

Details of Research Project

Section A: Overview of the Research Project

1. *A next generation hybrid RFSoc and GPU digital backend*
2. *Engineering*
3. *Doctoral*

4. *Abstract of research project*

FPGA-based platforms such as ROACH2 and Skarab have served the local radio astronomy community well for numerous years, but these platforms are starting to show their age. The SNAP2 FPGA based digital backend is becoming more popular, but the Xilinx Ultrascale+ RFSoc is showing tremendous potential as the digitisation is close to the feed array, while maintaining the processing capabilities. Similarly, GPU based digital backend processing is also showing great potential. Both RFSoc and GPU technologies are driven by commercial requirements, leading to improved technology and reduced cost. The next cadence of hardware evolution for radio astronomy is very likely the combination of the technologies in a hybrid platform. This project will aim to develop a RFSoc and GPU hybrid architecture for radio astronomy by demonstrating spectrometry and correlation functionality.

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. Dr Stefanus Petrus van den Heever
- b. South African Radio Astronomy Observatory (SARAO)

Section B: Details of Research Project

1. *Scientific/Engineering merit:*

It comes as no surprise that wideband receivers require the capability of recording wideband data. A few examples of these include the DBBC3 that covers several GHz of IF bandwidth, the Mark 6 data recorder operating at 16 Gbps and the new Daejeon hardware correlator operating at up to 8192 Mbps. FPGA based platforms are very capable of handling such bandwidths. The CASPER processing platform matrix shows a steady adoption of the most recent and up to date high performance Xilinx FPGA devices, ranging from the early Virtex family devices to the more recent Ultrascale family devices. While FPGA-based platforms such as ROACH2 and Skarab have served the local radio astronomy community well for numerous years, these platforms are starting to show their age.

The RFSoc technology allows one to digitise close to the feed array, which reduces the complexity and analog components of the front-end while improving the fidelity of the signals. This has been recognised by CASPER and one of the more interesting recent advances by them is the inclusion and early adoption of the Zynq UltraScale+ RFSoc

platform, and the integration into the CASPER workflow being developed currently. This platform has also recently been used to implement a spectrometer (University of Oxford, Dec 2020) and a pulsar digital backend (Xinjiang Astronomical Observatory, Feb 2022), demonstrating not only its capability within the field of radio astronomy, but also the most recent trend for FPGA based hardware.

In addition to this, there has also been growing interest in GPU-based computing platforms. Furthermore, and the likely pinnacle of wideband receivers, is the current development towards hybrid RFSoc and GPU architectures. It is proposed that hybrid RFSoc+GPU architectures are investigated and pursued, and used to implement and demonstrate a spectrometer and correlator system.

2. Feasibility:

In a very recent study (Accepted Manuscript, 18 Feb 2022) by Xinjiang Astronomical Observatory, researchers demonstrated a digital beamforming topology and designed a PAF signal processing experimental system based on RFSoc+GPU hybrid architecture. The system employed a ZCU111 board as a front-end for RF-direct digitization and preprocessing to output streams through four 10 Gb links, feeding a GPU server equipped with Nvidia RTX GPUs with signals for high-throughput real-time beamforming. The beam former demonstrates the feasibility of a RFSoc+GPU hybrid architecture and it is envisioned that a similar approach can be adopted and adapted for spectrometry and correlation.

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. Suitable hardware for the digital backend will be acquired with the support of the Hartebeesthoek Radio Astronomy Observatory (HartRAO).

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

Y1: Complete a literature review, develop a research proposal, identify and acquire the necessary components of the platform, and complete integration and basic testing.

Y2: Develop a broadband spectrometer on the platform and take real data with either existing receivers (eg. at the AVN site in Ghana) or those developed locally.

Y3: Implement a correlator on the platform and conclude his thesis.

3. SARA0 research priority areas

The project directly ties in with the following main SARA0 postgraduate research focus areas in 2022:

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 SRAO 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 and CUDA (Nvidia GPU).

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, Electrical and Electronic Engineering**
University of Pretoria, South Africa, 2011
- **B.Eng (Hons), Electrical and Electronic Engineering**
University of Pretoria, South Africa, 2003
- **B.Eng, Electrical and Electronic Engineering**
University of Pretoria, South Africa, 2002

Awards, Distinctions and Fellowships

- SMEOS Best student paper runner up (2018)

Leadership positions

- Project Leader, NRF Thuthuka Research Project "Compact In-Line Holographic Microscopy for Particulate Matter Measurement".
- Head 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.
- **Lecturer**
Department of Electrical, Electronic and Computer Engineering, University of Pretoria, South Africa, January 2002 – 2003.

Teaching Activities

Postgraduate:

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

Undergraduate:

- Research project EES424, UP, 2016-current.
- Analogue electronics ENE310, 2014-current
- 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, 2016-current
- Undergraduate: Project EPR400/402, UP, 2003-present

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 4 postgraduate students (M.Eng and PhD)

Current Research Grants

- NRF Thuthuka Grant (2021 – 2023)

Publication Metrics

- Total journal papers: 6
- Total international conference papers: 17
- Total national conference papers: 8
- Total citations in Scopus: 53
- h-index: 4

Top Publications

1. 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.
2. 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>
3. 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/>
4. 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/>
5. 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/>
6. 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/>

CURRICULUM VITAE

1. Personal information

Surname: van den Heever
Full names: Stefanus Petrus
Name: Fanie
Gender: Male
Identity number: 8504035013088
Passport number: A01321301
Date of birth: 03 April 1985
E-mail address: fvdheever@sarao.ac.za/
fanie@hartrao.ac.za
Citizenship: S.A. Citizen
Home language: 1. Afrikaans, 2. English
Marital status: Married
Current position: Staff Astronomer, South African Radio
Astronomy Observatory (SARAO) , South
Africa

2. Research interests

Star formation, Stellar evolution, Numerical modeling, Masers.

3. Current status

Staff Astronomer at South African Radio Astronomy Observatory.

4. Tertiary education

Institution: North-West University (Potchefstroom Campus)

Field of study: Physics (Astrophysics)

Degrees obtained:

P.hD. in Astrophysics awarded at October 2017 graduation ceremony (North-West University), Title of dissertation: "Periodic methanol masers and colliding wind binaries". Supervisor: Prof. D.J. van der Walt.

M.Sc. in Physics, awarded in 2011 (North-West University). Title of dissertation: "Numerical modelling of stellar winds for Supernova progenitors". Supervisor: Prof. S.E.S. Ferreira.

B.Sc. Hons. in Physics, obtained in 2008 (North-West University).

B.Sc. degree in Physics, Mathematics and Applied Mathematics, 2004-2007 (North-West University).

5. Teaching experience

Physics I practicals. Forms part of the 1st year B.Sc. physics curriculum. Assisted from 2008 to 2015.

Physics III practicals. Forms part of the 3rd year B.Sc. physics curriculum. Assisted from 2013 to 2015, demonstrating one experiment and evaluating reports.

Give the lectures for Spectroscopy for the DARA/AVN project programme, 2018- present.

6. Postgraduate students supervised

Co-supervised two the Honours projects of two Honours students in 2014 and 2017.

Co-Supervised a masters student from the DARA/AVN project in 2017-2018.

Currently co-supervising a engineering student for the development and commissioning of the new Spectrometer at the Hartebeesthoek site of SARAO.

7. Memberships of professional societies

Member of the South African Institute of Physics (SAIP) (2008 – 2014).

8. Conference and workshop attendance

International

Attended the 20 year symposium of Chandra, that was held in Boston in the USA, December 2019.

Attended a workshop on Water Vapour Radiometry, July 2019.

Attended Green Bank Telescope: Observers training Workshop, January 2019.

Attended a workshop on Water Vapour Radiometry, January 2019.

Attended the International Astronomical Union Symposium 336, “Astrophysical masers: Unlocking the mysteries of the Universe”, being held in Cagliari Sardinia, Italy , 2017.

Attended the conference “Soul of High-Mass Star Formation”, hosted by the Universitat de Chile, held in Puerto Varas, Chile, 2015.

Attended the workshop “Neapolitan of masers”, held in Sydney, Australia, May 2013.

Attended the International Astronomical Union Symposium 287, “Cosmic masers-from OH to Ho.”, held in Stellenbosch, South Africa (2012).

National

Attended the NWU & SARA0 VLBI winter school, June 2019.

Attended the 54th annual conference of the South African Institute of Physics (SAIP) held at the University of Pretoria, July 2009.

Attended the 56th annual conference of the South African Institute of Physics (SAIP) held at the University of Pretoria, July 2011.

9. Papers in international journals

Author:

Van den Heever, S.P., van der Walt, D.J., Hoare, M.G., Pittard, J.M.,
“Periodic methanol masers: from a CWB perspective”, 2019.

*Van den Heever, S.P., van der Walt, D.J., Hoare, M.G., Pittard, J.M.,
International Astronomical Union Symposium 336 proceedings:
“Periodic methanol masers and colliding binaries”, 2018.*

Van den Heever, S.P., van der Walt, D.J., Hoare, M.G., Pittard, J.M.,
International Astronomical Union Symposium 287 proceedings: “*On
the methanol masers in G9.62+0.20E: Preliminary colliding-wind binary
(CWB) calculations*”, 2012.

Co-author:

*Vol’vach, L.N., et al., “Monitoring a methanol maser flare associated
with the massive star-forming region G358.93-0.03”, MNRAS,
submitted 2020.*

*Sitwala, M., et al., “Preliminary design of 20-50 GHz radio astronomy
receiver”, submitted to SPIE, 2020.*

Burns, R., et al., “A heat-wave of accretion energy traced by masers in
the G358-MM1 high-mass protostar.”, Nature Astronomy, accepted
2019.

*Vol’vach, L. N., et al., “A Giant Water Maser Flare in the Galactic
Source IRAS 18316-0602”, A&EP, 63,49, 2019.*

*Goedhard, S., et al., “Periodic variability of the mainline hydroxyl
masers in G9.62+0.20E”, MNRAS, 485, 4676, 2019.*

*MacLeod, G. C., et al., “Detection of new methanol maser transitions
associated with G358.93-0.03”, MNRAS, 489, 3981, 2019.*

Hunter, T., et al., "Exciting phenomena powered by the ongoing accretion outburst in the massive protostar NGC6334I-MM1B", AAS 233, 354.13, 2019.

Vol'vach, L. N. et al., "Powerful bursts of water masers towards G25.65+1.05", MNRAS, 482, 90, 2019.

MacLeod, G.C., et al. "A masing event in NGC 6334I: contemporaneous flaring of hydroxyl, methanol, and water masers", MNRAS, 478, 1077, 2018.

Van der Walt, D.J., Maswanganye, J.P., Etoke, S., Goedhart, S., van den Heever, S.P., "Periodic methanol masers in G9.62 + 0.20E", *Astronomy and Astrophysics*, 588, 47, 2016.

9. International conference and workshop presentations

Posters

Presented during the 20 years of Chandra symposium, "Periodic methanol masers: possible confirmation of the CWB", held in Boston, USA, 2019.

Presented during the International Astronomical Union symposium 336, "Astrophysical masers: Unlocking the mysteries of the Universe", being held in Cagliari Sardinia, Italy , 2017.

Presented during the workshop "Neapolitan of masers" in Sydney Australia (2013): *Periodic methanol masers and the possible connection with colliding wind binaries.*

Presented during the International Astronomical Union Symposium 287, held in Stellenbosch, South Africa (2012): *On the methanol masers in G9.62+0.20E: Preliminary colliding-wind binary (CWB) calculations.*

Presented during the "Soul of High-Mass Star Formation" conference, held in Puerto Varas, Chile (2015): *Periodic methanol masers and colliding wind binaries.*

12. Research visits

As part of a new collaboration between the North-West University and University of Leeds for my doctoral project, I went to visit Julian Pittard and Melvin Hoare on a few occasions.

1. The first time with my supervisor Prof. D.J. Van der Walt, in September 2011.
2. Again on my own for 2 weeks in march 2013.
3. Then again in September 2014.
4. As part of the development and commissioning of the new Spectrometer at the Hartebeesthoek telescope, my student and I visited the Berkeley group that works on the CASPER tools in February 2019.

13. Research network

International:

Prof. Melvin. Hoare, Department of Physics and Astronomy, University of Leeds, Leeds, England.

Dr. Julian Pittard, Department of Physics and Astronomy, University of Leeds, Leeds, England.

From discoveries presented at the IAU 336 Maser conference, a group of people formed the Maser Monitoring Organization (M2O), a group of observatories who monitors maser sources for interesting phenomenon. Alerts are sent out for interesting events to be confirmed and Target of Opportunity (ToO) observations can be set up on Interferometers or VLBI as a result. This collaboration stretches across the globe.

Dr. Gordon MacLeod, Department of Physics at the University of Western Ontario, Canada.

Dr Stan Kurtz, UNAM Mexico.

National:

Prof. Johan van der Walt, North-West University

Dr. Jabulani Maswanganye, North-West University

Dr. James Chibueze, Department of Natural Sciences, North West University.

Dr. Sharmila Goedhart, SARAO.

14. Experience and Skills

Development of data reduction packages with various programming languages, including C++, C, Matlab/Octave, IDL, Fortran, Python.

Visual representation of data: Sigmaplot, Gnuplot, Excel, Matlab/Octave, IDL, Python.

Documentation: MS Word and Latex.

Presentations: MS Powerpoint and Latex Beamer.

Linux, Shell scripting.

Use of several Astrophysics packages for research.

Spectroscopy.

Developing and Commissioning of the new Spectrometer at the Hartebeesthoek Radio telescope.

15. References

Prof. D.J. Van der Walt.

North-West University (Potchefstroom campus),

tel: (018) 299 2408, email: Johan.vanderwalt@nwu.ac.za

Prof. S. E.S. Ferreira, Director of the Centre for Space Research,

North-West University (Potchefstroom campus),

tel: (018) 299 2412, email: stefan.ferreira@nwu.ac.za

Prof. P.J. Meintjies

University of Free State, Bloemfontein,

tel: (051) 401 2191, email: MeintjPJ@ufs.ac.za

Dr. G. MacLeod.

University of Western Ontario, Canada.

tel: (012) 301 3202, email: gord@hartrao.ac.za.

Dr A. de Witt,

South African Radio Astronomy Observatory.

Tel: (012) 301 , email: alet@hartrao.ac.za