Details of Research Project

Section A: Overview of the Research Project

1. An FPGA based digital pulsar dedispersion method using IIR filters
2. Engineering
3. Masters

4. Abstract of research project

Pulsars, high-speed rotating neutron stars with strong magnetic fields, emit beams of electromagnetic (EM) radiation from their poles. These beams are observed as stable cosmic clocks, in the form of pulses, when the Earth's line of sight crosses the pulsar. These pulses are very useful as they can be used as stable cosmic clocks for various experiments. However, detecting pulsar events can be challenging due to various factors, such as dispersion and scattering effects, which can alter the EM characteristics of the signals and affect our ability to detect them.

The detection of pulsars is very computationally expensive. Traditional approaches were focused on detecting them from recorded data. However, advancements in digital processing, especially FPGA and GPU development, has seen an increased interest in real-time pulsar detection, with significant advantages of observing rare transient events, improving the observational efficiency of an observatory, etc. In order to realise such a system requires careful thought on resource allocation, especially when expanding towards a more general real time pulsar search engine. This research project embarks on the first step towards this goal by applying a general mathematical method for implementing arbitrary dispersion profiles using second-order delay networks and implementing these in the pulsar backend as FIR and IIR filters, allowing for a comparison of resource utilisation.

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:

Real-time pulsar dedispersion offers some advantages over the well known post processing approach. Dispersed pulses can be recovered with increased sensitivity, allowing for the detection of weaker signals that would otherwise be undetectable. It allows astronomers to quickly detect pulsars while they are making other observations, improving the observational

efficiency. This is particularly important for large-scale surveys, where many pulsars may be present, and the detection of each one may require the analysis of a large amount of data.

Ideally, the dedispersion filter should have a group delay response equal to the negative of the interstellar medium delay transfer function to cancel the effect of the latter. There are two general approaches to designing these second order filter responses, being either finite or infinite impulse response (FIR or IIR). It is generally known and accepted that FIR filters are stable at the expense of requiring more filter taps, which translates directly to more digital resources. IIR filters can become unstable if not synthesised correctly, but can offer similar performance to FIR topologies with fewer taps. Herein lies the potential for reducing the number of logic elements required for FPGA synthesis of such a dispersion filter.

The development of a next generation FPGA based pulsar dedispersion method using IIR filters holds great potential to significantly reduce FPGA resource utilisation. This opens further avenues to power consumption reduction and demonstrates the first step towards the ultimate goal of implementing a bank of such filters that allows radio astronomers to search for new pulsars in real time while piggy backing off the already channelised digital data being prepared for other observations and experiments.

2. Feasibility:

Researchers of Xinjiang Astronomical Observatory and Key Laboratory of Radio Astronomy have recently (Feb 2022) studied and established that Radio Frequency System on Chip (RFSoC) offers great potential as a complete, single board radio astronomy signal processing system. They demonstrated a pulsar digital backend system based on the Xilinx ZCU111 RFSoC FPGA development board using conventional methods.

Recently, a mathematical method for implementing arbitrary dispersion profiles using second-order delay networks was demonstrated (Osuch et al, 2016). As a general approach to second-order delay networks, the method also applies to dedispersion profiles. The method was also demonstrated in the RF domain prior to digitisation (Osuch et al, 2019), where it was suggested for consideration in the digital domain.

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 FPGA based processing platform with sufficient RF bandwidth processing capability (Xilinx Ultrascale+ RFSoC evaluation board) and resources is 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 dedispersion 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 2022:

> *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 real-time detection of a pulsar with reduced resource cost and improve the observational efficiency of 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
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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 6 postgraduate students (M.Eng and PhD)

Current Research Grants

- NRF Thuthuka Grant (2021 – 2023)

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

Awards, Distinctions and Fellowships

- Coimbra Staff Exchange Fellowship (2014)
- 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

- Project Leader, SANRAL Research Project 1.2a, "Sensors".
- Co-PI, SA-Mexico Bilateral Programme on Water Vapour Radiometry (2018 – 2021)

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)

Employment History

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

Teaching Activities

- Postgraduate Communications Electronics EMK732, UP, 2017 – current.
- Electronic engineering design ELO320, 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): 8
- PhD (Electronic Engineering): 6

Current Student Supervision

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

Current Research Grants

- NRF Competitive Support for Rated Researchers (2022 – 2024), "OBT for RF electronics"
- SANRAL Project 1.2a, "Remote sensing of road texture"

Current Facilities Management

- mm-Wave coaxial and waveguide lab
- mm-Wave microelectronic wafer probe lab
- mm-Wave anechoic chamber
- Micron-precision 2.5D patterning and assembly lab
- Class 6 cleanroom

Publication Metrics

- Total journal papers: 25
- Total international conference papers: 52
- Total patents: 3
- Total citations in Scopus: 172
- h-index in Scopus: 6

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. H. P. Nel, F. C 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. 1 – 15, 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. F. Sagouo Minko, T. Stander, "Effect of TID Electron Radiation on SiGe BiCMOS LNAs at V-band", Microelectronics Reliability, Vol. 112, e113750, 2020.
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, 202