UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Engineering, Built Environment and Information Technology

Fakulteit Ingenieurswese, Bou-omgewing en Inligtingtegnologie / Lefapha la Boetšenere, Tikologo ya Kago le Theknolotši ya Tshedimošo

Low-cost water vapour radiometry

Prospects and progress

Tinus Stander, Pr.Eng, PhD, SMIEEE

Hilo, 13 June 2017

Agenda

- Introduction to CEFIM mm-wave group
- Project Context
    - An engineer’s view of WVR
    - Current systems
    - Development Opportunities
- Project Details
    - Funding
    - Participants
    - Goals
    - Progress
- Conclusion

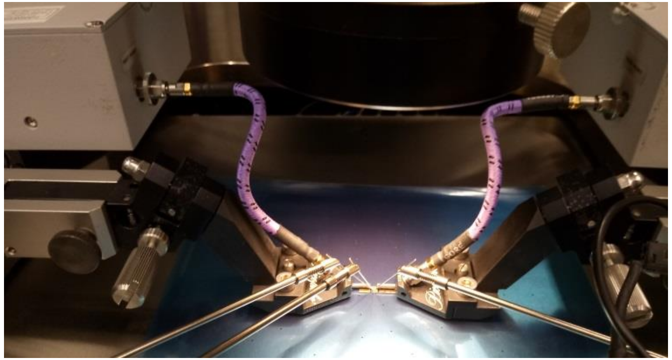
Introduction to CEFIM

The Carl and Emily Fuchs Institute for Microelectronics

- Founded 1981
- 4 academic staff
- Focus Areas
  - Si / CMOS devices & detectors
  - MEMS devices
  - *Microwave and mm-Wave devices*

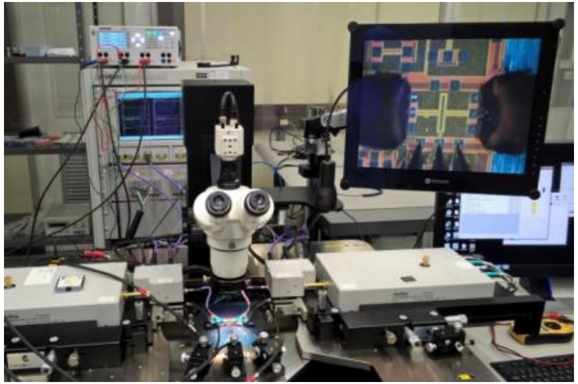
Microwave and mm-wave microelectronics

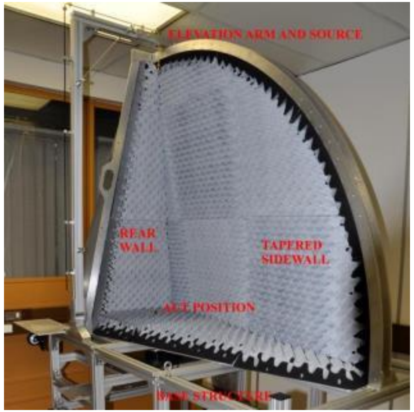
- Principal Investigator: T. Stander
- Students (full-time):
  - 3 PhD, 6 M.Eng, 2 B.Eng IV
- Research Interests
  - mm-Wave communications front-ends
    - System-on-chip front-end components (filters, oscillators, LNAs, PAs)
    - Low-cost hybrid integration
    - On-chip electromagnetic modelling
  - mm-Waves for CubeSat
    - Wideband receivers for solar radiation monitoring
    - Radiation degradation modelling and monitoring
  - Radio Astronomy
    - Fast Digitizers in hybrid GaAs / CMOS
    - Analogue signal pre-processing
    - *Water vapour radiometry*



Facilities

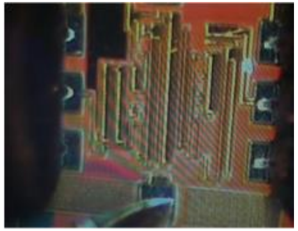
- VNA (110 GHz)
- 300mm probe station
- mm-Wave anechoic chamber
  - 50 GHz +
  - Designed in-house
- 50 GHz signal analyzer
  - Extensions 50 – 110 GHz
  - Spectrum analysis, phase noise, NF, comms analysis



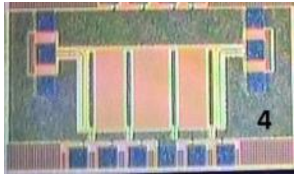


Recent Work

- On-chip antenna,
  85 – 89 GHz

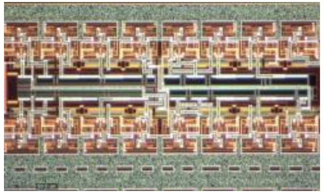


- SiGe LNA,
  65 - 100 GHz

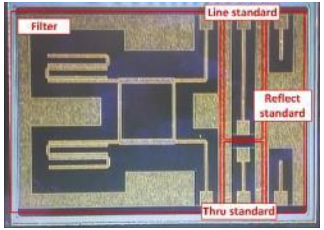


- SiGe active enhanced filter,
  83 – 83.5 GHz

- CMOS DC radiation reference circuit



- CMOS Current Conveyor, L-band



- Dual notch filter,
  W-band

Project Context

One engineer’s perspective of WVR

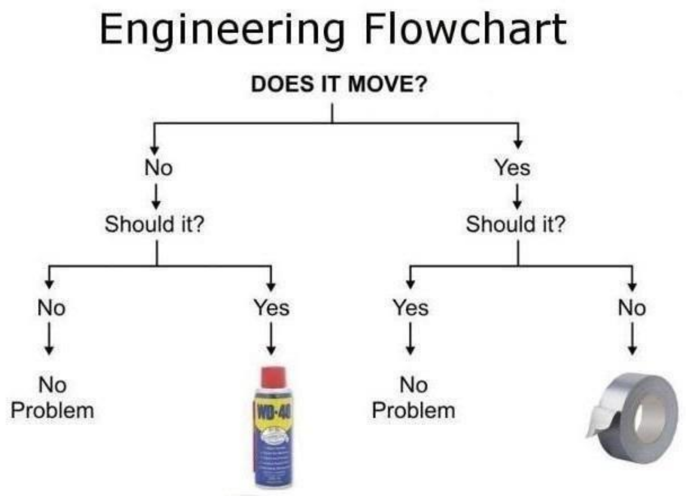
- Point a mm-wave antenna at the sky, measure noise power, give data to clever people.
  - Some bands give info on water vapour, some on liquid water.
  - Concentration vs. height extraction possible
    - Not the client need
  - Used for data correction in VLBI
    - More important > 10 GHz.
  - Used for site surveys in mm-wave radio astronomy

Astronomers Me

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

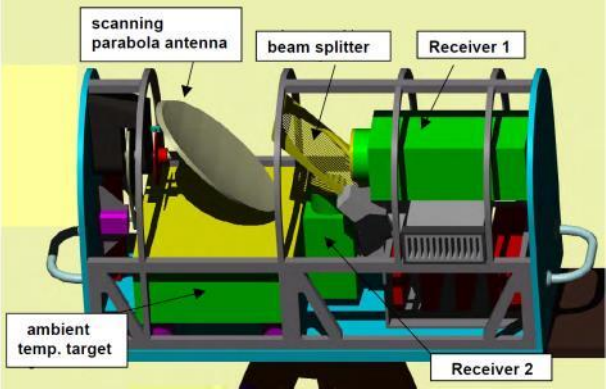
How an RF engineer sees the problem

- Low noise receiver (Tsys < 300 K)
- High resolution (< 0.1K)
- Stable gain
- Excellent calibration
  - Thermal stabilization
- Multiple channels (noise spectrum)
  - 22 GHz for WV, 31 GHz for LW
    - 183 GHz for WV in dry environments
    - Perhaps consider later
- Scanning antenna
  - Elevation, azimuth
  - Low dwell time (< 1s)
- Narrow beamwidth antenna (< 5°)
  - <u>Very</u> low sidelobes



Commercial Systems (1)

- Radiometer Physics
  - LWP basic
- Liquid water path + Integrated water vapour
  - Total, not vertical profile
- Scanning parabola
- Coax, waveguide integration
- Discrete filters for each channel
  - No variable downconversion



Source: Radiometer Physics (www.radiometer-physics.de)

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Commercial Systems (2)

- Radiometrics
  - PR-Series Radiometers
  - MP-Series Profilers
  - Anticipated similar internals

Source: Radiometrics Corporation (www.radiometrics.com)

Research Systems (1)

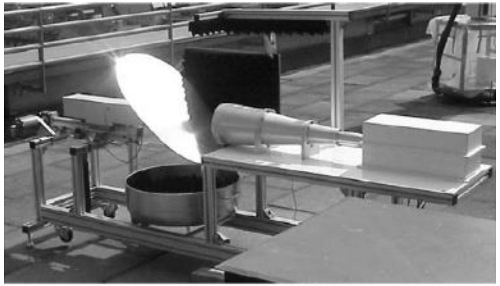
- Effelsberg
  (Max Planck Institute for Radio Astronomy)
- Modular / waveguide integration
- Thermal stabilization
- Scanning dish
  - Sky dip

Frequency	18.3 GHz to 26.0 GHz
Channels	25
Bandwidth	900 MHz
$T_{receiver}$	200 K
Physical temperature	25 °C
Temperature stabilization	Peltier cooler
Thermal noise	61 mK in 0.025 s per spectrum (= 0.27 mm path length noise, assuming 4.5 mm K^{-1})
Absolute accuracy	~ 1 % of T_{sys} (= 9 mm path length systematic offset assuming 4.5 mm K^{-1})
Gain stability	2.7×10^{-4} over 400 s
Sweep Time	5 s
Beamwidth	1.3° for best main-beam overlap
Gain calibration	noise injection or measured $T_{internal}$

Source: Roy et al, "The Water Vapour Radiometer at Effelsberg", Proc. 7th European VLBI Network Symposium, 2004

Research Systems (2)

- MIAWARA
  - University of Bern
  - WV extraction 20 – 80km
  - Horn feed
  - Waveguide components
  - Uncooled
  - Single channel



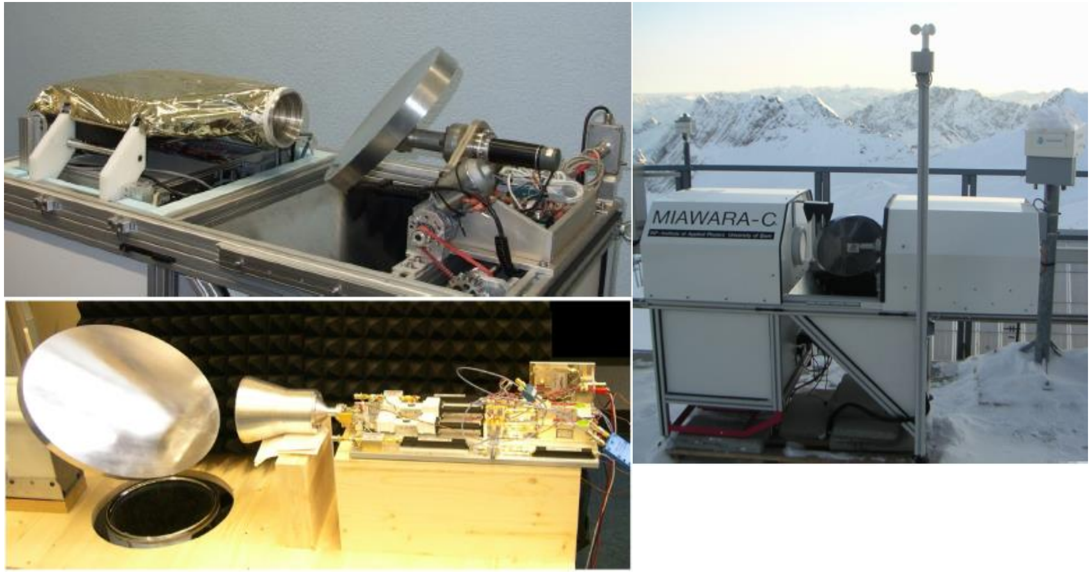
Calibration technique	Balanced calibration
Operational mode	Single sideband (SSB) mode
Sideband filter	Waveguide bandpass filter (22.235 ± 0.75 GHz, 50 dB sideband suppression, insertion loss: 0.35 dB)
RF Amplification	2 uncooled HEMT amplifiers (Gain: 35 dB each, Noise Figure: 1.49 / 1.85 dB, manufacturer: Miteq Inc AMFWW series)
Mirror	Plane mirror (gaussbeam optimised shape), edge taper = 45.9 dB
Antenna	Corrugated horn (θ_{HPBM} 6 deg)
Receiver noise-temperature	135 K single side band
Radio-frequency range	21.735 – 22.735 GHz
Broadband spectral analysis	Acousto-optical spectrometer (channels: 1725, f: 1.6–2.6 GHz, Δf_{FWHM}: 1.2 MHz)
Narrowband spectral analysis	Chirp transform spectrometer (channels: 4200, f: 390–430 MHz, Δf_{FWHM}: 14.07 kHz)

Source: Deuber et al, "A new A New 22-GHz Radiometer for Middle Atmospheric Water Vapor Profile Measurements", IEEE Trans. GeoScience Remote Sensing, 42(5), 2004.

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Research Systems (3)

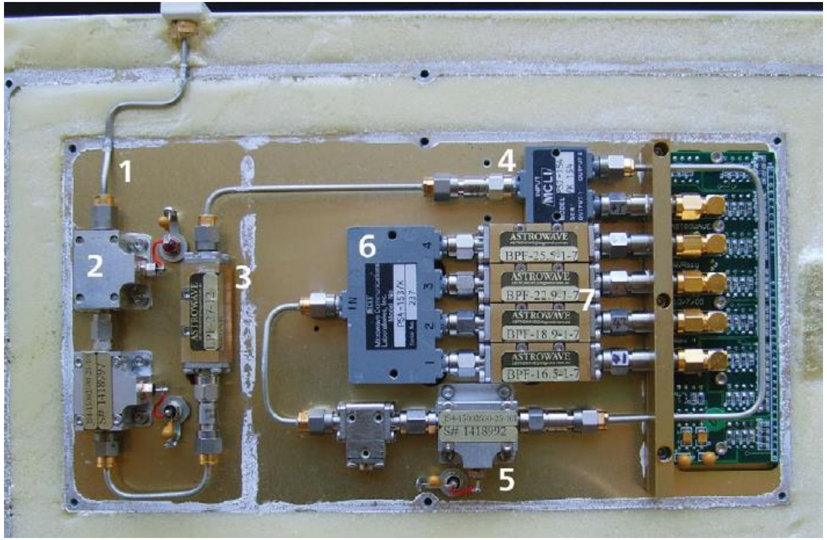
- MIAWARA-C (Compact)
    - University of Bern
    - Horn feed
    - Rotating mirror
    - Waveguide, cables
    - Pattern emerging…



Source: Straub et al, "MIAWARA-C, a new ground based water vapor radiometer for measurement campaigns", Atmos. Meas. Tech., 3, 1–15, 2010

Research Systems (4)

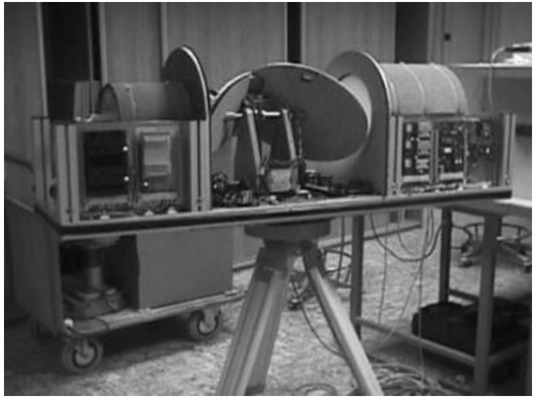
- ATCA
  - Cable and module integration
  - Uncooled
  - 16 – 26 GHz
  - Horn feed + reflector



Source: Indermuehle et al, "Water Vapour Radiometers for the Australia Telescope Compact Array", PASA, v. 30, e035, 2013

Trends in current systems

- Modular WG/cable integration
- Mechanical motor steering
- Reflector + horn antennas
- Not cooled
  - Sometimes temp stabilized
- Typ. two channels



Source: Pottiaux et al, “First Experiences with a Water Vapor Radiometer at the Royal Observatory of Belgium”, Symp. EUREF, 2002

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Development opportunities (1)

- RF PCB integration?
  - Ku / Ka band SatCom receivers!
  - Cost! But sensitivity?
  - Custom components?
  - Cooling? Temp. stabilization?
  - How many corners can we cut??

Source: Leica Geosystems (http://metrology.leica-geosystems.com/)

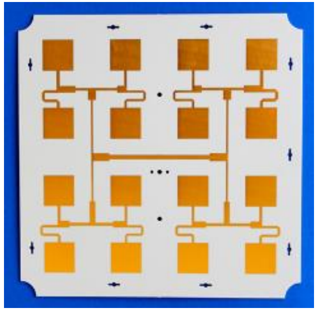
Source: Teledyne Microwave Solutions (www.teledynemicrowave.com)

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Development opportunities (2)

- Phased array antenna?
  - No more mechanical maintenance
  - Beam shape? Steering? Noise?
  - Conformal array?
    - Electronic azimuth & elevation
- Retrieval Methods
  - Reasonable data from low-cost receiver?
  - Is it worthwhile?

Source: ESA (www.esa.int)



Source: CST (www.cst.com)

Project Details

Project Funding

- National Research Foundation of South Africa (NRF)
- Collaborative Postgraduate Training programme
  - Emphasis on postgraduate student development
- 2017 – 2020
- ±8 students p.a.
- 60% bursaries, 40% consumables & small equipment budget

Project Participants

- University of Pretoria
  - mm-Wave components
  - Testing
- Tshwane University of Technology
  - System design
  - Digital & Microwave Engineering
- North-West University
  - Retrieval Algorithms
  - Site surveys
- Stellenbosch University
  - Antennas
- Hartbeeshoek Radio Astronomy Observatory
  - The end user!

UNIVERSITEIT STELLENBOSCH UNIVERSITY

Tshwane University of Technology

NORTH-WEST UNIVERSITY YUNIBESITI YA BOKONE-BOPHIRIMA NOORDWES-UNIVERSITEIT

NRF National Research Foundation

HartRAO Hartebeesthoek Radio Astronomy Observatory

Project Goals (1)

- Low-cost planar integrated WVR channel card
  - Possible? Feasible?
  - SIW?
  - (Some) commonality across bands?
- Solid-state phased array antennas for WVR
  - Conformal array?
  - Synthesis method?
  - Hardware?

Project Goals (2)

- Radiometric site surveying
  - Off-the-shelf downconverters
    - Lab blocks / equipment
    - Until system available
  - Total power radiometer
  - Comparison to other survey methods
- New retrieval algorithm development
  - Suited to low-cost equipment

Project Progress

- Preliminary system specs defined (SM Walker, TUT)
- System simulation environment established (SM Walker, TUT)
  - System trade-off study ongoing
- Student Recruitment
  - 3 B.Sc.Hons (Astronomy), NWU
  - 1 M.Sc (Astronomy), NWU
    - Topic: Retrieval methods
  - 1 M.Sc.Eng (Electronic Engineering), SU
    - Antenna array
  - 1 M.Eng (Electronic Engineering), TUT
    - Digital control, data capture, DSP

Conclusion

Conclusion

- We need WVRs for long-term site surveys
    - Maybe for mm-wave VLBI
- Cheap, minimal maintenance
- RF PCB + phased array integration ideal
- Electronic steering ideal
- Full system in 3 years unlikely
    - Train students for future development
- Indication of whether concept is feasible
- Pathfinder components

Tinus Stander

Senior Lecturer
Carl and Emily Fuchs Institute for Microelectronics
Dept. EEC Engineering
University of Pretoria
Pretoria, 0002
South Africa

+27 12 420 6704
tinus.stander@ieee.org

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

http://www.up.ac.za/en/electronics-and-microelectronics-/article/2147601/microwave-and-mm-wave-