Section A: Overview of the Research Project Proposal

1. Academic level of research project
Masters
2. Broad field of research
Engineering
3. Title of the research project
Efficient modelling of large-scale radio astronomy 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, 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 an industrial-grade, optimized solver for large-scale radio astronomy antennas with electrically interconnected elements. A customized, integral equation based approach is required. Past groundwork in the literature and at Stellenbosch University (SU) has been done towards reducing the numbers of unknown coefficients to be solved, by grouping them together into macro basis functions (MBFs), suitable for interconnected array elements (some schemes are only suited to disjoint cases). Recent work at SU has also been done on efficiently constructing the MBF-based system matrix and solving it. These methods must be combined in the solver and it must furthermore be compiled for execution on large-scale computing facilities. The final goal is to use this industrial-grade solver to analyse real-world interconnected-element array antennas of interest to the SKA.
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 entirely feasible. Both in the research literature on MBFs for reduction of unknowns in case of connected array elements, as well as through very recent work at SU on MBF technology for connected domains (MBF construction and directional ACA for fast system matrix setup), it is well established that these methods lead to more efficient solutions. With this project these technologies will be tailored to the antenna applications of interest, in aid of faster design capabilities. The focus will be on industrial-grade, optimized code implementation of these recently verified methods, for execution on large-scale computing facilities (e.g. CHPC and/or SU in-house systems, all of which are already in place).

The milestones for Year 1 are to gain familiarity with the state-of-the-art in MBF methods for analysis of arrays with connected elements, as well as with existing, experimental code infrastructure. At SU there are two full-time staff members and a sizable group of postgraduate students focussed upon computational electromagnetics (CEM), thus the ideal environment for this work is in place.

The milestones for Year 2 are to implement an industrial-grade, optimized solver for large arrays with connected elements, based upon existing, in-house code infrastructure. The work will slot into a coordinated CEM code development effort underway within the research group. Furthermore, the solver must be made to execute on large-scale (parallel) computing platforms. Finally, it must be used to solve real-world radio astronomy, connected-element array antennas and benchmarked against existing state-of-the-art solvers (commercial and/or from other research groups). Writing up the thesis and potentially a conference/journal paper is the final milestone.

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 Bachelor's degree in engineering. Interests in mathematics, physics and computation are required.