`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.

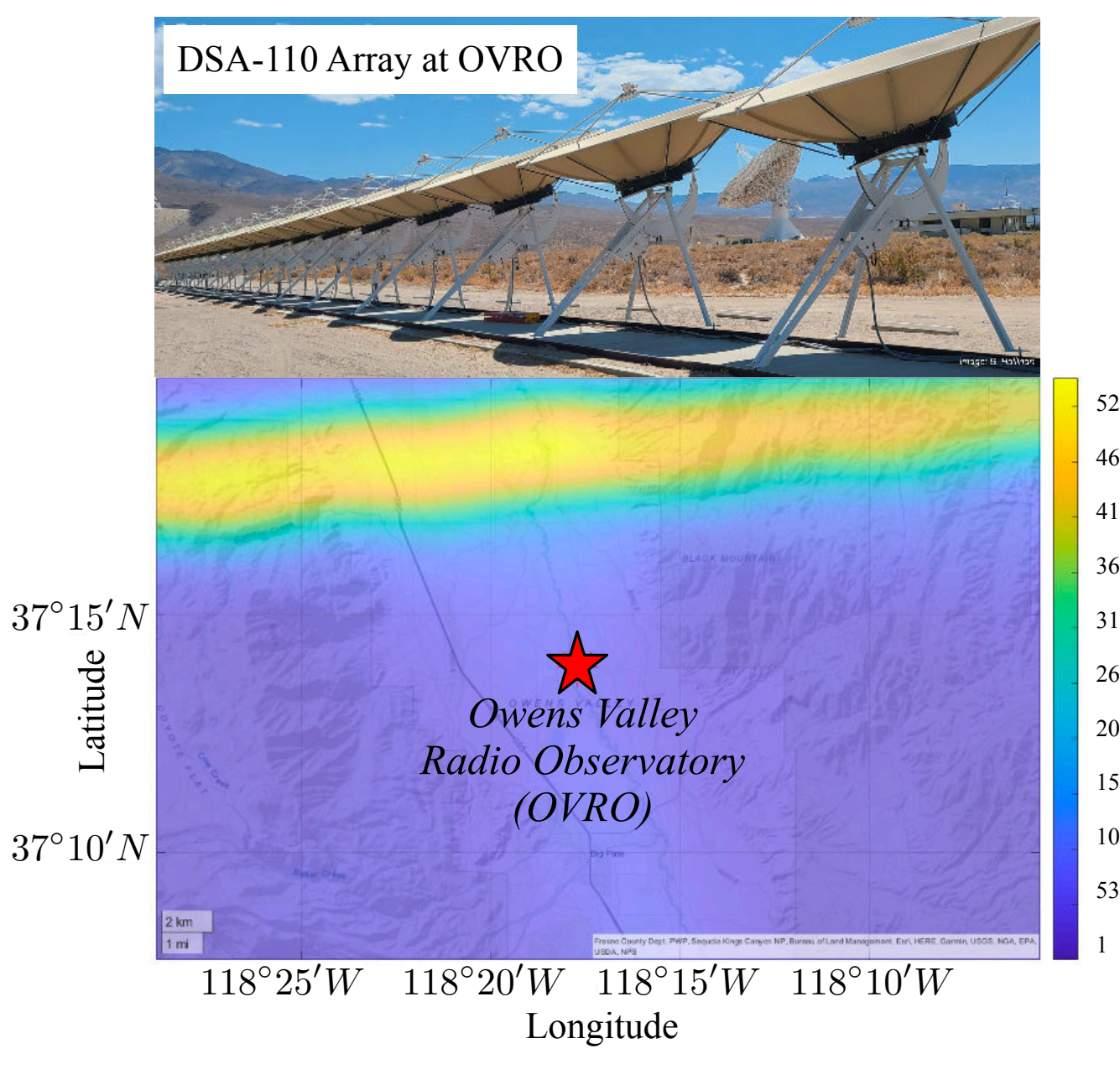


Figure 1. Air traffic density around OVRO.

Project Summary

First work to cancel RFI in radio telescope using Reconfigurable Intelligent Surface (RIS).

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:
  - Detect, estimate and track the DoA of the airborne RFI source at very low SNR.
  - Estimate phase and amplitude of the incident RFI at the telescope.
- 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

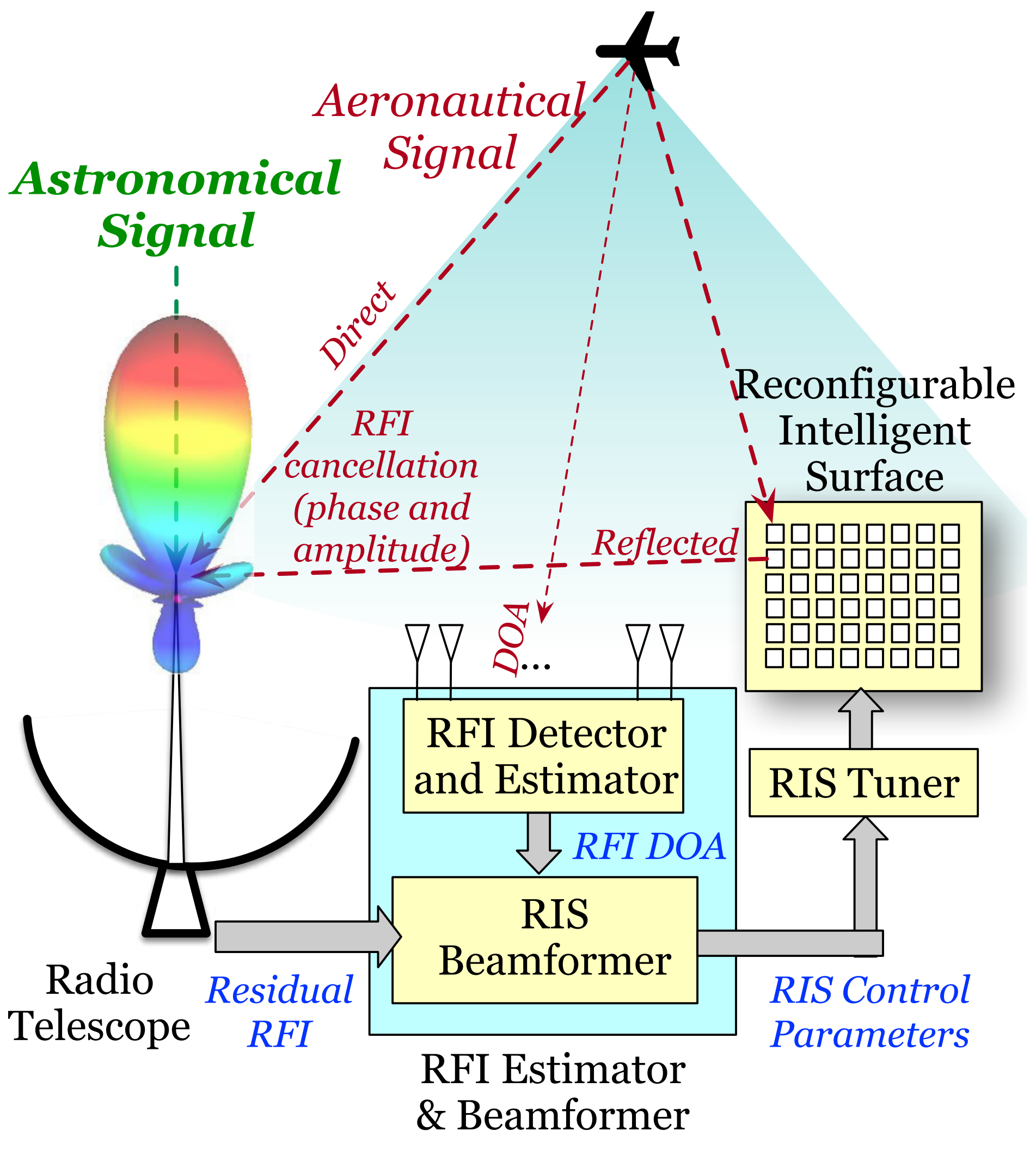


Figure 2. Cancelling RFI from airborne transmitters at the radio telescope by reconfigurable intelligent surfaces.

`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:

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

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

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

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

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

- **Amplitude Solution**: the magnitude of the reflection coefficient:

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

where G_r is the gain of each RIS element.

- r_1 is calculated using the 3D geometry shown in Figure 3 along with the knowledge of the DoA.

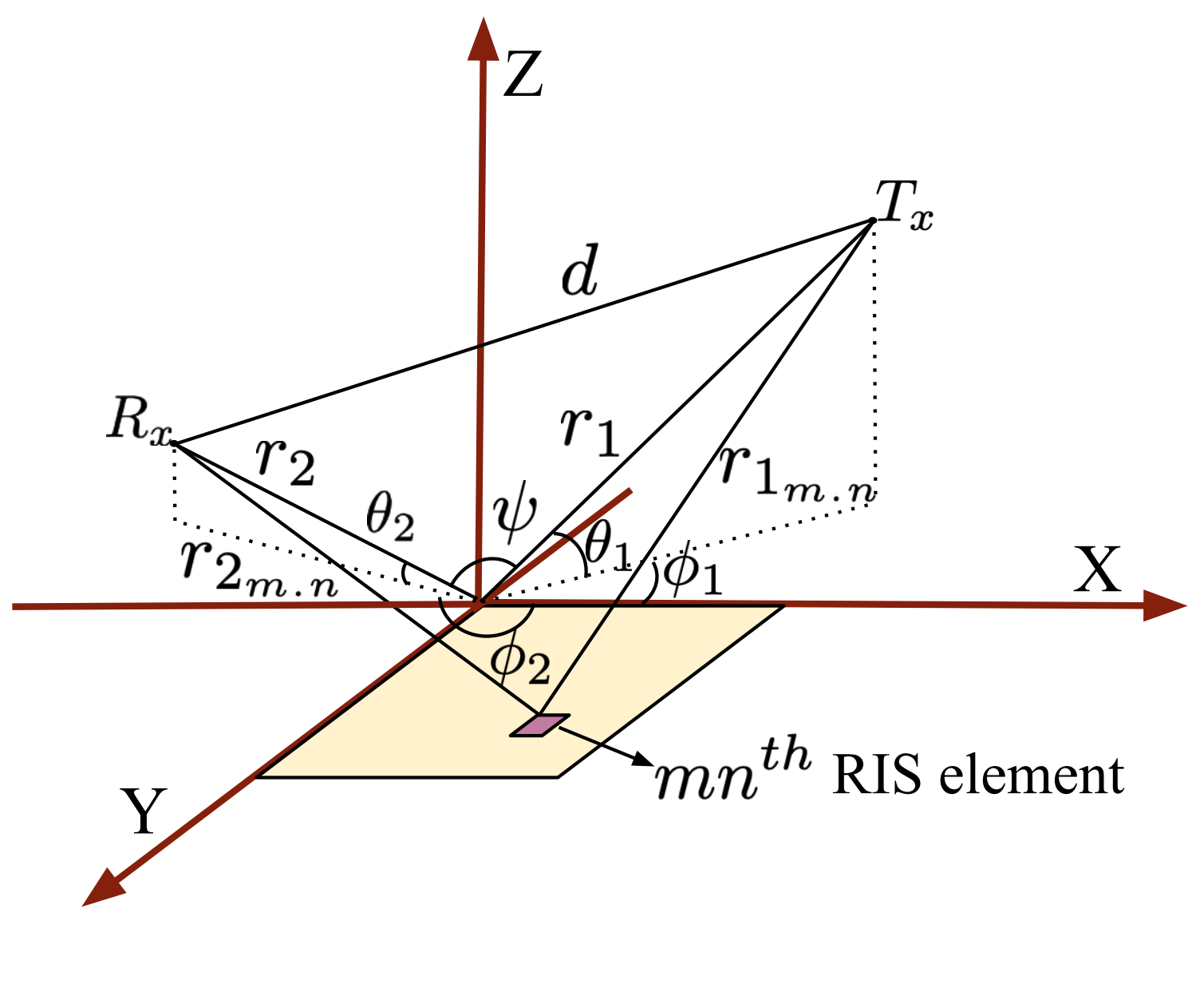
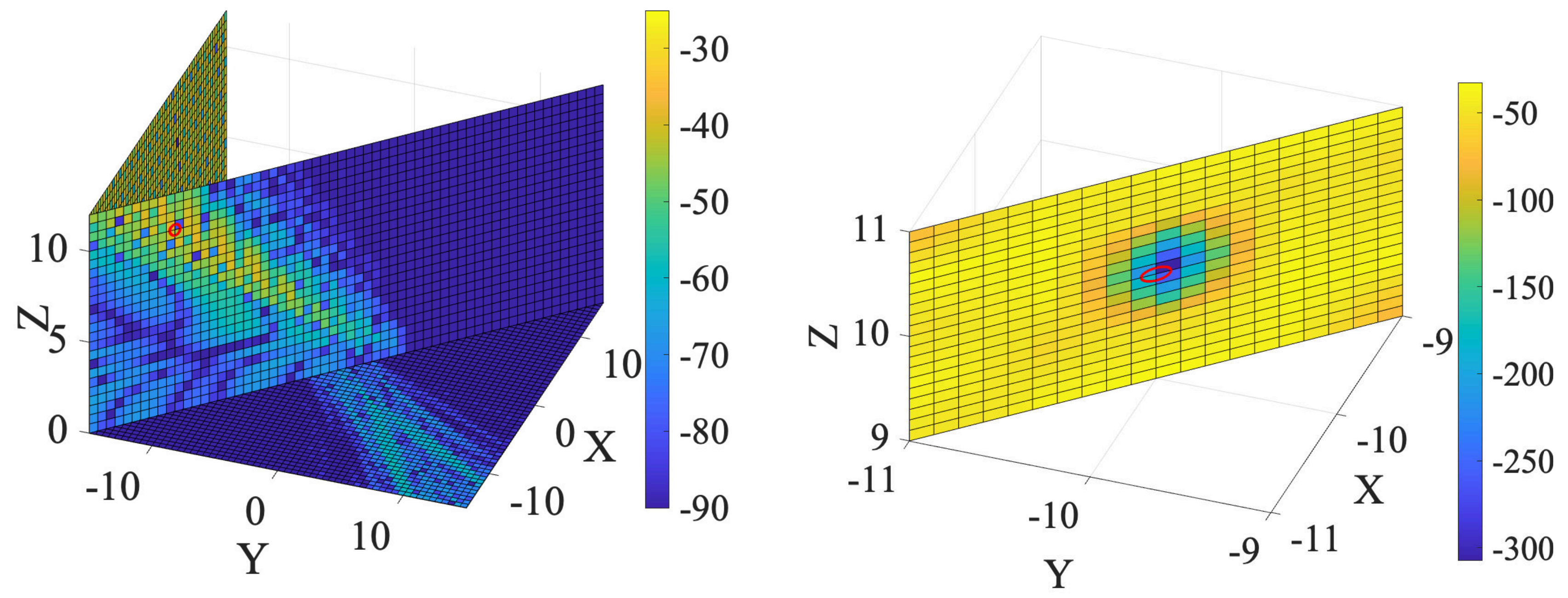


Figure 3. 3D geometric view of the RFI cancellation system: The airborne RFI source, T_x, with Az-El: $[\phi_1, \theta_1]$, is at an unknown distance, r_1 from the origin $(0,0,0)$, the top-left corner of the RIS located on the ground (X-Y) plane. The telescope receiver, R_x is located at a known distance, r_2 from the origin with a known Az-El: $[\phi_2, \theta_2]$.

- 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.

`SCISRS`: Simulation Results



(a) Energy field of the RIS reflected wave towards the R_x.

(b) Zoomed in EM Quiet Zone at the R_x location.

Figure 4. Dynamic Construction of *EM Quiet Zone* at the Radio Telescope.

Unlike National Radio Quiet zone, the ***EM quiet zone****, is dynamically created in a targeted small area around the radio telescope receiver where there is no radio signal.*

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.

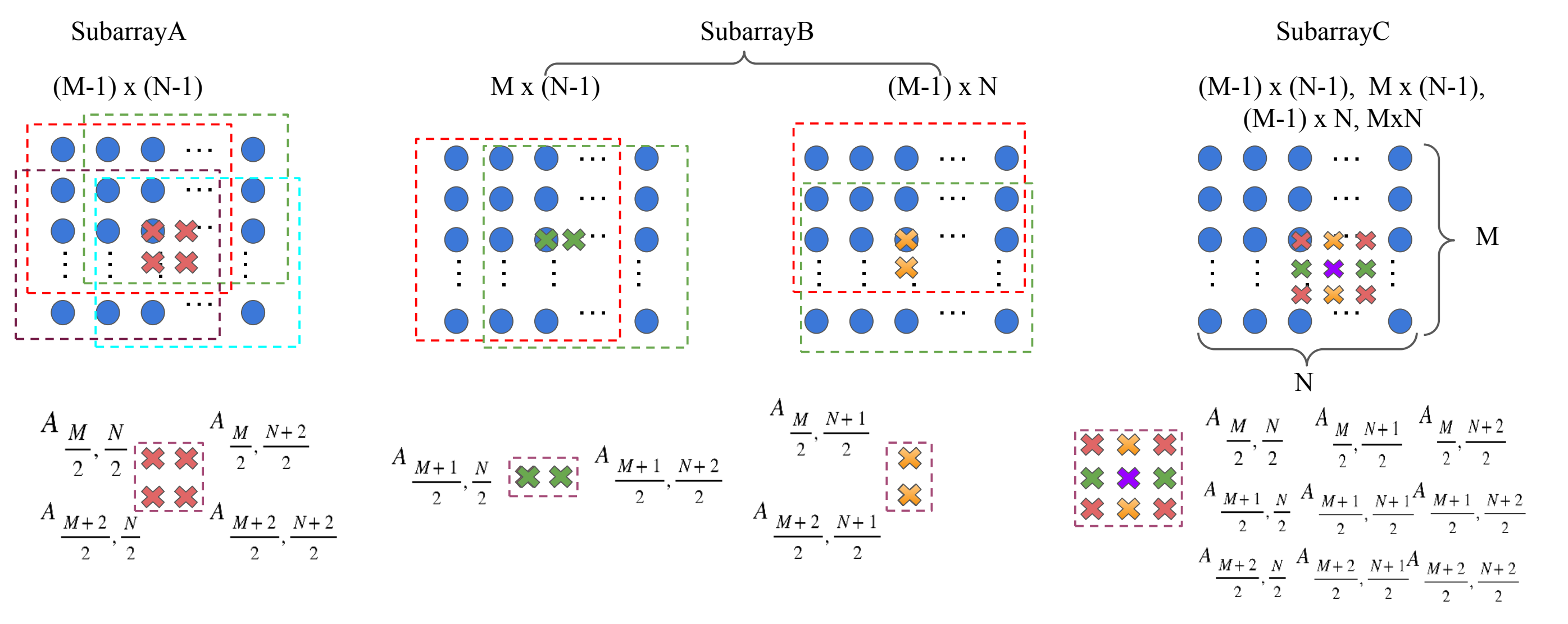


Figure 5. Different types of subarray configurations used in `IDOL` for accurate estimation of the DoA.

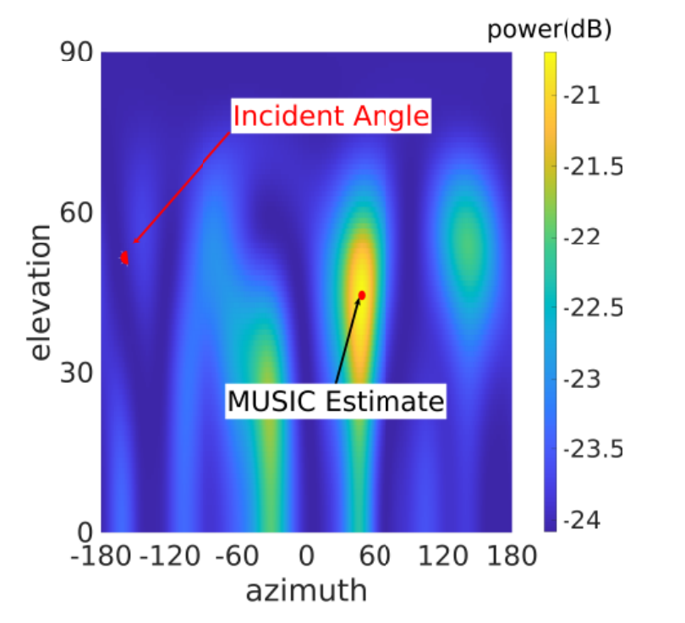
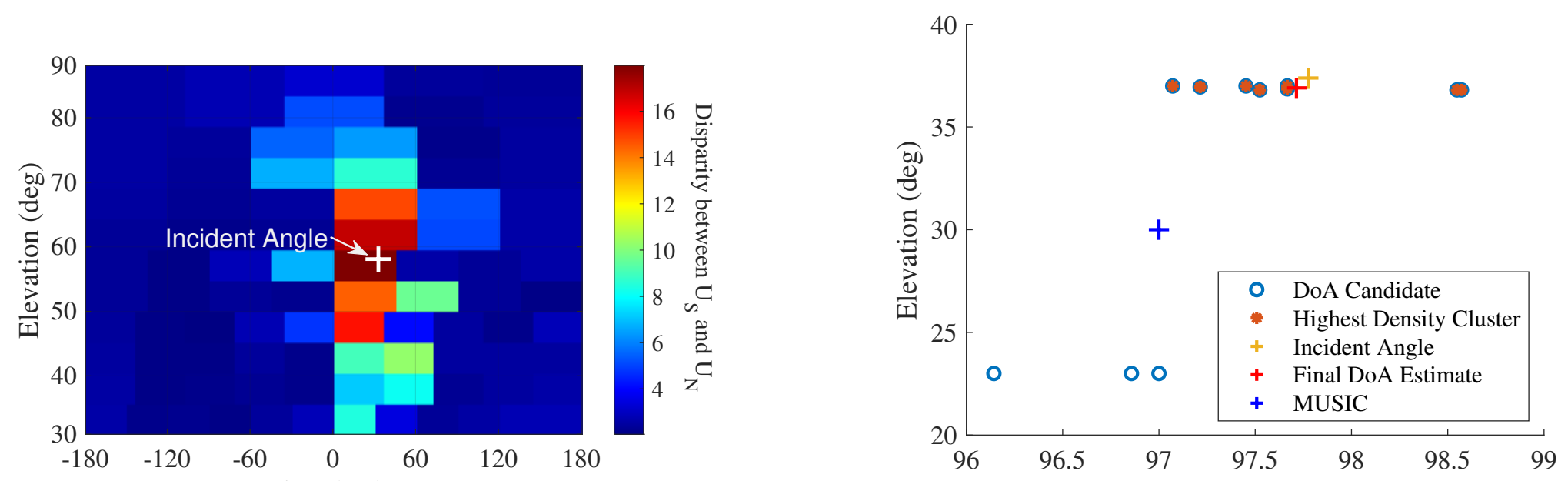


Figure 6. MUSIC algorithm fails to detect RFI at low SNR.

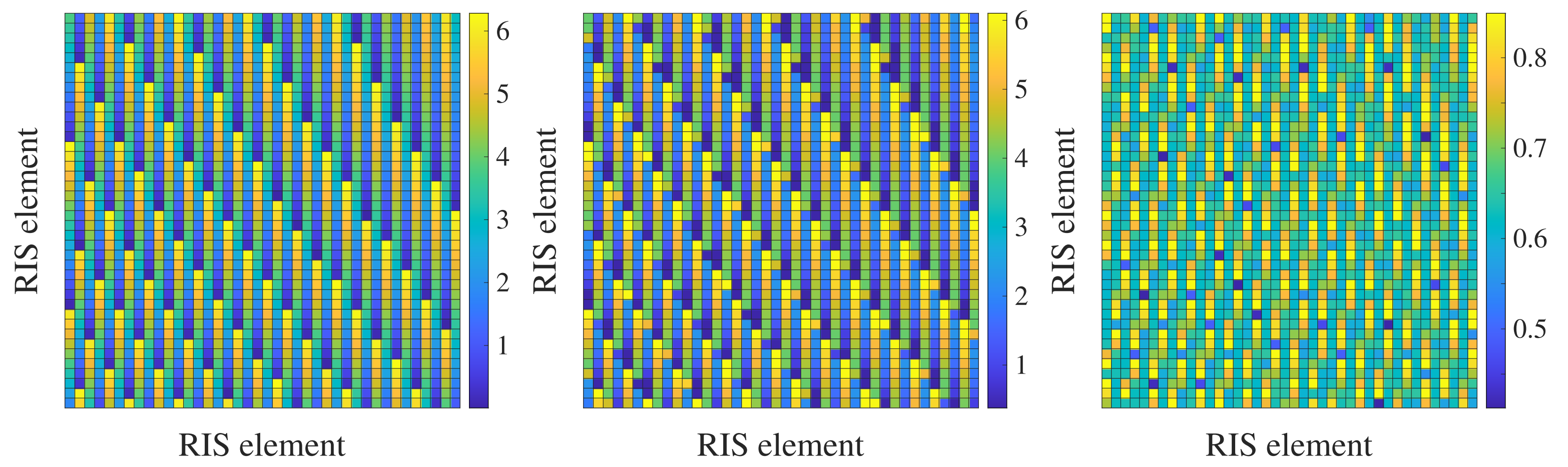


(a) Step 1: possible area of incident direction.

(b) Step 3: the final DoA estimation after clustering.

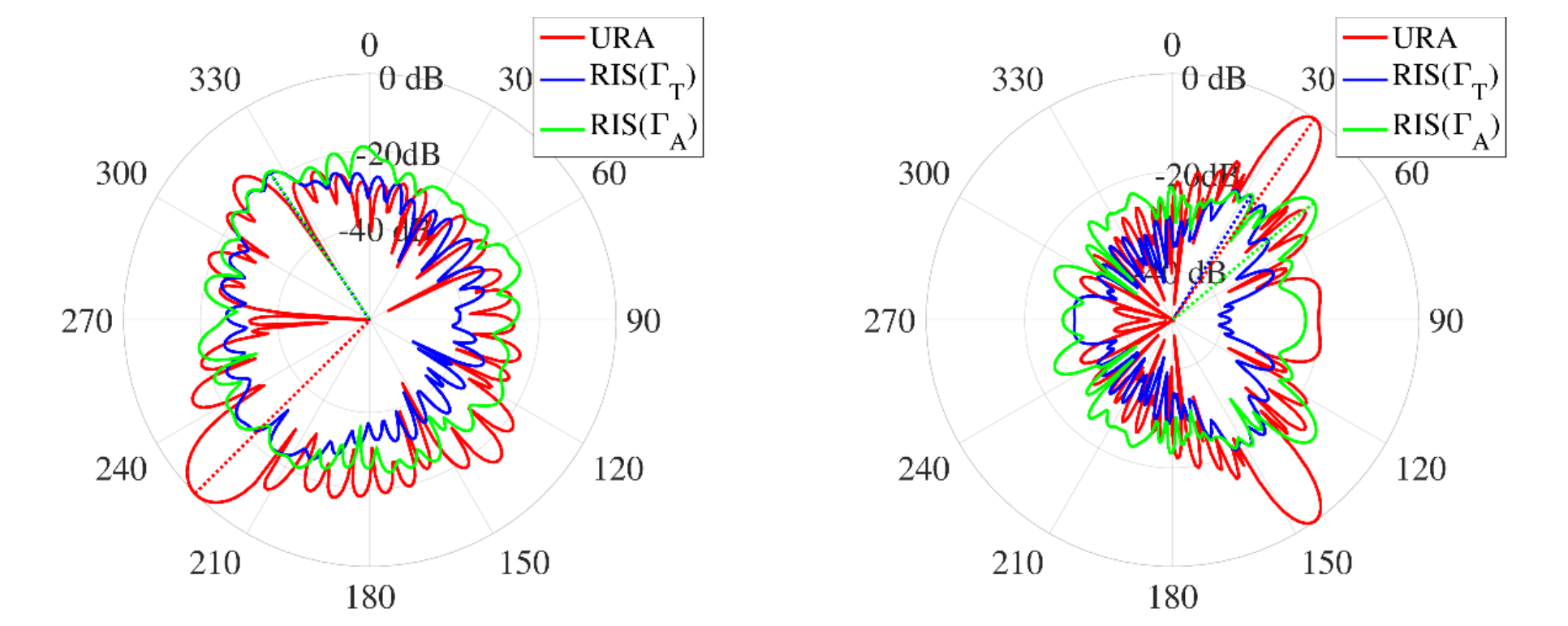
Figure 7. Output of `IDOL`

Reflection from RIS



(a) Phase-Γ_T (b) Phase-Γ_A (c) Mag-Γ_A

Figure 8. Target reflection coefficient (Γ_T) and achieved reflection coefficient (Γ_A).



(a) Az cut (b) El cut

Figure 9. Comparing beam patterns between using URA and RIS array.

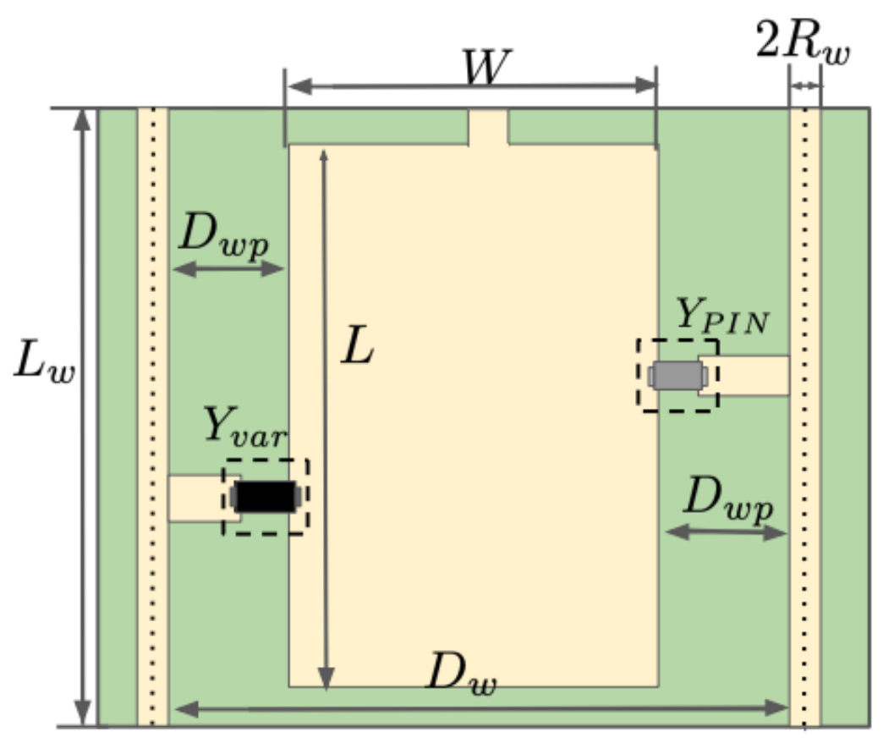
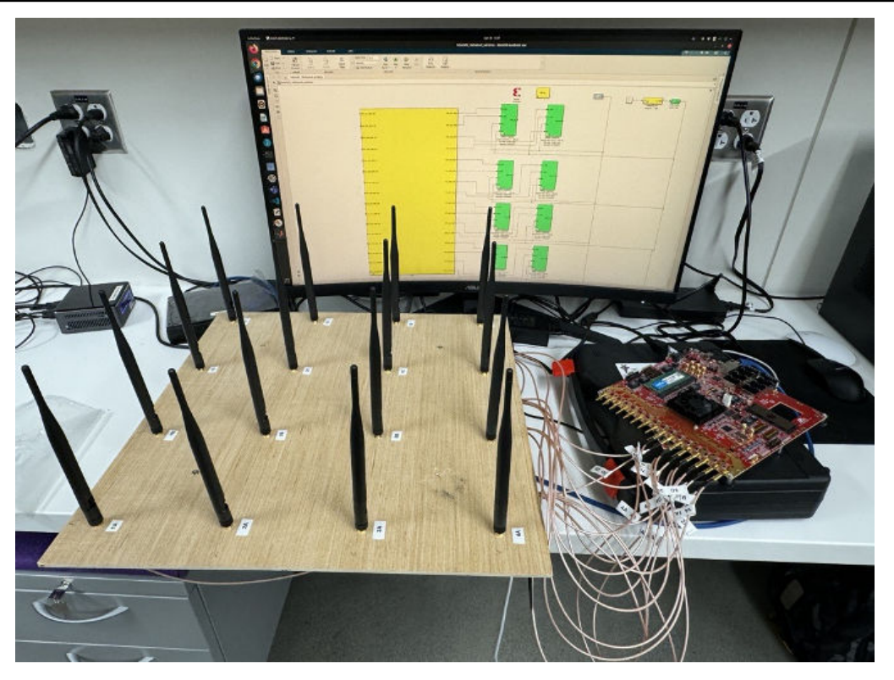


Figure 10. Layout of RIS Unit Cell

Future Research

- Prototype RFI Detector and Estimator on FPGA (16 Rx RFSoC) using CASPER framework.
- Prototype the RIS unit with ≈ 300 elements in ≈ 1 GHz.
- Refurbish a small radio telescope on rooftop for research and teaching.
- On-site validation at OVRO.

(a) Radio Telescope at UAlbany Rooftop.



(b) 16 Rx RFSoC for RFI Detection and Estimation.

Intellectual Merit

1. *Calculate* the direction of arrival of air- and space-borne RFI sources and measure phase and amplitude of the incident RFI at radio telescope.
2. *Cancel* RFI with reflecting EM waves from reconfigurable intelligent surfaces.
3. *Develop* a prototype RIS system and experimental validation at Owens Valley Radio Observatory.

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.

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**.

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