Section A: Overview of the Research Project

1. Title of the research project
New methods for efficient modelling of large-scale antenna arrays with tightly coupled elements

2. Broad area of research (Engineering or Science)
Engineering

3. Academic level of research project (Masters or Doctoral)
Doctoral

4. Abstract of research project
Tightly coupled array antennas (i.e. arrays with elements which are electrically connected and in close proximity to each other) are an important component of the SKA, for the mid-frequency aperture array (MFAA) stations of SKA Phase 2, and for phased array feeds. The Stellenbosch University (SU) research group is part of the international MFAA consortium. Designing such arrays require extensive numerical modelling. The analysis of a single candidate geometry at a single frequency is very expensive with conventional methods. Thus, analysis is a major bottleneck in the design process. The implication is that design spaces are restricted by the computational capabilities of commercial field solvers, leading to sub-optimal designs. The objective of this work is to develop new integral-equation based methods for fast and accurate analysis of array antennas with tightly coupled elements. Significant groundwork has already been done at SU. Approaches which have already been developed for disjoint array elements, must be extended to tightly coupled elements. Development of such leading-edge modelling capabilities for the noted classes of SKA-related arrays would constitute a valuable contribution by South Africa to the international radio astronomy engineering community.

5. Primary supervisor's details:
a. Full name of primary supervisor
Matthys M. Botha

b. Primary supervisor's email address (please note that if this project is approved, this email address will be made available to students to contact the primary supervisor)
mmbotha@sun.ac.za

c. University where primary supervisor is employed
Stellenbosch University

6. Co-supervisor/Research supervisor's details (if relevant)
a. Full name of co-supervisor/research supervisor
N/A

b. University where co-supervisor/research supervisor is employed
N/A

Section B: Details of Research Project

1. Scientific/Engineering merit: describe the objectives of the research project, placing them in the context of the current key questions and understanding of the field.
Tightly coupled array antennas (i.e. arrays with elements which are electrically connected and in close proximity to each other) are an important component of the SKA, for the mid-frequency aperture array (MFAA) stations of SKA Phase 2, and for phased array feeds. The Stellenbosch University (SU) research group is part of the international MFAA consortium. Designing such arrays require extensive numerical modelling. The analysis of a single candidate geometry at a single frequency is very expensive with conventional methods. Thus, analysis is a major bottleneck in the design process. The implication is that design spaces are

restricted by the computational capabilities of commercial field solvers, leading to sub-optimal designs. Optimal performance is crucial to the SKA, therefore the scientific merit is very strong for advancing solver technology for these challenging problems.
The objective of this work is to develop new integral-equation based methods for fast and accurate analysis of array antennas with tightly coupled elements. Significant groundwork has already been done at SU. Three approaches which have already been developed for disjoint array elements, must be investigated for extension to tightly coupled elements. These are macro basis functions (MBFs) to reduce the number of unknown coefficients to solve, hp-adaptive analysis and to solve the global problem as a collection of localized solutions. This work will be at the international research forefront. This project is in 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. Through very recent work at SU on MBF, hp-adaptive and localized solver technology, it is well established that these methods lead to more efficient solutions. Their extension to the case of tightly coupled array elements, is the challenge. This will require physical insight and creativity. At SU there is a sizable and highly capable computational electromagnetics research group, to support this work on radio astronomy array antennas.
The milestones for Year 1 are to gain familiarity with the state-of-the-art in MBF, hp-adaptive and localized solver methods 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 and implement extended formulations of the noted solver methods, for arrays with tightly coupled elements. Any positive 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 journal paper to be submitted to the top international journal in the antenna field. Work should also be presented at conferences and 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 2021 (refer to Section 5 of the Application Guide), and explain in some detail how the proposed research will contribute to the priority area(s).

"Antenna and receiver systems associated with radio telescope instruments supported and hosted by SARAO."
Tightly coupled array antennas are an important component of the SKA, for the mid-frequency aperture array (MFAA) of SKA Phase 2, and for phased array feeds. The Stellenbosch University (SU) research group is part of the international MFAA consortium. Development of leading-edge modelling capabilities for both these classes of SKA-related arrays would constitute a valuable 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.

MMBotha

Matthys M. Botha, 2020/02/07