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

Yield optimisation of microwave antenna array elements

4. Research project abstract/summary

The manufacture of antenna elements include several processes, each of which results in the statistical distribution of some critical design dimensions around the nominal design value. When high numbers of elements are manufactured, these variations can create elements which fail specifications, or a less than 100% yield. Statistical analysis of antenna elements are expensive and time-consuming, as very large numbers of numerical electromagnetic analyses must be performed for a Monte-Carlo analysis.

The Polynomial Chaos (PC) technqiue allows designers to evaluate the statisical yield profile of structures very quickly, by exploiting the orthogonal properties of specific mathematical functions. This project aims to develop PC-models for antenna array elements, and use these models for yield analysis of single elements, and full arrays using these elements. This can lower the final costs of a large array significantly, as higher yield firstly requires fewer elements to be manufactured, and secondly increases the reliability of the full array.

Section B: Supervisor(s) Details

1. Primary supervisor's details

a. Title and full name

Prof. Petrie Meyer

b. Name of South African university

Stellenbosch University

c. Email address and/or contact telephone

pmeyer@sun.ac.za

0218084458

d. Supervision of postgraduate students.

i. Doctoral Students:

Student	Degree	Designation (South Africa)	Subject	Year Graduated
C van Niekerk	PhD	White Male	Modelling GaAs FET's using parameter extraction techniques	2000
R Lehmensieck	PhD	White Male	Interpolation models for microwave devices	2001
W Steyn	PhD	White Male	Dual and triple mode cavity filters and diplexers	2002
C Vale	PhD	White Male	Multimode waveguide devices	2001
R Geschke*	PhD	White Female	Hybrid FEM/MM Analysis of Waveguide Discontinuities	2004
T Sickel	PhD	White Male	X-band Limiters	2005
M Schoeman	PhD	White Female	Modelling of Microwave Resonators	2006
D de Villiers	PhD	White Male	Design of Conical Line Power Dividers	2007

T Stander	PhD	White Male	Absorptive Filters	2009
D Smith	PhD	White Male	Image Forming in mm-wave Imaging Systems	2009
S Nasser	PhD	Black Female	Planar Filters in LCP and LTCC Technologies	2016
D Prinsloo	PhD	White Male	Quad-Mode Antenna arrays	2015
T Beukman	PhD	White Male	Integrated LNA Quad-Ridge Horn Feeds	2015
G Brand*	PhD	White Male	Multiband Filters	2014
S Maas*	PhD	White Female	SIW X-band filters	2015-
E Botes*	PhD	White Female	Tunable X-band filters	2018
S Sharma	PhD	Indian Male	Planar Filters	2018
R Kenned	PhD	Black Male	Optimum noise matching of very large connected antenna arrays	2016-
DB Davidson	DEng	White Male	Computational Electromagnetics	2016-2017
WJ Perold	DEng	White Male	Superconductor Logic	2016-2016
* all PhD's within 3 years, except marked with *, which were part-time				

ii. Masters students:

Student	Degree	Designation (South Africa)	Subject	Year Graduated
JE van Zyl	MSc	White Male	A Calibration Procedure for Superconducting Microwave Measurements using One Calibration Standard	1994
C Smit	MSc	White Male	An Investigation into Spread Spectrum Communication Systems	1994
C van Niekerk	MSc	White Male	An Investigation into the Manufacture and Measurement of Superconducting Microwave Devices	1996
JC Kruger	MSc	White Male	High Power Divider/Combiners in Waveguide	1998
WJ van Brakel	MSc	White Male	Numerical Analysis of Microwave Networks	1998
W Steyn	MSc	White Male	Superconductor Receiver design	1998
JD Theron	MSc	White Male	Narrow Band Low-Loss Diplexers	1999
CAW Vale	MSc	White Male	Multimode Waveguide Low-Pass Filters	Upgraded to PhD in 2000

M Müller	MSc	White Female	Neural Network Models of Microwave Structures	2000
R van der Colff	MSc	White Male	Automatic Tuning of Coupled Cavity Microwave Filters	2001
K Cherenak	MSc	White Female	Analysis Techniques for Dielectric Resonators	2002
L Sam	MSc	Black Male	Coupled Co-axial Cavity Filters	2002
M Schoeman	MSc	White Female	Method-of-Moments Analysis of Planar Microwave Structures	2004
M Strydom	MSc	White Female	Ultra wideband power dividers	2004
T Sickel	MSc	White Male	X-band Limiters	Upgraded to PhD in 2004
N Coetzee	MSc	White Female	Asymmetric Coaxial Filters	2005
P Netshifhire*	MSc	Black Male	Microwave Receiver Front End	2005
D de Villiers	MSc	White Male	X-band Combiners	Upgraded to PhD in 2006
T Stander	MSc	White Male	Design of Microwave Loads	Upgraded to PhD in 2007
E Hansmann	MSc	White Female	Narrowband Filters	2008
S Maas	MSc	White Female	Microwave Filters for RADAR Applications	2011
S Otto	MSc	White Female	Microwave aspects of radio astronomy	2010
M van der Walt*	MSc	White Female	Multimode Horn Antennas	2010
K Schoeman	MSc	White Female	Wide-band Antenna Feeds for KAT	2010
D Prinsloo	MSc	White Male	Differential Low-Noise Amplifiers for MEERKAT	2011
S Nasser	MSc	Black Female	Low-Cost Microwave Filters	2011
P Terblanche	MSc	White Male	Multi-Octave Tunable HF Filters	2011
D Botes	MEng	White Male	LNA for midband SKA	2014
E Botes	MEng	White Female	Tunable Filters for radio astronomy applications	Upgraded to PhD in 2014
M van Wyk*	MEng	White Male	High-Performance Microphones	2017
R Kenned	MEng	Black Male	Optimum noise matching of very large connected antenna arrays	Upgraded to PhD in 2016
G van Tonder	MEng	White Female	Beam forming of very large connected antenna arrays	2016
P Benson	MEng	White Male	UHF Protection Filters	2017
L Johnson	MEng	White Female	Pedestal SIW Microwave Filters	2017-

A Bester*	MEng	White Female	Antenna chamber characterisation	2017-
* all M's within 2 years, except marked with *, which were part-time				

Section C: Full Research Project Proposal
Maximum of three A4 pages, written for a professional who is not necessarily an expert in the relevant subfield

1. Scientific merit:

The manufacture of antenna elements include several processes, such as etching, laser-cutting, milling, turning, 3D-printing and a host of assembly techniques. All of these processes result in variations in the dimensions of the final product, in this case an antenna element for a very large array, such as the SKA MFAA. When such high numbers of elements are manufactured, a number of elements will have dimensions deviating so much that the element will fail specifications, causing a less than 100% yield. Yield is inversely proportional to cost, therefore it is very advantageous if the probable yield can be obtained through simulation before manufacturing.

Yield optimisation is yet another step onward from yield analysis. Here, the antenna is structurally optimised to give a high yield, often using slightly less than optimal electrical performance for the design. Optimising for yield therefore results in structures with low sensitivity to structural errors.

Yield predictions are normally made from a Monte-Carlo analysis – a technique using thousands of analyses, each with a small, randomly perturbed set of dimensions. From this set, a number of statistical predictions are then made. Statistical analysis of antenna elements are however expensive and time-consuming, as very large numbers of numerical electromagnetic analyses must be performed for a typical multi-variable Monte-Carlo analysis.

The Polynomial Chaos (PC) technqiue is a statistical modelling technique which has been appropriated for engineering use over the last decade. It allows designers to evaluate the statistical yield profile of structures using orders of magnitude fewer analyses, by exploiting the orthogonal properties of specific mathematical modelling functions. The technique has been used for RFI and EMC predictions, and small microwave devices, but never for antennas.

This project aims firstly to develop PC-models for antenna array elements aimed at the proposed SKA MFAA, and use these models for yield analysis of single elements, and full arrays using these elements. An analysis of this kind is vital to predict the success of such a large roll-out of elements, and the PC-technique offers the promise of doing this in the shortest times currently possible.

As a next phase, the yield analysis will be inserted into an optimisation loop to produce elements which are structurally and electrically optimised for high yield. This can lower the final costs of a large array significantly, as higher yield firstly requires fewer elements to be manufactured, and secondly increases the reliability of the full array.

2. Feasibility:

The PC-technique has been proven in various engineering fields to work extremely well, including microwave subsystems such as filters. It is therefore eminently feasible to use this for the design of antenna array elements. The group at Stellenbosch University has all the necessary modelling software, computing hardware, and state-of-the-art measurement facilities to support this project, and many years of demonstrated expertise in modelling and numerical electromagnetic analysis amongst its staff members. In addition, Prof Meyer has an ongoing cooperation with Ghent University in Belgium, probably the leading institution in Europe on the use of PC in microwave design. The research is also highly publishable, as it forms part of a current wave of design algorithms making use of modelling in optimisation.

The project is fully aligned with the area of radio astronomy antennas and receivers.

3. <u>SARAO research priority area</u>:
Radio astronomy antennas and receivers.

4. <u>Qualifications, academic abilities, skills and/or experience required:</u>
The successful candidate for this project needs a BEng degree in electronic engineering – with specific capabilities in electromagnetics and mathematics. A strong interest in advanced mathematical techniques is certainly required.

P Meyer, 2018/08/26