Section A: Overview of the Research Project

1. Title of the research project

New solver formulations for large-scale radio astronomy antenna array analysis

2. Broad area of research (Engineering or Science)

Engineering

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

Doctoral

4. Abstract of research project

Large-scale array antennas are a vital component of radio astronomy instruments. Examples of particular current interest in South Africa, are the HIRAX and HERA systems. Other examples are the SKA-LOW array under development in Australia and the CHIME instrument in Canada. Accurate computational electromagnetic analysis of these arrays, taking into account the complex mutual coupling effects, are crucial to both the design and precise calibration of these instruments, to maximise observational performance.

The analysis of a single candidate/actual array geometry consisting of many elements, with a single element excited, at a single frequency, is expensive by itself, with conventional methods. Thus, analysis is a major bottleneck in the design and characterisation of these instruments, where many such analyses are required. For design, the implication is that search spaces are restricted by the computational capabilities of commercial field solvers, leading to sub-optimal designs. For calibration characterisation, the implication is that approximate results may have to suffice.

The Stellenbosch University (SU) research group has been working on new computational methods for very efficient and reliable electromagnetic simulation of large arrays, over a number of years. Various lines of exploration have been followed, with the work now starting to bear fruit, as the solvers are starting to overtake the capabilities of commercial tools and other known schemes. It is envisaged that the tools will be of interest both locally and abroad, for radio astronomy applications. The objective of this work is to do further novel algorithmic developments to enhance and extend the capabilities and efficiency of the new formulations under development. In other words, the candidate will join an active research group to extend array solver technology beyond the current state-of-the-art. The work will involve developing alternative ways to more efficiently incorporate the effects of non-local currents (far interactions), to efficiently deal with electrically connected array elements, to develop parallelisation strategies and possibly efficient real-ground formulations. The final goal is to use this industrial-grade solver to analyse real-world array antennas of interest to the radio astronomy 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.

Accurate and efficient electromagnetic modelling of large-scale array antennas are vital to the development and optimal operation of radio astronomy instruments in South Africa. Such instruments include the HIRAX and HERA systems, for which the importance of modelling was emphasised again recently, at the SARAO postgraduate conferences in Dec 2022 and Dec 2023. Designing and calibrating such arrays require extensive numerical modelling. The analysis of a single candidate geometry at a single frequency is very expensive with conventional methods and commercial tools. This bottleneck is due to limitations of existing field solvers which are not explicitly tailored to the array applications of interest. Implications are that design search spaces are restricted, leading to sub-optimal designs; and that characterisation error tolerances are large. Optimal performance is crucial to these instruments; therefore, the scientific merit is very strong for advancing solver technology for these challenging problems.

This main objective of advancing the state of the art, with respect to new modelling technologies for large arrays, is currently the primary focus of the computational electromagnetics research group at SU. The aim is to use the solver to analyse real-world radio astronomy array antennas more accurately and efficiently than before, in both SA and abroad; and to continue publishing new findings in top-tier international journals. At SU, PhD students and a postdoc are currently working on the development of new solver technologies. This **doctoral project** is aimed at making novel contributions to improve the accuracy and efficiency of the array antenna solver schemes under ongoing development, continuing with the excellent progress of the research group to date. It is envisaged that the candidate will develop alternative ways to more efficiently incorporate the effects of non-local currents (far interactions), to develop extensions to our new methods to efficiently deal with electrically connected array elements (this is a particularly challenging task), to work on parallelisation, and possibly contribute to developing solver support for modelling the effect of a real ground. All project advisors involved in radio astronomy antenna research at SU, coordinate their efforts and 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 very feasible, as it is in support of ongoing, leading-edge research on array analysis algorithms at SU. At SU there is a sizable and highly capable computational electromagnetics research group, to support this work.

The milestones for Year 1 are to gain familiarity with the radio astronomy antenna arrays of interest, with the state-of-the-art in the noted solver technologies being developed, as well as with existing, experimental code infrastructure.

The milestones for Year 2 are to develop new solver schemes to deal efficiently with far-current coupling, in the context of the application arrays of interest, and to work on parallelisation of the solver. Also, to consider ideas on how to support electrically connected elements. An international conference/journal paper should be submitted on the work to date.

The milestones for Year 3 are to continue with work on connected elements and submit a publication on any breakthroughs in this regard; to possibly work on real-ground solver support; and to work further on parallelisation. Writing up the thesis and an international conference/journal paper on the final results, is the final milestone.

The work will slot into a coordinated CEM code development effort underway within the research group. It is envisaged that the solver should be made to execute on large-scale (parallel) computing platforms. It must be used to solve real-world radio astronomy array antennas and benchmarked against existing state-of-the-art solvers.

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 2024 (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, receiver, (analogue and digital) signal processing, data analysis and data recording systems associated with radio telescopes and geodesy instruments supported and hosted by SARAO.”

Tightly coupled array antennas are an important component of current and future radio astronomy instrumentation in SA, including HIRAX, HERA and SKA projects. Such arrays also feature in phased array feeds for large reflectors, which is an area of intense specialisation in SA. Development of leading-edge modelling capabilities for these radio astronomy related arrays would constitute a valuable contribution by South Africa to the local and 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.

Section C: CV of Primary Supervisor

Attached.

Matthys M. Botha, 2024/02/26

Curriculum Vitae: Matthys M. Botha

Professor, Department of Electrical and Electronic Engineering, Stellenbosch University, South Africa

February 26, 2024

1 Overview

Age:	47
Highest qualification:	Ph.D., Stellenbosch University, Dec. 2002
Accreditation/Affiliation:	ECSA PrEng, IEEE Senior Member, EurAAP Member
Book chapters:	1
Peer-rev. intl. jnl. articles:	30 published, 3 submitted
Peer-rev. intl. conferences:	79 published (75% at the top three conferences), 3 submitted
Journal editor:	Associate Editor, *IEEE Antennas and Propagation Magazine*, Guest Editor, *Electromagnetics*
Intl. conf. organizer:	Technical Programme Chair, Vice-chair LOC, Chair LOC
Natl. conf. organizer:	3 × General Chair
Soc./Conf. management:	ICEAA Steering Committee Permanent Member, ICEAA Scientific Committee Permanent Member, EurAAP Regional Delegate, SA URSI Commission B Alternate Chair, Chair of SA IEEE AP/MTT/EMC Joint Chapter
Employment history:	2003–2004 Post-doctoral Research Associate, UIUC 2005–2008 Research Fellow, SU 2008–2010 Application Engineer, EMSS SA 2011–Present Professor (2018), Associate Professor (2011), SU

2 General personal information

Surname, first names:	Botha, Matthys Michiel
Nationality and gender:	South African, male
Mailing address:	Room 2015, Department of Electrical and Electronic Engineering, Decanting Facility, Stellenbosch University, Private Bag X1, Matieland 7602, Stellenbosch, South Africa
E-mail:	mmbotha@sun.ac.za
Telephone (work):	+27 (0)21 808 4318

3 Education

Qualification	Duration	Description
B.Eng (cum laude)	Feb-1995 to Dec-1998	**Bachelor's degree in Electronic Engineering** obtained at the University of Stellenbosch, South Africa.
	Feb-1999 to Dec-2002	**Doctor of Philosophy degree in Engineering** obtained at the University of Stellenbosch, South Africa. Thesis title: *Efficient finite element electromagnetic analysis of antennas and microwave devices: the FE-BI-FMM formulation and a posteriori error estimation for p adaptive analysis.*

4 Publications

Book chapters

1. J.-M. Jin and M. M. Botha, "Finite element analysis," in *Encyclopedia of RF and Microwave Engineering* (K. Chang, ed.), vol. 2, pp. 1589–1601, New York: Wiley, 2005.

Peer-reviewed journal articles

Note: *Source Normalized Impact per Paper (SNIP), measures actual citations received relative to citations expected for the serial's subject field (Scopus). In any given year, the Impact Factor (IF) of a journal is the number of citations, received in that year, of articles published in that journal during the two preceding years, divided by the total number of articles published in that journal during the two preceding years (Web of Science). The values' years of applicability are noted.*

1. M. M. Botha and D. B. Davidson, "Application of the Fast Multipole Method to the FE-BI Analysis of Cavity Backed Structures with Comprehensive FMM Error Control," *Electromagnetics* (Special Issue: Selected papers from the 5th Finite Elements Workshop for Microwave Engineering, Boston, USA, June 2000), vol. 22, pp. 393–404, July 2002.
2. M. M. Botha and D. B. Davidson, "A quasi-static condition for enhancing p-adaptive, mixed-order element, FE analysis", *Electromagnetics* (Special Issue on Finite Element Methods for Microwave Engineering), vol. 24, pp. 13–24, 2004.
3. M. M. Botha and J.-M. Jin, "On the Variational Formulation of Hybrid Finite Element-Boundary Integral Techniques for Electromagnetic Analysis," *IEEE Transactions on Antennas and Propagation*, vol. 52, no. 11, pp. 3037–3047, November 2004.
4. X. Wang, M. M. Botha and J.-M. Jin, "An Error Estimator for the Moment Method in Electromagnetic Scattering," *Microwave and Optical Technology Letters*, vol. 44, no. 4, pp. 320–326, February 2005.
5. M. M. Botha and J.-M. Jin, "Adaptive Finite Element-Boundary Integral Analysis for Electromagnetic Fields in 3-D," *IEEE Transactions on Antennas and Propagation*, vol. 53, no. 5, pp. 1710–1720, May 2005.
6. M. M. Botha and D. B. Davidson, "An Explicit *a Posteriori* Error Indicator for Electromagnetic, Finite Element-Boundary Integral Analysis," *IEEE Transactions on Antennas and Propagation*, vol. 53, no. 11, pp. 3717–3725, November 2005.

7. M. M. Botha and D. B. Davidson, "The Implicit, Element Residual Method for *a Posteriori* Error Estimation in FE-BI Analysis," *IEEE Transactions on Antennas and Propagation*, vol. 54, no. 1, pp. 255–258, January 2006.
8. M. M. Botha and D. B. Davidson, "Investigation of an Explicit, Residual-Based, a Posteriori Error Indicator for the Adaptive Finite Element Analysis of Waveguide Structures," *Applied Computational Electromagnetics Society Journal*, vol. 21, no. 1, pp. 63–71, March 2006.
9. M. M. Botha, "Solving the Volume Integral Equations of Electromagnetic Scattering," *Journal of Computational Physics*, vol. 218, issue 1, pp. 141–158, October 2006.
10. M. M. Botha and D. B. Davidson, "Rigorous, auxiliary variable-based implementation of a second-order ABC for the vector FEM," *IEEE Transactions on Antennas and Propagation*, vol. 54, no. 11, pp. 3499–3504, November 2006.
11. D. B. Davidson and M. M. Botha, "Evaluation of a Spherical PML for Vector FEM Applications," *IEEE Transactions on Antennas and Propagation*, vol. 55, no. 2, pp. 494–498, February 2007.
12. M. M. Botha, "Fully hierarchical divergence-conforming basis functions on tetrahedral cells, with applications," *International Journal for Numerical Methods in Engineering*, vol. 71, issue 2, pp. 127–148, July 2007.
13. R. G. Marchand, M. M. Botha and D. B. Davidson, "Total and Scattered Field Decomposition for the Vector Helmholtz Equation Using the FETI", *Electromagnetics*, vol. 28, no. 1–2, pp. 77–91, January 2008.
14. M. M. Botha, "A Family of Augmented Duffy Transformations for Near-Singularity Cancellation Quadrature," *IEEE Transactions on Antennas and Propagation*, vol. 61, no. 6, pp. 3123–3134, June 2013.
15. M. M. Botha, "Accuracy of Near-Singularity Cancellation Quadrature Schemes for the Dynamic MoM Kernel," *IEEE Antennas and Wireless Propagation Letters*, vol. 12, iss. 1, pp. 714–717, December 2013.
16. W. J. Strydom and M. M. Botha, "Charge Recovery for the RWG-Based Method of Moments," *IEEE Antennas and Wireless Propagation Letters*, vol. 14, pp. 305–308, 2015.
17. M. M. Botha, "Numerical integration scheme for the near-singular Green function gradient on general triangles," *IEEE Transactions on Antennas and Propagation*, vol. 63, no. 10, pp. 4435–4445, October 2015.
18. D. P. Xiang and M. M. Botha, "Efficient shadowing determination at grazing incidence, for mesh-based physical optics scattering analysis," *Electronics Letters*, vol. 52, no. 22, pp. 1893–1894, 2016.
19. W. J. Strydom and M. M. Botha, "Current recovery for the RWG-based method of moments," *IET Science, Measurement & Technology*, vol. 10, iss. 8, pp. 831–838, 2016.
20. D. J. Ludick, M. M. Botha, R. Maaskant and D.B. Davidson, "The CBFM-enhanced Jacobi method for efficient finite antenna array analysis," *IEEE Antennas and Wireless Propagation Letters*, vol. 16, pp. 2700–2703, 2017.
21. M. M. Botha and T. Rylander, "Analysis and estimation of quadrature errors in weakly singular source integrals of the method of moments," *International Journal of Numerical Modelling: Electronic Networks, Devices and Fields*, vol. 31, e2269, pp. 1–19, 2018.
22. D. P. Xiang and M. M. Botha, "MLFMM-based, fast multiple-reflection physical optics for large-scale electromagnetic scattering analysis," *Journal of Computational Physics*, vol. 368, pp. 69–91, September 2018.
23. M. M. Botha, "Estimating Quadrature Errors in the EFIE-based MoM Matrix, Due to Inner Integrals," *IEEE Antennas and Wireless Propagation Letters*, vol. 17, no. 8, pp. 1449–1453, 2018.

24. C. J. Fourie, K. Jackman, M. M. Botha, S. Razmkhah, P. Febvre, C. L. Ayala, Q. Xu, N. Yoshikawa, E. Patrick, M. Law, Y. Wang, M. Annavaram, P. Beerel, S. Gupta, S. Nazarian and M. Pedram, "ColdFlux Superconducting EDA and TCAD Tools Project: Overview and Progress," *IEEE Transactions on Applied Superconductivity*, vol. 29, no. 5, pp. 1300407 (7 pages), August 2019.
25. B. A. P. Nel and M. M. Botha, "MLACA With Modified Grouping Strategy for Efficient Superconducting Circuit Analysis," *IEEE Transactions on Applied Superconductivity*, vol. 29, no. 5, pp. 1100705 (5 pages), August 2019.
26. B. A. P. Nel and M. M. Botha, "An Efficient MLACA-SVD Solver for Superconducting Integrated Circuit Analysis," *IEEE Transactions on Applied Superconductivity*, vol. 29, no. 7, pp. 1303310 (10 pages), October 2019.
27. P. I. Cilliers and M. M. Botha, "Goal-Oriented Error Estimation for the Method of Moments to Compute Antenna Impedance," *IEEE Antennas and Wireless Propagation Letters*, vol. 19, no. 6, pp. 997–1001, 2020.
28. D. P. Xiang and M. M. Botha, "Efficient and Robust Shadowing Determination for Mesh-Based Physical Optics Analysis," *IEEE Transactions on Antennas and Propagation*, vol. 70, no. 11, pp. 10787–10799, November 2022.
29. M. Chose, A. S. Conradie, P. I. Cilliers and M. M. Botha, "Physics-Based Iterative Scheme for Computing Antenna Array Embedded Element Patterns," *Microwave and Optical Technology Letters*, vol. 65, iss. 8, pp. 2359–2365, August 2023.
30. A. S. Conradie, M. Chose, P. I. Cilliers and M. M. Botha, "Antenna Array Analysis by Iterative DGFM-Based Local Solutions," *IEEE Transactions on Antennas and Propagation*, vol. 71, no. 6, pp. 5199–5211, June 2023.

Journal articles: accepted/submitted/draft

- A. S. Conradie and M. M. Botha, "Preconditioned Localized-Solution Iterative Solver With Nested Cross Approximation for Large Arrays," 2023, submitted to *IEEE Transactions on Antennas and Propagation.*
- W. R. Dommisse, J. T. du Plessis, P. I. Cilliers, M. M. Botha and T. Rylander, "Macro Basis Functions for Efficient Analysis of Thick Wires in the MoM," 2023, submitted to *IEEE Transactions on Antennas and Propagation.*
- K. Sewraj and M. M. Botha, "Macro Basis Function Methods with Multilevel DCA Acceleration for Antenna Array Analysis," 2023, submitted to *IEEE Transactions on Antennas and Propagation.*

Peer-reviewed international symposia

Note: *The three highest-profile, peer-reviewed conferences in my field of research, are the IEEE International Symposium on Antennas and Propagation (IEEE AP-S), the European Conference on Antennas and Propagation (EuCAP) and the International Conference on Electromagnetics in Advanced Applications (ICEAA).*

1. M. M. Botha and D. B. Davidson, "Design of broadside, uniformly fed, planar aperture coupled microstrip patch arrays," in *Proceedings of IEEE Africon'99*, Cape Town, South Africa, September 1999, vol. 2, pp. 1021–1024.
2. D. B. Davidson, F. J. C. Meyer, R. H. Geschke and M. M. Botha, "Integration of a Finite Element solver within the FEKO hybrid code suite," in *Proceedings of AP2000*, Davos, Switzerland, April 2000. Full paper on CD-ROM (4 pages).

3. M. M. Botha and D. B. Davidson, "Modeling cavity backed antennas with the FEM," presented at the *5th Finite Elements Workshop for Microwave Engineering*, Boston, USA, June 2000. Abstract only.

4. M. M. Botha and D. B. Davidson, "Analyzing cavity backed, perforated substrate, microstrip patch antennas with a FMM, FE-BI hybrid formulation," in *Proceedings of the 2001 URSI International Symposium on Electromagnetic Theory*, Victoria, Canada, May 2001, pp. 627–629.

5. M. M. Botha and D. B. Davidson, "Comparison of a posteriori error estimation results for FE analysis of waveguides and FE-BI analysis of cavity backed apertures," presented at the *6th International Workshop on Finite Elements for Microwave Engineering*, Chios, Greece, May 2002. Abstract only. Page 9 in the book of abstracts.

6. M. M. Botha and D. B. Davidson, "A posteriori error estimation results for the FEM analysis of a waveguide filter," in *Proceedings of IEEE Africon'02*, George, South Africa, October 2002, vol. 2, pp. 541–544.

7. M. M. Botha and D. B. Davidson, "Comparison between two a posteriori error indicators for adaptive microwave FE analysis," in *Proceedings of the 19th Annual Review of Progress in Applied Computational Electromagnetics*, Monterey, California USA, March 2003, pp. 228–233.

8. M. M. Botha and D. B. Davidson, "P-adaptive FE-BI analysis of homogeneous, lossy regions for SAR- and far-field calculations," in *Proceedings of IEEE International Symposium on Antennas and Propagation (IEEE AP-S)*, Columbus, Ohio USA, June 2003, vol. 1, pp. 684–687.

9. M. M. Botha and J.-M. Jin, "A Stationary FE-BI Formulation for 3D Electromagnetic Analysis," in *Proceedings of IEEE International Symposium on Antennas and Propagation (IEEE AP-S)*, Monterey, California USA, June 2004, vol. 4, pp. 3493–3496.

10. M. M. Botha and J.-M. Jin, "A Posteriori Error Indicators for 3D Electromagnetic FE-BI Analysis," in *Proceedings of IEEE International Symposium on Antennas and Propagation (IEEE AP-S)*, Monterey, California USA, June 2004, vol. 4, pp. 3497–3500.

11. X. Wang, M. M. Botha and J.-M. Jin, "A Simple Error Estimator for the Moment Method in Electromagnetic Scattering," in *Proceedings of IEEE International Symposium on Antennas and Propagation (IEEE AP-S)*, Monterey, California USA, June 2004, vol. 3, pp. 3385–3388.

12. M. M. Botha, T. Rylander and J.-M. Jin, "A Numerical Investigation into the Accuracy of FE-BI and MoM for Canonical Structures," presented at the *USNC/URSI National Radio Science Meeting*, Monterey, California USA, June 2004. Abstract only.

13. T. Rylander, M. M. Botha and J.-M. Jin, "Application of Preconditioned Iterative Solvers to the Time-Domain Finite Element Method," presented at the *USNC/URSI National Radio Science Meeting*, Monterey, California USA, June 2004. Abstract only.

14. J.-M. Jin, D. Jiao, M. M. Botha, Y. Li, J. Liu, Z. Lou and T. Rylander, "Higher-Order Finite Element Solutions for 3D Wave Scattering," presented at the *Progress in Electromagnetics Research Symposium*, Nanjing, China, August 2004. Abstract only.

15. M. M. Botha and D. B. Davidson, "Hierarchical divergence-conforming basis functions of arbitrary order on tetrahedrons," in *Proceedings of the International Conference on Electromagnetics in Advanced Applications (ICEAA)*, Torino, Italy, September 2005, pp. 447–450.

16. D. B. Davidson, M. M. Botha and N. Marais, "Recent progress with vector elements for RF and microwave finite element applications," in *Proceedings of the International Conference on Electromagnetics in Advanced Applications (ICEAA)*, Torino, Italy, September 2005, pp. 837–840.

17. M. M. Botha and J.-M. Jin, "Adaptive analysis with a stationary FE-BI formulation," presented at the *8th International Workshop on Finite Elements for Microwave Engineering*, Stellenbosch, South Africa, May 2006. Abstract only.

18. M. M. Botha and D. B. Davidson, "Decomposition of the mixed first-order, divergence-conforming function space on a tetrahedral mesh," presented at the *8th International Workshop on Finite Elements for Microwave Engineering*, Stellenbosch, South Africa, May 2006. Abstract only.

19. M. M. Botha and T. Rylander, "Numerical Evaluation of Near-Singular Integrals on Curvilinear Triangular Domains," in *Proceedings of IEEE International Symposium on Antennas and Propagation (IEEE AP-S)*, Honolulu, Hawaii USA, June 2007, pp. 4837–4840.

20. M. M. Botha, "The Electromagnetic, Volume Integral Equation Method of Moments, with Curl-Conforming Discretizations," in *Proceedings of IEEE International Symposium on Antennas and Propagation (IEEE AP-S)*, Honolulu, Hawaii USA, June 2007, pp. 5628–5631.

21. M. M. Botha and T. Rylander, "Error analysis of singularity cancellation quadrature on curvilinear triangles," in *Proceedings of the International Conference on Electromagnetics in Advanced Applications (ICEAA)*, Torino, Italy, September 2007, pp. 810–813.

22. D. B. Davidson, M. M. Botha and A. Young, "Progress on radiation boundary conditions for electromagnetic finite element analysis," in *Proceedings of the International Conference on Electromagnetics in Advanced Applications (ICEAA)*, Torino, Italy, September 2007, pp. 952–955.

23. R. G. Marchand, M. M. Botha and D. B. Davidson, "Aspects of electromagnetic analysis with the FETI," presented at the *9th International Workshop on Finite Elements for Microwave Engineering*, Bonn, Germany, May 2008. Abstract only.

24. M. M. Botha, "Analysis and augmentation of the Duffy transformation for near-singular integrals," in *Proceedings of IEEE International Symposium on Antennas and Propagation (IEEE AP-S)*, Chicago, Illinois USA, July 2012, 2 pages.

25. M. M. Botha, "Comments on the construction of near-singularity cancellation transformations for triangle domains," in *Proceedings of the International Conference on Electromagnetics in Advanced Applications (ICEAA)*, Cape Town, South Africa, September 2012, pp. 824–826.

26. M. M. Botha and W. J. Strydom, "Integrating the dynamic MoM kernel with near-singularity cancellation quadrature schemes," in *Proceedings of IEEE Africon'13*, Mauritius, September 2013, 3 pages.

27. W. J. Strydom and M. M. Botha, "Investigating Antenna Radiation Properties with Characteristic Mode Analysis," in *Proceedings of IEEE Africon'13*, Mauritius, September 2013, 5 pages.

28. M. M. Botha, "Comparison of near-singularity cancellation quadrature schemes for curvilinear triangle domains," in *Proceedings of the International Conference on Electromagnetics in Advanced Applications (ICEAA)*, Torino, Italy, September 2013, pp. 1060–1063.

29. M. M. Botha, "Progress with numerical integration of the near-singular Green function gradient on general triangle domains," in *Proceedings of the International Conference on Electromagnetics in Advanced Applications (ICEAA)*, Aruba, Dutch Antilles, August 2014, pp. 442–445.

30. D. P. Xiang and M. M. Botha, "Aspects of efficient shadowing calculation for physical optics analysis of meshed objects," in *Proceedings of the International Conference on Electromagnetics in Advanced Applications (ICEAA)*, Aruba, Dutch Antilles, August 2014, pp. 492–495.

31. W. J. Strydom and M. M. Botha, "Recovery-Based a Posteriori Error Estimation for the Charge in the Method of Moments," in *Proceedings of the 9th European Conference on Antennas and Propagation (EuCAP)*, Lisbon, Portugal, April 2015, 4 pages.

32. M. M. Botha, "Evaluation of Near-Singularity Cancellation Quadrature Schemes for the Green Function Gradient on Higher-Order Triangles," in *Proceedings of the 9th European Conference on Antennas and Propagation (EuCAP)*, Lisbon, Portugal, April 2015, 4 pages.

33. D. P. Xiang and M. M. Botha, "Further progress with fast and reliable shadowing determination for mesh-based PO analysis," in *Proceedings of the International Conference on Electromagnetics in Advanced Applications (ICEAA)*, Torino, Italy, September 2015, pp. 958–961.

34. W. J. Strydom and M. M. Botha, "Ideas on recovery-based a posteriori error estimation for RWG-based currents in the Method of Moments," in *Proceedings of the International Conference on Electromagnetics in Advanced Applications (ICEAA)*, Torino, Italy, September 2015, pp. 966–969.
35. D. J. Ludick, M. M. Botha, D. B. Davidson and U. Jakobus, "Introducing the Iterative Domain Green's Function Method for Finite Array Analysis," in *Proceedings of the 2016 IEEE International Conference on Wireless Information Technology and Systems (ICWITS) and Applied Computational Electromagnetics Society (ACES)*, Honolulu, Hawaii, USA, March 2016, 2 pages.
36. M. M. Botha, "A Single Domain Approach to Weak Near-Singularity Cancellation Quadrature on Triangle Domains," in *Proceedings of the 10th European Conference on Antennas and Propagation (EuCAP)*, Davos, Switzerland, April 2016, pp. 2743–2746.
37. D. P. Xiang and M. M. Botha, "Acceleration of Multiple Reflection Physical Optics Scattering Analysis with the MLFMM," in *Proceedings of the 10th European Conference on Antennas and Propagation (EuCAP)*, Davos, Switzerland, April 2016, pp. 3803–3805.
38. D. J. Ludick, M. M. Botha, R. Maaskant and D. B. Davidson, "Comparison of the Iterative Jacobi Method and the Iterative Domain Green's Function Method for Finite Array Analysis," in *Proceedings of the 10th European Conference on Antennas and Propagation (EuCAP)*, Davos, Switzerland, April 2016, pp. 2756–2760.
39. D. P. Xiang and M. M. Botha, "Acceleration of mesh-based physical optics for electromagnetic scattering analysis," in *Proceedings of the VII European Congress on Computational Methods in Applied Sciences and Engineering (ECCOMAS 2016)*, Crete Island, Greece, June 2016, 9 pages.
40. D. P. Xiang and M. M. Botha, "Fast multiple-reflection physical optics (FMRPO) through comprehensive MLFMM acceleration," in *Proceedings of IEEE International Symposium on Antennas and Propagation (IEEE AP-S)*, San Diego, California USA, July 2017, pp. 1565–1566.
41. M. M. Botha and T. Rylander, "Results in quadrature error estimation for weak near-singular MoM integrals," in *Proceedings of IEEE International Symposium on Antennas and Propagation (IEEE AP-S)*, San Diego, California USA, July 2017, pp. 1555–1556.
42. D. J. Ludick, M. M. Botha, R. Maaskant and D. B. Davidson, "Enhancing the Jacobi Method with the CBFM for array antenna analysis," in *Proceedings of IEEE International Symposium on Antennas and Propagation (IEEE AP-S)*, San Diego, California USA, July 2017, pp. 727–728.
43. M. P. Richardson and M. M. Botha, "Comparative results for multiple-reflection physical optics (MRPO) and iterative physical optics (IPO)," in *Proceedings of IEEE International Symposium on Antennas and Propagation (IEEE AP-S)*, San Diego, California USA, July 2017, pp. 2365–2366.
44. K. Sewraj and M. M. Botha, "Generalized Characteristic Basis Function Definitions for Efficient Antenna Array Analysis in 2D," in *Proceedings of the International Conference on Electromagnetics in Advanced Applications (ICEAA)*, Verona, Italy, September 2017, pp. 984–987.
45. B. A. P. Nel and M. M. Botha, "Adaptive cross approximation (ACA) acceleration of superconducting circuit analysis," in *Proceedings of the International Conference on Electromagnetics in Advanced Applications (ICEAA)*, Verona, Italy, September 2017, pp. 1186–1189.
46. D. P. Xiang and M. M. Botha, "Performance Evaluation of Fast Multiple-Reflection Physical Optics for Scattering Analysis," in *Proceedings of the International Conference on Electromagnetics in Advanced Applications (ICEAA)*, Verona, Italy, September 2017, pp. 1001–1003.
47. M. M. Botha and T. Rylander, "Quadrature Error Estimation for MoM Matrix Entries," in *Proceedings of the International Conference on Electromagnetics in Advanced Applications (ICEAA)*, Verona, Italy, September 2017, pp. 973–975.
48. D. J. Ludick, M. M. Botha, R. Maaskant and D. B. Davidson, "Accelerating the CBFM-enhanced Jacobi Method," in *Proceedings of the International Conference on Electromagnetics in Advanced Applications (ICEAA)*, Verona, Italy, September 2017, pp. 346–349.

49. K. Sewraj and M. M. Botha, "Higher-Order Characteristic Basis Functions for Antenna Array Analysis with the MoM in 2D," in *Proceedings of IEEE Africon'17*, Cape Town, South Africa, September 2017, pp. 625–629.

50. K. Sewraj and M. M. Botha, "Comparison of macro basis function sets for antenna array analysis with the MoM," in *Proceedings of IEEE International Symposium on Antennas and Propagation (IEEE AP-S)*, Boston, Massachusetts USA, July 2018, pp. 2357–2358.

51. M. M. Botha and T. Rylander, "An improved quadrature error estimate for nearly-singular MoM integrals," in *Proceedings of IEEE International Symposium on Antennas and Propagation (IEEE AP-S)*, Boston, Massachusetts USA, July 2018, pp. 2431–2432.

52. B. A. P. Nel and M. M. Botha, "Investigation of Multilevel Adaptive Cross Approximation (MLACA) Acceleration for Superconducting Circuit Analysis," in *Proceedings of the International Conference on Electromagnetics in Advanced Applications (ICEAA)*, Cartagena, Colombia, September 2018, pp. 258–260.

53. K. Sewraj, R. C. Beswick and M. M. Botha, "Efficiency of Various Macro Basis Function Schemes for Antenna Array Analysis," in *Proceedings of the International Conference on Electromagnetics in Advanced Applications (ICEAA)*, Cartagena, Colombia, September 2018, pp. 254–257.

54. M. M. Botha, "Singularity Cancellation Quadrature Scheme Development and Error Characterization," in *Proceedings of the International Workshop on Computing, Electromagnetics, and Machine Intelligence (CEMi'18)*, Stellenbosch, South Africa, November 2018, pp. 61–62.

55. D. J. Ludick and M. M. Botha, "Application of Dynamically Constructed Macro Basis Functions to Antenna Arrays with Interconnected Elements," in *Proceedings of the International Workshop on Computing, Electromagnetics, and Machine Intelligence (CEMi'18)*, Stellenbosch, South Africa, November 2018, pp. 55–56.

56. B. A. P. Nel and M. M. Botha, "Performance of MLACA with Modified Grouping for Superconducting Circuit Analysis," in *Proceedings of the International Conference on Electromagnetics in Advanced Applications (ICEAA)*, Granada, Spain, September 2019, pp. 404–407.

57. K. Sewraj and M. M. Botha, "Computation of MBF Reaction Matrices for Antenna Array Analysis, with a Directional Method," in *Proceedings of the International Conference on Electromagnetics in Advanced Applications (ICEAA)*, Granada, Spain, September 2019, pp. 385–389.

58. M. Chose and M. M. Botha, "Improvements to the Domain Green's Function Method for Antenna Array Analysis," in *Proceedings of the International Conference on Electromagnetics in Advanced Applications (ICEAA)*, Granada, Spain, September 2019, pp. 392–395.

59. K. Sewraj and M. M. Botha, "Directional Method to Compute Reduced Matrix System in MBF Solvers," in *Proceedings of the European Conference on Antennas and Propagation (EuCAP)*, Copenhagen, Denmark, March 2020, pp. 1–5.

60. M. Chose and M. M. Botha, "An Iterative Method for the Analysis of Large Disjoint Antenna Arrays," in *Proceedings of the European Conference on Antennas and Propagation (EuCAP)*, Copenhagen, Denmark, March 2020, pp. 1–4.

61. K. Sewraj and M. M. Botha, "Application of the Inverse Fast Multipole Method to Antenna Array Analysis," in *Proceedings of IEEE International Symposium on Antennas and Propagation (IEEE AP-S)*, Montréal, Canada, July 2020, pp. 1993–1994.

62. M. Chose and M. M. Botha, "Efficient Iterative Method for Computation of Antenna Array Embedded Element Patterns," in *Proceedings of IEEE International Symposium on Antennas and Propagation (IEEE AP-S)*, Montréal, Canada, July 2020, pp. 1051–1052.

63. P. I. Cilliers and M. M. Botha, "Results in Goal-Oriented Error Estimation for MoM Input Impedance Computation," in *Proceedings of IEEE International Symposium on Antennas and Propagation (IEEE AP-S)*, Montréal, Canada, July 2020, pp. 1055–1056.

64. K. Sewraj, M. Chose and M. M. Botha, "Developments in the Analysis of Large Antenna Arrays with Disjoint Elements," in *Proceedings of the European Conference on Antennas and Propagation (EuCAP)*, Düsseldorf, Germany, March 2021, pp. 1–3.
65. J. T. du Plessis and M. M. Botha, "A Macro Basis Function Formulation for Thick Wires in the Method of Moments," in *Proceedings of the European Conference on Antennas and Propagation (EuCAP)*, Düsseldorf, Germany, March 2021, pp. 1–4.
66. K. Sewraj and M. M. Botha, "Development of a Sparse Direct Solver for Antenna Array Analysis," in *Proceedings of the International Conference on Electromagnetics in Advanced Applications (ICEAA)*, Waikiki, Hawaii USA, August 2021, pp. 280–282.
67. A. S. Conradie and M. M. Botha, "Improved Iterative DGFM Convergence, Towards Large-Scale Antenna Array Analysis," in *Proceedings of the European Conference on Antennas and Propagation (EuCAP)*, Madrid, Spain, March 2022, pp. 1–4.
68. D. P. Xiang and M. M. Botha, "Results on Shadowing Determination with Linear Cost Scaling for Physical Optics Analysis," in *Proceedings of the European Conference on Antennas and Propagation (EuCAP)*, Madrid, Spain, March 2022, pp. 1–4.
69. I. Zhabitskiy and M. M. Botha, "Array Antenna Solver Based on Macro Basis Functions, with Improved Accuracy," in *Proceedings of the International Conference on Electromagnetics in Advanced Applications (ICEAA)*, Cape Town, South Africa, September 2022, pp. 329–331.
70. P. I. Cilliers and M. M. Botha, "Computing Surface Integral Equation Matrices with Shared Memory Parallelization," in *Proceedings of the International Conference on Electromagnetics in Advanced Applications (ICEAA)*, Cape Town, South Africa, September 2022, pp. 123–125.
71. D. P. Xiang and M. M. Botha, "Fast Point Source Shadowing Determination for Mesh-Based Physical Optics Analysis," in *Proceedings of the International Conference on Electromagnetics in Advanced Applications (ICEAA)*, Cape Town, South Africa, September 2022, pp. 397–399.
72. A. S. Conradie and M. M. Botha, "Iterative DGFM Solver Extensions for Fast Sparse Array Analysis," in *Proceedings of the International Conference on Electromagnetics in Advanced Applications (ICEAA)*, Cape Town, South Africa, September 2022, pp. 4–7.
73. J. T. du Plessis, W. R. Dommisse, M. M. Botha and T. Rylander, "Scattering Analysis of Thick Wires with the MoM using Macro Basis Functions," in *Proceedings of the International Conference on Electromagnetics in Advanced Applications (ICEAA)*, Cape Town, South Africa, September 2022, pp. 340–342.
74. T. Rylander and M. M. Botha, "Exact-Kernel Thin-Wire MoM with Geometric Representation by Bézier Curves," in *Proceedings of the EMC Europe Symposium*, Göteborg, Sweden, September 2022, pp. 389–393.
75. K. Sewraj and M. M. Botha, "Overview of Macro Basis Function Research for Antenna Array Solvers," in *Proceedings of the IEEE International Conference on Emerging Trends in Electrical, Electronic and Communications Engineering (ELECOM2022)*, Mauritius, November 2022, pp. 1–5.
76. A. S. Conradie and M. M. Botha, "Modelling of MFAA Candidate Arrays Using a New Solver Based on Localised Solutions," in *Proceedings of the European Conference on Antennas and Propagation (EuCAP)*, Florence, Italy, March 2023, pp. 1–5.
77. R. J. McDougall, P. I. Cilliers and M. M. Botha, "Results in Adaptive MoM Analysis with Goal-Oriented Error Estimation," in *Proceedings of the European Conference on Antennas and Propagation (EuCAP)*, Florence, Italy, March 2023, pp. 1–5.
78. K. Sewraj, A. S. Conradie and M. M. Botha, "Progress on Iterative Methods for Efficient Antenna Array Analysis," in *Proceedings of 8th IEEE RADIO International Conference*, Balaclava, Mauritius, May 2023, pp. 1–2.

79. A. S. Conradie and M. M. Botha, “Array Analysis by Iterative Localized Solutions with Improved Convergence,” in *Proceedings of the International Conference on Electromagnetics in Advanced Applications (ICEAA)*, Venice, Italy, October 2023, pp. 390–392.

International symposia: accepted/submitted

- M. M. Botha, K. Sewraj, P. I. Cilliers, A. S. Conradie, W. R. Dommisse and T. Rylander, “Developments in macro basis function methods for electromagnetic analysis,” in *Proceedings of the European Congress on Computational Methods in Applied Sciences and Engineering (ECCOMAS)*, Lisbon, Portugal, June 2024, 1-page abstract, submitted.
- A. S. Conradie and M. M. Botha, “Efficient Localized-Solution Iterative Solver for Large-Scale Antenna Array Analysis,” in *Proceedings of IEEE International Symposium on Antennas and Propagation (IEEE AP-S)*, Florence, Italy, July 2024, pp. 1–2, submitted.
- W. R. Dommisse, M. M. Botha and T. Rylander, “Modelling of Thick Conducting Wires with Macro Basis Functions,” in *Proceedings of IEEE International Symposium on Antennas and Propagation (IEEE AP-S)*, Florence, Italy, July 2024, pp. 1–2, submitted.

5 Career profile

Postgraduate supervision at Stellenbosch University

Master’s degrees

Name	Degree	Topic	Mark	Duration
Renier G. Marchand	MEng	Finite Element Tearing and Interconnecting for the Electromagnetic Vector Wave Equation in Two Dimensions (Joint supervision with Prof. D. B. Davidson.)	Degree awarded	Jan-2005 to Mar-2007
Willem J. Strydom	MEng	Recovery Based Error Estimation for the Method of Moments	Degree awarded	Jan-2013 to Mar-2015
Keshav Sewraj	MEng	Extensions to the characteristic basis function method, for antenna array analysis	Degree awarded	Jan-2016 to Mar-2018
Michael P. Richardson	MEng	Physical Optics Based Methods for Scattering Analysis	Degree awarded	Jan-2016 to Mar-2018
Ben A. P. Nel	MEng	Adaptive Cross Approximation for Electromagnetic Analysis of Superconducting Circuits	Degree awarded	Jan-2017 to Mar-2019
Robey C. Beswick	MEng	The Development of MATLAB Based Tools for Antenna Array Analysis	Degree awarded	Jan-2018 to Mar-2020
Pierre I. Cilliers	MEng	Numerical electromagnetic analysis for radio astronomy antennas	Upgraded to PhD	Jan-2019 to Dec-2020
Tameez Ebrahim	MEng	Fast Array Analysis Using Parallelised Domain Decomposition Methods (Joint supervision with Dr. D. J. Ludick.)	Degree awarded	Jan-2019 to Dec-2020
Jacques T. du Plessis	MEng	Efficient Electromagnetic Simulation of Wires	Degree awarded	Jan-2019 to Mar-2021

Ntombi Mtetho	MEng	Characterisation of the Transient Array Radio Telescope (TART) (Joint supervision with Dr. D. J. Ludick.)	Degree awarded	Jan-2018 to Dec-2021
André S. Conradie	MEng	Efficient modelling of large-scale radio astronomy antenna arrays with interconnected elements	Upgraded to PhD	Jan-2021 to Dec-2022
Cullen D. Stewart-Burger	MEng	Radar Target Identification and classification using machine learning (Joint supervision with Dr. D. J. Ludick and Dr. M. Grobler.)	Degree awarded	Jan-2021 to Mar-2023
Willem F. de la Bat	MEng	Intelligent CEM solver selection using machine learning (Joint supervision with Dr. D. J. Ludick and Dr. T. L. Grobler.)	Degree awarded	Jan-2021 to Mar-2023
William R. Dommisse	MEng	Computational electromagnetics methods for cable coupling analysis (Joint supervision with Prof. T. Rylander.)	Upgraded to PhD	Jan-2022 to Dec-2023

Doctoral degrees

Name	Degree	Topic	Mark	Duration
Dao P. Xiang	PhD	Fast Mesh-Based Physical Optics for Large-Scale Electromagnetic Analysis	Degree awarded	May-2013 to Dec-2016
Keshav Sewraj	PhD	Adaptive Cross Approximation Methods for Fast Analysis of Antenna Arrays	Degree awarded	Jan-2018 to Mar-2021
Matthews Chose	PhD	Analysis of Large Disjoint Antenna Arrays by Localised Solutions	Degree awarded	Jan-2018 to Mar-2023
Pierre I. Cilliers	PhD	Enhanced Method of Moments Performance Through Efficient Implementation and Error Estimation	Degree awarded	Jan-2019 to Mar-2023
André S. Conradie	PhD	Efficient modelling of large-scale radio astronomy antenna arrays with interconnected elements	—	Jan-2021 to Present
Iakov Zhabitskiy	PhD	Novel Macro Basis Function Methods for Array Antenna Analysis (Joint supervision with Dr. J. J. van Tonder.)	—	Mar-2021 to Present
William R. Dommisse	PhD	Computational electromagnetics methods for cable coupling analysis (Joint supervision with Prof. T. Rylander.)	—	Jan-2022 to Present

Postdoctoral researchers

Name	Degree	Topic	Mark	Duration
Danie J. Ludick	—	Efficient analysis of large antenna arrays	—	Jul-2015 to Dec-2016
Keshav Sewraj	—	ACA-based methods for analysis of large antenna arrays	—	Mar-2021 to Aug-2021
Pierre I. Cilliers	—	Advanced Improvements to the Method of Moments	—	Jan-2023 to Dec-2023