Irregular wideband array: time-domain microwave imager for radio astronomy and biomedicine

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Crazy idea

- Biomedical and Radio astronomical imaging could benefit from each other
  - Both in
    - Algorithms
    - Technology
- Create an instrument technology and algorithms that could be used for both
  - Dubbed IWA (irregular wideband array)
- Submit proposal to FET-Open (Future & Emerging Technologies)

Prosposal response and evaluation (so far)

- Has been very good
  - Evaluation score in 1st phase for scientific novelty/quality was 4,5 (where 4 is very good and 5 is excellent)
  - Evaluation of final proposal has also been very good
    - Stand a good chance of funding
- This BASP conference is further evidence that there is an interest in this cross-discipline

IWA proposal background

- FET OPEN call is for highly innovative high-risk projects
  - funded by EU FP7
- Budget: 2.2M Eu over 3 years
- usually only 2-3% of the applications funded
  - After phase 1, 10% best proposals

Proposal Team

- Put together by
- Chalmers University of Technology (CHALMERS) SE (Biomedical & Radio astronomy groups)
- Curtin University (CURTIN) AUS
- The Netherlands Institute for Radio Astronomy (ASTRON) NL
- University Carlos III De Madrid (UC3M) ES
- University of Manchester (UNIMAN) UK
- Université catholique de Louvain (LOUVAIN) BE

IWA proposal abstract

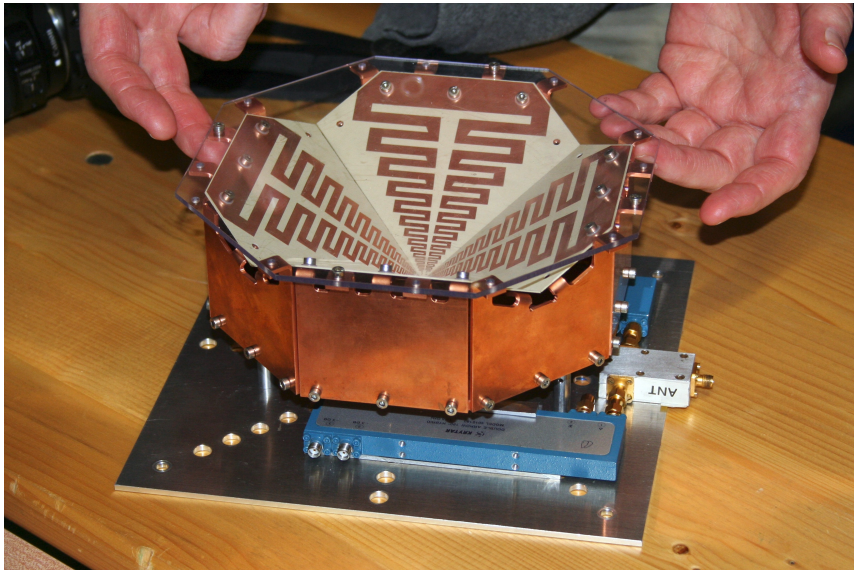
- Basic idea
  - Create synergy in imaging technology between biomedicine and radio astronomy
- Use
  - Microwave arrays
  - Novel Ultra wideband technology
  - New interferomeric imaging algorithms

IWA technology overview

- Two prototypes:
  - 32 element array at 70-800 MHz for radio astronomy
  - 5 element array, mechanically scanned, at 500-4000 MHz Rx plus transmitter for biomedicine
- But similar technologies:
  - Ultrawide band (UWB) system
  - Time-domain based
  - Irregular array configuration

IWA antennas

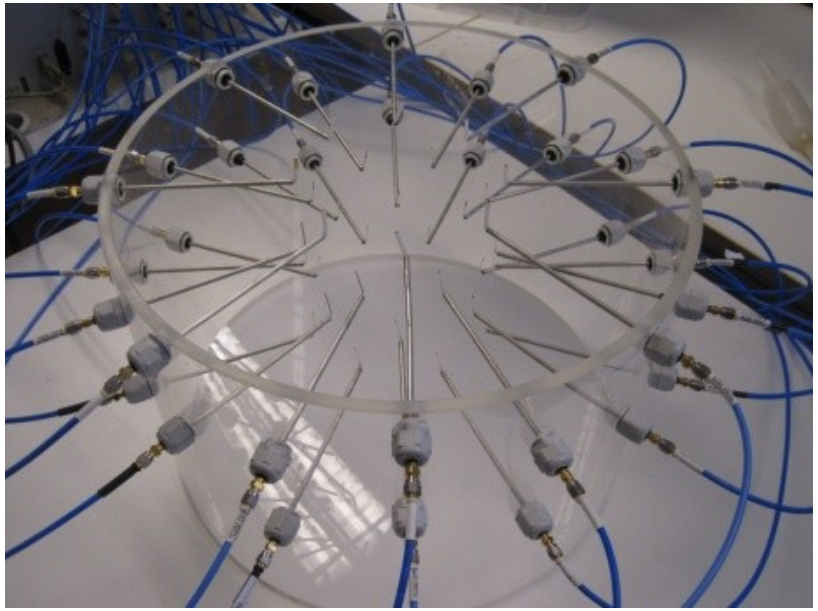
- Will use ”Eleven feed”-like antennas
  - (10:1) relative bandwidth
  - 11 dBi directivity
  - Dual-polarized
  - Developed at Chalmers
  - Phase reference center does not vary with frequency



IWA novelity: temporal domain processing

- Main focus will be to explore time-domain based processing for
  - Interferometry
    - Contrast to traditional frequency-domain which assumes
      - stationary sources
      - stable observations
      - Far-fields
    - Will better handle
      - Transient sources
      - Time-frequency smearing
      - Near-fields
  - Channel sounding
    - Contrast to frequency scanning

IWA science: Biomedicine



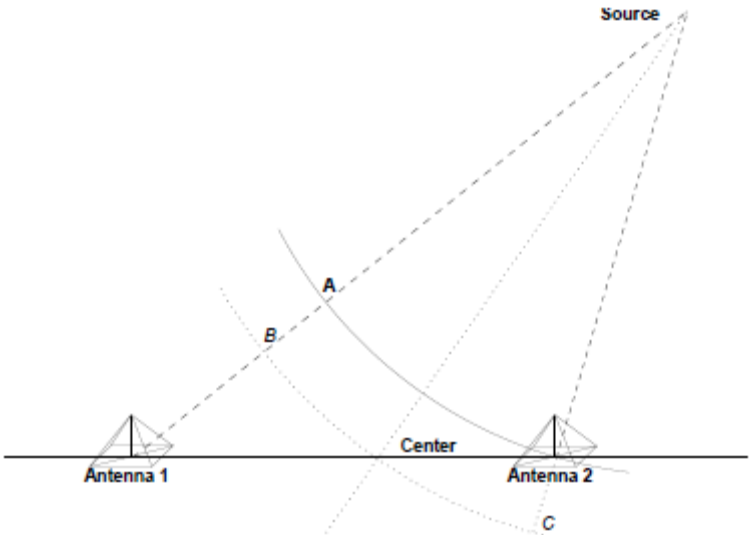
- UWB Microwave imaging
  - advantages:
    - Nonionizing radiation
    - Cheap
    - Compact
  - Disadvantages:
    - Resolution is low (~cm)
- Scenarios:
  - Quick diagnostics in ambulance or at accident sites
  - Alternative in mammography to minimize false detections (traditional X-ray has low contrast, microwave hi contrast)

IWA science: Radio astronomy

- Microwave domain is very important in radio astronomy
  - Stationary sources are assumed, leading to
    - Frequency-domain based technology (banded) and imaging
- UWB system could either
  - Be a cheaper solution (only one band rather than several)
  - Open door for new time-domain based imaging
- Scenarios
  - Fast transient sources: pulsars, air showers, solar radio bursts etc.

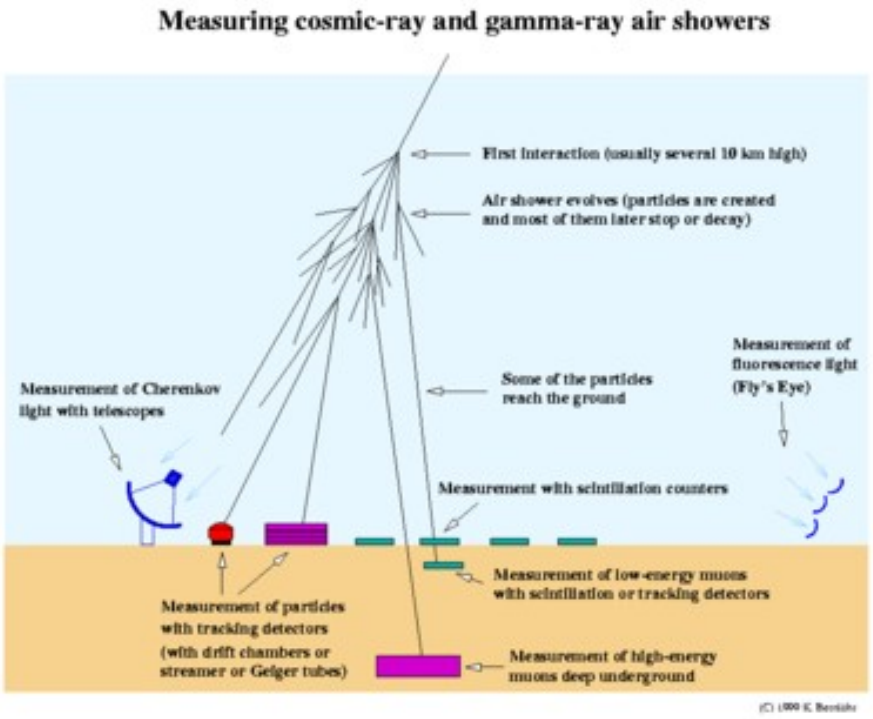
Time domain imaging astronomy

- Basic time domain interferometry uses time delays on baselines rather than phase delays
- "Closure-errors" between three elements are expected for Near-fields
  - Triangulation gives minimal unique source localization
    - Four delays needed for closure-errors



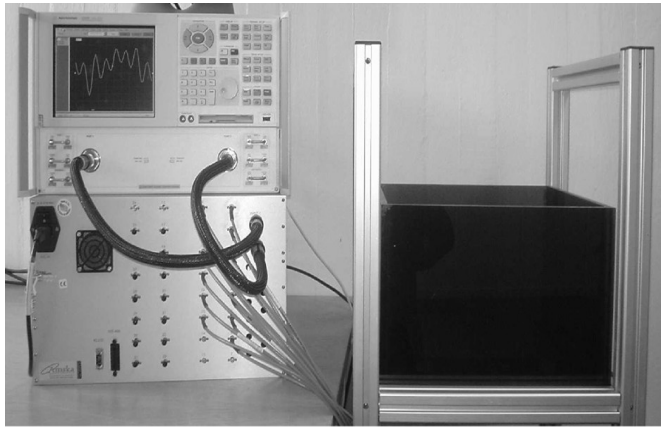
Ref: *Horneffer* Ph.D. 2006

Example: Air showers



Time domain radio scan in biomedicine

- Frequency domain imaging in biomedical applications
  - Network analyser sweeps through band frequency by frequency
  - Slow, bulky
- Time domain (non-impulsive)
  - Pulsed system
  - Fast, compact



Example: biomedical radio scans

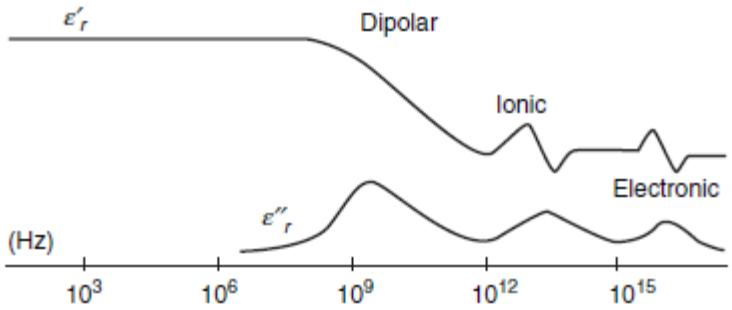
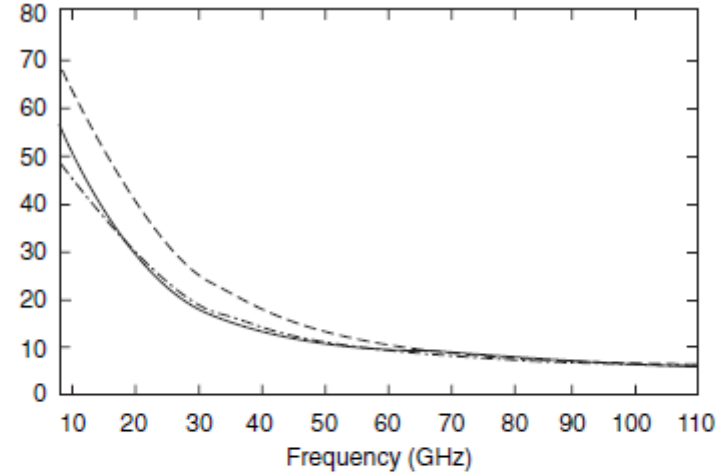


FIGURE 1.3 Permittivity as a function of frequency (from [3], courtesy of De Boeck, Brussels).



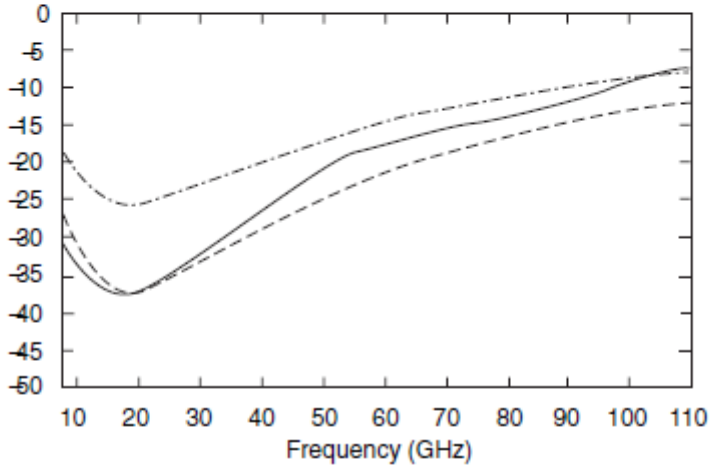


FIGURE 2.6 Real and imaginary parts of permittivity of beef blood.

Similarities with Faraday Rotation Measures in astronomy

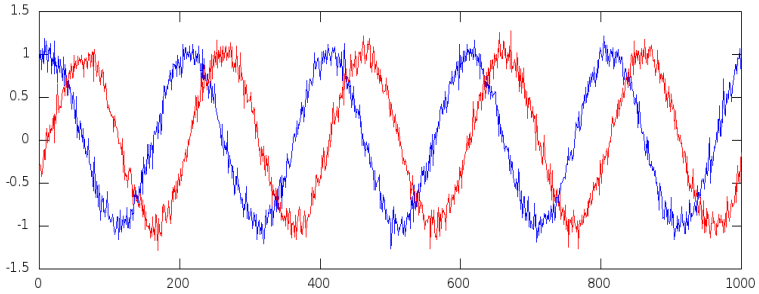
Figures taken from *A. Vander Vorst* "RF/Microwave Interaction with Biological Tissues" 2006

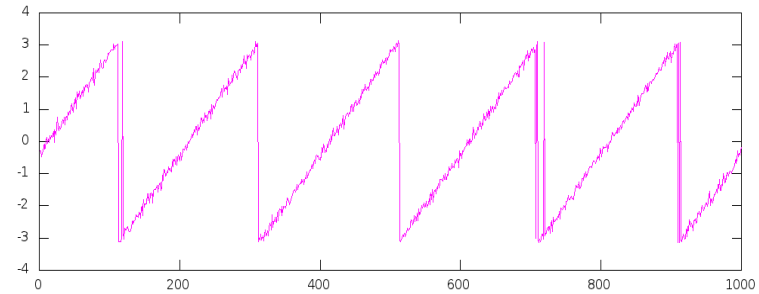
Algorithm development

- Radio astronomy
  - Explore time-domain interferometry
    - Free to use wavelets to channelize voltage streams instead of Fourier transform (improve time-frequency smearing)
    - Free to use Wigner-Ville transform instead of power spectral channels (discover coherent sources)
- Biomedicine
  - Explore time-domain sounding
  - and polarimetric sounding
    - Faraday rotation effects?

Extreme Fourier sampling: instantaneous frequency estimation

- For certain signals, frequency can be determined from just 2 time samples!
  - “Beats” Heisenberg uncertainty
- How?
  - Many radio receivers use inphase-quadrature (IQ) sampling
  - If Q channel not available, use Hilbert transform of I channel
  - Compute phase of this complex signal as function of time
  - Derivative wrt time is instantaneous estimate of frequency of single component source

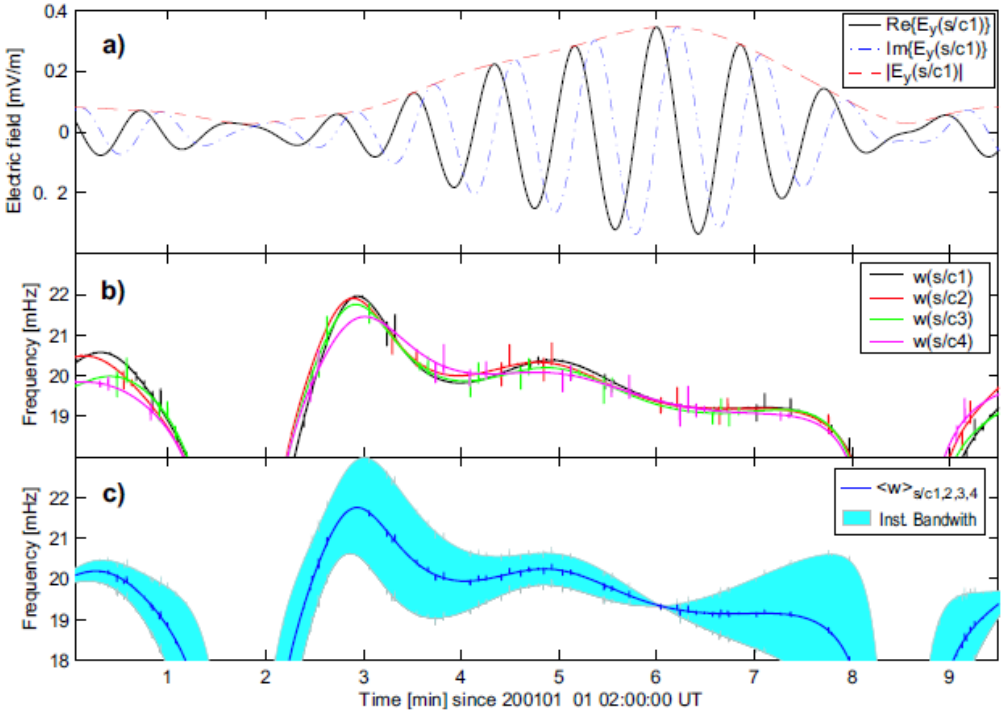




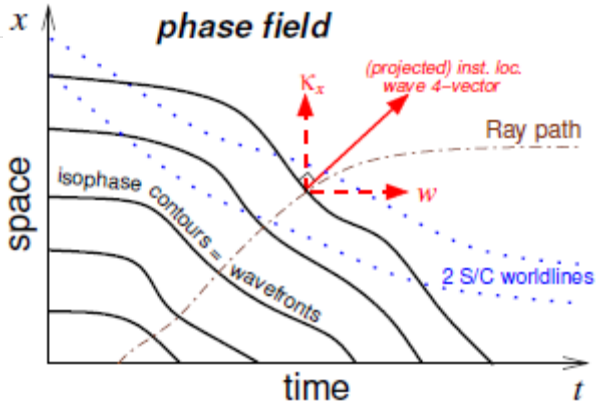
$$\omega_{\mathrm{inst}} = \frac{d}{dt} \arg(s_{\mathrm{I}} + \mathrm{i}s_{\mathrm{Q}})$$

Instantaneous frequency example

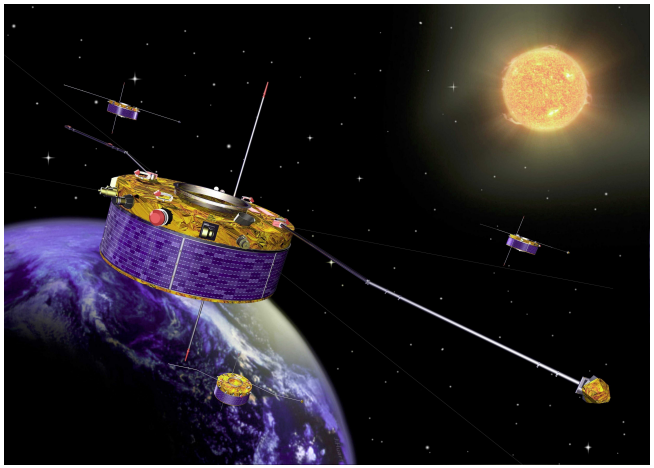
- real-valued electric field measurements from Cluster spacecraft in Solar wind
- were complexified using Hilbert transform
- Inst. freq. was found to wobble
- But we also had multiple spatial samples...

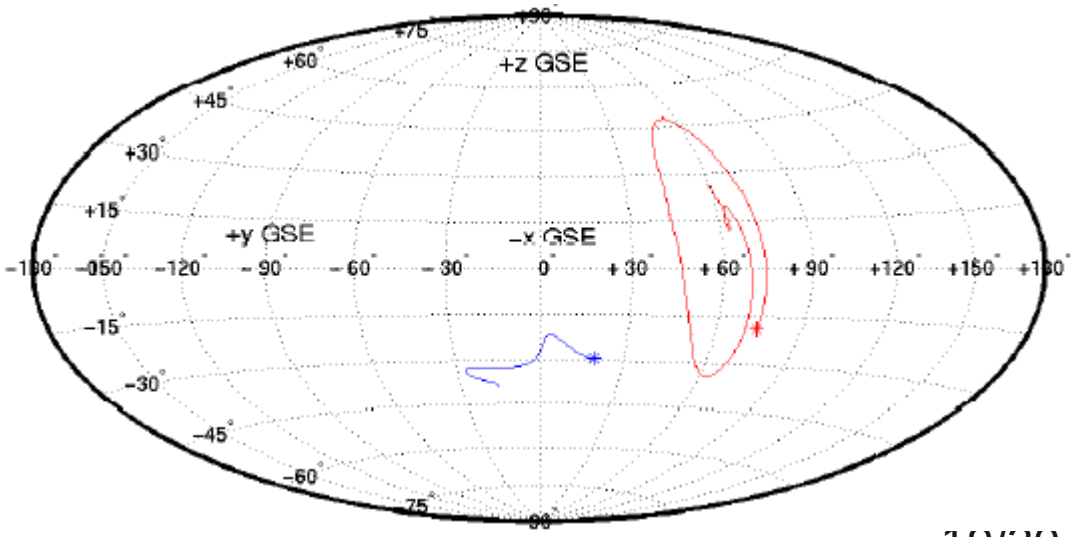


Local wavenumber vector estimation



- Local wavenumber vector can be estimated analogously to instantaneous frequency (replace time with space)
- 3D sampling of wave field allows discrete estimation of spatial gradient of phase
- Local-instantaneous estimate of wave vector gives position or “image” of transient/moving source
- e.g.: Carozzi et al (2004) used this technique with 4 Cluster spacecraft





Conclusion & Future

- Crazy idea – combine astronomy and biomedicine imaging within one instrument technology – seems to have some traction
- Hopefully I will be able to come back year with the first result from this cross-disciplinary project