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
New methods for efficient modelling of large-scale antenna arrays with interconnected elements
4. Full names of supervisor and co-supervisor
Matthys M. Botha
5. University where postgraduate student would be registered
Stellenbosch University

Section B: Research Project Proposal

1. Scientific merit: describe the objectives of the research project, placing them in the context of the current key questions and understanding of the field.
A variety of array antenna systems are currently being developed for future expansions to the SKA (e.g. MFAA and phased array feeds). Designing these complex arrays with the property of electrically interconnected elements (e.g. a shared ground plane), require extensive numerical modelling. This is very challenging, not so much because a single analysis (i.e. fixed geometry, frequency and excitation configuration) of such antennas is unachievable, but because such a single analysis is expensive. The many required analyses altogether are a major bottleneck in the design process. Design spaces are thus restricted by the computational capabilities of commercial electromagnetic field solvers. This generally leads to sub-optimal designs. In radio astronomy, even a small improvement to antenna performance may be crucial. The scientific merit of advancing solver technology for these challenging problems is thus very strong, to yield more thoroughly optimized radio astronomy antennas.
The main objective of this work is to develop new integral-equation based methods for fast and accurate analysis of large-scale radio astronomy array antennas with electrically interconnected elements. Significant groundwork has already been done as reported in the literature, and at SU. In particular, two approaches which have already been developed at SU in the context of disjoint array elements, must be investigated for extension to interconnected elements. The first is a method of dynamically constructed macro basis functions (MBFs) to dramatically reduce the number of unknown coefficients to be solved. The second is the domain Green's function method (DGFM), which is being refined at present for highly-parallelizable analysis of arrays with disjoint elements.
Since this is a challenging research task which will require creative problem solving on a high technical level, it is not possible to say what shape the final, best solution will take. This will be work at the international research cutting edge.
This project is in crucial support of ongoing research on radio astronomy antennas at SU, where the project advisors coordinate their efforts. The student will join a team with a common goal of excellence in antenna technology.

2. Feasibility: outline the methods that will be used to achieve the objectives. Provide details on the availability of required data / access to required equipment / availability of research facilities and other resources required. Include any relevant expected intermediate milestones and associated timeframes towards attaining the overall objectives of the project.
This project is challenging but feasible. Both in the research literature on MBFs for reduction of unknowns in case of antenna array analysis, as well as through very recent work at SU on MBF and DGFM technology, it is well established that these methods lead to more efficient solutions. Their extension to the case of interconnected array elements, such that the same efficiency can be achieved as for disjoint elements, is the challenge. This will require strong physical insight and creativity. Luckily, at SU there is a sizable and highly capable computational electromagnetics research group, to support this exciting, capstone research on radio astronomy array antenna analysis.

The milestones for Year 1 are to gain familiarity with the state-of-the-art in MBF and DGFM methods (as well as other less familiar schemes) for analysis of large-scale antenna arrays. Also, in-depth familiarity with existing experimental code infrastructure must be established.
The milestones for Year 2 are to develop extended formulations of the dynamic MBF solver concept and the DGFM, for arrays with interconnected elements. As ideas are developed they must be implemented within the experimental solver code framework, and tested. Any positive initial results should be immediately written up and submitted for journal publication (possibly a fast-track, letter-format journal). Work should also be presented at conferences.
The milestones for Year 3 are to further develop and refine the methods and then document them in a solid journal paper to be submitted to the top international journal in the antenna field. Work should also be presented at conferences and finally, the thesis must be written up.
The relevant commercial software and computer hardware infrastructure is in place for this project, as well as academic expertise and literature resources. SU has comprehensive journal subscriptions.

3. Link the proposed project to one or more of the SARAO research priority areas for 2020 (refer to Section 4 of the Application Guide), and explain in some detail how the proposed research will contribute to the priority area(s).
"Radio astronomy antennas and receiver systems (including digitisation) associated with supported and hosted instruments."
This project is closely aligned with the design of physical antenna and receiver systems in that it deals with the challenges of modelling massive antenna arrays above a common ground plane as in the MFAA (i.e. electrically connected antenna elements), which also encompasses efficient phased array feed modelling. The project's contribution to the priority area will be in establishing leading-edge modelling capability to enable tractable, rigorous design optimization of these challenging antenna systems. Development of such modelling capabilities would constitute a critical contribution by South Africa to the international radio astronomy engineering community.

4. If relevant, describe any particular qualifications, academic abilities, skills and/or experience that a student should have in order to successfully deliver on the objectives of the research proposed.
The successful candidate for this project needs a Master's degree in engineering. Interests in mathematics, physics and computation are required.