Designing, building and testing an RFI horizon antenna for radio frequency interference mitigation

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SUMMARY

The radio frequency interference (RFI) horizon antenna is designed to detect frequencies at which radio frequency interference occurs, so that they can be filtered out of radio observations. The antenna was designed in CST Studio Suite and tested at the Algonquin Radio Observatory (ARO). Preliminary tests suggest that the antenna is performing well. Future work, including further tests and possible design modifications, is still necessary to optimise the antenna's performance.

INTRODUCTION

One of the main difficulties in radio astronomy is that measurements are easily polluted by RFI from man-made sources. This includes signals from radio stations, power lines and even mobile phones. The goal of the RFI 'horizon' antenna is to detect when and at which frequencies this interference happens, so that is can be discarded from measurements. In particular, this antenna isn't pointed at the sky, but rather at the horizon, so that it solely detects man-made radio signals rather than those reaching us from space. To be of use to modern radio telescopes, such an antenna needs to be ultra-wide band, have a large field of view and have high sensitivity.

Figure 1: The horizon antenna set up for testing at the Algonquin Radio Observatory.

METHODS

Designing the antenna in CST

The antenna design was performed using CST Studio Suite, a widely-used EM simulation package. The building block of the antenna design is referred to as a 'petal', and is essentially a modified Vivaldi feed (Mackay et al. (2023)). The first step in building the antenna was to make sure the petals were working as expected. That is, the petals needed good S_{11} parameters, a close impedance match with the LNAs that would be attached to it, and farfield plots that show it has high sensitivity.

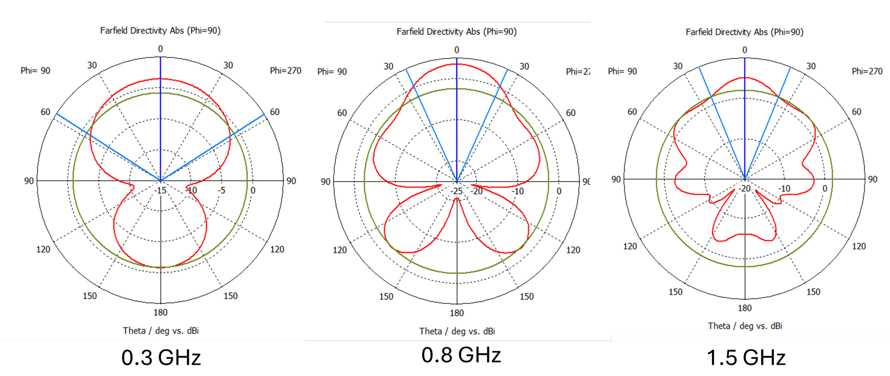

Figure 2: Farfield plots for a single petal at 0.3, 0.8 and 1.5 GHz. The farfield plots give the petal's radiation pattern and gain in a given direction.

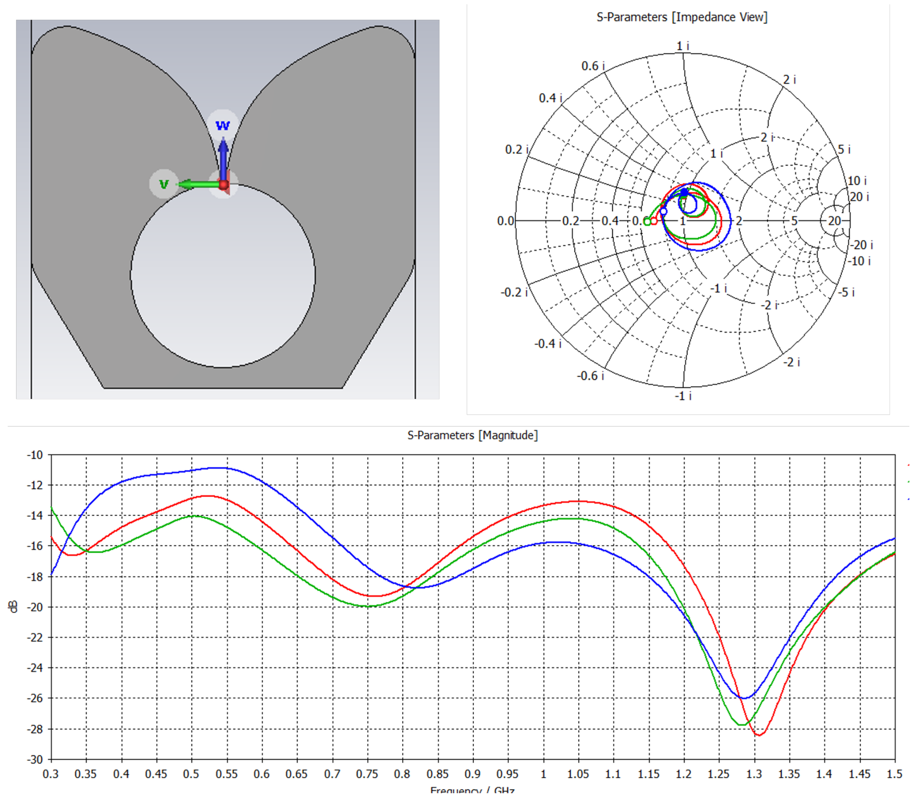

Figure 3: **Top left** A petal. **Top right** Smith chart showing petal impedance for backshort radii of 50mm (blue), 70mm (red), and 90mm (green), normalized to the LNA's minimum noise impedance. **Bottom** S_{11} parameters of the petal for the same radii, with low S_{11} values indicating better performance.

The final antenna model is shown below:

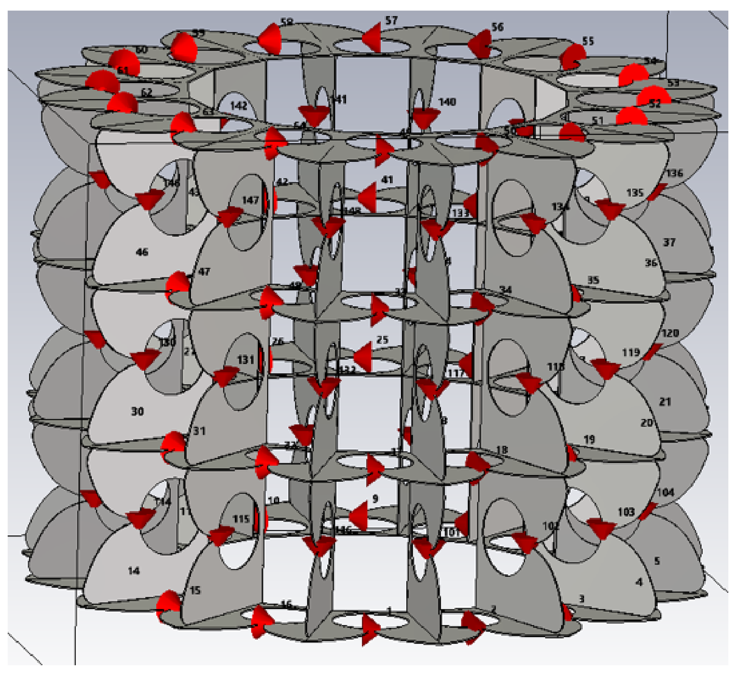

Figure 4: Final design of the horizon antenna in CST. It is 1.125m high, 1.619m wide and has 112 ports.

Assembling the antenna

Assembling the antenna involved cutting it from aluminum sheets, including slots and screw holes. Only a third of the 360° antenna was made, spanning 120°. Assembly took about 2 hours with 3 people. Four 1st and 2nd stage amplifiers were connected. The final product is shown in Figure 1.

Testing the antenna at the Algonquin Radio Observatory

Testing occurred at the Algonquin Radio Observatory (ARO), which has low RFI and enabled better signal analysis and performance verification. The setup was as follows:

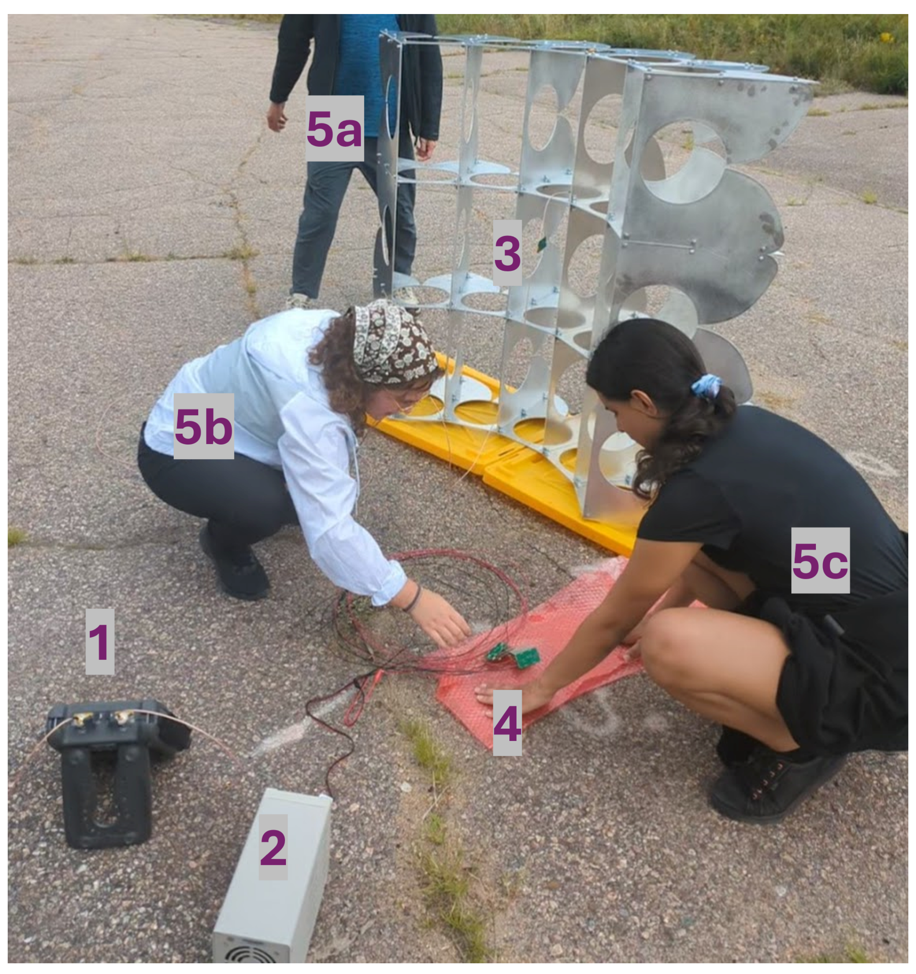

Figure 5: Setup for the antenna test. 1.VNA, 2.Power supply, 3. 1^{st} stage amplifier, 4. 2^{nd} stage amplifiers, 5a,5b,5c. helpful people. Not pictured is a 1GHz antenna that was used to emit signals 40m away from the horizon antenna.

To test the RFI antenna, we placed a 1GHz emitter 40m away and looked for a 1GHz peak on the VNA. We repeated this for multiple ports, connecting to each individually, and then combined the signals from three ports.

RESULTS

The plot below shows the signal detected when the VNA was connected to a port on the top row of petals. There is a clear peak at 1GHz, indicating that the RFI antenna is detecting the signal emitted from the antenna placed 40m away.

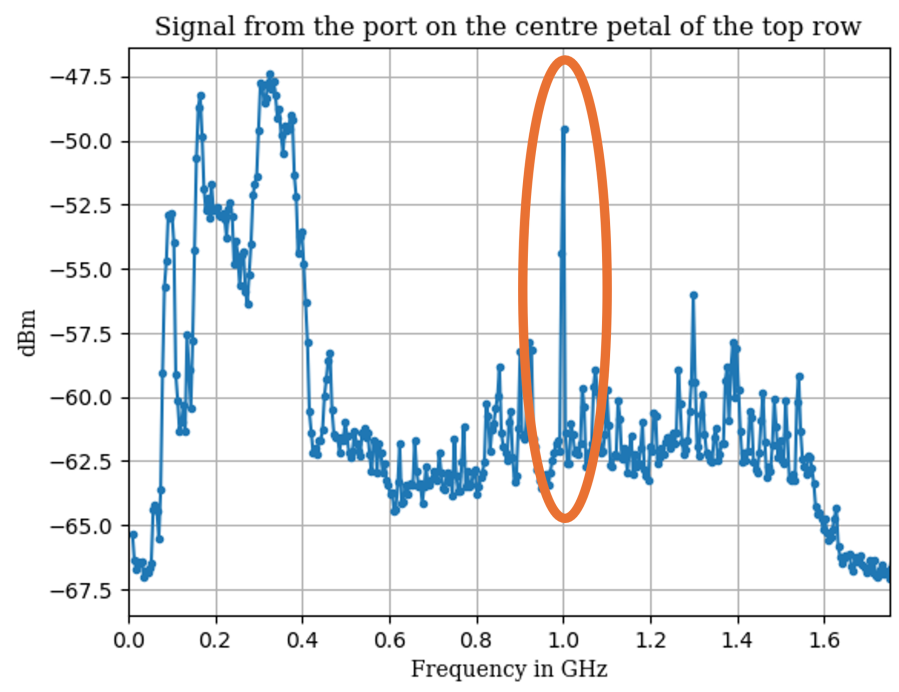

Figure 6: Plot of the signal detected from central petal on the top row of the antenna, as a function of frequency. The signal emitted from the second antenna placed 40m away is clearly visible as a peak at 1GHz.

Due to time and weather constraints and some technical difficulties, this was the extent of the data we were able to collect at ARO. However, it is enough to suggest the antenna is working.

DISCUSSION & CHALLENGES

- A key challenge was ensuring that the antenna's impedance matched the LNA's minimum noise impedance, to minimize additional noise and maximize the SNR. To achieve this, the antenna's impedance needs to be close to 1 on the Smith Chart, given that the chart is normalized to the LNA's minimum noise impedance. This required adjusting the shape of the petals and analyzing how these changes affected the Smith Chart. I eventually developed a petal design that gave satisfactory results.
- At 0.9 GHz, an unexpected null appeared in some of the petals' farfield plots. As shown in Figure 7, peaks appear on either side of the petal's centre, where there is a dip. The source of the null was unclear and puzzling for a long time, but it was eventually concluded to be a non-issue. This is because the peaks of adjacent petals at the same frequency point towards the nulls of the other petals. Therefore, the overall gain in the direction of a petal's null remains high.

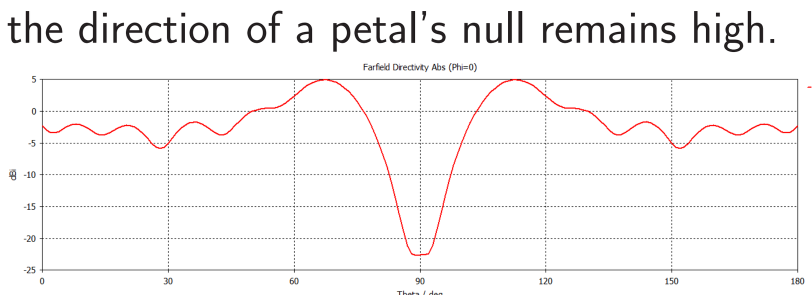

Figure 7: Plot of the farfield directivity at 0.9 GHz of one of the antenna's petals, at $\phi = 0°$. A null is visible at $\theta = 90°$ and symmetric peaks occur at $\theta \approx 70°$ and $\theta \approx 110°$.

- Getting sufficient gain in the horizontal direction was also challenging. The antenna was designed with the CHORD telescope in mind, aiming for it to be several times more sensitive to the horizon than the CHORD array itself. The key factor was the size and number of petals: more petals increase sensitivity but can also increase cross-talk, leading to double-counted signals. To balance all this, we converged on the antenna's current shape, which provides high enough sensitivity to be used for CHORD while limiting cross-talk between petals.

FUTURE WORK

- Early-stage tests suggest the horizon antenna is picking up RFI accurately, but more tests are needed to confirm this
- Measurements were taken for only one of the antenna's polarizations, so it is necessary to measure the other one too.
- Due to technical difficulties with some boards, we were dissatisfied with measurements combining signals from multiple ports, requiring a retest.
- Assembly and disassembly of the antenna is time-consuming, taking around 6 hours each for the full antenna. A more efficient assembly method, such as different manufacturing or fewer screws, would help.
- The antenna's current set-up tells us at which frequency RFI occurs. In the future, it would be interesting to develop a way to also determine the direction from which the RFI is coming, so that the source can be identified. This would require a more complete and complex set-up, with amplifiers at every petal.

CONCLUSION

In conclusion, the antenna shows promising potential, but further testing is required to confirm it is performing as expected.

Figure 8: Me standing next to the horizon antenna at the Algonquin Radio Observatory. The red bubble wrap is used to weather-proof the LNAs attached the the petals and the yellow boards are used to elevate the antenna off the ground.

REFERENCES

Mackay, V., Lai, M., Shmerko, P., Wulf, D., Belostotski, L., & Vanderlinde, K. (2023, January). Low-Cost, Low-Loss, Ultra-Wideband Compact Feed for Interferometric Radio Telescopes. *Journal of Astronomical Instrumentation*, *12*(4), 2350008. doi: 10.1142/S2251171723500083

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