchers at Antwerp University developed a mathematical algorithm to quickly and accurately resolve the required roots from the two sub-arrays in noisy data. The method promises to allow very fast and efficient implementations on digital back-end systems of fully digital arrays, but so far have only been evaluated in simulation for linear array systems.
This project will investigate a number of details of the proposed algorithm – as applied to radio astronomy systems. Theoretical work will include extension of the current linear array direction of arrival algorithm to the planar case, before the important beamforming and imaging applications are developed and implemented. Practical work will include the construction of a simple narrow-band demonstrator system. Once the method and demonstrator are available, comparisons with the two limiting cases (sparse random and dense regular) can be performed – specifically for the 500 – 1500 MHz band of interest for SKA2.

2. Feasibility:

Much of the theoretical development required for this project will be done with the help of the original inventors, and therefore close collaboration with the team from Antwerp University will be maintained throughout the project. However, previous experience of working with mathematicians developing methods for practical system application shows that the development and implementation of engineering test systems is critical for the success of such a new method. One of the main roles of the candidate will therefore be to act as the link between the engineering requirements and the theoretical algorithm development. To that end, it is foreseen that some collaboration with ASTRON will also be required, to set the radio astronomical targets for the system. Discussions between Stellenbosch University, Antwerp University and ASTRON has already been made, and the plan for such a collaboration is in place. The collaboration mechanism will mostly be through outgoing visits of the candidate to Europe, as well as incoming visits from a PhD student at Antwerp to Stellenbosch to assist with the theoretical implementation. Funding for the visits will be made available from all three institutions, while an application for a large European Training Network grant to expand this idea to a variety of applications is currently being prepared.
Stellenbosch University, as well as ASTRON, have access to expertise and hardware for the development and measurement of large antenna systems. It is foreseen that a linear demonstrator will be constructed within the first year of the project. The second year will be dedicated to the expansion of the algorithm to the 2D case (much of the basics are in place already), while using experience from the linear demonstrator to inform the practical limitations and requirements of the planar case. The final year will be used for measurements, comparison with current systems, and writing up of results in journal papers as well as the dissertation. Conference presentations will be used to present the intermediate results throughout the project.

3. SARAO research priority area:

Radio astronomy antennas and receivers.

4. Qualifications, academic abilities, skills and/or experience required:

The successful candidate for this project needs a Masters (or equivalent) degree in antenna engineering – preferably with some experience in mathematical modelling of antenna systems or array processing. A strong interest in advanced mathematical techniques is certainly required, since much of this project will involve implementation of exponential analysis algorithms.

Dirk de Villiers, 2018/08/26