Details of Research Project

Section A: Overview of the Research Project

1. An FPGA based digital pulsar dedispersion filter bank
2. Engineering
3. Doctoral

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 de-dispersion of pulsars can ostensibly be achieved with all-pass IIR filters which mitigate the pulsar specific dispersion functions. A bank of such filters that spans a range of candidate dispersion parameters or profiles, and furthermore the candidate pulse periods, could constitute a pulsar surveying engine. This platform could continuously monitor a telescope's feed for matching pulsar signals, advancing the search for pulsars and fast-radio bursts while improving observation efficiency, or it could test multiple dispersion profiles against a targeted pulsar to refine the definitive properties. The feasibility of such a complexly parallel and dynamic engine will require a precise design and a rigorous implementation.

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

Section B: Details of Research Project

1. Scientific/Engineering merit:

The detection of pulsars is very computationally expensive. Traditional approaches are focused on detecting them from recorded data. However, advancements in digital processing, especially FPGA and GPU development, have 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.

Real-time pulsar de-dispersion 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.

By applying a general mathematical method for implementing arbitrary dispersion profiles using second-order delay networks, digital filters that coherently de-disperse the pulsar's signals can be designed. Such filters would efficiently de-disperse pulsar signals enabling real-time detection or surveyance. A bank of these filters would enable parallel real-time searches (within reason) for pulsars matching multiple candidate dispersion profiles or dispersion measures (DMs). A bank of dispersion profiles could alternatively refine the defined parameters of a targeted pulsar.

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.

Hessels et al. (2017) demonstrates enabling of pulsar and fast transient searches using coherent dedispersion. Their method is based on a coherent dedispersion algorithm as implemented in coherent dispersion measure trials (CMDT) using a convolving synthetic filterbank that allows for many different DMs.

Finally, a recent mathematical method for implementing arbitrary dispersion profiles using second-order delay networks was demonstrated (Osuch et al, 2016) at our facility. As a general approach to second-order delay networks, the method also applies to de-dispersion 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 emulation of pulsar dispersion and confirmation of an automated de-dispersion filter design system in a high-level language.
Y2: VHDL/FPGA design, implementation, prototyping and testing with integration of the automated de-dispersion filter design system. Experimental measurement and performance characterisation.

Y3: Evaluation of the platform with real-world radio astronomy receivers, leading to a journal article.

3. SARAO research priority areas

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

> *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, potentially even as MeerKAT User Supplied Equipment (USE). 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
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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".
- Deputy function head: Undergraduate teaching (electronic engineering) at the University of Pretoria (UP)
- Xilinx University Program respresentative for UP

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, MDPI Engineering proceedings
- 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

Completed Postgraduate Supervision
- M.Eng (Electronic engineering): 2

Current Student Supervision
Supervisor or co-supervisor to 7 M.Eng and PhD students

Publication Metrics
- Total journal papers: 9
- Total international conference papers: 21
- Total national conference papers: 8
- Total citations: 68
- 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. 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
3. 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.
4. 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
5. 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
6. 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
7. 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
8. 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
9. Hurter L., Laue H.E.A. and Schoeman J., "Addressing Manufacturing and Cost Challenges Toward Solving Low-Cost In Situ Digital Holographic Microscopy Problems", Eng. Proc. 2025, 109(1), 14, https://doi.org/10.3390/engproc2025109014