South African Radio Astronomy Observatory Research Project Proposal for Masters and Doctoral Research in 2019

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Section A: Overview of the Research Project Proposal

1. Academic level of research project

Master's degree

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Engineering

3. Title of research project

Wideband conformal antenna array synthesis

4. Research project abstract

The synthesis of wideband, conformal arrays presents many challenges. This project will address these practical challenges, by investigating and developing the necessary theoretical techniques, with specific focus on the application thereof in the field of radio astronomy. Grating lobe mitigation and conformal antenna array synthesis will be addressed, in combination with electronic beam forming optimization techniques. The beam forming optimization technique will include the optimization of polarization in the main beam direction and main beam and side lobe shaping.

Section B: Supervisors' details

1. Primary supervisor's details

a. Title and full name

Prof. Johann Wilhelm Odendaal

b. Name of South African university at which the primary supervisor is a permanent academic staff member

University of Pretoria

c. Contact details

Email address: wimpie.odendaal@up.ac.za

Telephone number: +27 12 420 3545

d. Supervision of postgraduate students

i. Doctoral students

Name of student	Nationality	Date started	Date completed	Title of thesis	Co-supervisor
M. Potgieter	South African	January 2016	December 2017	A study of bistatic simulations, measurements and calibration	Prof. J. Joubert (Co-supervisor)
C. Blaauw	South African	January 2016	December 2017	RCS simulations and measurements of electrically large, complex airframes and dielectric structures	Prof. J. Joubert (Co-supervisor)

Name of student	Nationality	Date started	Date completed	Title of thesis	Co-supervisor
W. P. du Plessis	South African	January 2008	December 2009	A Comprehensive Investigation of Retrodirective Cross-Eye Jamming	Prof. J. Joubert (Co-supervisor)
J. P. Jacobs	South African	January 2002	December 2007	Mutual admittance between CPW-fed slots on conductor-backed two-layer substrates	Prof. J. Joubert (Supervisor)
P. Niemand	South African	January 1999	December 2004	Null Synthesis with cylindrical antenna arrays	Prof. J. Joubert (Supervisor)
G. Mayhew-Ridgers	South African	January 1999	September 2004	Development and modelling of new wideband microstrip patch antennas with capacitive feed probes	Prof. J. Joubert (Co-supervisor)
M. W. da Silveira	South African	January 1999	September 2004	Analysis of spatially distributed adaptive antenna array systems in cellular networks	Prof. J. Joubert (Co-supervisor)
W. H. Theunissen	South African	January 1996	December 1999	Reconfigurable contour beam antennas using an adjustable subreflector and a single feed	Prof. J. Joubert (Co-supervisor)

ii. Master's students

Name of student	Nationality	Date started	Date completed/ will complete	Title of thesis	Co-supervisor
E. Coetzee	South African	January 2018	December 2018	Low-profile WLAN antenna	Prof. J. Joubert (Co-supervisor)
M. Gerber	South African	January 2018	December 2018	Double-ridged horn antenna with improved radiation performance	Prof. J. Joubert (Co-supervisor)
V. Reynders	South African	January 2016	December 2018	High gain WLAN array	Prof. J. Joubert (Supervisor)
M. van den Berg	South African	January 2016	December 2017	Metamaterial surface as polarizers for planar antennas	Prof. J. Joubert (Supervisor)
R. Ferreira	South African	January 2016	December 2017	Hybrid Ring Coupler using a Microstrip□ to□Slotline Inverter	Prof. J. Joubert (Supervisor)

Name of student	Nationality	Date started	Date completed/ will complete	Title of thesis	Co-supervisor
M. Roestorff	South African	January 2016	September 2017	Design of an Electrically Small Wearable Antenna with a Reactive Impedance Substrate Operating at 433 MHz	Prof. J. Joubert (Co-supervisor)
R. J. Moraal	South African	January 2015	September 2017	Pattern Synthesis and Design of a Microstrip Wire Grid Monopulse Antenna	Prof. J. Joubert (Supervisor)
C. Kenny	South African	January 2015	December 2015	Wideband Antenna for 4G LTE Applications	Prof. J. Joubert (Co-supervisor)
M. van Rooyen	South African	January 2015	December 2015	Dual-Band Directional WLAN Antenna with High Gain	Prof. J. Joubert (Co-supervisor)
L. Potgieter	South African	January 2012	September 2015	Design of Centre-Fed Printed Rectangular Grid Slot Arrays	Prof. J. Joubert (Supervisor)
K. H. Kloke	South African	January 2011	December 2013	End-Launched Coaxial and Microstrip to Partial H-Plane Waveguide Adapters	Prof. J. Joubert (Supervisor)
M. Nel	South African	January 2007	September 2013	A Wideband Double-Ridged Guide Horn Antenna as Complex Antenna Transfer Function Standard	Prof. J. Joubert (Supervisor)
P. H. van der Merwe	South African	January 2011	September 2013	An optimized, dual-polarized, quad-ridged horn antenna with pyramidal sidewalls	Prof. J. Joubert (Co-supervisor)
O. B. Jacobs	South African	January 2011	December 2011	Quad-Ridge Horn Antenna with Elliptically Shaped Sidewalls for use as a Reflector Feed for Radio Astronomy	Prof. J. Joubert (Co-supervisor)

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B. Jacobs	South African	January 2008	December 2010	The effect of manufacturing and assembling tolerances on the performance of 1-18 GHz double-ridged guide horn antennas	Prof. J. Joubert (Co-supervisor)
J. B. du Toit	South African	January 2006	December 2009	Characterisation and phase compensation of a coplanar waveguide to coplanar strip line balun	Prof. J. Joubert (Co-supervisor)
J. M. Steyn	South African	January 2008	September 2009	A dual-band dual-polarized antenna for WLAN applications	Prof. J. Joubert (Co-supervisor)
D. M. De Haaij	South African	January 2000	September 2003	Wide band matching techniques for patch antenna elements	Prof. J. Joubert (Supervisor)
P. Niemand	South African	January 1997	September 1998	The Characterization of Electromagnetic Absorber Material in a Free Space Facility	-
G. Mayhew-Ridgers	South African	January 1997	September 1998	Accuracy of the Gain Transfer Method for Aperture Antenna Gain Measurements	Prof. J. Joubert (Co-supervisor)
E. M. Romanowska	South African	January 1993	September 1995	On the use of time-domain gating techniques for electromagnetic scattering measurements in a compact range	Dr. D.J.J. van Rensburg (Co-supervisor)

2. Co-supervisor's details

a. Title and full name

Prof. Johan Joubert

b. Name of South African university at which the primary supervisor is a permanent academic staff member

University of Pretoria

c. Contact details

Email address: jjoubert@up.ac.za

Telephone number: +27 12 420-2680

d. Supervision of postgraduate students

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J. P. Jacobs	South African	January 2002	December 2007	Mutual admittance between CPW-fed slots on conductor-backed two-layer substrates	Prof. J. W. Odendaal (Co-supervisor)
F. V. Minnaar	South African	-	December 1999	The analysis and synthesis of a novel ultra-wideband microwave differential phase shifter	J. C. Coetzee (Co-supervisor)
E. Botha	South African	-	December 1999	Contributions to the synthesis of planar and conformal arrays	-
P. Niemand	South African	January 1999	December 2004	Null Synthesis with cylindrical antenna arrays	Prof. J. W. Odendaal (Co-supervisor)
G. Mayhew-Ridgers	South African	January 1999	September 2004	Development and modelling of new wideband microstrip patch antennas with capacitive feed probes	Prof. J. W. Odendaal (Supervisor)

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W. H. Theunissen	South African	January 1996	December 1999	Reconfigurable contour beam antennas using an adjustable subreflector and a single feed	Prof. J. W. Odendaal (Supervisor)
L. T. Hildebrand	South African	-	December 1996	Full-wave analysis of a new microstrip-to-waveguide interconnect configuration	-

iv. Master's students

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E. Coetzee	South African	January 2018	December 2018	Low-profile WLAN antenna	Prof. J. W. Odendaal (Supervisor)
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Name of student	Nationality	Date started	Date completed/ will complete	Title of thesis	Co-supervisor
M. D. Kabadi	South African	-	December 2003	Designing wideband dipoles using lumped element reactive loading at discrete intervals	-
D. M. De Haaij	South African	January 2000	September 2003	Wide band matching techniques for patch antenna elements	Prof. J. W. Odendaal (Co-supervisor)
K. H. Hirsch	South African	-	December 2002	Wideband filter using lumped circuit elements	-
G. Mayhew-Ridgers	South African	January 1997	September 1998	Accuracy of the Gain Transfer Method for Aperture Antenna Gain Measurements	Prof. J. W. Odendaal (Supervisor)
H. J. du Preez	South African	-	December 1997	An augmented design procedure for slotted waveguide arrays	-
P.A. van Jaarsveld	South African	-	December 1996	An integral equation moment method analysis of a rectangular cavity partially loaded with a lossy dielectric	-
M. J. Rossouw	South African	-	December 1996	A case of non-uniformly spaced antenna arrays	-
A. R. Roberts	South African	-	December 1996	An examination of higher-order differentiation in the finite difference time domain technique	-

Section C: Full Research Project Proposal

1. Scientific merit

The synthesis of wideband conformal antenna arrays will require the intersection of different research areas. The wideband requirement justifies an investigation into grating lobe mitigation, while conformal antenna array synthesis is a subject with considerable breadth and depth, and a thorough investigation in this focus area should be conducted as well. The objectives of the wideband conformal antenna array synthesis project can be summarized as follows:

- Investigate existing grating lobe mitigation techniques for planar arrays and their possible application to conformal arrays.
- Investigate the practical application of grating lobe mitigation methods in conformal antenna array synthesis. Therefore, address the challenges that will stem from implementing electronic beam steering with a conformal antenna that uses relevant grating lobe mitigation techniques.
- Address the practical antenna synthesis problems that arise when using conformal elements in a wideband array, such as mutual coupling and polarization optimization.
- Manufacture a prototype that will validate the developed theory and synthesis techniques for application in the radio astronomy focus area.

With conformal antenna arrays, the pattern multiplication principle used to express array radiation patterns is no longer applicable, since the radiation pattern characteristics is different for every antenna element and it is difficult to obtain an analytical expression for the array factor of a uniquely curved surface. Different optimization techniques used for conformal antenna array synthesis exist in literature, such as Particle Swarm Optimization, Genetic Algorithm, Adaptive Array Theory etc. Further, while various theoretical methods have been developed for grating lobe mitigation of planar antenna arrays, very little research has been conducted regarding the practical implementation of these techniques to conformal arrays, which adds significant complexity to the problem. Grating lobe studies focus primarily on the derivation of an array factor for ideal, isotropic elements. The combination of grating lobe mitigation using subarrays, conformal array synthesis and electronic beam steering have not been investigated in depth. Practical factors such as antenna polarization, mutual coupling, the use of wideband, conformal elements and different feeding methods are also not commonly addressed for conformal arrays. An important part of this project will be to investigate polarization optimization of the conformal array consisting of dual-polarized elements, in order to improve the antenna array's efficiency. Lastly, planar array feeds (PAFs) are commonly used for reflector dishes. The use of conformal antenna arrays as feeds have not been thoroughly investigated and may have potential advantages.

2. Feasibility

The student will primarily use MATLAB or Python 3.x to simulate the developed theoretical techniques and designs. Computational electromagnetic simulation software, such as FEKO or CST will further be used to simulate the designed antenna arrays. The University of Pretoria has academic licenses to all the aforementioned software available for use by post-graduate students. The manufactured prototype can be tested at the Compact Antenna Test Range at the Centre of Electromagnetism, University of Pretoria.

The student will be required to publish two papers in international peer-reviewed publications (one for each year of the Master's degree). The first paper will be focus on implementing optimized

polarization for antenna arrays that utilizes specific grating lobe mitigation techniques. The second will focus on the fusion of the grating lobe mitigation techniques with conformal arrays.

3. Contribution to SARAO research priority area

The SARAO research priority area to which wideband, conformal antenna array synthesis will be relevant is Radio Astronomy Antennas and Receivers. There are multiple applications in the radio astronomy arena for the theory and synthesis techniques that will be developed in this project.

Single-element feeds are not nearly as efficient as phased array feeds for reflector antennas. There are many different types of phased array feeds that have been investigated, such as Vivaldi and chequerboard feed arrays, as mentioned by the SKA Dish Consortium. However, the use of conformal, wideband antenna arrays as feed elements have not been sufficiently researched, as planar feed arrays are used predominantly, but the use of wideband, conformal antenna arrays as novel feeds for parabolic reflectors is very promising. The various advantages that using wideband, conformal antenna arrays as feed arrays for the SKA Dishes can bring, warrants further investigation. In this project, conformal antenna array synthesis will be studied in coherence with beamforming optimization techniques. This can lead to various advantages such as multiple primary beams, beam shaping resulting in reduced spill-over, less obstruction leading to increased aperture efficiency, optimized polarization in the main beam direction and a wider scan angle.

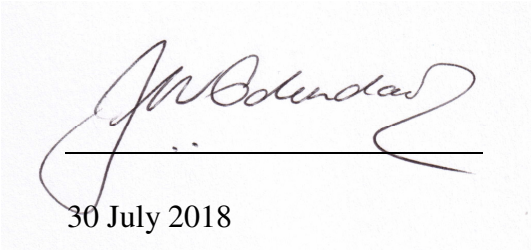
The presence of grating lobes is a common problem for wideband arrays - an antenna array with a wideband response will invariably have element spacings that are greater than half a wavelength. If a wideband response is indeed required, increasing the upper frequency of the frequency range will require smaller inter-element spacings if grating lobes still want to be avoided. This will, however, increase the mutual coupling between elements, which will negatively influence the antenna array's radiation properties. The impact of mutual coupling in the phase feed array and the thermal radiation of adjacent elements can also be reduced if elements are spaced further apart. While there are many grating lobe mitigation techniques for planar arrays that have been studied in literature, this project will focus on the use of subarrays and specifically for conformal arrays. The placement of the antenna elements of the feed array in similar subarrays decreases manufacturing costs and construction time, while still decreasing grating lobes by rotating and translating the subarrays. The study of grating lobe mitigation techniques for conformal arrays will form an integral part of the project.

The grating lobe mitigation techniques that will be investigated can also be applied to the different types of aperture arrays that are used in the radio-astronomical observations. Different aperture arrays may be placed further than a wavelength apart, leading to grating lobes, and since any wideband antenna array faces the problem of spatial aliasing caused by large antenna element spacing, the mitigation methods can be applied at a larger scale as well. By combining the grating lobe mitigation and conformal array synthesis techniques, the antenna arrays will also no longer be limited to planar layouts, opening up the possibility of aperture antenna array layouts that were not previously possible.

4. Master's candidate abilities

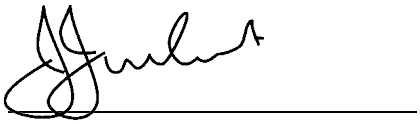
The candidate should have a strong academic background (preferably with a grade point average of 75%+). In order to be able to complete the proposed project in the stated time limit, the student should also have prior knowledge about electromagnetism, antenna theory and design, phased arrays and conformal antenna array synthesis.

Section D: Signatures



30 July 2018

Prof. J. W. Odendaal (Supervisor)



30 July 2018

Prof. J. Joubert (Co-supervisor)