**Details of Research Project**

**Section A: Overview of the Research Project**

*1. Calibration of wideband interleaved ADC structures*
*2. Engineering*
*3. Masters*

*4. Abstract of research project*
Reliable, wideband signal digitization is critical to the development of SKA Band 5 (4.8-15.3 GHz) observations. The current baseline design employs a single, 4-bit, 16 Gsps monolithic flash ADC. Due to its limited effective number of bits (ENOB) at these high frequencies and wide bandwidth, an alternative digitization strategy is considered. It will require multiple interleaved digitizers, with accurate and stable time delays and gain calibration. This project will aim to develop improved digitizer time synchronisation and gain calibration techniques. Digital signal processing (DSP) techniques will be developed to optimise the delay of multiple digitizer cores inside an ADC module, while RF techniques (to optimise delay between two separate ADC modules) will be pursued as a secondary goal.

*5. Primary supervisor's details:*
a. Dr Johan Schoeman
b. j.schoeman@up.ac.za
c. University of Pretoria

*6. Co-supervisor/Research supervisor's details*
a. Prof Tinus Stander
b. University of Pretoria

**Section B: Details of Research Project**

*1. Scientific/Engineering merit:*

SKA Band 5 (4.8-15.3 GHz) will require a digitizer (or analog-to-digital converters, ADCs) that challenge the state-of-the-art in digitization speeds with commercially available ADCs. Typically, to reach the required sampling rates, multiple ADCs are interleaved. Time-interleaved analogue to digital converters (TI-ADC) are widely used in high speed data communication systems, instrumentation and measurement systems. They have risen in popularity as they alleviate problems like limited comparator regeneration time, amplifier settling time and amplifier linearity issues related to power consumption, all of which are associated with achieving high sampling rates using other architectures. This is achieved by using multiple sub-ADCs in parallel, each one slightly offset relative to the others in the time domain. The technique may also be applied to parallel placement of multiple ADC modules on the same PCB.

The bulk of the commercial and academic developments of both discrete PCB based system level and RF system-on-chip (SoC) TI-ADC families are largely driven by the increasing demand in wide-band communication systems. This limits the available experimental data

from the manufacturer to limited frequency bands, rather than the entire bandwidth. For wide-band radio astronomy applications, it is essential to have performance evaluation over the entire bandwidth of the TI-ADC. This warrants further investigation into the wideband performance of the proposed hardware architecture.

Second, and even more relevant to the above, the dynamic performance of a TI-ADC system is significantly deteriorated by channel mismatches due to component mismatches among the distinct analogue sub-ADCs, or even ADC cores inside a multi-core packaged ADC. The sampled signal in each sub-ADC suffers from gain and offset mismatches, as well as timing skew. This is compounded by the variation of these over frequency in wideband setups. Finally, interleaving spurs also introduce unwanted spectral components.

TI-ADC systems will, therefore, greatly benefit from a calibration strategy aimed specifically at transforming them into wideband ADCs. However, which practically realisable FPGA based strategy is best suited to address the needs of a radio astronomy receiver remains an unanswered question in literature. In addition, wideband high-frequency layout and control techniques for interleaving multiple ADC modules similarly remains an open question.

*2. Feasibility:*

A recent study (Dec 2021) by Oxford researchers have evaluated an RFSoC based TI-ADC using floating point, off-line post-processing, to isolate the performance of the ADCs from any concerns about fixed-point arithmetic in the FPGA,as well as a single-channel spectrometer implemented in the FPGA operating in real-time. This was done without the proposed calibration in this proposal.

A number of calibration methods are known, which may feasibly be pursued toward a viable calibration strategy. They can be broadly divided into two categories, being i) analogue and mixed signal techniques, and ii) all digital techniques. The most popular digital approaches include non-blind and blind techniques, with the latter being the focus of this project. The application of any of these, or in combination, could lead to a feasible and synthesizable FPGA based solution, although this has not yet been demonstrated.

The Carl and Emily Fuchs Institute for Microelectronics at the University of Pretoria has significant experience in the design of RF and microwave components, as well as digital signal processing techniques. The lab is further equipped with all the necessary laboratory facilities for measurement, as well as software for circuit, EM, and system modelling and digital design. A suitable TI-ADC based sampling analogue and mixed signal front-end, as well as a suitable FPGA based processing platform with sufficient RF bandwidth processing capability and resources, are also available.

The potentially expected intermediate milestones and associated timeframes towards attaining the overall objectives of the project would include:

Y1: Literature review. Digital simulation of the calibration methodology in a high level language. Design and verification of experimental setup.
Y2: VHDL/FPGA design, implementation, prototyping and testing. Experimental measurement and performance characterisation.

*3. SARAO research priority areas*

The project directly ties in with the following main SARAO postgraduate research focus areas in 2024/2025:

> *5.2.1 Radio astronomy antennas and receiver systems (including digitisation) associated with supported and hosted instruments.*
>
> *5.2.2 Real-time digital signal processing instrumentation for radio astronomy, specifically using FPGA and GPU platforms.*

The proposed techniques, if successful, will lead to increased bandwidth performance and improved measurement accuracy of currently installed and operating SARAO receivers. It will also develop critical skills in digital signal processing for radio astronomy.

4. *The preferred candidate* would have at least a firm undergraduate background in digital system and algorithmic design in VHDL/FPGA.

# Dr Johan Schoeman

***Pr.Eng, PhD(Eng)(UP), SMIEEE***

## *Personal details*


| | |
|---|---|
| Gender: | Male |
| Nationality: | South African |
| Current residence: | Pretoria, South Africa |
| Contact number: | +27 12 420 2955 |
| Contact e-mail: | j.schoeman@up.ac.za |


## *Education*

- **PhD, Electronic Engineering**
  University of Pretoria, South Africa, 2018.
- **M.Eng, Electronic Engineering**
  University of Pretoria, South Africa, 2011
- **B.Eng (Hons), Electronic Engineering**
  University of Pretoria, South Africa, 2003
- **B.Eng, Electronic Engineering**
  University of Pretoria, South Africa, 2002

## *Awards, Distinctions and Fellowships*

- SMEOS Best student paper runner up (2018)

## *Leadership positions*

- Principle investigator, NRF Thuthuka Research Project "Compact In-Line Holographic Microscopy for Particulate Matter Measurement".
- Principle investigator, NRF Research Project "Characterisation and modelling of a novel dual element uncooled MEMS IR sensor".

## *Professional Activities*

- Registered as Professional Engineer with the Engineering Council of South Africa
- Senior member of the IEEE
- Consultant to AMTS on project "Uncooled MEMS IR microbolometers" (2008 - 2012)
- Member of the Technical Programme Committees: IEEE AFRICON 2007 and International Conference on Telecommunications ICT 2005
- Journal Reviewer: ELSEVIER Vacuum
- External Examiner: UNISA

## *Employment History*

- **Senior Lecturer**
  Department of Electrical, Electronic and Computer Engineering, University of Pretoria, South Africa, January 2020 – present.
- **Lecturer**
  Department of Electrical, Electronic and Computer Engineering, University of Pretoria, South Africa, January 2003 – 2019.
- **Assistant Lecturer**
  Department of Electrical, Electronic and Computer Engineering, University of Pretoria, South Africa, January 2002 – 2003.

## *Teaching Activities*

*Postgraduate:*

- Research project: Theory EPT732, UP, since 2018
- Research project: Design and laboratory EPT733, UP, since 2018
- Digital Electronics EDG780, UP, 2006-2011

*Undergraduate:*

- Research project EES424, UP, since 2016
- Analogue electronics ENE310, since 2014
- Specialization (Advanced Digital Design) EES424, 2011-2015
- Specialization (VHDL for Engineers) EES423, 2009-2010
- Advanced Electronics ENE410, UP, 2004-2013
- Electronic Components ELK220, UP, 2004-2008
- Computer Architecture COS284, UP, 2003
- Modulation Systems EMS310, UP, 2003

*Study leader:*

- Postgraduate: Introduction to research EIN732, UP, since 2016
- Undergraduate: Project EPR400/402, UP, since 2003

## *Research Interests*

- Digital signal processing for holographic microscopy.
- Digital signal processing for terrestrial communications.
- Digital signal processing for radio astronomy.
- Additive manufacturing for microfluidics and in-line digital microscopy components and packaging.
- Uncooled MEMS IR sensor (bolometer) characterisation and modelling.
- Digital signal processing for wireless communications.

## *Research Activities*

**Current Student Supervision**

Supervisor or co-supervisor to 8 postgraduate students (M.Eng and PhD)

**Publication Metrics**

- Total journal papers: 8
- Total international conference papers: 17
- Total national conference papers: 8
- Total citations in Scopus: 54
- h-index: 4

**Top Publications**


1. M. G. Maritz and J. Schoeman, "Programmable Aperture Using a Digital Micromirror Device for In-Line Holographic Microscopy," in IEEE Journal of Quantum Electronics, vol. 58, no. 5, pp. 1-8, Oct. 2022, Art no. 5700108, doi: 10.1109/JQE.2022.3190501.
2. Schoeman, J. and du Plessis, M. "A two-port electrothermal model for suspended MEMS device structures with multiple inputs", J. Sens. Sens. Syst., 8, 293–304, https://doi.org/10.5194/jsss-8-293-2019, 2019.
3. Schoeman J. and Du Plessis M., "An analytic model employing an elliptical surface area to determine the gaseous thermal conductance of uncooled VOx microbolometers", Sensors and Actuators A: Physical Volume 250, 15 October 2016, pp. 229-236, http://dx.doi.org/10.1016/j.sna.2016.09.033
4. Schoeman J. and Du Plessis M., "Characterisation of the electrical response of a novel dual element thermistor for low frequency applications", SAIEE Africa Research Journal, Vol. 103 (1), March 2012, pp. 9-13, http://www.saiee.org.za/
5. Maclean W., Du Plessis M. and Schoeman J., "Optimization of CMOS compatible microbolometer device performance", SAIEE Africa Research Journal, Vol. 103 (1), March 2012, pp. 3-8, http://www.saiee.org.za/
6. Du Plessis M., Schoeman J., Maclean W. and Schutte C, "The electro-thermal properties of integrated circuit microbolometers", SAIEE Africa Research Journal, Vol. 102 (2), June 2011, pp. 40-48, http://www.saiee.org.za/
7. Schoeman J. and Linde L.P., "Employing a measure of sparseness to investigate sparse data compression in AWGN conditions", SAIEE Africa Research Journal (Africon '04 – Special Issue 1: Towards Next Generation Wireless Communication Systems) Sept. 2006, Vol. 97, No. 2, pp. 157-161, http://www.saiee.org.za/
8. M. E. Goosen, P. J. Venter, N. M. Faure, P. N. Msomi, J. Schoeman and T-H. Joubert, "Hot Carrier Degradation of Mixed-mode Polysilicon Light Emitting Diodes", accepted for publication, Materials Science & Engineering B, Febr. 2023

# Prof Tinus Stander

***Pr.Eng, PhD(Eng)(SU), SMIEEE***

## *Education*

- **PhD, Electronic Engineering**
  Stellenbosch University, South Africa, 2009.
- **B.Eng, Electrical and Electronic Engineering with Computer Science**
  Stellenbosch University, South Africa, 2005
- **M.Eng (Engineering Management)**
  University of Pretoria, South Africa, 2024 (current)

## *Short Courses and Certifications*

- **Programme in Project Management**
  University of Pretoria, South Africa, 2023.

## *Awards, Distinctions and Fellowships*

- Erasmus Mundus EUROSA III scholarship (2013)
- Awarded NRF C-rating (2020)
- Awarded SANRAL B-category researcher rating (2020)
- IEEE MTTSAT Challenge Phase 2 participant (2020)

## *Leadership positions*

- Vice-Chair: SAIEEE APS/MTTS/EMC Chapter (2019 – 2022)
- Project Leader, SANRAL Research Project 1.2a, "Sensors".
- Co-PI, SA-Mexico Bilateral Programme on Water Vapour Radiometry (2018 – 2021)
- Advisor to VIP team, "Reliable Systems"

## *Professional Activities*

- Registered as Professional Engineer with the Engineering Council of South Africa
- Consultant to South African National Roads Agency (SANRAL), leader of Project 1.2s: "Sensors"
- Scientific advisor to Multifractal Semiconductors (Pty) Ltd.
- Senior member of the IEEE (2005 – present)
- Member of the Technical Programme Committees:
  IEEE AFRICON 2013 & 2017, 9th Global Symposium on Millimeter Waves (GSMM), 7th ESA Workshop on Millimetre-Wave Technology and Applications, TELSIKS 2023
- Journal Reviewer: IEEE T-MTT, IET MAP, IET CDS, IEEE EDL, IEEE MWTL, IJCTA, IJRFMWCAD

## *Employment History*

- **Professor**
  Department of Electrical, Electronic and Computer Engineering, University of Pretoria, South Africa, January 2023 – present.
  - Previously Senior Lecturer (2013 – 2019) and Associate Professor (2020 – 2022).
- **Radio frequency and microwave engineer**, Denel Dynamics, Centurion, South Africa, 2010 – 2012

## *Teaching Activities*

- Postgraduate Wireless Electronics EMK732,
  UP, 2017 – current.
- Electronic engineering design EPR320, UP, 2014-current.
- Advanced Electronics ENE410, UP, 2014-current.
- Digital Electronics ERS 220, UP, 2013.
- Postgraduate Analogue Electronic Design EME 732,
  UP, 2013-2014.
- Analogue Electronics ENE310, UP, 2013.
- Microwave Filters for RADAR, UCT, 2013.
- Microwave Engineering EMW040, CPUT, 2008.

## *Research Interests*

- mm-Wave microelectronics for terrestrial communications.
- Built-in self-testing of RF and mm-wave electronics
- mm-Wave radiometry for radio astronomy
- mm-Wave remote sensing for transportation applications
- Additive manufacturing for microwave and mm-wave components and packaging.

## *Research Activities*

### Completed Postgraduate Supervision

- M.Eng (Electronic and Microelectronic Engineering): 9
- PhD (Electronic Engineering): 6

### Current Student Supervision

Supervisor or co-supervisor to 7 postgraduate students (M.Eng and PhD) and 1 postdoctoral fellow

### Current Research Grants

- NRF Competitive Support for Rated Researchers (2022 – 2024)
- SANRAL Research Project 1.2a, "Sensors" (2022 – 2024)

### Current Facilities Management

- mm-Wave microelectronic wafer probe lab
- mm-Wave anechoic chamber
- Class 6 cleanroom
- Microelectronics packaging line
- PCB patterning and assembly line

### Publication Metrics

- Total journal papers: 27
- Total international conference papers: 52
- Total patents: 3
- Total citations in Scopus: 207
- h-index in Scopus: 7

### Top Publications


1. J. J. P. Venter, T. Stander and P. Ferrari, "X-band Reflection-Type Phase Shifters Using Coupled Line Couplers on Single Layer RF PCB", IEEE Microwave and Wireless Components, Vol. 28, no. 9, pp. 807 – 809, 2018.
2. A. Simonovic, E. Rohwer, T. Stander, "SLA-Printed K-Band Waveguide Components Using Tollens Reaction Silver Plating", IEEE Transactions on Components, Packaging and Manufacturing Technology, Vol. 13, no. 2, pp. 230 – 239, 2023.
3. P. J. Osuch, T. Stander, "A Millimeter-Wave Second-Order All-Pass Delay Network in BiCMOS", IEEE Microwave and Wireless Components Letters, Vol. 28, no. 10, pp. 912 – 914, 2018.
4. J. B. Cloete, T. Stander, D. N. Wilke, "Parametric Circuit Fault Diagnosis Through Oscillation-Based Testing in Analogue Circuits: Statistical and Deep Learning Approaches", IEEE Access, Vol. 10, pp. 15671 – 15680.
5. N. Singh, T. Stander, "E-band Active Q-enhanced pseudo-combline E-band resonator 130nm SiGe BiCMOS", Journal of Infrared, Millimeter, and Terahertz Waves, Vol. 39, No. 10, pp 949–953, 2018.
6. H. P. Nel, F. Dualibe, T. Stander, "Influence of PVT Variation and Threshold Selection on OBT and OBIST Fault Detection in RFCMOS Amplifiers", IEEE Open Journal of Circuits and Systems, Vol. 4, pp. 70-84, 2023.
7. J. J. P. Venter, T. Stander, "Phase Shifters with Multiple Independently Controllable Bands Utilizing Frequency-Selective Variable Gain Networks", IET Microwaves, Antennas and Propagation, Vol. 15, no. 2, pp. 143-153, 2021.
8. P. J. Osuch, T. Stander, "High-Q second-order all-pass delay network in CMOS", IET Circuits, Devices and Systems, Vol. 13, no. 2, pp. 153 – 162, 2019.
9. J. J. P. Venter, R. Maharaj, T. Stander, "Additive Manufacturing of Interdigital Filters with Arbitrary Line Cross Section", IEEE Transactions on Components, Packaging and Manufacturing Technology, Vol. 10, no. 4, pp. 686–693, 2020.
10. F. Sagouo Minko, T. Stander, "A comparison of three-dimensional electromagnetic and RC parasitic extraction analysis of mm-wave on-chip passives in SiGe BiCMOS low-noise amplifiers", International Journal of RF and Microwave Computer-Aided Engineering, vol. 30, no. 2, e22019, 2020.