Details of Research Project

Section A: Overview of the Research Project

1. A dual band digital sideband separating spectrometer with digital compensation for high SRR
2. Engineering
3. Masters

4. Abstract of research project
High atmospheric noise is usually prominent in the sub-millimeter range utilised for observational radio astronomy. Sideband-separating receivers are typically preferred in such cases. However, due to imbalances in the different analog components it is unavoidable that signal leakage occurs between the sidebands. Calibration methods exist in the analogue, digital and hybrid domains, but it is the digital approach that offers best results. This project will aim to develop digital techniques that can address the issue of calibration to improve SRR. The platform will be demonstrated as calibrated digital sideband separating spectrometers (both wideband and narrowband) on a Xilinx Ultrascale+ RFSoC development board for radio astronomy applications.

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:

The next generation of radio astronomy instruments, such as the ngVLA will see smaller receivers with wider frequency coverage, with particular interest to the K-band (18 - 27 GHz) and Q-band (33 - 50 GHz). The science case for such a receiver includes the study of the water maser line, silicon monoxide in the K-band and methanol maser lines within the Q-band.

However, high atmospheric noise is usually prominent in the wavelength range suggested for next generation observational radio astronomy instruments. Although a number of receiver architectures exist, sideband-separating receivers are typically preferred in such cases. However, due to imbalances in the different analog components it is unavoidable that signal leakage occurs between the sidebands. Therefore, the sideband rejection ratio (SRR) is typically rather poor; if not compensated for. Analogue methods exist for improved sideband rejection, but these are typically limited to SRR figures of 7 to 30 dB, the latter for hybrid approaches. Recently the details of a concept demonstrator for an 18 - 45 GHz

receiver to be demonstrated at Hartebeesthoek Radio Astronomy Observatory (HartRAO) station in South Africa was published (Mundia et al., 2022) by researchers of the M4 lab situated at CEFIM, University of Pretoria. Their findings again confirmed some shortcomings with analogue RF SRR compensation.

It is the digital calibration counterparts that will truly shine and improve performance of these receivers. It is not only their very high SRR above 40 dB that is appealing, but also their flexibility. Since the digital compensation can be conducted as part of the digital backend of the receiver, the same method can also be applied to the digital backend of existing sideband-separating receivers of alternative bands (notably the L, S and C bands) without the need to replace or modify these existing analogue frontends.

This project will aim to develop a digital backend that can address the issue of calibration for improved SRR. The implementation will be demonstrated as calibrated digital sideband separating spectrometers (both wideband and narrowband) on a Xilinx Ultrascale+ RFSoC development board for radio astronomy applications as identified by HartRAO. The existing 18 - 45 GHz receiver, without calibration, will be utilised with an additional mixing stage to prepare the designed 4 - 11 GHz lower and upper sidebands for digitisation.

2. Feasibility:

Recently researchers of the M4 lab situated at CEFIM, University of Pretoria (Mundia et al., 2022) published work on a concept demonstrator for an 18 - 45 GHz receiver to be demonstrated at Hartebeesthoek Radio Astronomy Observatory (HartRAO) station in South Africa. The need for compensation to address and improve SRR was identified. The existing receiver structure can be utilised with or without analogue RF compensation.

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 approach will be the focus of this project. It aims to combine the input signals with different calibration gains. The concept was first demonstrated by Morgan & Fisher (2010) utilising a PC as DSP backend. More recently, Finger et al. (2013) and Rodriguez et al. (2018) demonstrated the next evolution by building real-time, calibrated, sideband separating receivers using FPGA technology.

Finally, 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.

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 sideband separating receiver as well as a Xilinx Ultrascale+ RFSoC

FPGA 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. A further stage of mixing is required to prepare the existing receiver outputs for digitisation. 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.