SCISRS: Signal Cancellation using Intelligent Surfaces for Radio Astronomy Services

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Motivation

- Radio Frequency Interference (RFI) from space- and air-borne mobile transmitters, e.g., airplanes, LEO satellites, unmanned aerial vehicles (UAVs).
- Active collaboration will introduce more RFI, hence need passive methods.
- Mobile RFI will result in time-varying DoA and RFI characteristics.
- **Opportunity:** Reuse spectrum for Radio Astronomy Services (RAS) if RFI is continuously eliminated from the telescope.
- *First work* to cancel RFI in radio telescope using Reconfigurable Intelligent Surface (RIS).

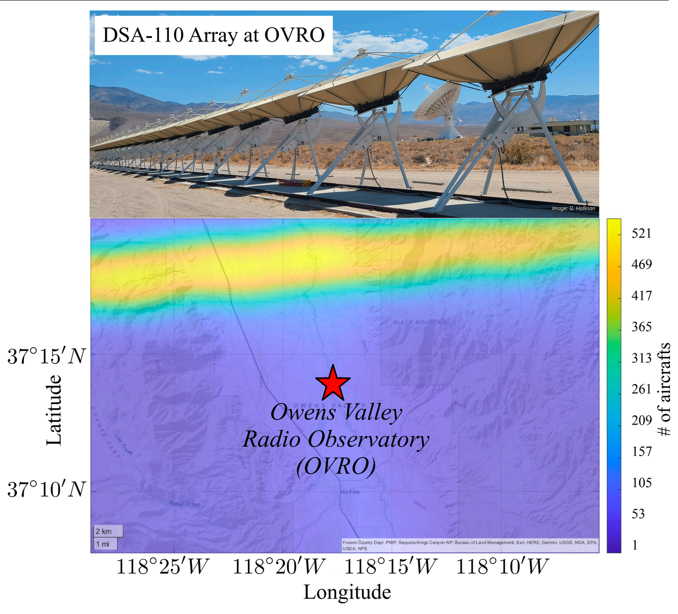


Figure 1. Air traffic density around OVRO.

Project Summary

Objectives:

- **Cancel incident RFI** at the telescope receiver by creating a destructive wavefront using a RIS.
- Create an **EM quiet zone** around the telescope receiver.
- **Remove RFI** before it reaches the ADCs of the telescope.
- **Eliminate** post-processing and excision.

Main Stages:

- RFI Detector and Estimator:
  - Estimate DoA, phase-amplitude of the incident RFI from airborne sources as rborne RFI source at very low SNR.
- RIS Beamformer and Tuner:
  - Dynamically change the RIS element phases to steer the incident RFI towards the telescope receiver.
- Real-time Feedback:
  - Provide feedback from the telescope to fine-tune the beamformer

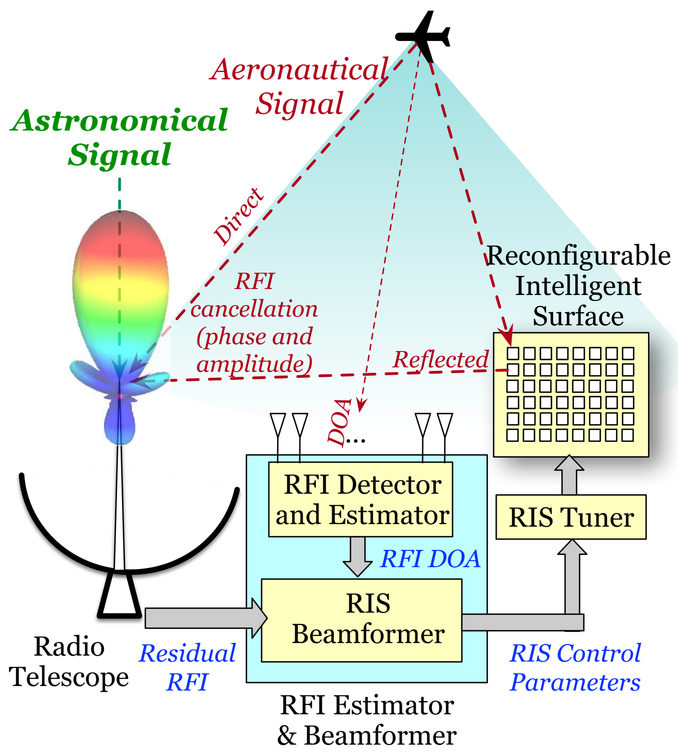


Figure 2. Cancel RFI from airborne transmitters at the radio telescope by RIS.

SCISRS: System Model

- Received RFI power at telescope (Friis formula)

$$P_R = P_T \frac{G_T G_R \lambda^2}{(4\pi d)^2}$$

- Received signal at telescope after introduction of RIS:

$$y = \underbrace{a_d e^{j\phi_d} x}_{\text{LOS path}} + \underbrace{\Sigma_{m=1}^{M} \Sigma_{n=1}^{N} a_{m,n} \Gamma_{m,n} e^{j\phi_{\Gamma_{m,n}}} x}_{\text{Reflected by } M \times N \text{ RIS array}} + v$$

- Perfect cancellation is achieved when the residual RFI, both *phase* and *amplitude*, measured at the receiver is "0"

$$\left| a_d e^{j\phi_d} + \Sigma_{m=1}^{M} \Sigma_{n=1}^{N} a_{m,n} \Gamma_{m,n} e^{j\phi_{\Gamma_{m,n}}} \right| = 0 \qquad (1)$$

- Phase Solution: the phase of the reflection coefficient for each element:

$$\phi_{\Gamma_{m,n}} = \pi + 2\pi \frac{d - r_{1_{m,n}} - r_{2_{m,n}}}{\lambda} \qquad (2)$$

- Amplitude Solution: the magnitude of the reflection coefficient:

$$|\Gamma_{m,n}| = \frac{4\pi r_1 r_2}{MNdG_r\lambda} \sqrt{\frac{G_R}{G_R'}} \qquad (3)$$

where G_r is the gain of each RIS element.

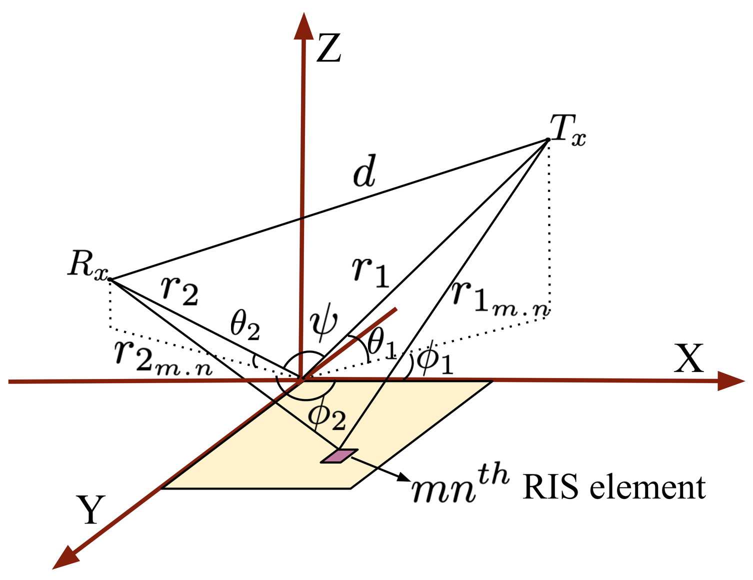
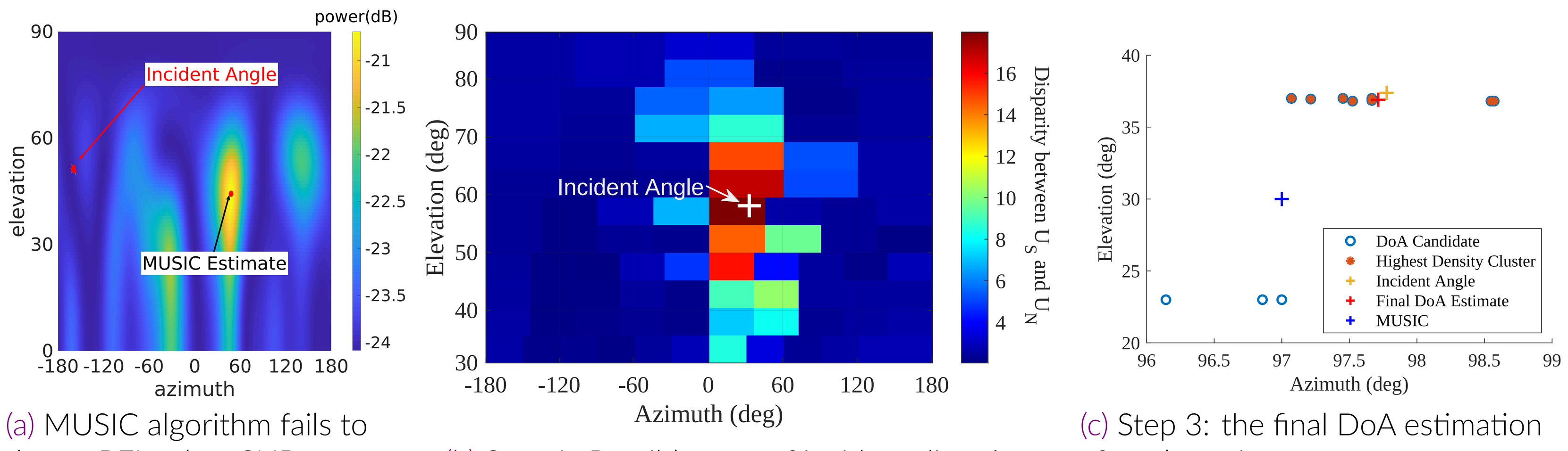


Figure 3. 3D geometric view of the RFI cancellation system:

- Given this 3D geometry, the goal is to design an $M \times N$ RIS array with prior knowledge of the DoA and the DoR (fixed) relative to the RIS array.

Direction of Arrival at Low SNR

- RAS operates at very low SNR (existing algorithms fail)
- Proposed IDOL: Iterative Direction Of Arrival in Low SNR
  – Coarse DoA Estimation, Fine-grain DoA Estimation, Iteration and Clustering
- Results outperform existing methods using ADS-B signals.



(a) MUSIC algorithm fails to detect RFI at low SNR. (b) Step 1: Possible area of incident direction. (c) Step 3: the final DoA estimation after clustering.

Figure 4. Output of IDOL

Broader Impacts

- **Spectral coexistence of active and passive services** will improve the sensitivity of the next-generation radio telescopes while expanding broadband connection to remote users.
- **Advancing education** by training graduate and undergraduate students in real time signal processing, wireless communication and RF instrumentation and RIS.
- **Bridge between radio astronomy and wireless community** through active dissemination of research results and design prototypes.

Reflection from RIS

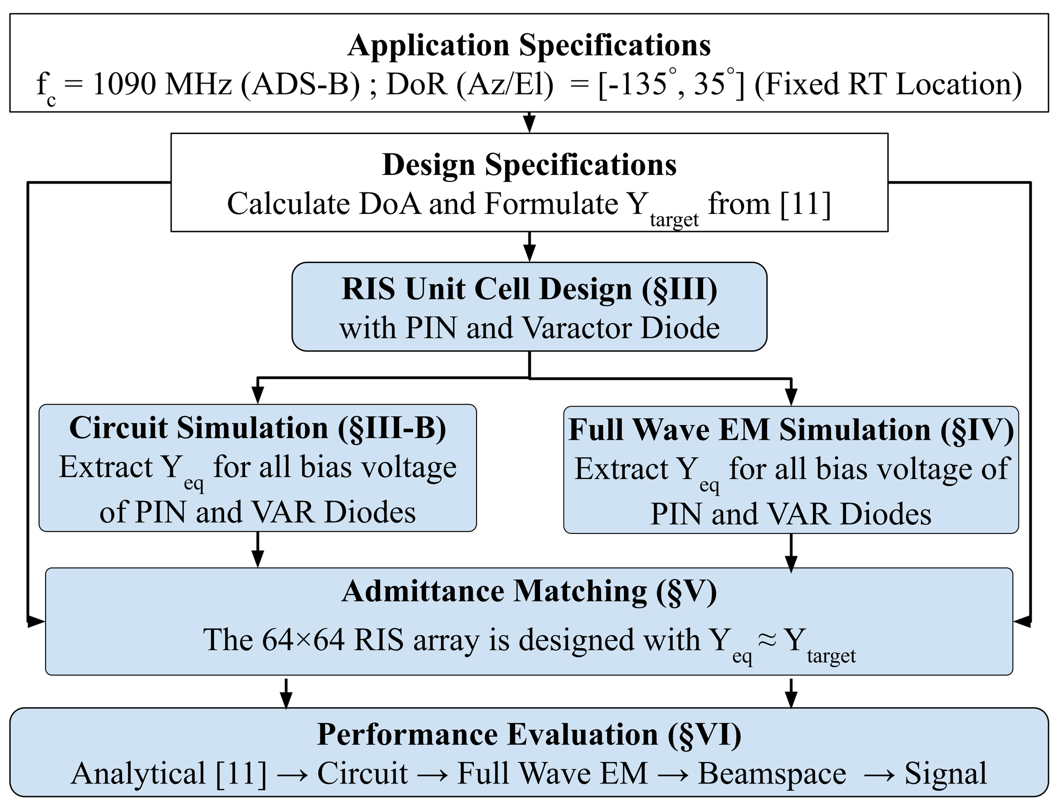
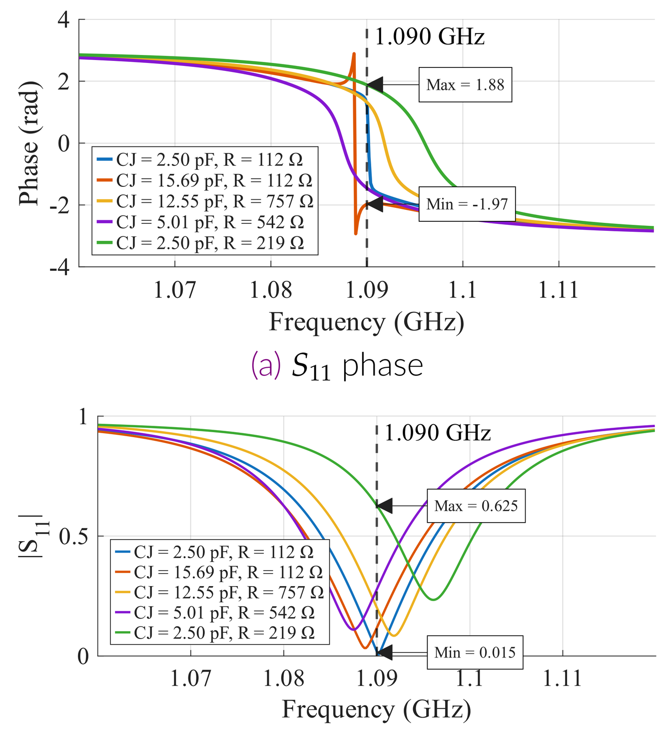


Figure 5. Design flow for RIS-based interference suppression



(a) S_{11} phase

(b) S_{11} magnitude

Figure 6. Full-wave electromagnetic (HFSS) simulation of the proposed RIS unit cell.

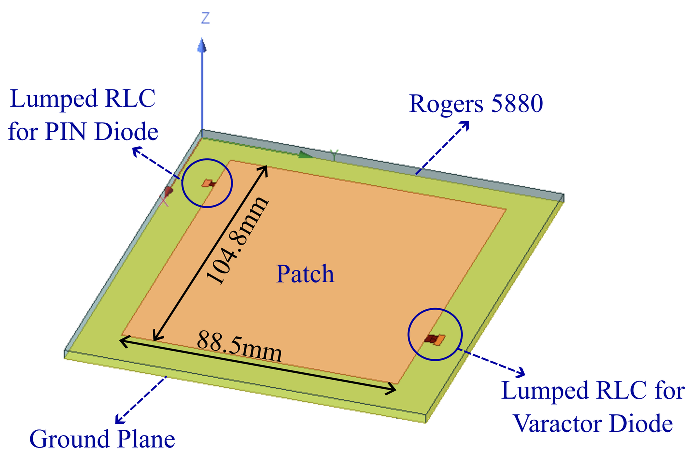


Figure 7. RIS unit cell layout (HFSS)

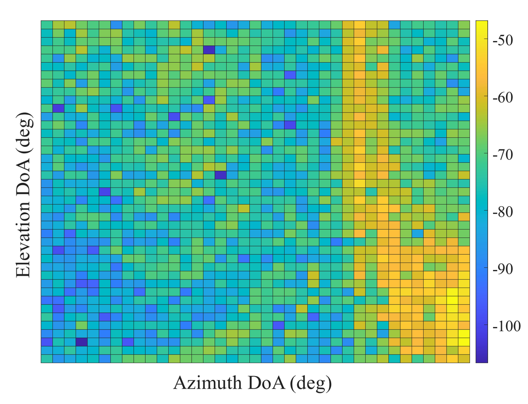


Figure 8. Beamspace error across direction of arrivals

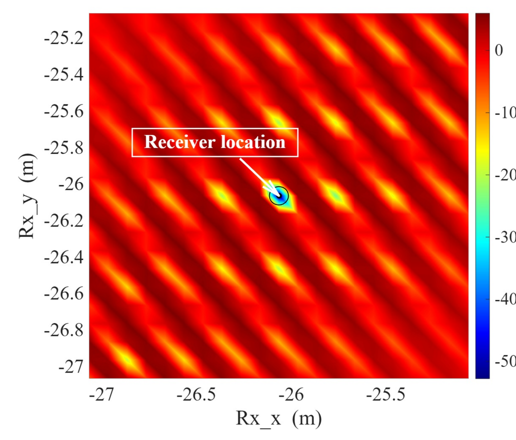
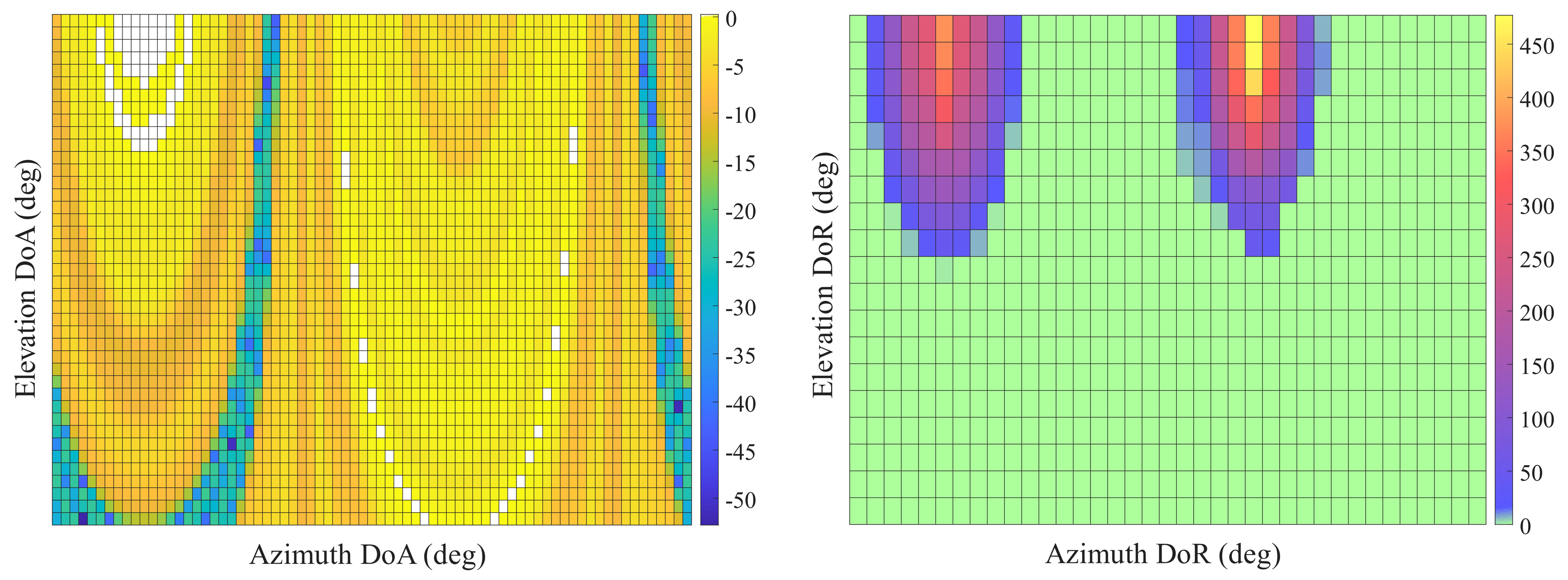


Figure 9. Dark zone formation at the receiver location

SCISRS: Simulation Results



(a) Cancellation error across 2993 DoAs and fixed DoR. (b) Number of failed DoAs for each DoR

Figure 10. RIS cancellation performance across incoming directions and reflection geometries.

RIS cancels interference over nearly all signal directions. Failures are rare and linked to array edge effects. Optimal DoR placement ensures consistent, reliable cancellation performance.

Hardware Implementation

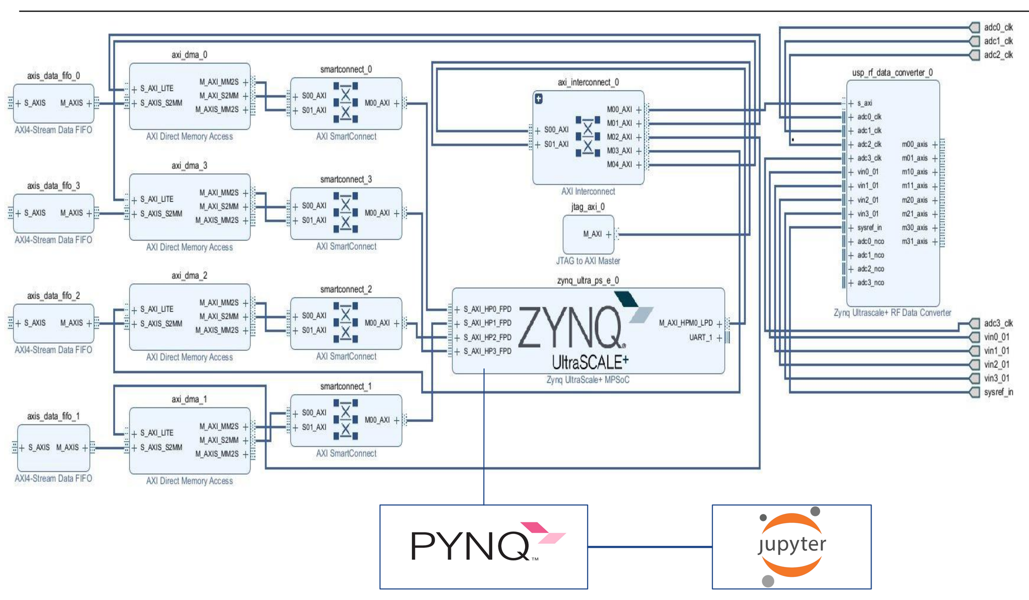


Figure 11. Block Diagram for Data Acquisition with ZU49DR

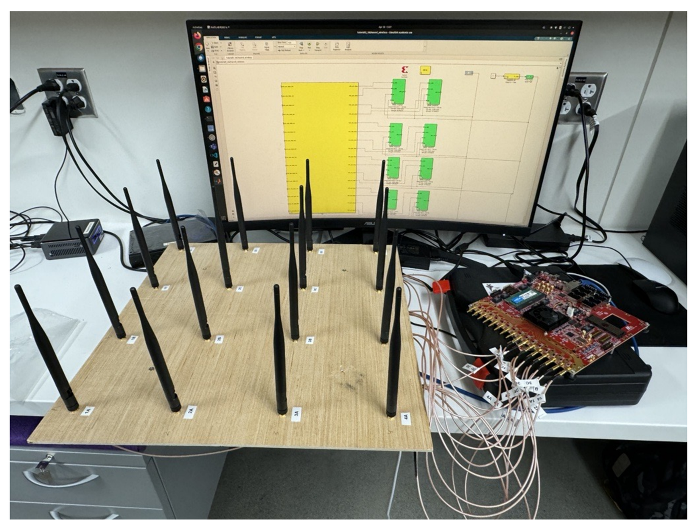
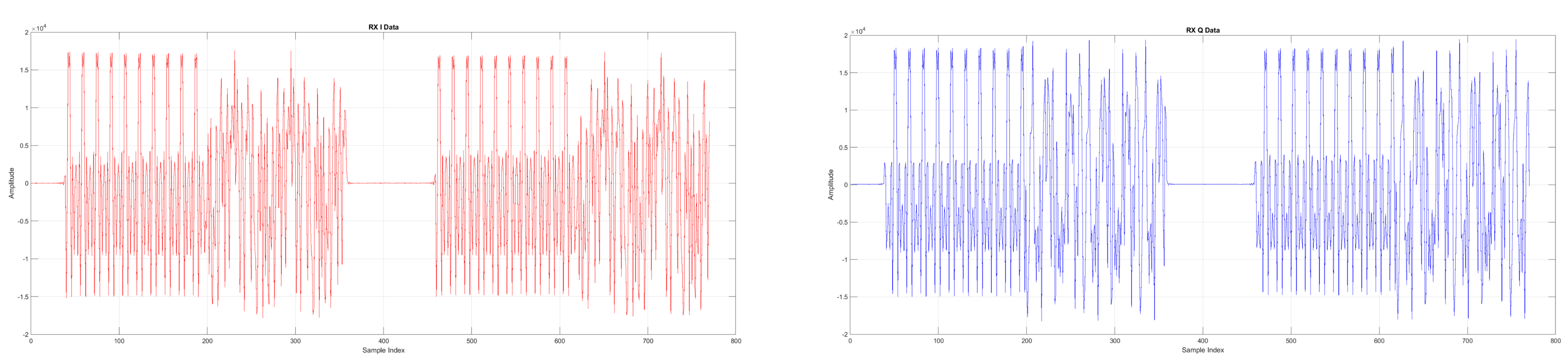


Figure 12. 16 channel Rx RFSoC.



(a) I Trace (b) Q trace

Figure 13. I/Q samples captured from the FPGA board

Publications

1. Zhibin Zou, Xue Wei, Dola Saha, Aveek Dutta, Gregory Hellbourg, *"SCISRS: Signal Cancellation using Intelligent Surfaces for Radio Astronomy Services"*, in **IEEE GLOBECOM 2022**.
2. Xue Wei, Dola Saha, Gregory Hellbourg and Aveek Dutta, *"Multistage 2D DOA Estimation in Low SNR"*, in **IEEE ICC 2023**.
3. Xue Wei, Anushka Gupta, Aveek Dutta, Dola Saha and Gregory Hellbourg, *"RIS for Signal Cancellation in 3D"*, in **IEEE DySPAN 2024**.
4. Xue Wei, Dola Saha, Gregory Hellbourg and Aveek Dutta, *"IDOL: Iterative Direction of Arrival in Low SNR"*, in **Journal of Astronomical Instrumentation**, Vol 14, 2025.
5. Anushka Gupta, Aveek Dutta, Dola Saha and Gregory Hellbourg, *Tunable RIS for Mitigating RFI in Radio Telescopes, Under Review*

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