Antenna design for a Global 21 cm experiment: REACH

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The REACH approach

• Priority to understand all parts of the system.

• Compensate for systematics present

• Inbuilding analysis pipeline into design process
Design process

Antenna design style selection

Mock detection pipeline and figure of merit assessment

Blade dipole

Large sample space generated using EM solver

Large number of designs

Prototypes

Figure of merit refinement

Mock detection pipeline

Principle component analysis

Conical log spiral

Preliminary design
Antenna temperature

\[ T_{\text{ant}}(v) = \frac{1}{4\pi} \int D(v, \Omega) (T_{\text{sky}}(t, v, \Omega) + I_1(v)(\Omega) + I_2(v)(\Omega)) (1 - |F_A(v)|^2) \left( G_{\text{Rx}}(t, v) + N(t, v) \right) dt \]
Figures of Merit approach

• Quantifiable values for the most important aspects of the antenna:
  • Beam chromaticity ($\sigma$)
  • Antenna impedance ($\alpha, \beta, \gamma, \delta$)
  • 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

Prototype REACH antenna design, July 2020

Mozdzen et al. 2017, 2019
Proper scaling explanation

\[
\Phi = \left( \frac{1}{1 + \left( \frac{F}{x} \right)^4} \right)^{-1}
\]

- **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
- Aperture / Horn
- Log-Periodic

**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

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

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)