Wideband Horn Antennas

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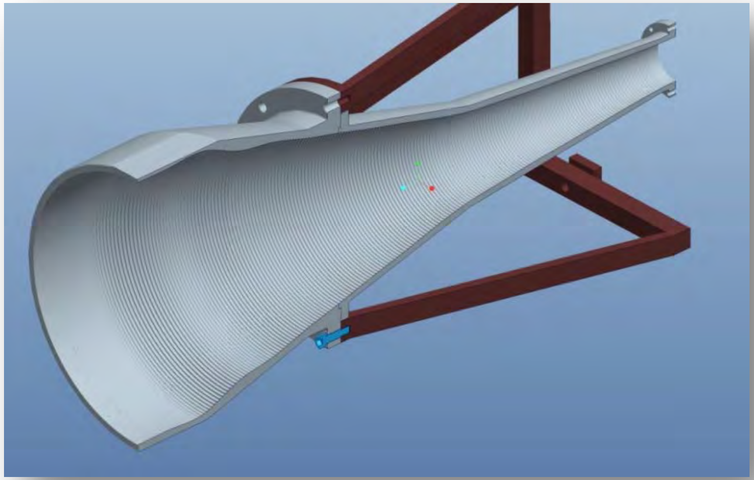
Feed Horn Antennas

- Horn antennas are widely used as feeds for high efficiency reflectors, for applications such as satellite communications and radio astronomy
- The feed horn is characterised by:
  - A circularly symmetrical radiation pattern with low cross-polarisation
  - Moderate gain
  - A radiation pattern that can be calculated very accurately using analytical methods



Wideband feed for the ATCA

SATCOM-on-the-Move Feed

Multimode Horn Antennas

- Horn antennas operating predominantly in the fundamental waveguide mode can only operate efficiently over a narrow bandwidth
- To improve the performance, discontinuities are introduced into the waveguide. These generate higher-order waveguide modes.
- By controlling the phase and amplitude of these modes, the aperture field of the horn is synthesised to give high performance over a wider bandwidth
- Successful approaches to synthesis of wideband horns include:
  - Corrugated horns
  - Profiled smooth-walled horns
  - Coaxial horns
  - Dielectric-loaded horns
- These geometries can by analysed using classical modal analysis, giving very accurate prediction of radiation pattern

A Horn for EoR?

- There is a vast experience in designing, building, and testing feed horns for satellite communications that meet very stringent requirements for radiation pattern and return loss.
- This design capability is built upon very accurate modal analysis methods that avoid many of the uncertainties of numerical analysis methods such as the finite-element method, etc.
- Could this approach be used to design a “calculable” antenna for the EoR application? The requirements (as we understand them) are:
  - A radiation pattern that can be predicted very accurately
  - Port reflection coefficient that can be predicted very accurately
  - Very low far-out sidelobe level to reduce ground pick-up
  - A radiation pattern with very high degree of circular symmetry
- The next slides show some very basic “ballpark” estimates for this idea

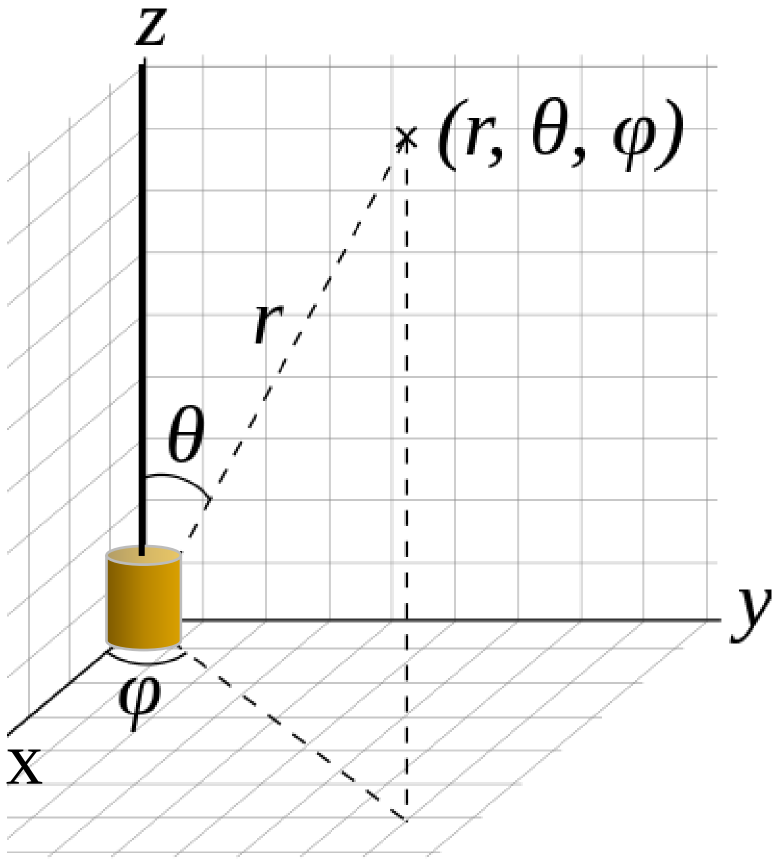
Ballpark Calculations for an EoR Horn

- Antenna Noise Temperature T_A:

$$T_A = \frac{1}{4\pi} \int_0^{2\pi} d\varphi \int_0^{\pi} \sin\theta \, d\theta \, T(\theta,\varphi) \, P(\theta,\varphi)$$

- Here $T(\theta,\varphi)$ is the environmental temperature distribution around the antenna and $P(\theta,\varphi)$ is the normalised power pattern of the antenna.
- For an antenna pointed at zenith, the ground pick-up contribution to T_A is:

$$T_A^{(\text{ground})} = \frac{1}{4\pi} \int_0^{2\pi} d\varphi \int_{\frac{\pi}{2}}^{\pi} \sin\theta \, d\theta \, T(\theta,\varphi) P(\theta,\varphi)$$



Ballpark Calculations for an EoR Horn (2)

- Assuming:
  - Circularly symmetric radiation pattern
  - Uniform ground temperature $T_{\text{ground}} = 300K$
  - An average far-out sidelobe level P_{av}
- Then:

$$T_A^{(\text{ground})} \approx 150\, P_{av}$$

- For a ground pickup $T_A^{(\text{ground})} \leq 30mK$ we require:

$$P_{av} \approx -37dBi$$

- This is a reasonable requirement for a low-sidelobe feed horn. We now need to estimate the required directivity

Ballpark Calculations for an EoR Horn (3)

- Assuming a circularly-symmetric Gaussian radiation pattern

$$P(\theta, \varphi) = e^{-b\theta^2}$$

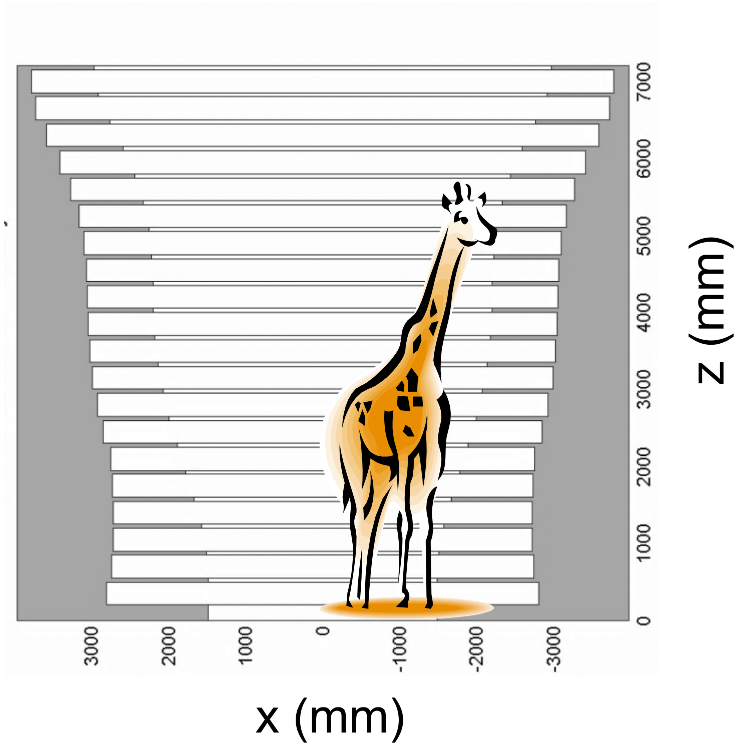
- This gives a required directivity of approximately $13\ \mathrm{dBi}$
- The corresponding half-power beamwidth is 44°
- This is a modest requirement for a waveguide feed horn → a small horn in terms of wavelengths
- Surprisingly, the radiation pattern requirements for the EoR application look to be in the ballpark…
- Of course, a horn antenna operating at these wavelengths will not be a small structure! The following slides show some initial design work done to estimate the size of possible implementations.

Basic specifications for a horn design

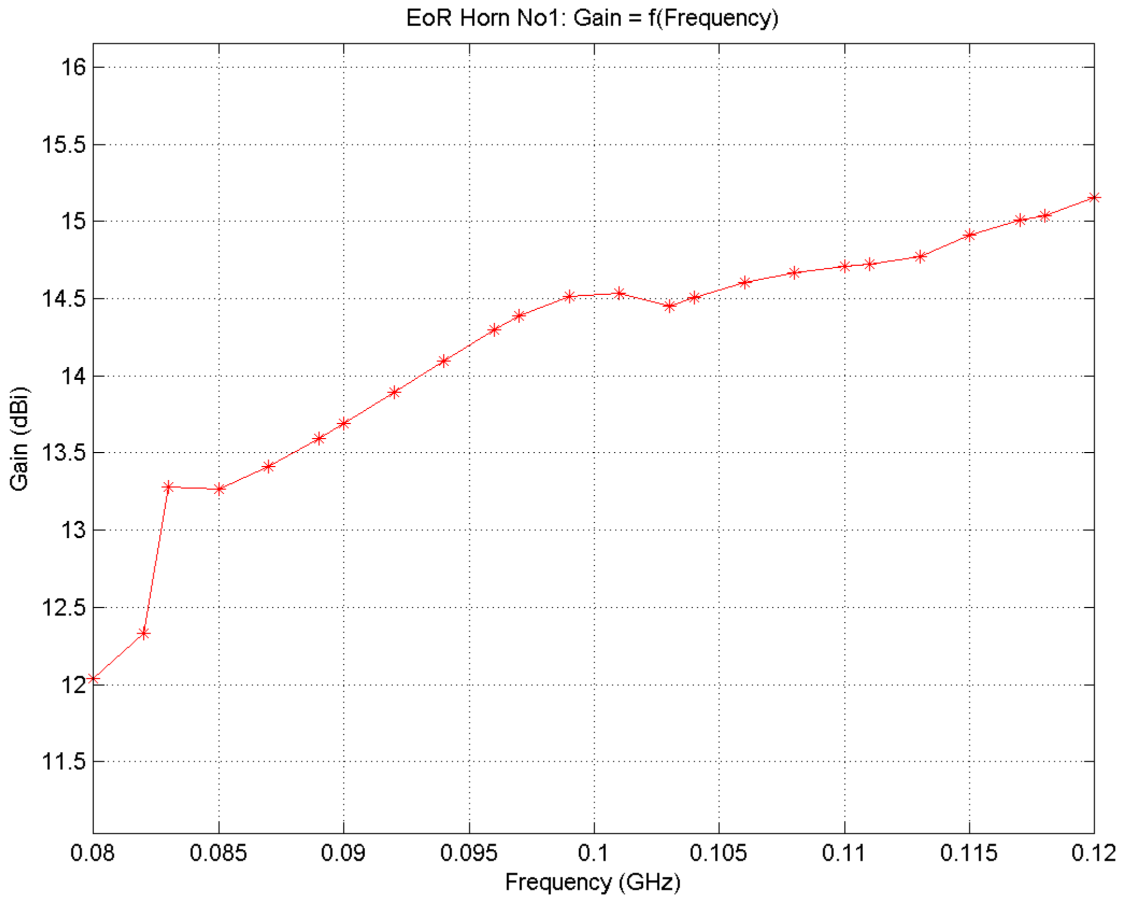
- As an exercise, we've looked at designing a horn for the following specifications:
  - Frequency range: 80 – 120 MHz ($\lambda \sim 3.75 - 2.5\mathrm{m}$)
  - Return Loss > 20dB (S_{11} < -20dB)
  - Cross-polarization better than -20dB below co-polar peak
  - Gain nominally 13 dBi
- Two possible implementations were considered:
  - A conventional corrugated horn
  - An axially-corrugated horn
- Here we are only looking at the waveguide horn antenna. Additional components are required to connect the antenna to the receiver. Essentially these would comprise a two-port network and could be accurately calibrated by network measurement.

Corrugated Horn

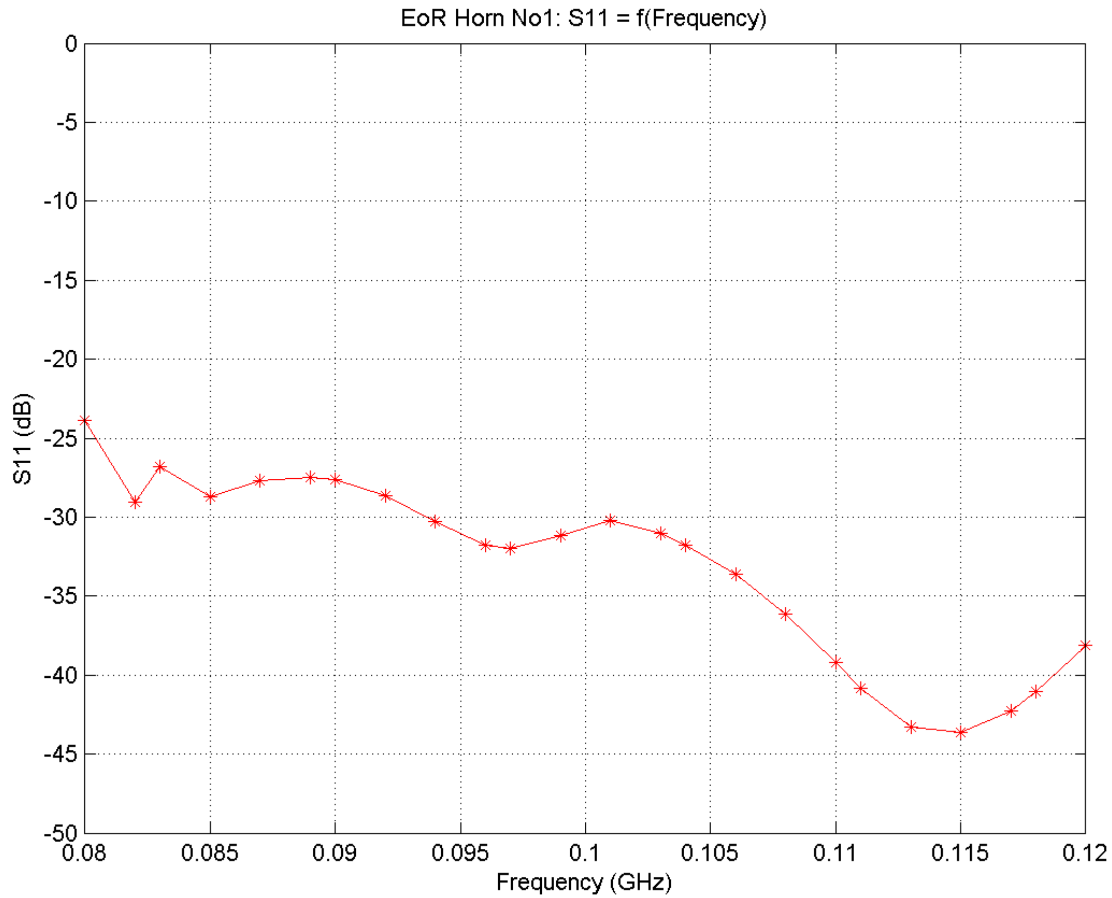
- This figure shows the cross-section of a preliminary design for a corrugated horn to meet these requirements
- The height of the horn and the diameter are both slightly greater than 7m
- This is a large structure, but could be made from e.g. metallised composite materials
- The skin depth in Al is around 10μ, so the metal thickness needed for low loss would be 50 μ to100 μ.
- The following slides show the gain, return loss, and radiation patterns



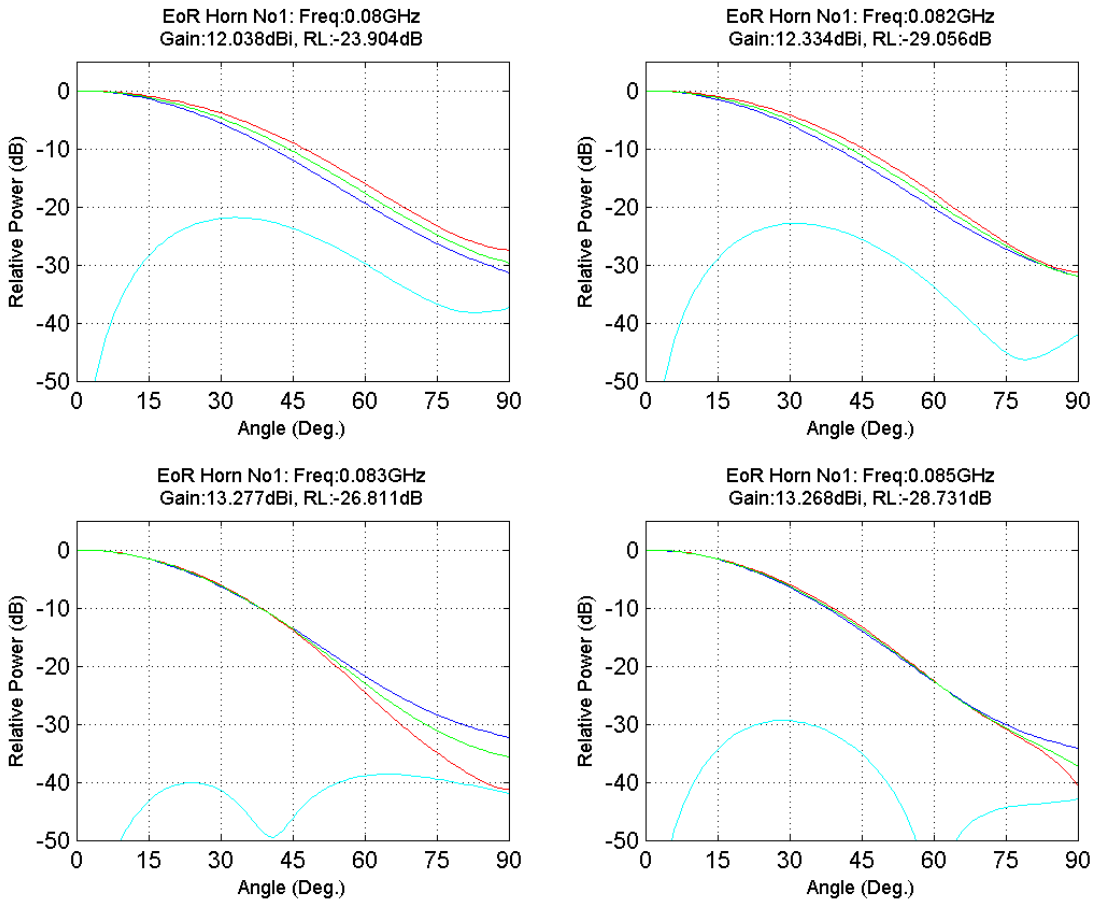
Corrugated horn: Gain



Corrugated horn: Return Loss



Radiation pattern (800 – 850 MHz)



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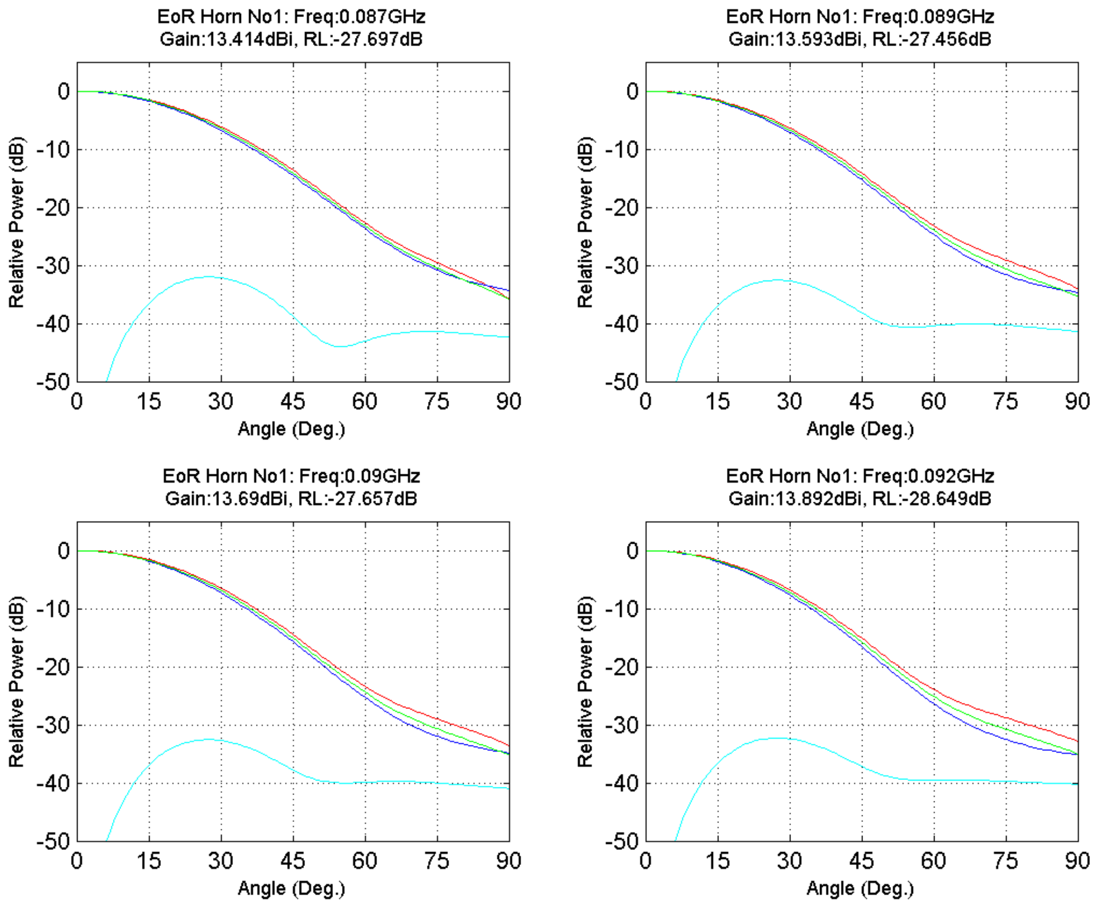
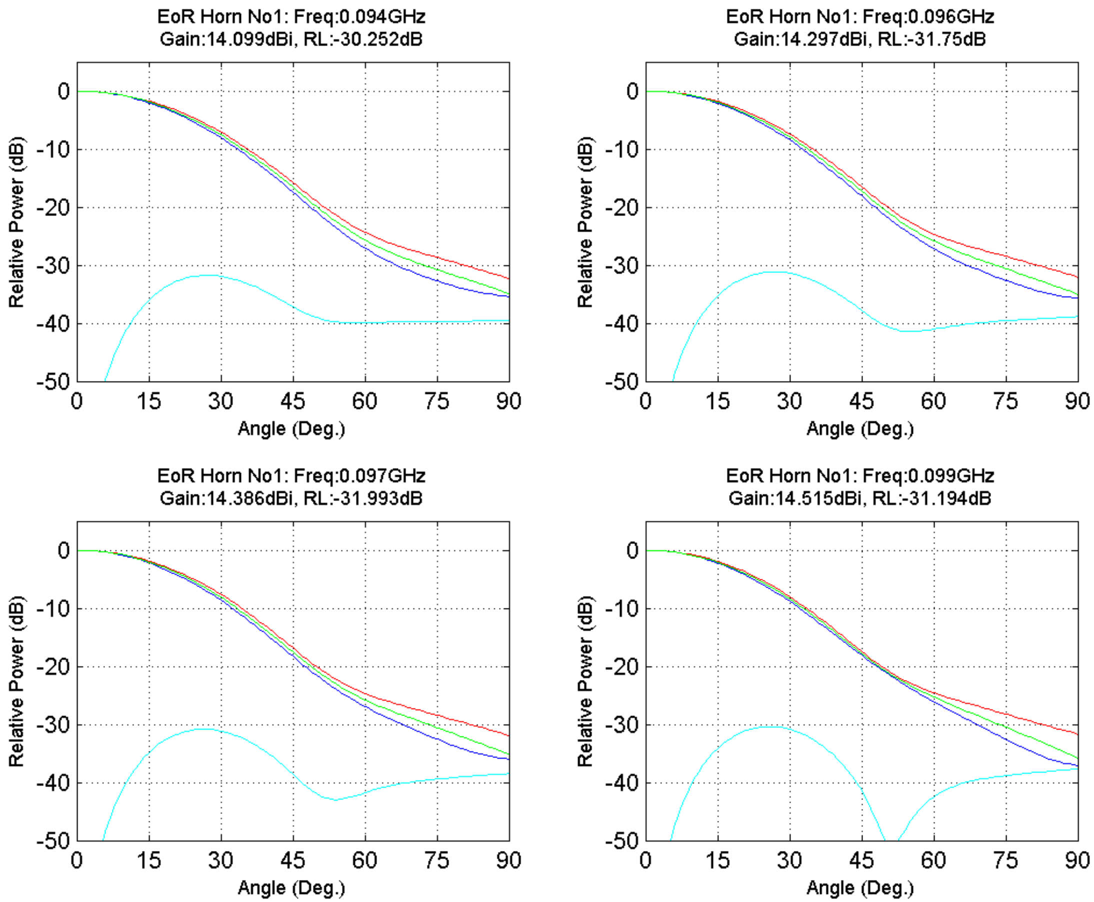
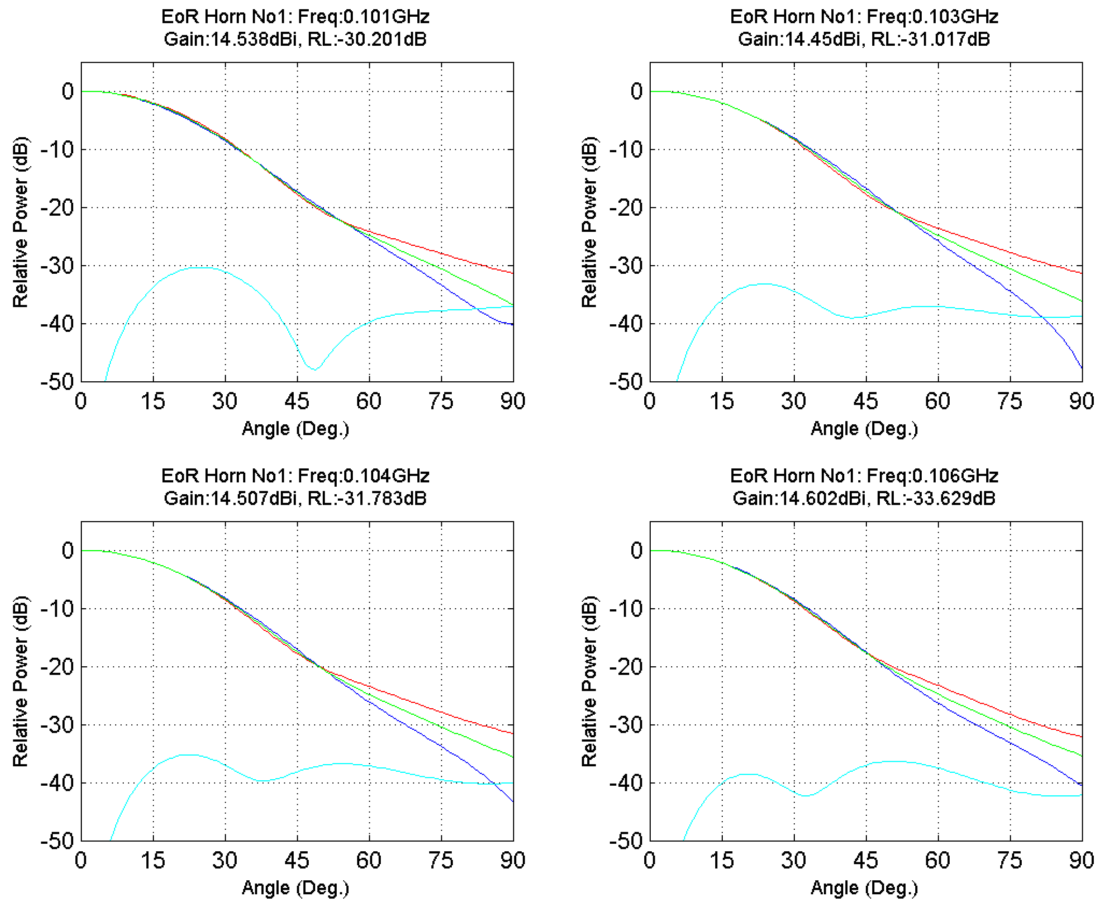
Radiation pattern (870 – 920 MHz)



Radiation pattern (940 – 990 MHz)



Radiation pattern (1010 – 1060 MHz)



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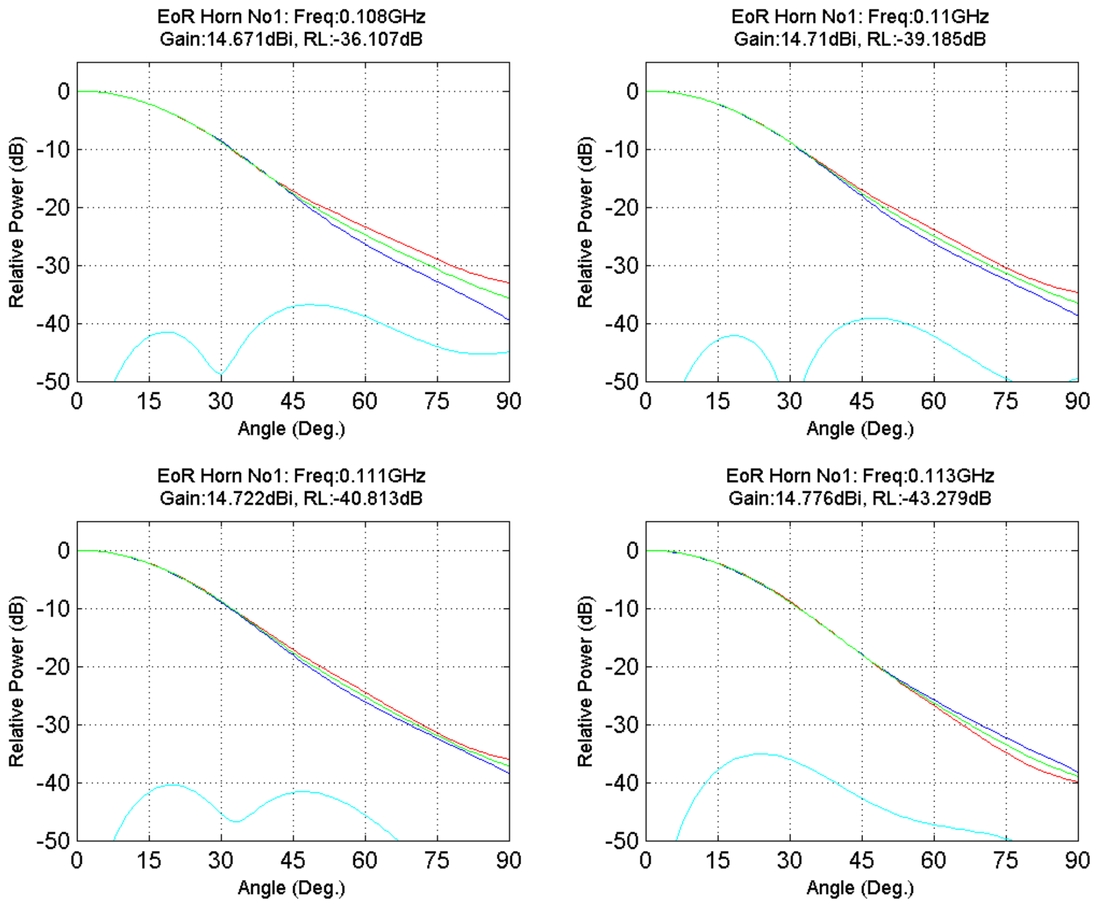
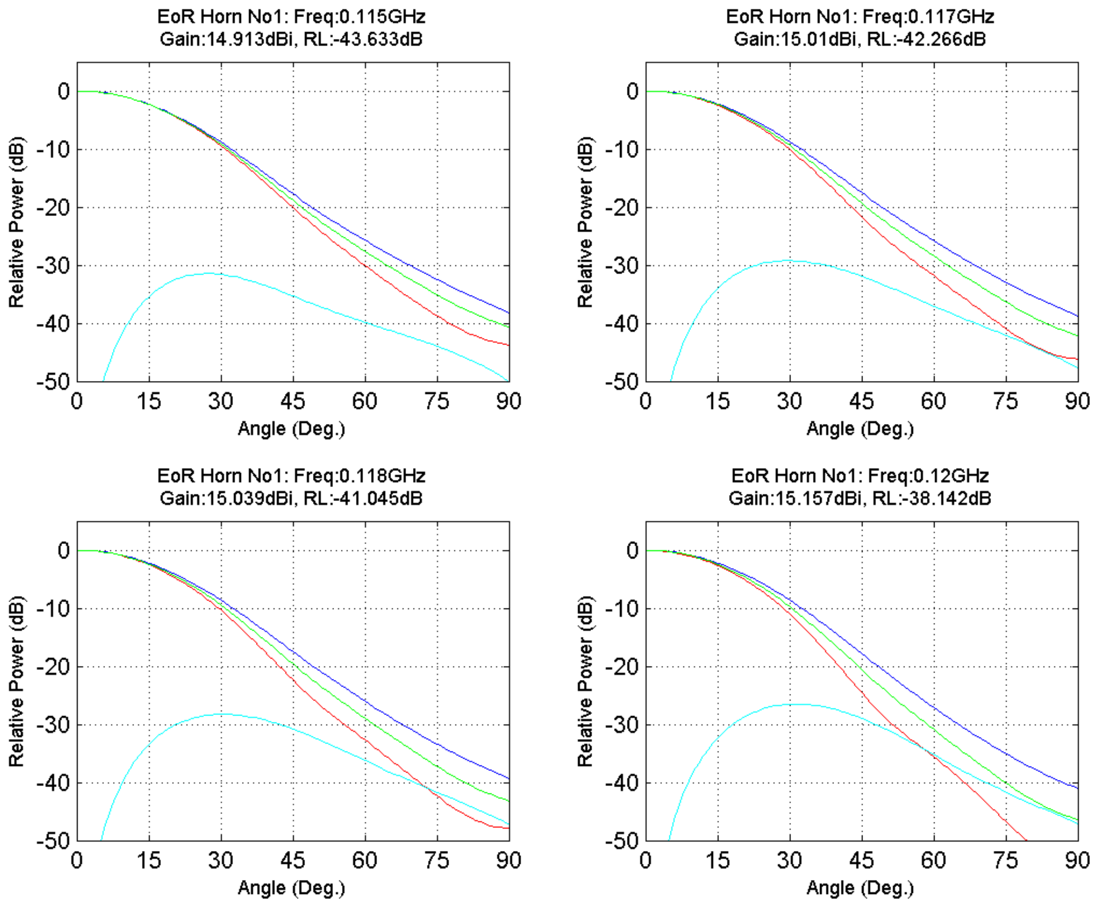
Radiation pattern (1080 – 1130 MHz)



Radiation pattern (1150 – 1200 MHz)



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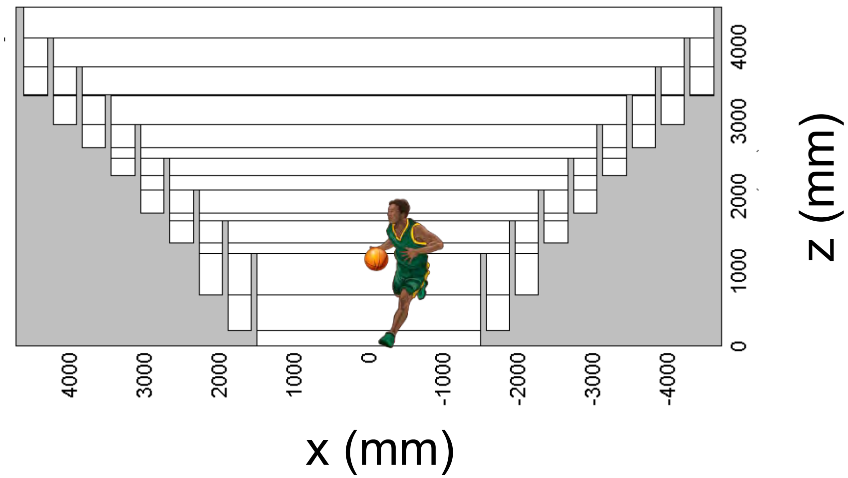
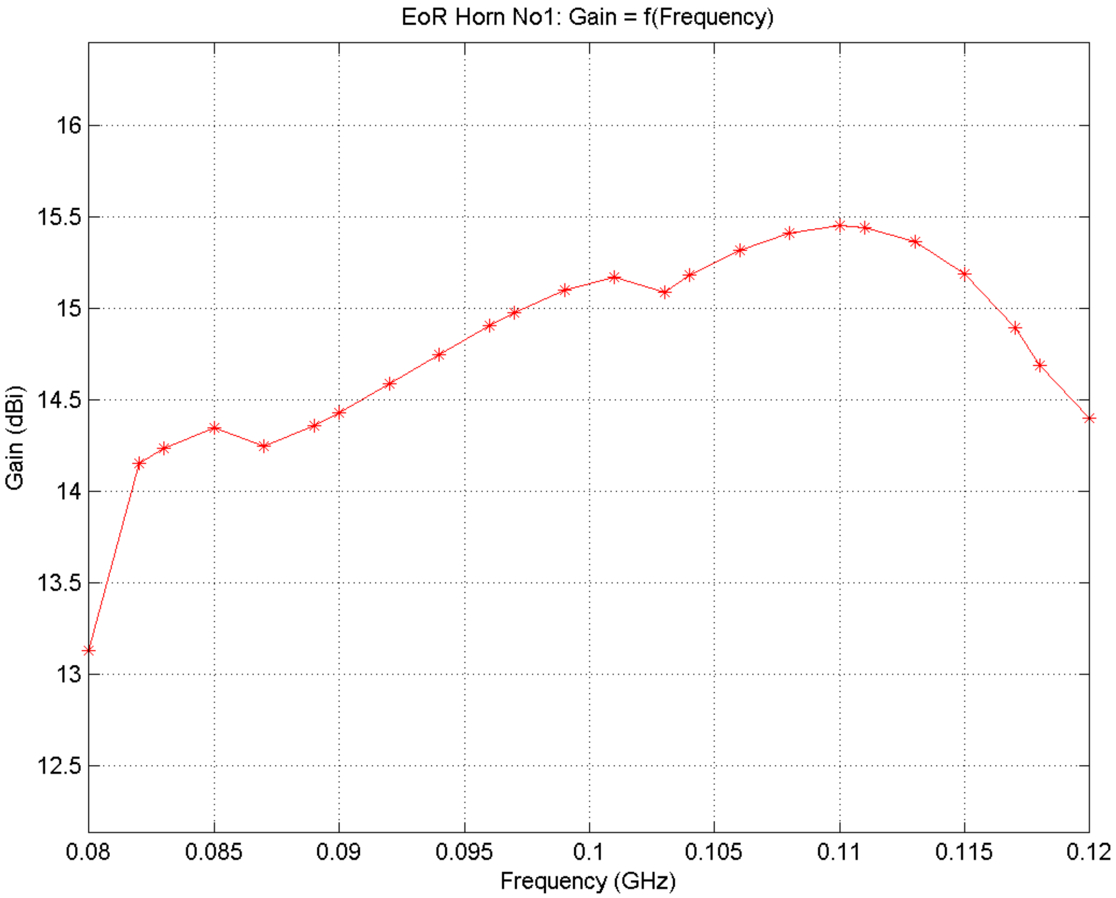
Axially corrugated horn

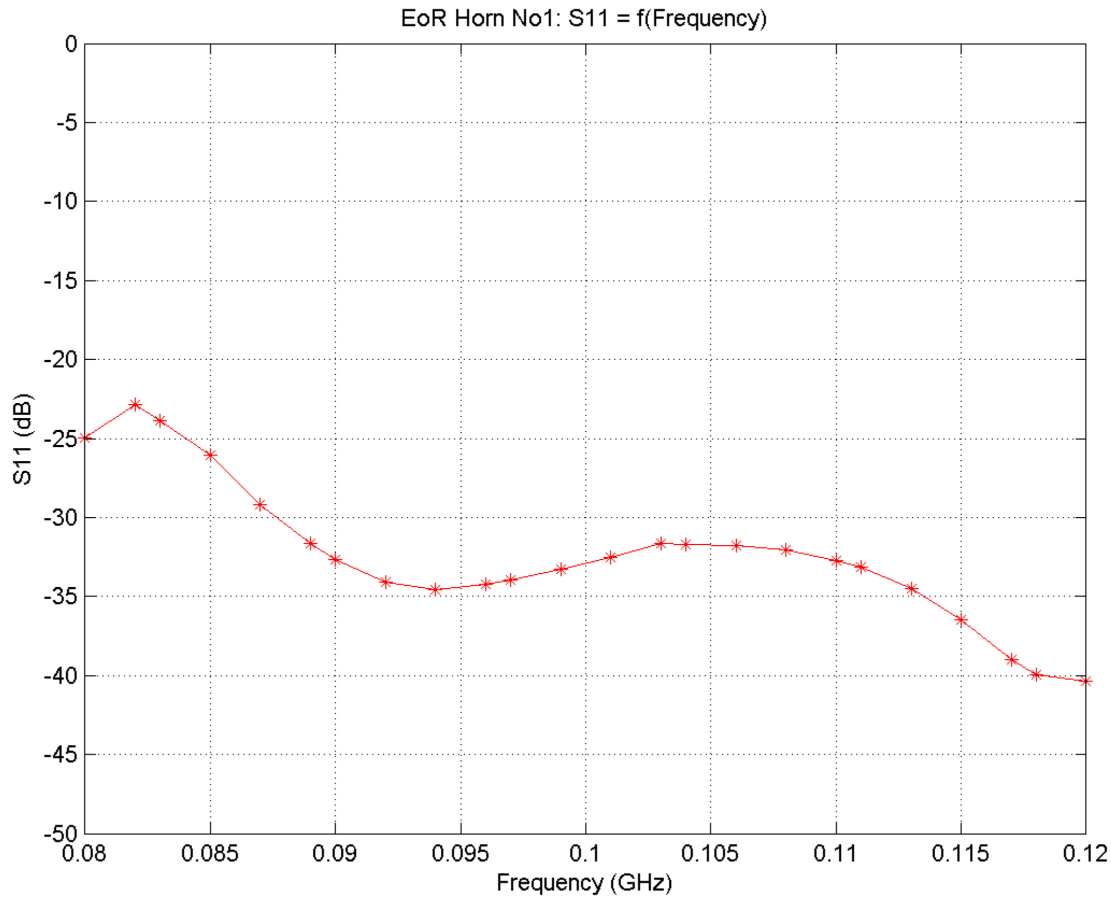
- This figure shows the cross-section of a preliminary design for an axially corrugated horn for this application
- The height of the horn is about 4.5m, and the diameter slightly less than 10m
- The following slides show the gain, return loss, and radiation patterns for the axially-corrugated horn.



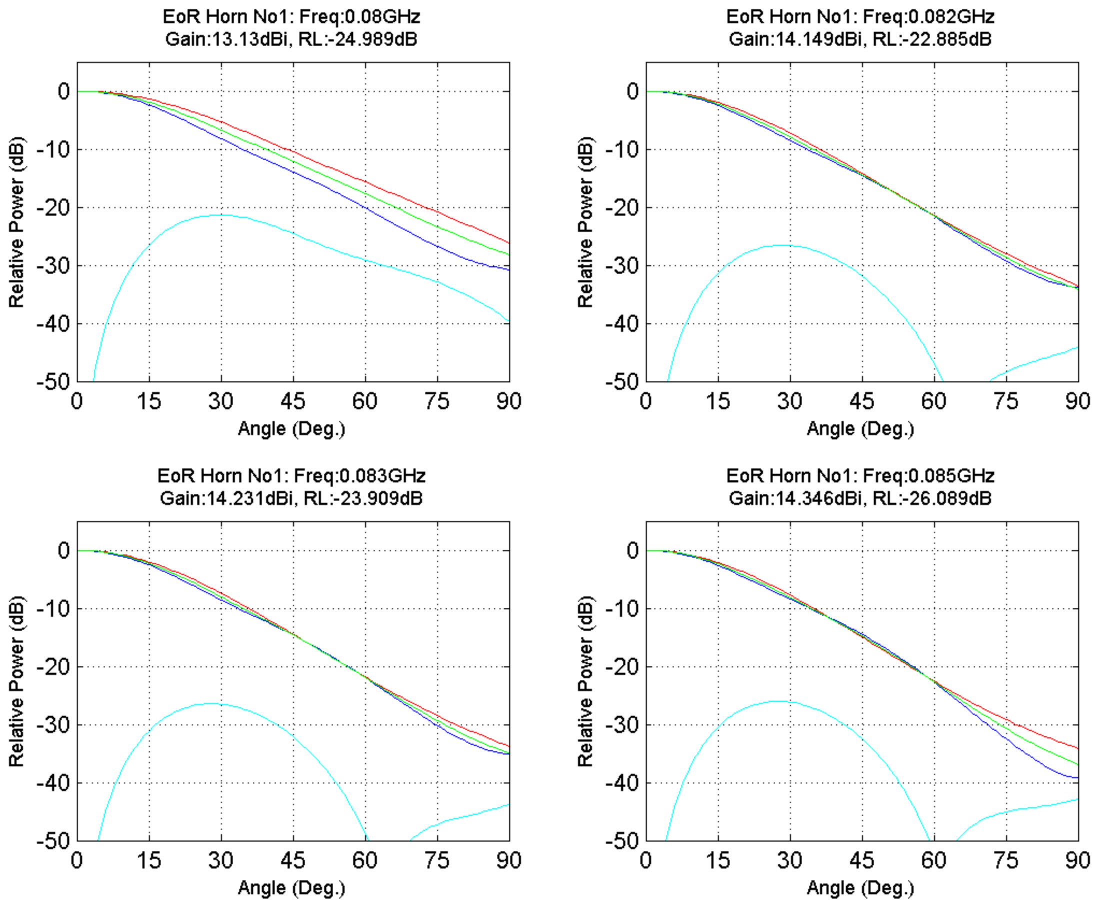
Axially corrugated horn: Gain



Axially corrugated horn: Return Loss



Radiation pattern (800 – 850 MHz)



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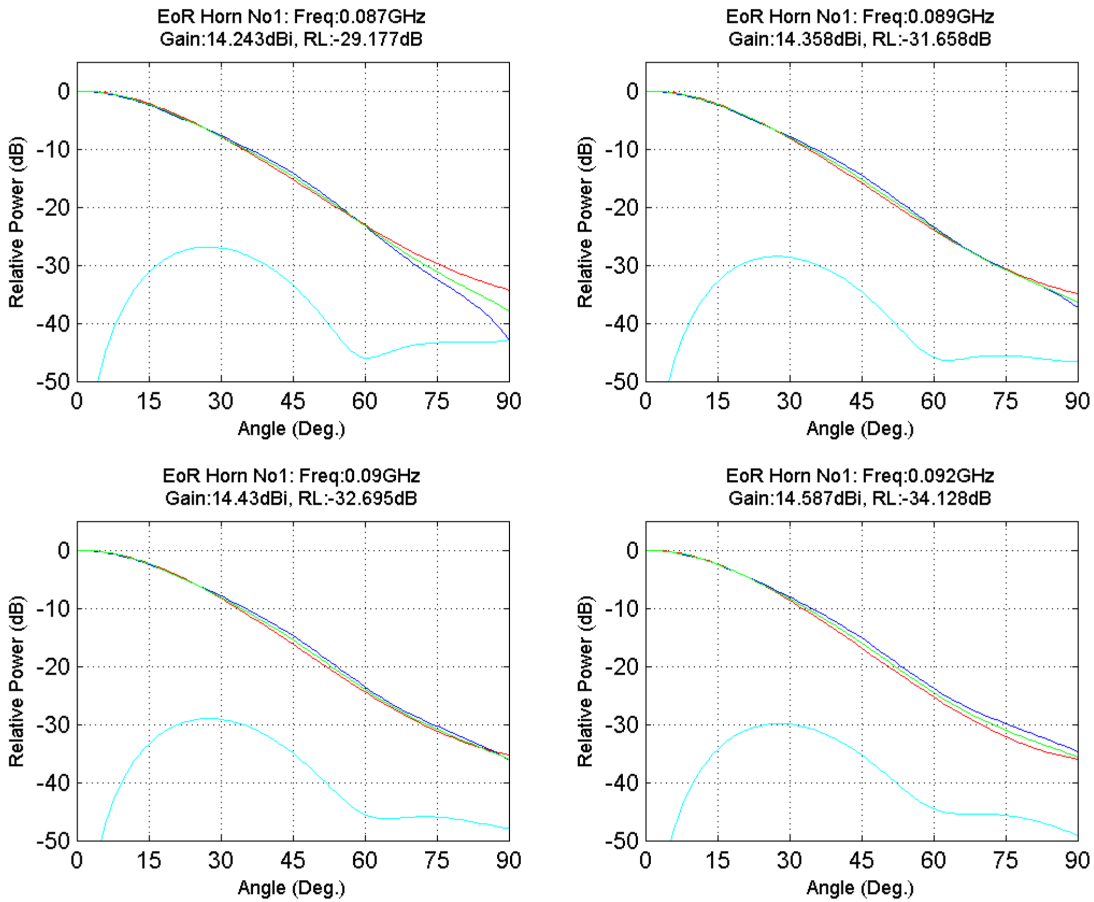
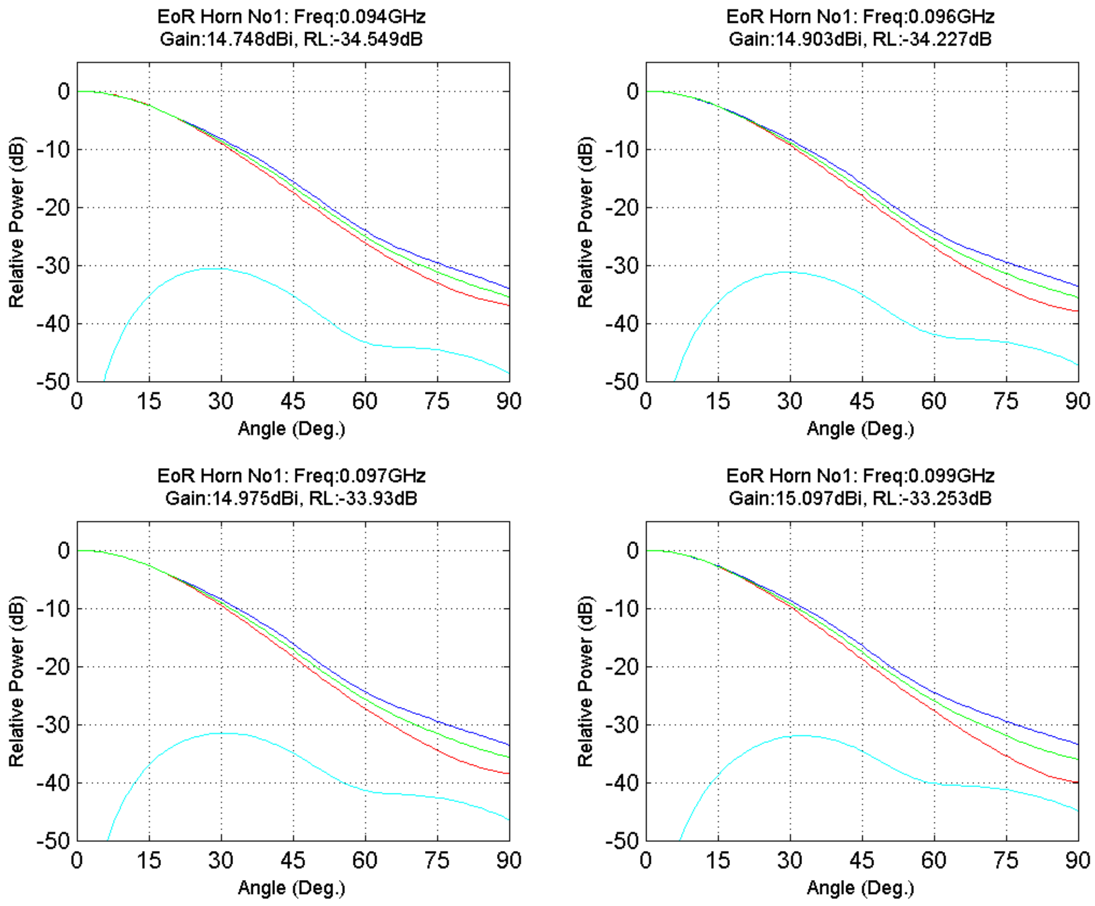
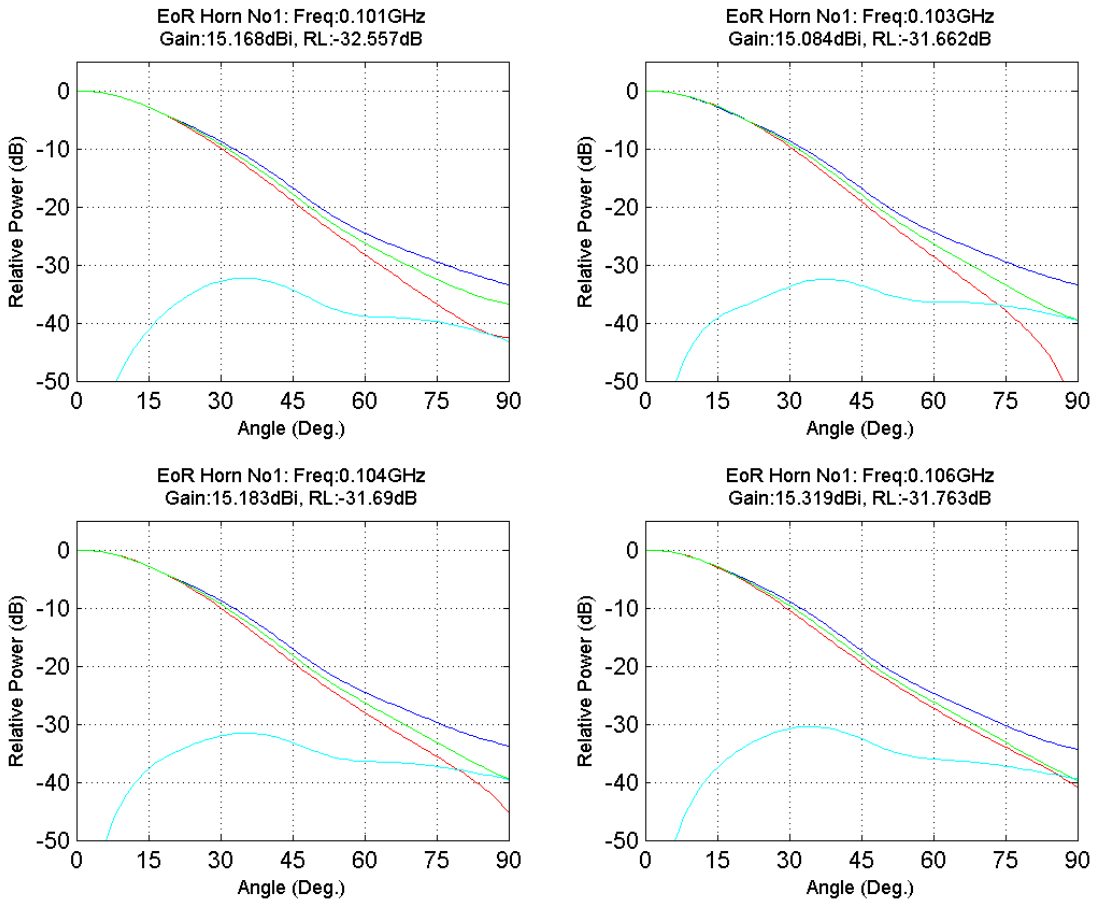
Radiation pattern (870 – 920 MHz)



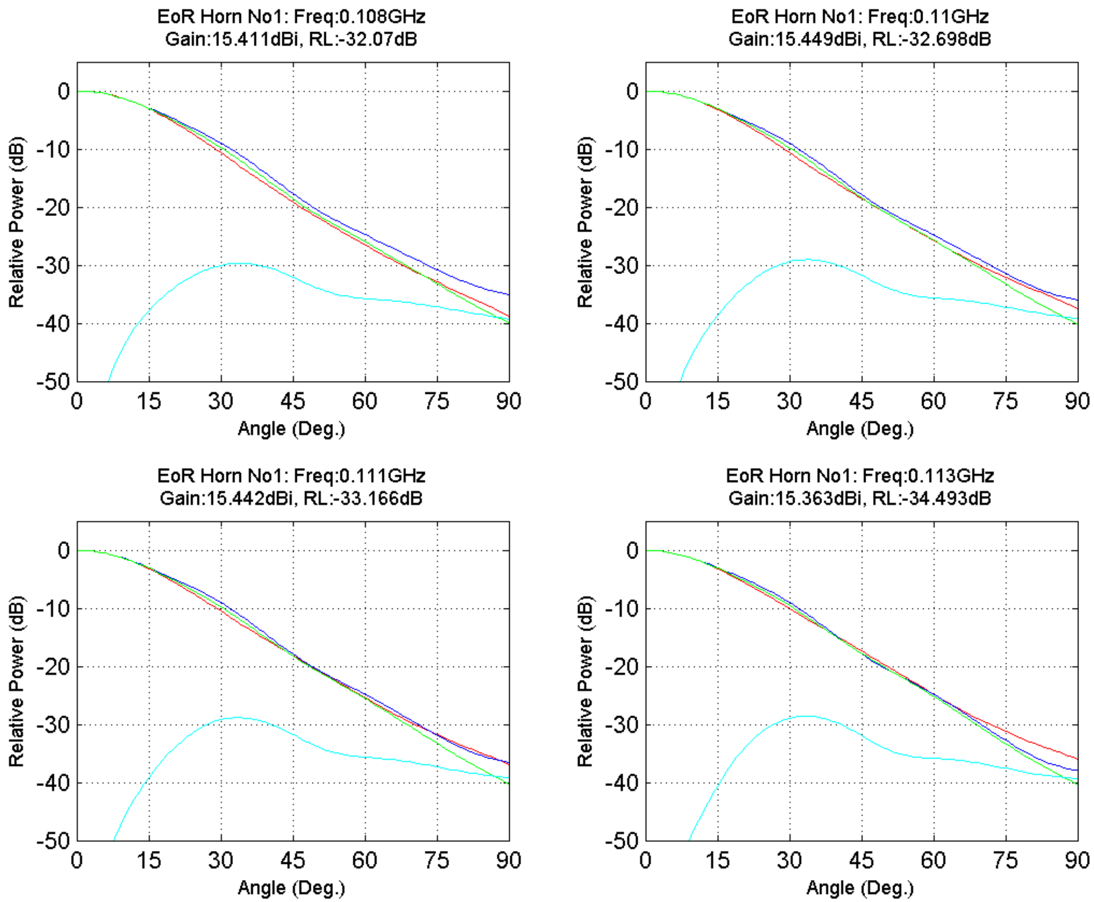
Radiation pattern (940 – 990 MHz)



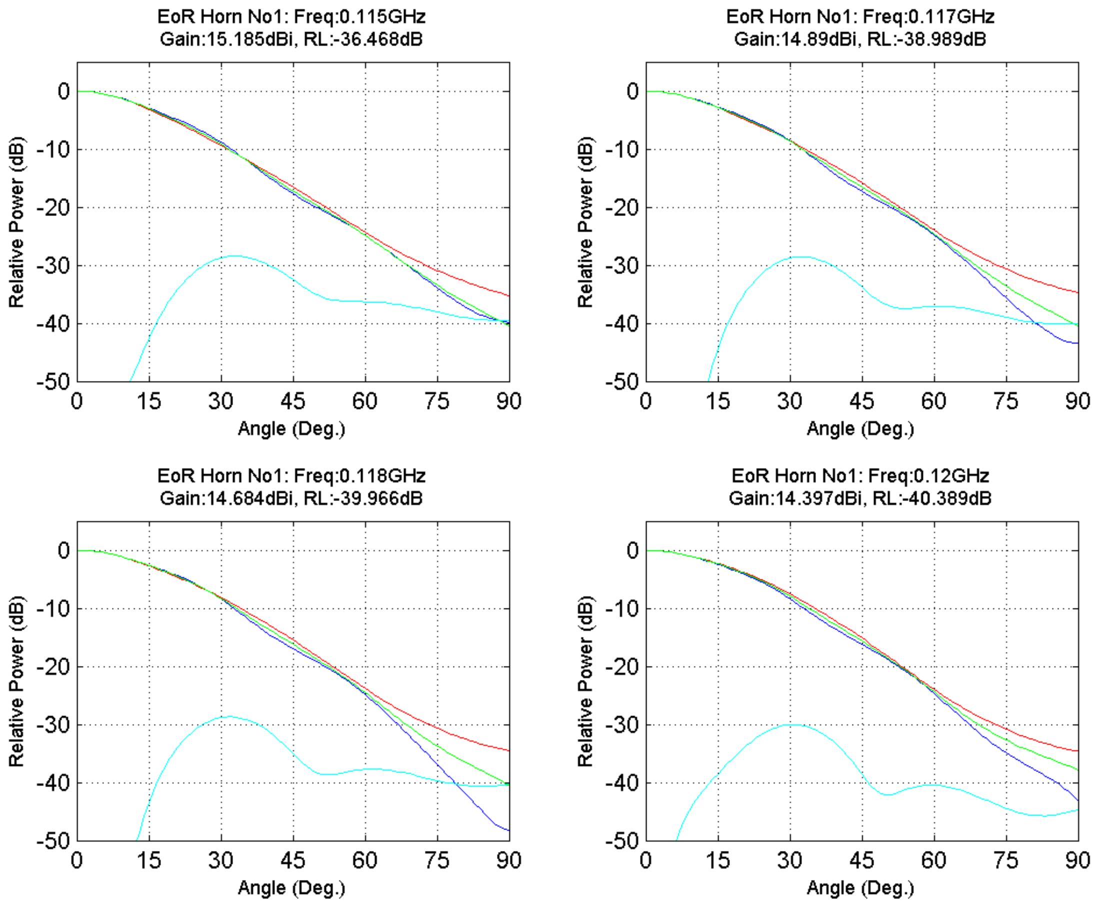
Radiation pattern (1010 – 1060 MHz)



Radiation pattern (1080 – 1130 MHz)



Radiation pattern (1150 – 1200 MHz)



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Preliminary Conclusions

- In general, horn antennas can generate high-quality radiation patterns that are accurately predictable
- We have done a very preliminary feasibility study of a horn antenna for the EoR application
- The radiation pattern requirements appear to be reasonable for a wideband horn antenna in terms of beamwidth and sidelobe levels
- The waveguide part of the horn can be analysed using classical modal analysis to predict input reflection coefficient and radiation pattern very accurately.
- Additional components to connect the horn to the receiver could be characterised by measurement with a VNA

Preliminary Conclusions

- We had a preliminary look at two possible realisations: a conventional corrugated horn, and an axially-corrugated horn
- Corrugated horns for this frequency are large, but relatively simple, structures. They could be made from e.g. metallised lightweight materials.
  - The skin-depth in Al at these frequencies is around 10 *μ*, so the metal thickness would only need to be 50 *μ* – 100 *μ* to achieve a low-loss structure
- Other options include smooth-walled horns and coaxial horns
- All results presented are *very* preliminary. A proper feasibility study would be needed:
  - To test some optimised designs against a proper set of requirements for this application
  - To establish quantitative estimates of gain and noise temperature uncertainties.