Low-cost water vapour radiometry

Prospects and progress

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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
How an RF engineer sees the problem

- Low noise receiver (Ts < 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°)
  - Very 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)
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

MIAWARA

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

Research Systems (3)

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

Research Systems (4)

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

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
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: Teledyne Microwave Solutions (www.teledynemicrowave.com)

Source: Leica Geosystems (http://metrology.leica-geosystems.com/)
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: CST (www.cst.com)
Source: ESA (www.esa.int)
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!
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
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http://www.up.ac.za/en/electronics-and-microelectronics-/article/2147601/microwave-and-mm-wave-