The Lüneburg Lens as a SKA Element

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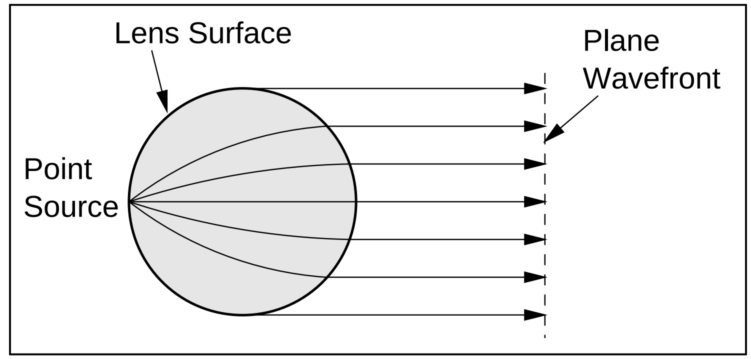
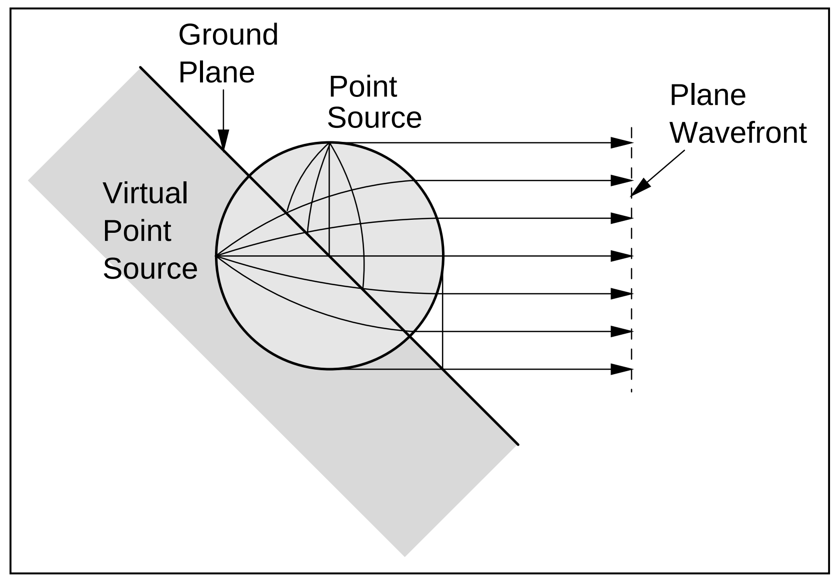
The Lüneburg Lens

- Full Lüneburg Lens



- Virtual Source Lüneburg Lens



Features of the SKA

- Large collecting area
- Hierarchical configuration
- Wide bandwidth (0.2 to 2 GHz primary)
- Full sky coverage
- Large clean beam dynamic range
- Multiple independent beams
- Dual polarisation
- Interference mitigation requirements
- Low cost, low maintenance

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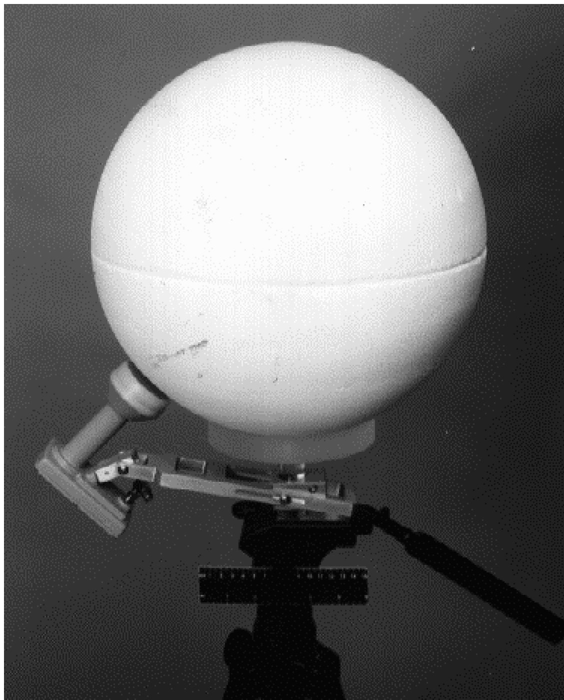
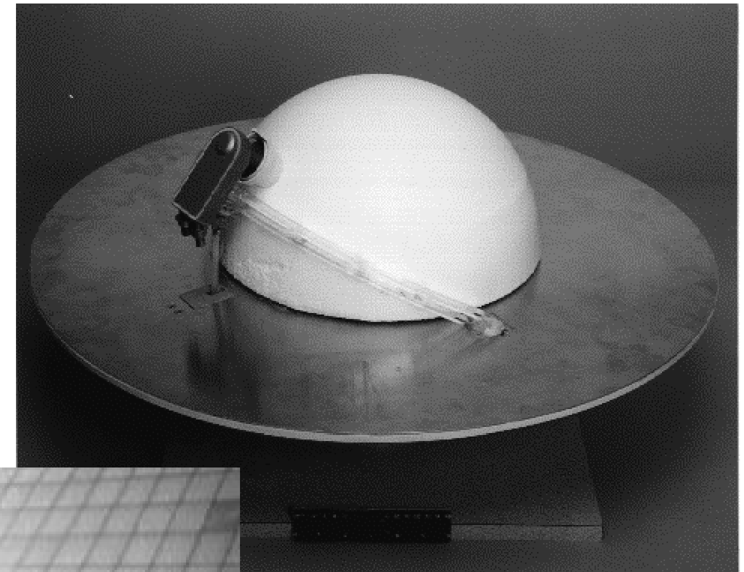
Issues for the Lüneburg Lens

- Materials
  - Loss, homogeneity, isotropy
  - Frequency limitations
  - Manufacturing (cost)
- Feed systems
  - Flexible upgrade paths (technology, cost)
  - Single moving feeds or line feeds
  - Fixed focal plane arrays
  - Integrated feed and shell-lens design

Nike Zeus Acquisition Radar

Small Commercial Lenses





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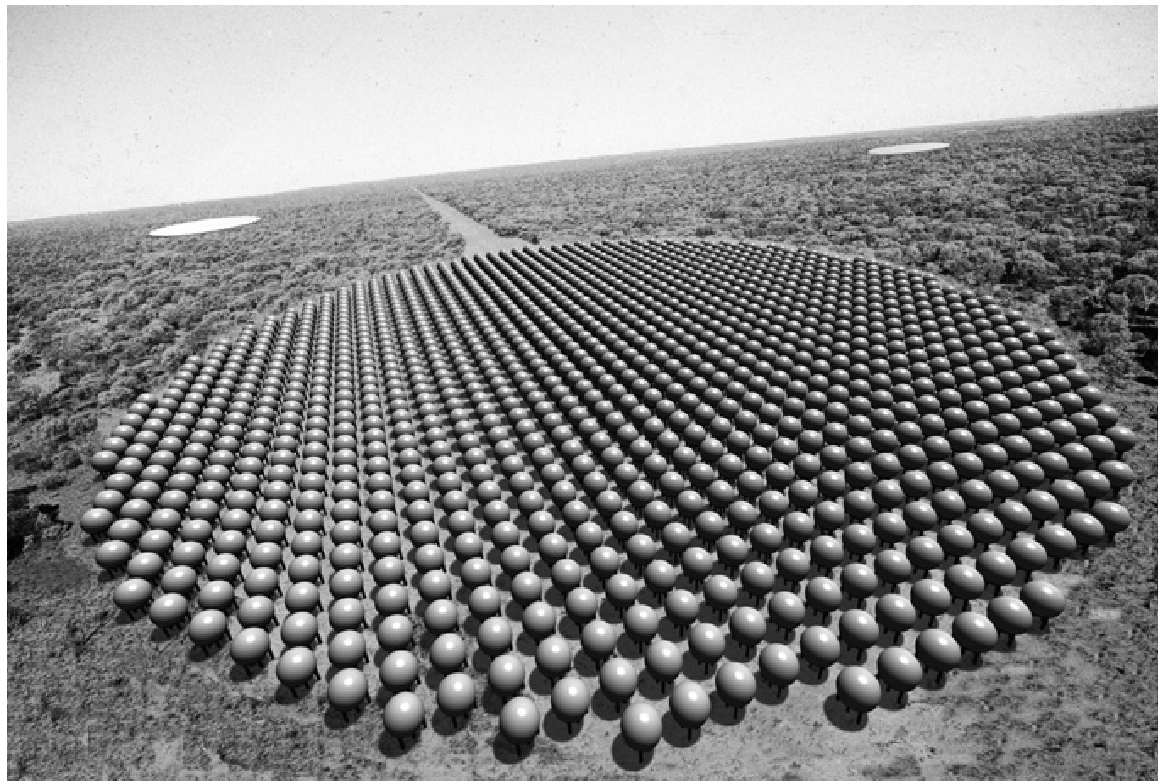
Small Lens SKA Station

- 5 - 10 m diameter
- Fixed or movable feeds
- Small blockage
- Possibility of extension to high frequency
- Many lenses per station



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Virtual Source Lens Station

- 8 - 17.5 m diameter
- Movable feeds
- Blockage issues
- Ground screen
- Fewer lenses per station
- Simpler construction
- Limited upper frequency

Fabrication of Lenses

- Smart materials
  - dielectric properties (low loss, uniformity, isotropy)
  - very low density (cost)
- Smart manufacturing technology
  - structural design and construction methods
- Correction of aberrations via focal surface array

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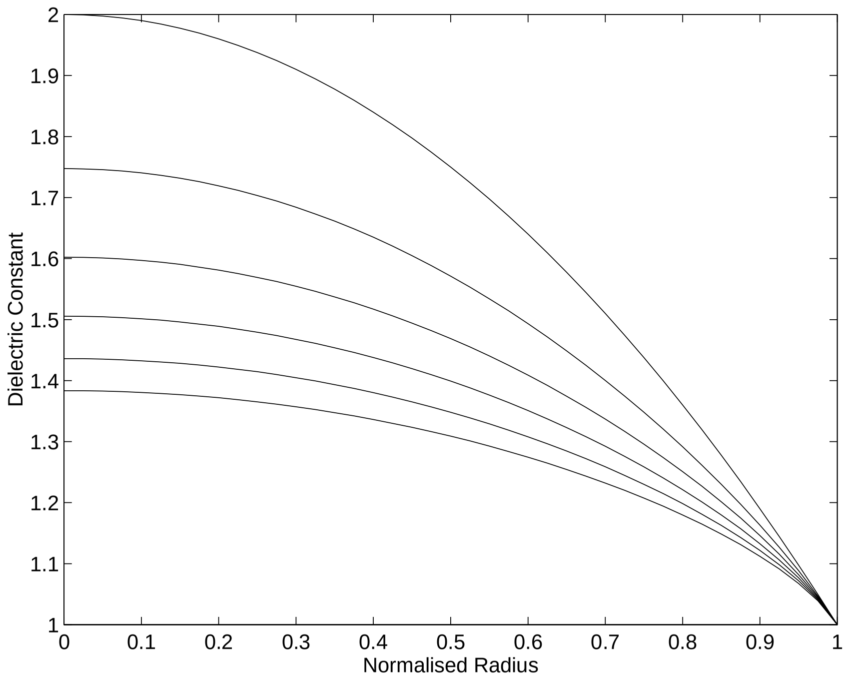
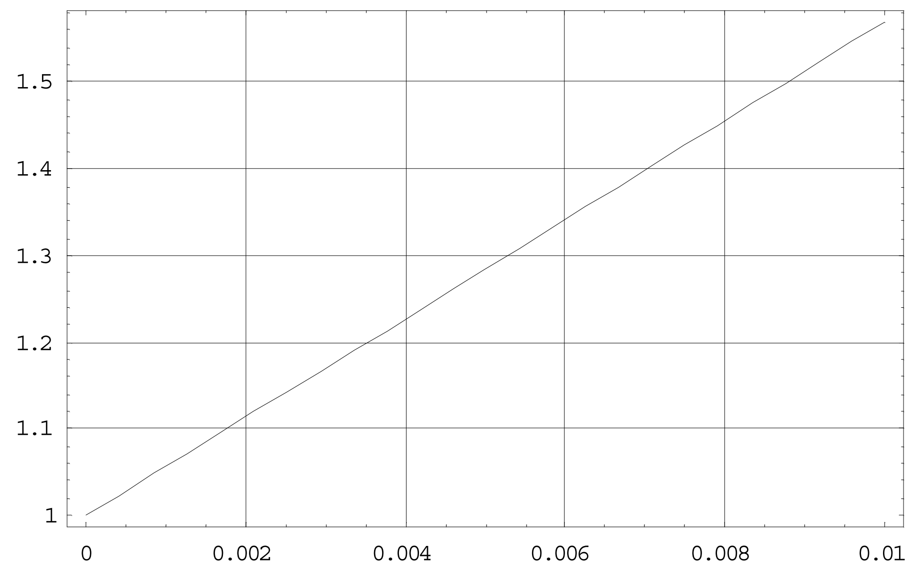
Dielectric Materials

- **Example: 8mm needles, 0.3mm diameter, ε_{eff} vs fractional volume**

```
Plot[εeff[0.15, 8, f], {f, 0, 0.01}, Frame → True,
 GridLines → Automatic]
```





- Graphics -

Dielectric Profiles

Artificial Dielectric Properties

Spot Measurement: 0.21% frac. vol., ε_{eff}=1.13, tan $\delta = 8 \times 10^{-5}$

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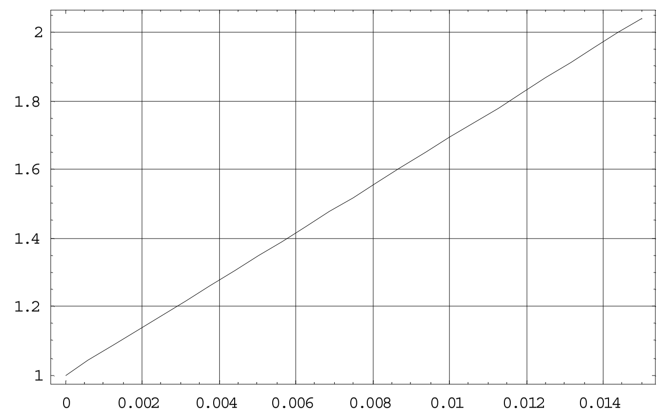
Some Artificial Dielectric Parameters

- **Example: 6mm needles, 0.2mm diameter, ε_{eff} vs fractional volume**

```
In[12]:= Plot[εeff[0.1, 6, f], {f, 0, 0.015}, Frame → True,
        GridLines → Automatic]
```

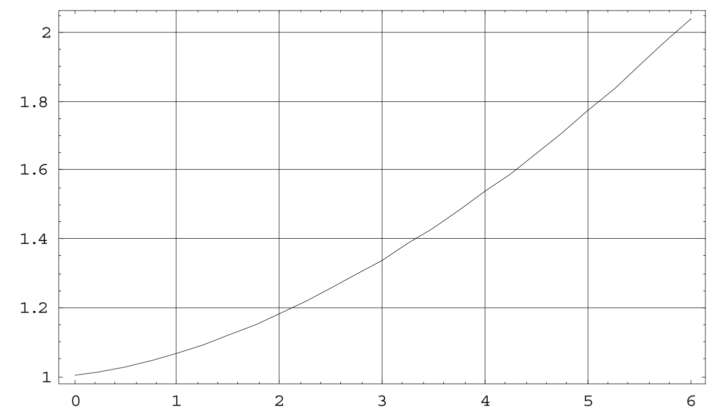


Out[12]= - Graphics -

Fixed Length, Variable Fractional Volume

- **Example: 1.5% fractional volume wires, 0.2mm diameter, ε_{eff} vs length**

```
In[13]:= Plot[εeff[0.1, l, 0.015], {l, 0, 6}, Frame → True,
        GridLines → Automatic]
```



ut[13]= - Graphics -

Fixed Fractional Volume, Variable Length

For short wires, little variation with frequency (theory and experiment)

CTIP/ATNF SKA Manufacturing Team

Estimated Completion Date: 2075

Lens Material and Loss

- Gain reduction due to material loss ($\tan \delta = 1 \times 10^{-4}$)
  - 5 m diameter lens
    - 200 MHz 0.01 dB (1 K)
    - 1000 MHz 0.05 dB (4 K)
    - 2000 MHz 0.10 dB (8 K)
  - 10 m diameter lens
    - losses approximately double the above
- Feed loss not yet included

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Feed Options

- Several movable feeds or line arrays
  - low cost
  - requires maintenance
  - upgradable at a later stage
- Focal plane array

  Only need to correlate adjacent elements

  – small moveable array
  - lower cost option
  - partial sky imaging

  – fully populated fixed array
  - costly to implement
  - simultaneous imaging of full sky

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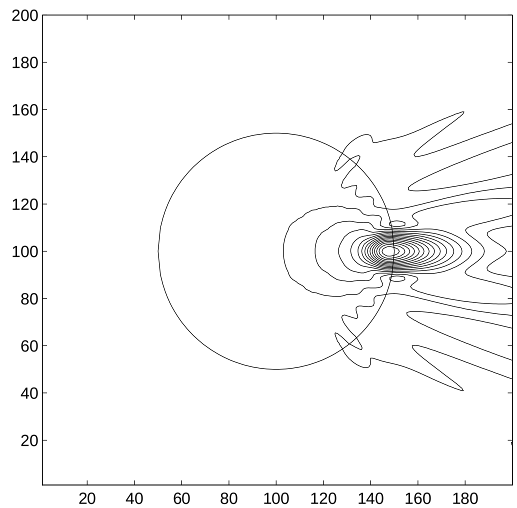
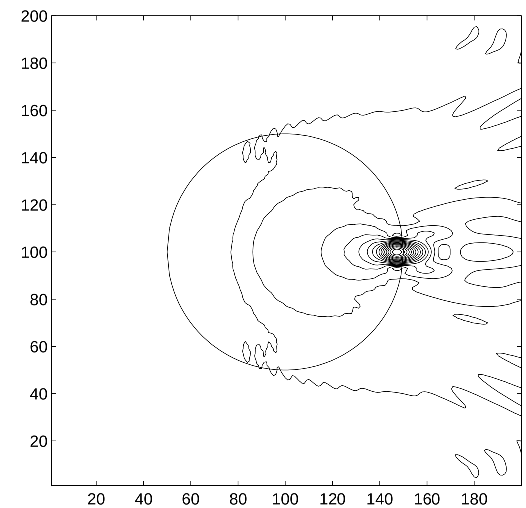
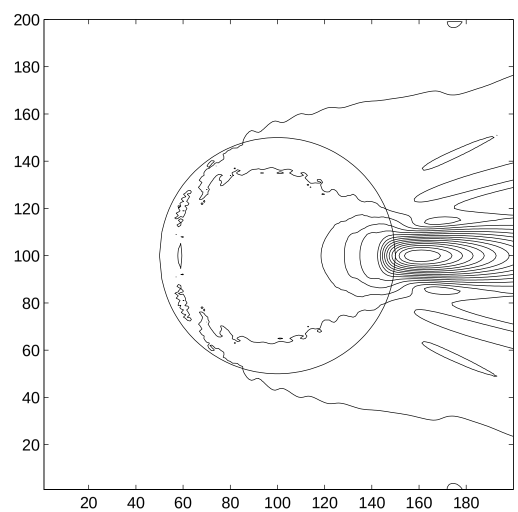
Focal Fields (Computed Using FDTD)



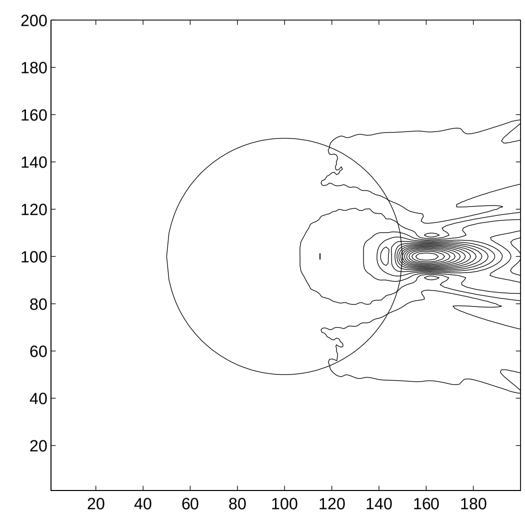
F / D = 0.5, 6.7λ diameter



F / D = 0.5, 10λ diameter



F / D = 0.65, 6.7λ diameter



F / D = 0.65, 10λ diameter

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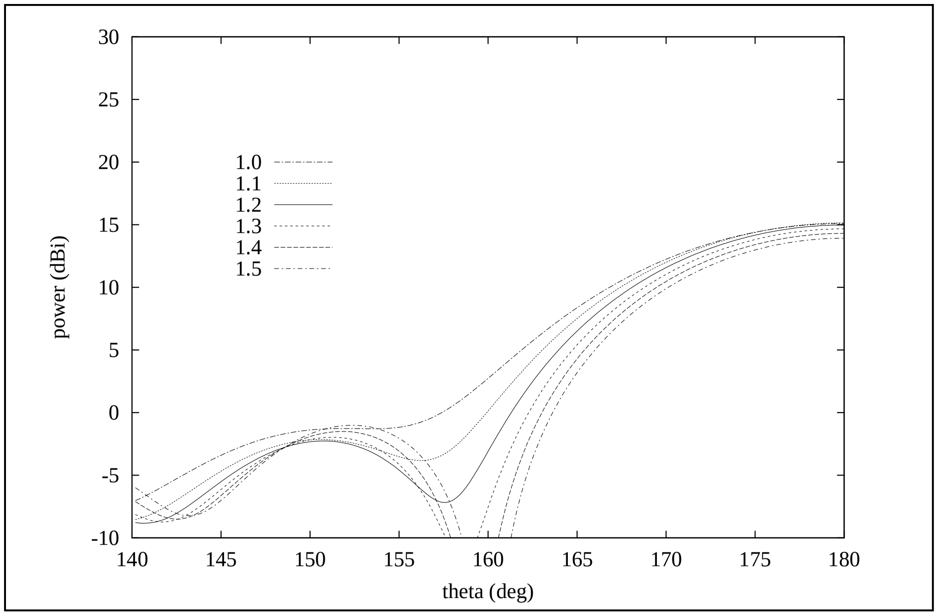
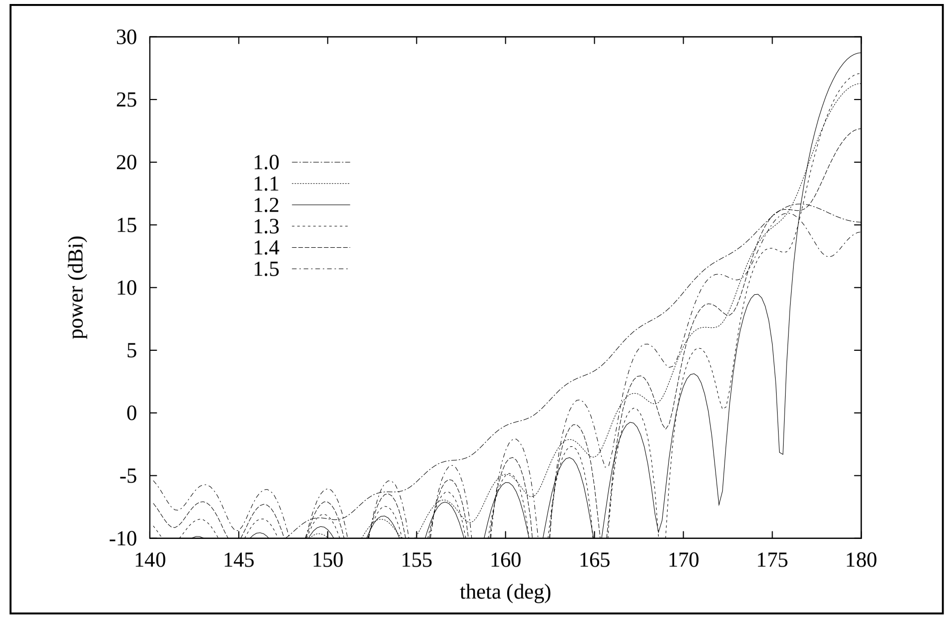
Radiation Patterns (Modal Analysis)



0.2 GHz, 5 m Lens



1.0 GHz, 5 m Lens

Some Suitable Feed Types

- Log-periodic crossed dipoles
  - matches focal field of lens and potentially wideband operation
  - hard to pack closely at high frequencies
  - appropriate for movable feed option
- Sinuous spiral array
  - planar or conformal elements
  - multiple layers required to achieve wide bandwidth
- Tapered slot antennas
  - egg-crate configuration for dual-polarised wideband operation
  - can be closely packed for a wideband focal plane array
  - phase centre shifts towards lens at low frequencies - OK from gain loss point of view

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Concluding Remarks

- Electromagnetically, a Lüneburg lens has many attractions
- Artificial dielectric materials appear to be suitable for constructing the lens
- Manufacturing holds the key to successful low cost implementation
- Compatible wide band feeds and focal plane arrays have been identified
- Trade-off study of overall system (EM lens design, materials, feed system, beam-forming) needed to determine feasibility

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