Multi-octave radio frequency systems: Developments of antenna technology in radio astronomy and imaging systems

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“Wideband” Systems

- A “wideband” signal in communications is stated to be when the signal bandwidth exceeds the coherence bandwidth of the channel.
- Ultra-wide band communications is the lesser of 20% bandwidth or 500MHz.
- Wideband radars are quoted with signal bandwidths in the region of 500 MHz to 1GHz.
- In this talk we will consider wideband antennas as more than one octave of RF frequency bandwidth.
What is “wide band” performance?

- **VSWR**
  - Relates to how well the antenna is matched to a given impedance - that is it is related the proportion of power applied to the antenna which is reflected back to the source

- **Efficiency**
  - Relates the power actually radiated to the applied input power

- **Gain**
  - Relates to the power radiated but also concentration of power in the radiation pattern

- **Radiation Pattern Effects**
  - Beamwidth changes with frequency
  - Sidelobes and Grating lobes
  - Cross polarisation
  - Phase Centre Stability
  - Etc

- The interpretation of “wide band” is system dependant

- Here all the above have to be controlled over the given bandwidth, though not necessarily a constant
The Square Kilometre Array (SKA) project is an international effort to build the world’s largest radio telescope, with eventually over a square kilometre (one million square metres) of collecting area.

- It is proposed to use two different types of arrays covering 70MHz to 400MHz and 400MHz to 1.4GHZ.
- Dish antennas will extend the frequency range to ~ 20GHz using multiple feeds.
The Quietest Locations in the World
Radio Noise Levels

Forte satellite: 131MHz
Dense Aperture Arrays 400-1400MHz

Dishes up to 20GHz?

3-Core Central Region

Sparse Aperture Arrays 70-400MHz

Artist renditions from Swinburne Astronomy Productions
- When completed the capacity of the digital network will be about 100 times that of the current total internet traffic worldwide.
- The sensitivity of the system would allow the detection of an airport radar 50 light years away.....
Questions that drive the specification

PROBING THE DARK AGES OF THE UNIVERSE

- What is the nature of dark energy?
- Is vacuum energy necessary for the expansion of the Universe?
- How do we develop a complete understanding of the early Universe?
- How far are planetary systems from the Sun?
- How do we understand the history of the Universe?
- What are the ages of the oldest stars and galaxies?
- What is the role of the cosmic microwave background?
- What is the future of the Universe?
Billion Galaxy Survey for cosmology, dark energy and neutrino masses
In this talk we will limit the broad topic of “All-sky” Survey imaging

- HI survey
- Based on SKA, but the principles can be (are being) widely applied
Sensitivity $\propto$ Effective Area

Field of View – driven by station performance

Correlator

$I(\theta)$

$\Delta \Theta = \frac{\lambda}{D}$
Survey Instrument drivers

- High sensitivity → Large effective area, low noise
- High resolution → Long Baselines
- Wide Bandwidth → Complex electromagnetics
- Polarimetry → Orthogonal Polarisations, Calibration
- High survey speed → Wide field of view, multiple beam forming
- High Dynamic Range → Well defined radiation pattern, Calibration, Low sidelobes
Survey Instrument drivers

- `Mapping speed’ $\propto$
  $\text{FoV} \times (A / T_{\text{sys}})^2$
  improved by $\sim 10^6$ !

At 1 GHz $\sim 10^8$ element
- each station will employ $\sim 10^6$ elements
- Cost per element crucial

“Radio Camera”
Broadband electromagnetics

- Fully sampled arrays
- Sparse sampled arrays
- Sidelobe and Pattern Control
  Uses large number of Elements
- Trade Sidelobe and Pattern control for numbers of elements
- Interference Suppression
  - Point sources
  - EMC
Revision!
o Depends on spacing
  o Power received depends on effective area
    o Effective area = $\lambda^2 \cdot (\text{Gain}) \cdot (4\pi)^{-1}$
Wideband Effective Area of a Linear Isotropic Array Antenna

Effective Area of Array
(Effective area of one element \( x \text{N} \))

\[ u = \frac{d (\sin(\theta) - \sin(\theta_0))}{\lambda} \]

\[ \text{normalised } |E| \]

-3 -2 -1 0 1 2 3

0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1
Mutual Coupling

\[ V_e \quad S_{11} V_e \quad S_{m1} V_e \]
\[ \mathbf{V} = \mathbf{Z} \cdot \mathbf{I} \]

Where \[ \mathbf{Z} = \begin{bmatrix} z_{11} & \cdots & z_{1N} \\ \vdots & \ddots & \vdots \\ z_{N1} & \cdots & z_{NN} \end{bmatrix} \]
Aperture Array Antennas

FLOTT: (a)(d)
BECA: (b)(e)
ORA: (c)(f)
Normal radiation

Anomaly
The dipole array
The mutual coupled dipole array with dielectric layers

The tip capacitance together with additional dielectric layers yield a broader impedance matching over a wide scan angle.

Planar structure – printed or etched on polyester
700MHz
Surface current on the conducting sheets for a single element excitation

400MHz

900MHz

1400MHz
ORA typical VSWR performance

![Graph showing VSWR performance](image-url)
8-18GHz
25×25 dual polarised arrays
Spin off technology: ORA Basestation Antenna for LTE
Scanned arrays

- In tightly coupled arrays the array mutual coupling changes with frequency.
- Array weights need to form a high accuracy beam are very different to a simply array situation.
- Digital Beamforming allows:
  - Multiple narrow band channels (typically a few MHz wide) - weight stability
  - Accurate Calibration
  - Flexibility
Array Geometry
Summary

- Wideband antennas are critical to many applications – here we have looked at Radio Astronomy and the SKA in particular.
- These projects are vast, but when analysed down to element level the cost per element is extremely small.
- Close coupled arrays allow good pattern control but require many elements.
- Sparse arrays have much less pattern control but number of elements for a given sensitivity are reduced.
- Dual linear polarisation is important.
- Digital beamforming adopted technique wherever possible.
Blue Skies

Explaining electromagnetism to then Chancellor of the Exchequer William Gladstone, Michael Faraday was asked, ’But after all, what use is it?’ He famously, but perhaps apocryphally, replied, ’Why sir, there is every probability you will be able to tax it’.