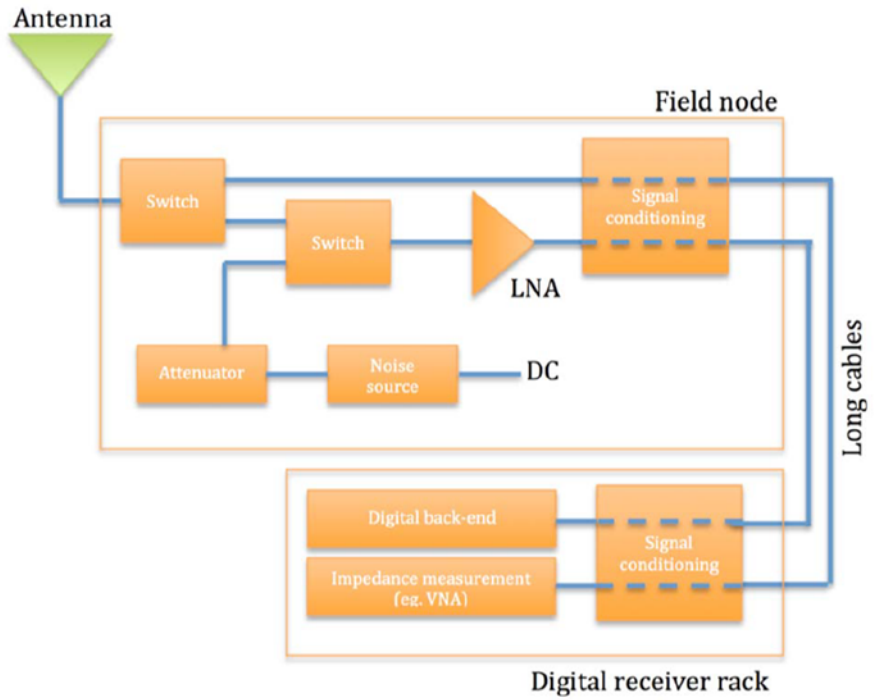
Antenna design for a Global 21 cm experiment: REACH

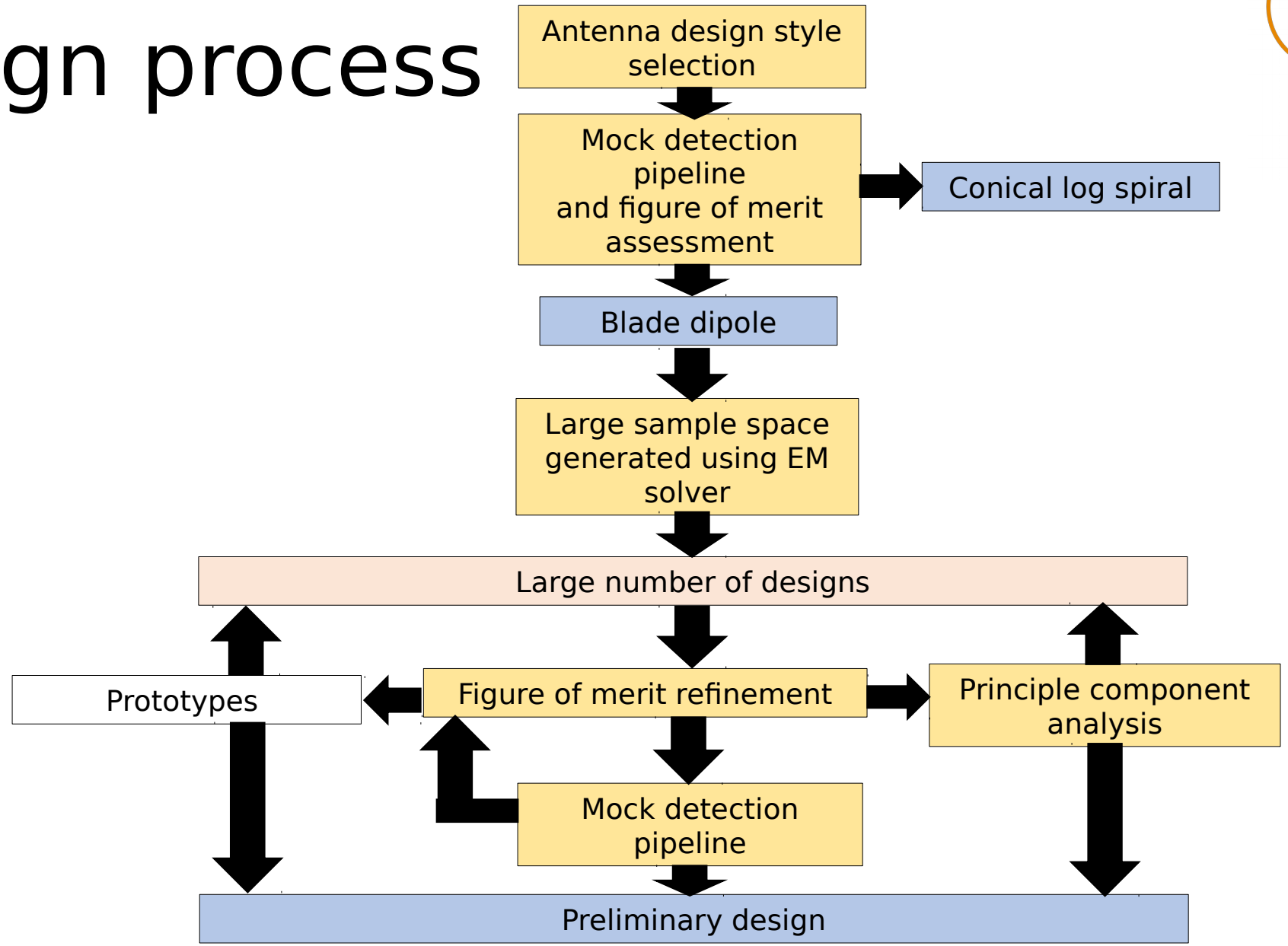
John Cumner

The REACH approach

- Priority to understand all parts of the system.
- Compensate for systematics present
- Inbuilding analysis pipeline into design process



Design process



Antenna temperature

Antenna directivity

Radiation efficiency

Background sky temperature

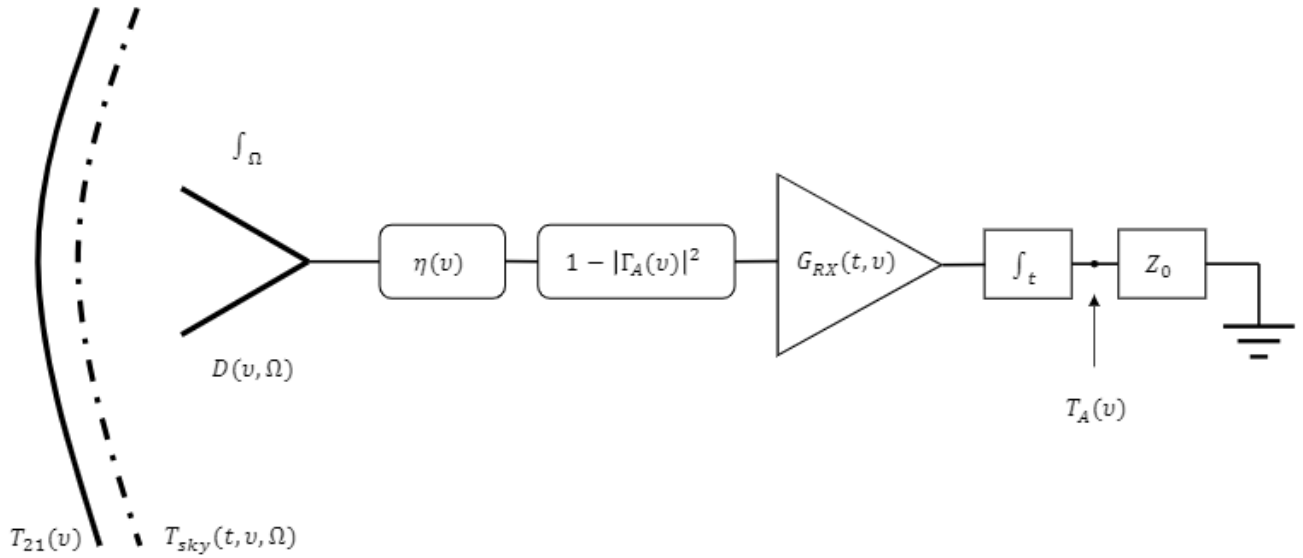
Global 21 cm Signal

Antenna reflection coefficient

Amplifier gain

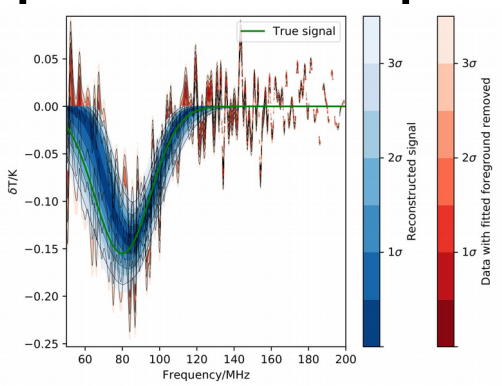
Additional noise

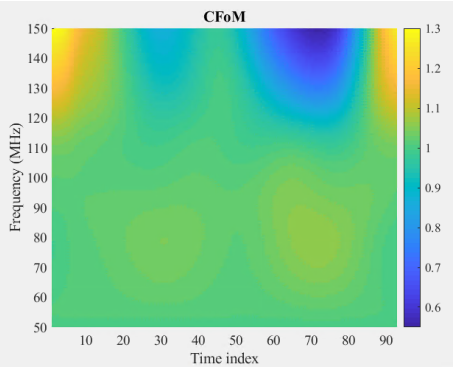
$$T_{ant}(\nu) = \int_t \left(\left(\frac{1}{4\pi} \int_\Omega D(\nu,\Omega)\eta(\nu)(T_{\text{sky}}(t,\nu,\Omega) + T_{21}(\nu))d\Omega \right) (1 - |\Gamma_A(\nu)|^2) G_{RX}(t,\nu) + N(t,\nu) \right) dt$$



Figures of Merit approach

- Quantifiable values for the most important aspects of the antenna:
  - Beam chromaticity (σ)
  - Antenna impedance (α,β,γ,δ)
  - Mock data analysis pipeline





- Other less quantifiable considerations:
  - Ease of building
  - Ease of modelling computationally

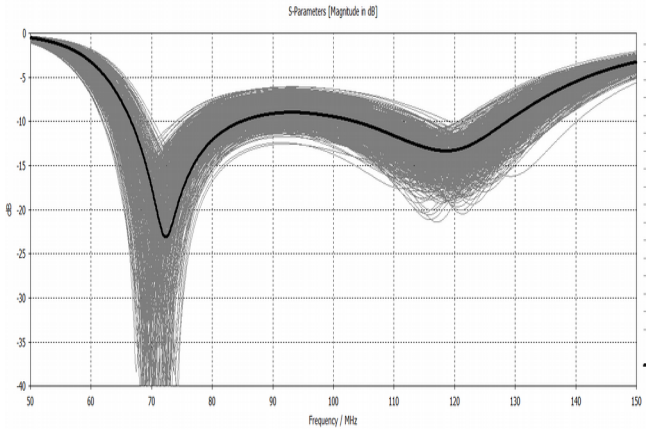
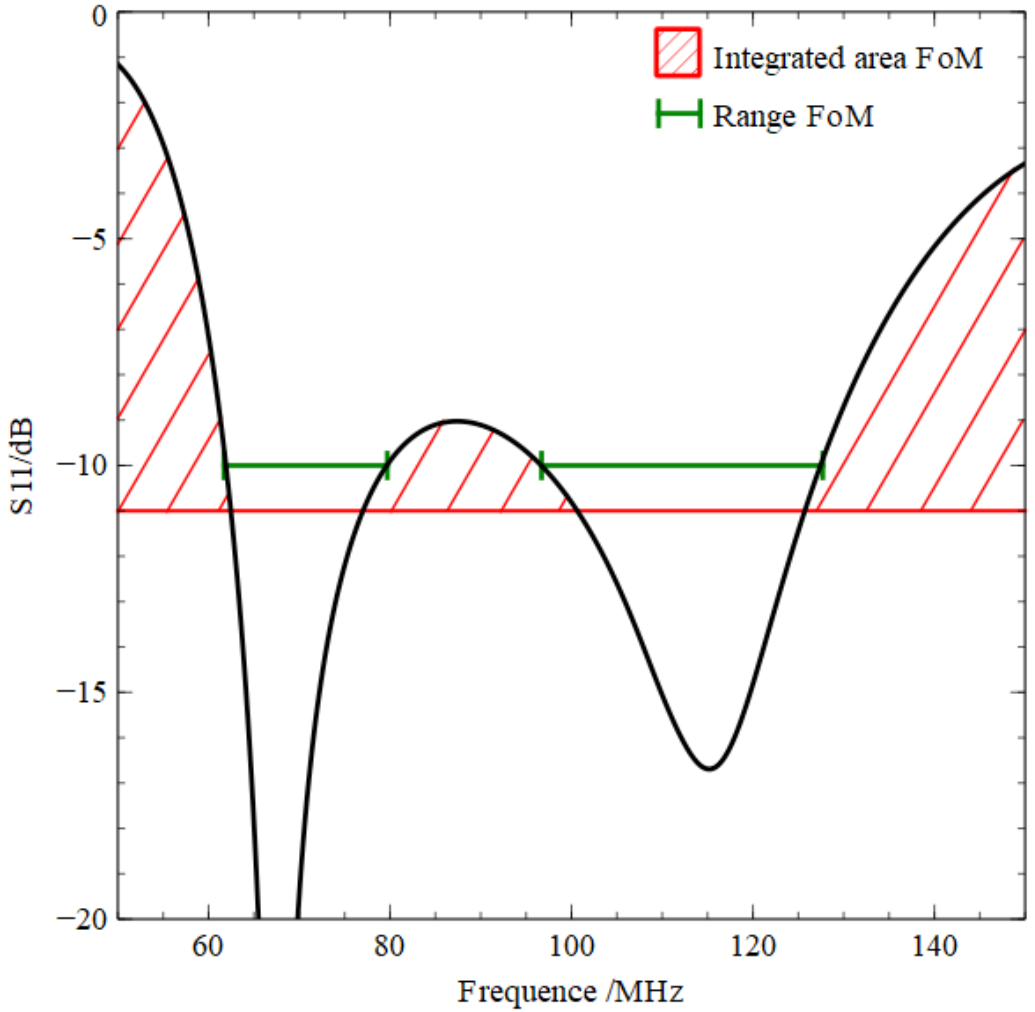


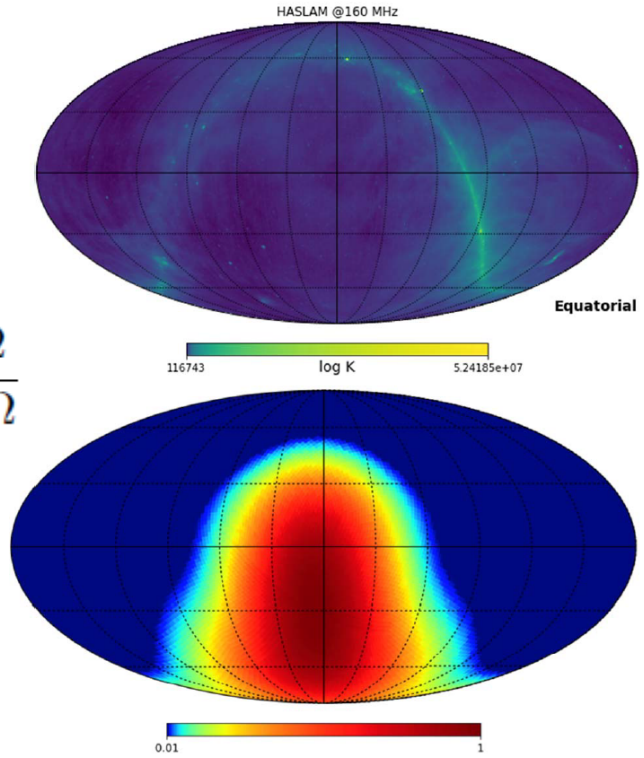
Figure of Merit: Impedance

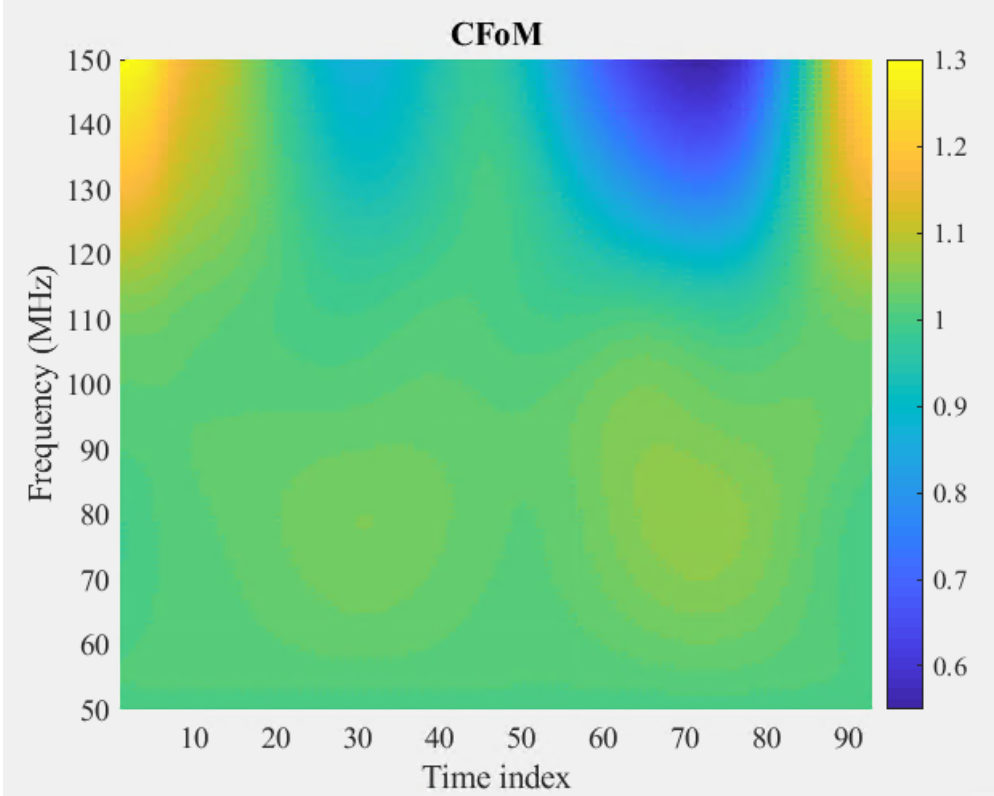
- -10dB range of S11
- Mean of S11
- Integrated percentage of S11 above 6 threshold values



Chromacitity FoM

$$CFoM(\nu) = \frac{\int_\Omega B(\nu,\Omega)T(\nu_0,\Omega)d\Omega}{\int_\Omega B(\nu_0,\Omega)T(\nu_0,\Omega)d\Omega}$$

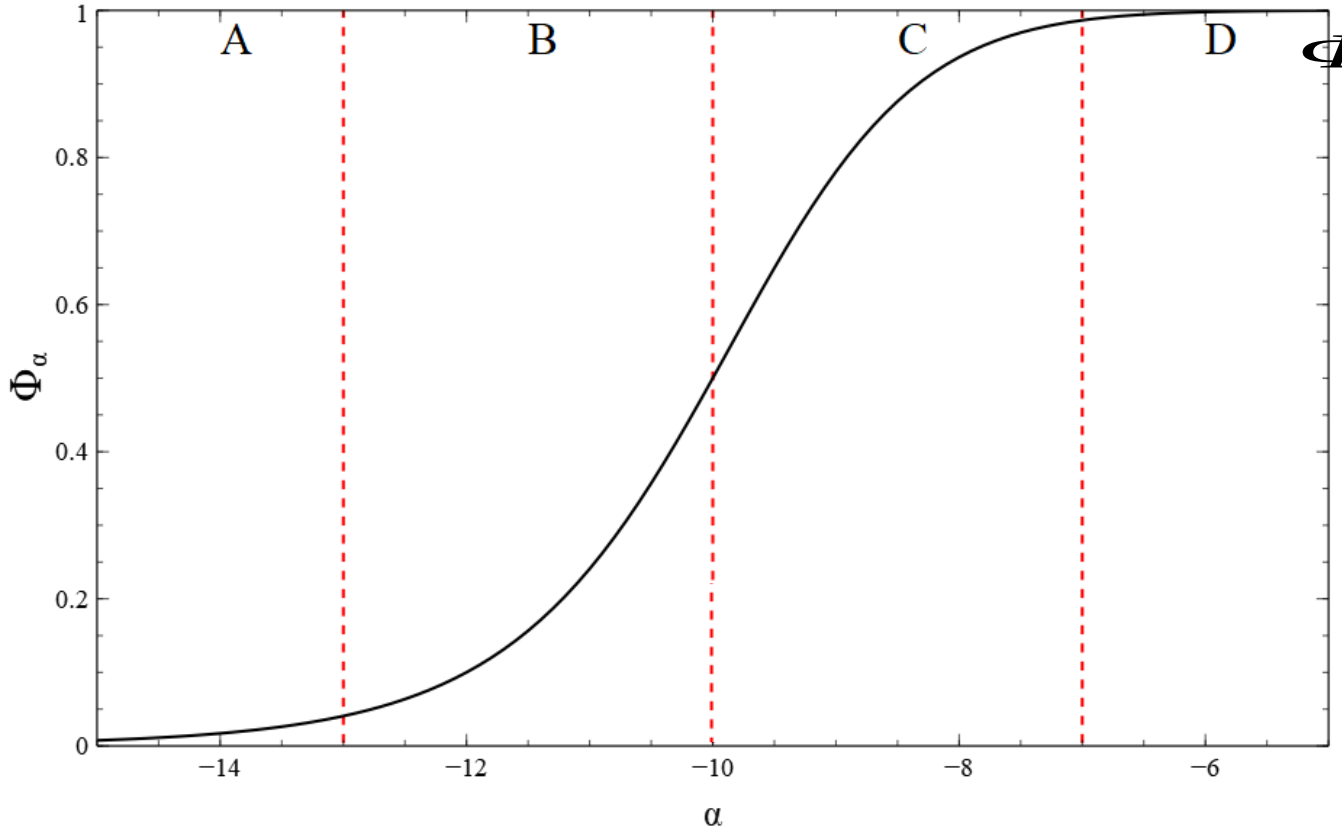




Prototype REACH antenna design, July 2020

Mozdzen et al. 2017, 2019

Proper scaling explanation



$$\Phi = \left(1 + \left(\frac{F}{x}\right)^{\alpha}\right)^{-1}$$

F: scaled figure of merit

x: defined on optimal and required values of FoM

A: Better than required, improve elsewhere.

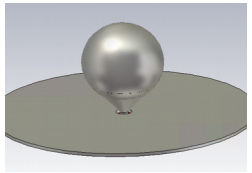
B: Diminishing returns, start to improve elsewhere.

C: Approaching optimal value.

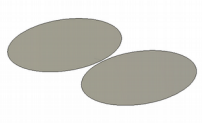
D: Unacceptable, requires improvement.

Candidate antennas

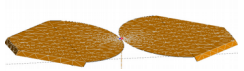
MONOPOLE



BROADBAND DIPOLE



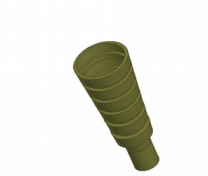
Elliptical Dipole



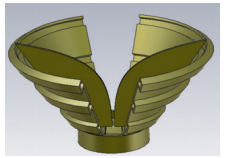
Trapezoidal Dipole

Bulbous Dipole

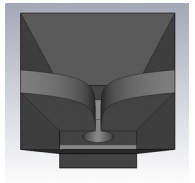
APERTURE / HORN



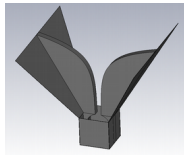
Corrugated Horn



TEM Corr. Horn

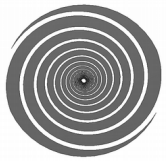


Rectangular Horn

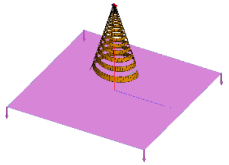


Rect. Horn (2 Walls)

LOG-PERIODIC



Planar Spiral



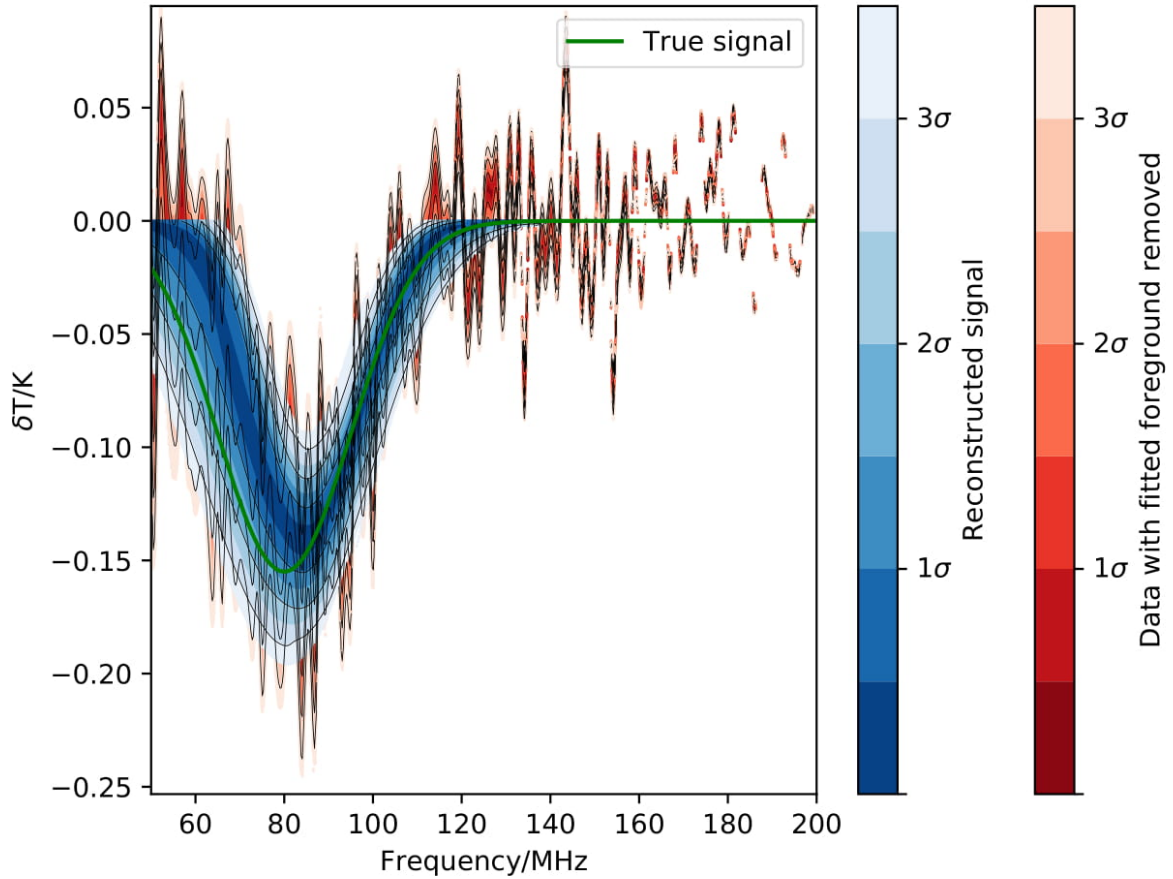
Conical Spiral

Pyramidal Sinuous

Conical Sinuous

Candidate selection

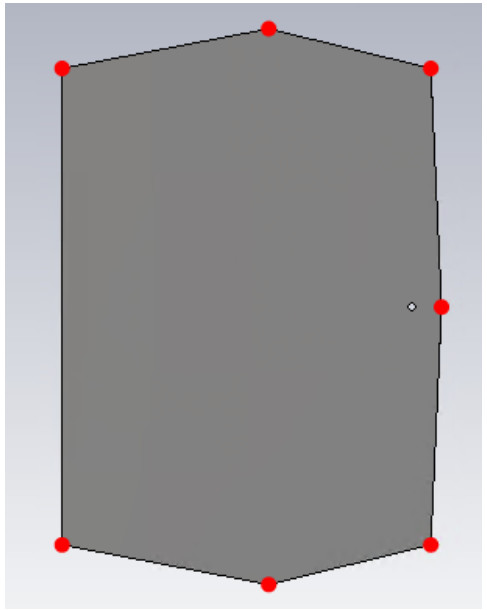
- Conical log spiral and blade dipole best in mock detection pipeline performance
- Significantly easier to construct and model the dipole than conical log spiral type

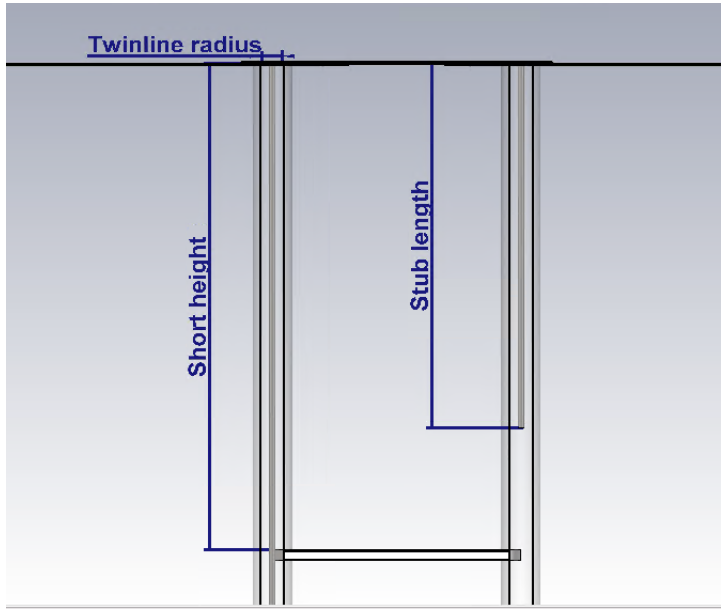


Reconstructed signal for a blade dipole antenna

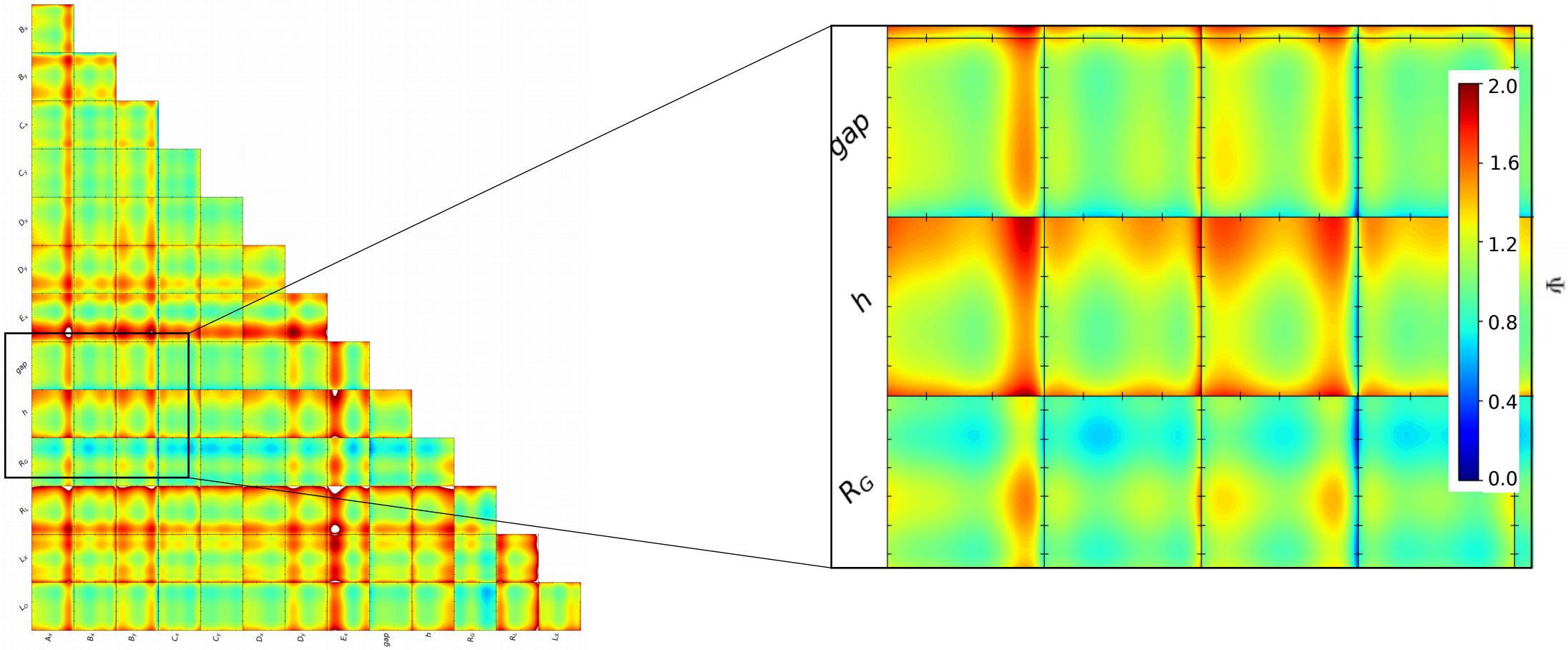
Parameter variation & sampling

- 14 Parameters:
  - 7 blade points
  - 4 balun structure
  - Distance between blades
  - Ground plane radius
  - Antenna height





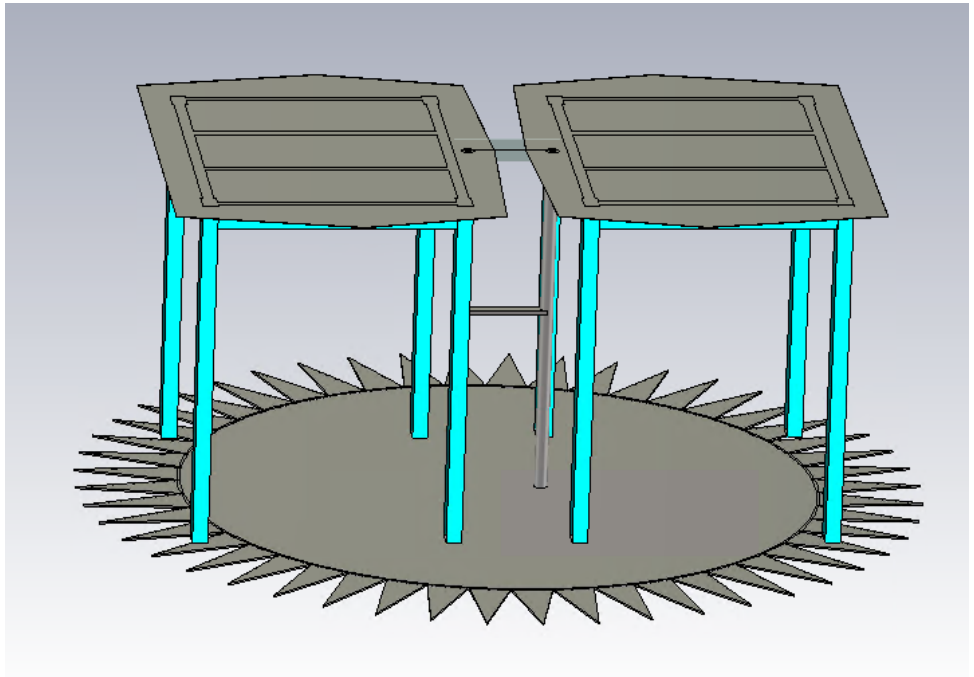
Polynomial fit for the figures of merit



$$\Psi = \sqrt{W_\sigma \Phi_\sigma^2 + W_\alpha \Phi_\alpha^2 + W_\beta \Phi_\beta^2 + W_\gamma \Phi_\gamma^2 + W_\delta \Phi_\delta^2}.$$

Here refitted with a sum of 14, 6th order polynomials (one per parameter)

First prototype

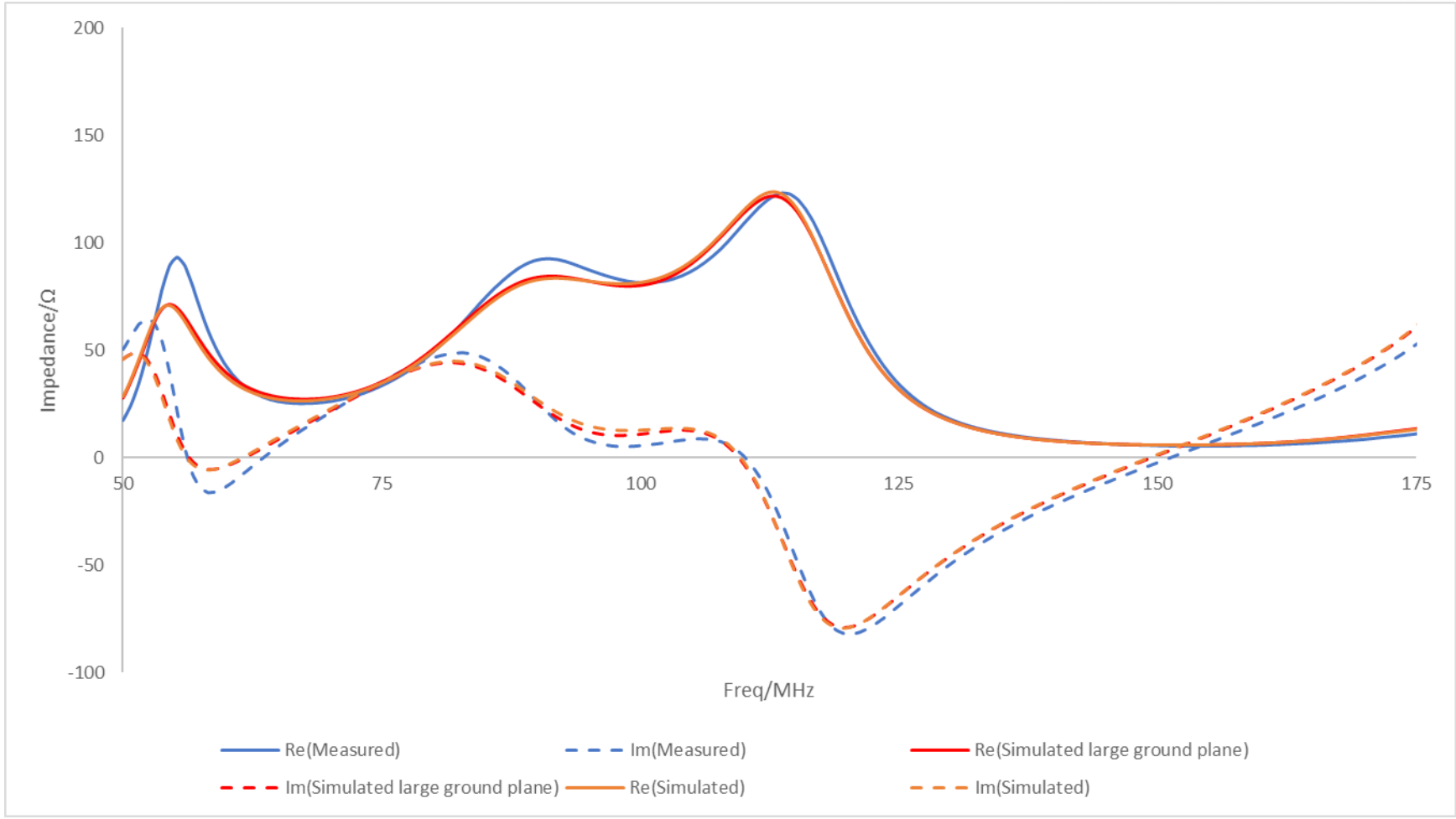


CST model

Prototype on the roof of Stellenbosh University

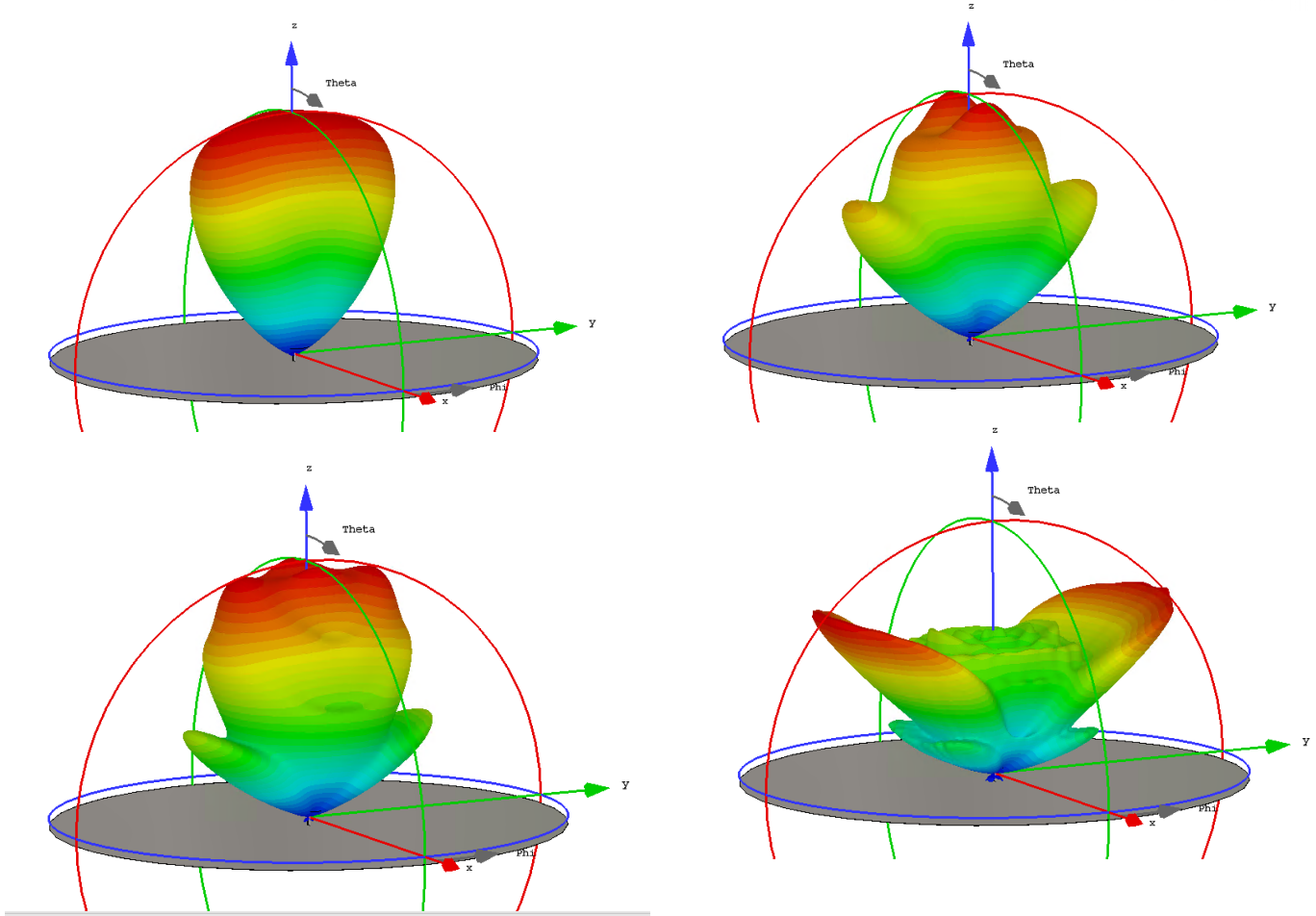
Simulation verification

- Initial verification of simulation and construction methods.
- Extra 250mm transmission line added to the simulation



What next?
Antenna beam uncertainties

- Assumed CST produces field accurate models for beam directivity
- Is this accurate?
- How can we mitigate it?



Some example dipole beams (This is NOT the REACH dipole)

REACH

CAVENDISH ASTROPHYSICS
CM-WAVE EXPERIMENTAL RADIO COSMOLOGY

Science Technology Engineering Mathematics

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