Development of a 21cm Multi-element Solar Radio Interferometric Array

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Abstract

Solar radio emissions account for different emission processes and the medium in which these are generated in the solar atmosphere. Radio astronomy is a field that is gradually growing in Colombia thanks to several projects aiming to a more viable way of performing astronomical studies in a country whose climate conditions are predominantly cloudy, as well as the contribution it presumes to the scientific and technological development that can have an impact on future generations of Colombian astronomers, scientists and engineers.

This work presents the development and implementation stages of a Solar Radio Interferometer with a novel antenna design, and the proposed configuration for a full interferometric array. We also present the time correlation system implemented with the Reconfigurable Open Architecture Computing Hardware (ROACH), in order to study solar radio emissions at 1.42 GHz, corresponding to the 21cm emission line, generated by gyro-resonance mechanisms.

Background

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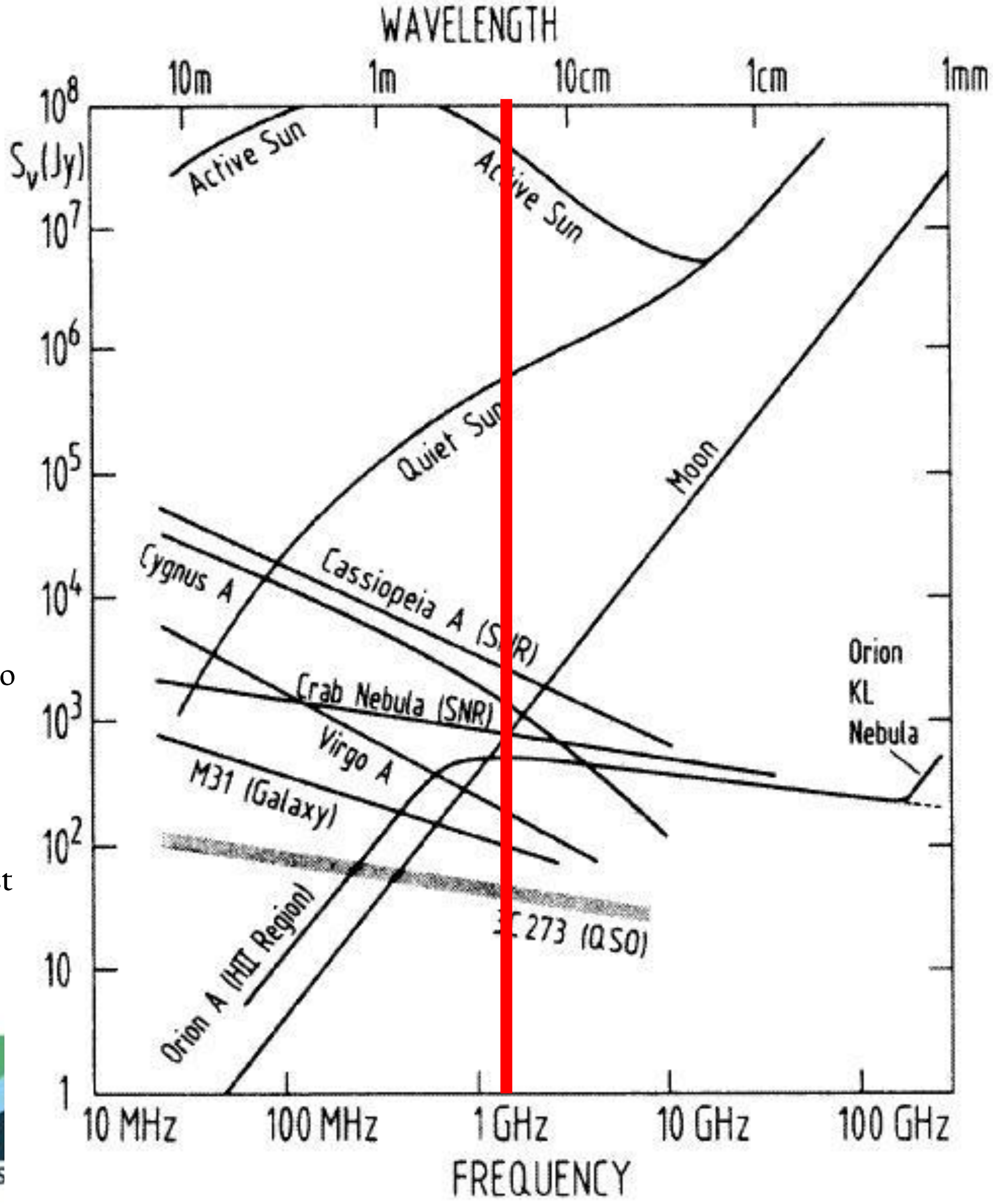

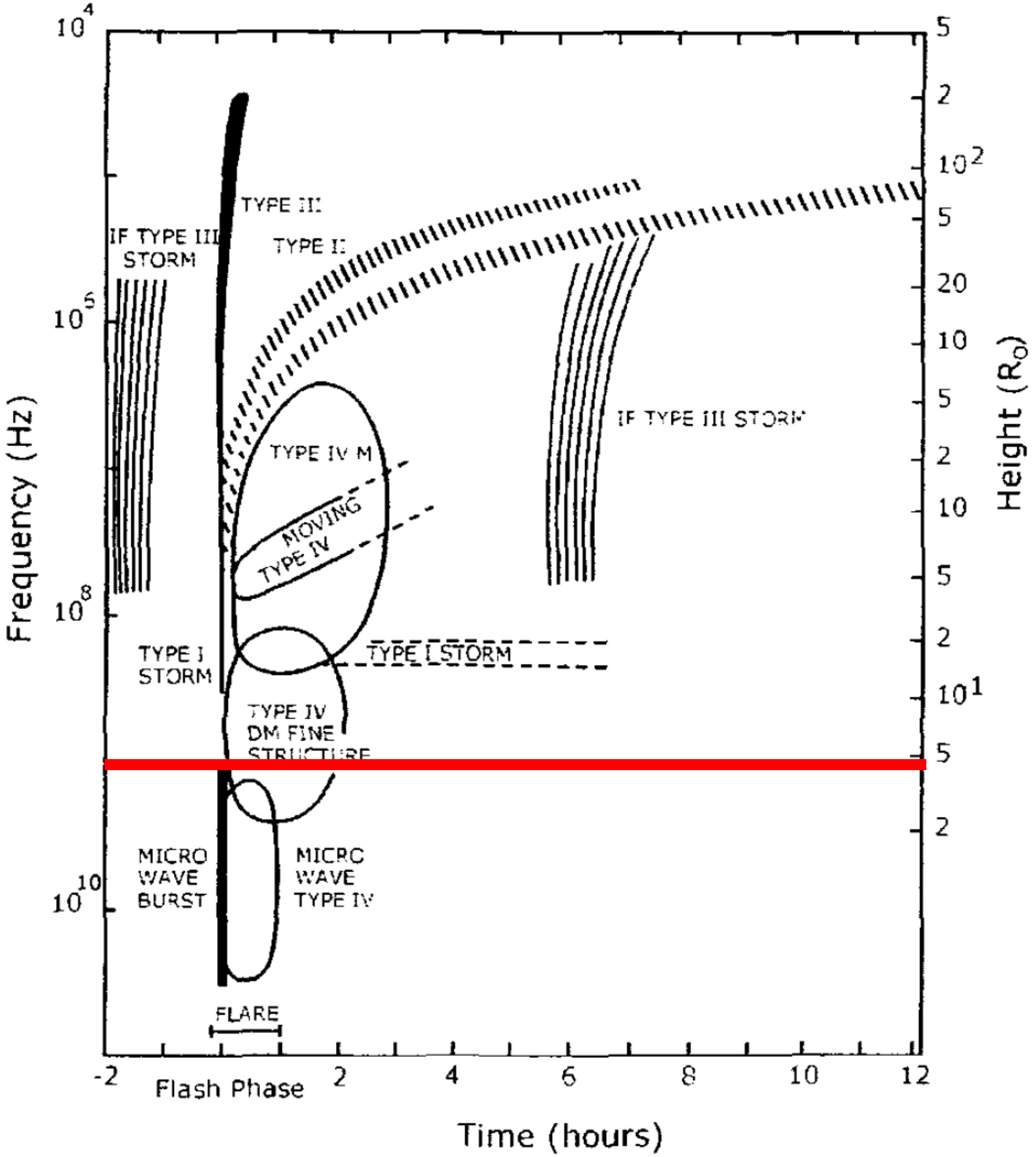

Figure 1: Flux of Several Astronomical Sources in Radio Frequency (Left). Classification of Solar Radio Bursts (Right).

The red line highlights the 1,42GHz frequency of interest for our instrument.

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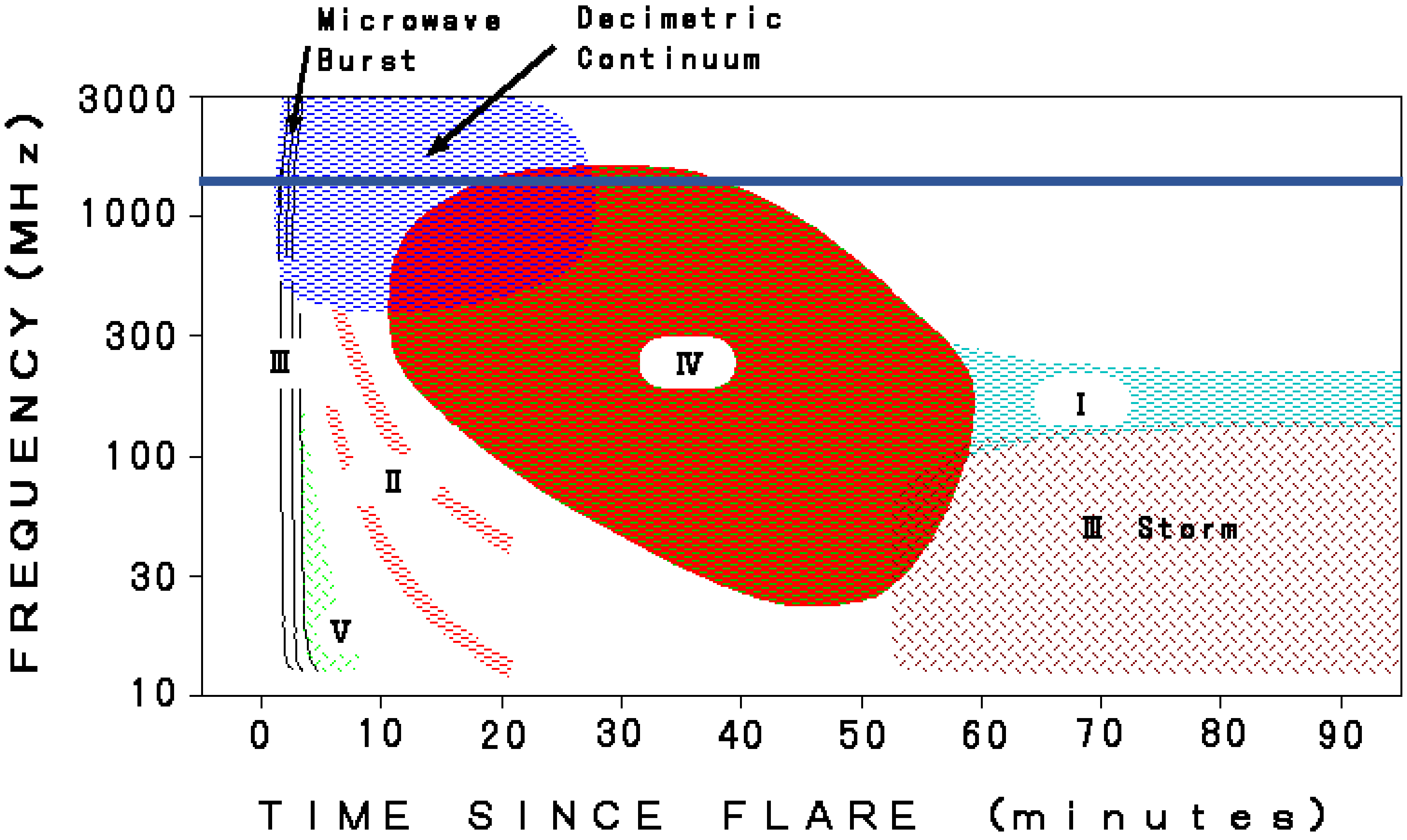

Figure 2: Schematic diagram showing the Classification of Solar Radio Bursts. Taken from NICT (http://sunbase.nict.go.jp/solar/denpa/hiras/types.html)

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III	Fast frequency drift bursts. Occur singularly, in groups or storms. Accompanied by a second harmonic	Single Burst: 1 - 3 s Groups: 1 - 5 min Storm: min - Hours	10 kHz -1 GHz	Active Regions, Flares
IV	Stationary Type IV. Broadband Continuum with fine structure	hours- days	20 MHz - 2 GHz	Flares, Proton emission
	Moving Type IV. Broadband, slow frequency drift with smooth continuum	30 min - 2 hours	20 - 400 MHz	Eruptive prominences MHD shock waves
	Flare Continua. Broadband, smooth Continuum	3 - 45 min	25 - 200 MHz	Flares, Proton emission

Figure 3: Classification of Solar Radio Bursts. Taken from Space Weather Services, Australian Bureau of Meteorology (http://www.sws.bom.gov.au/World_Data_Centre/1/9/3)

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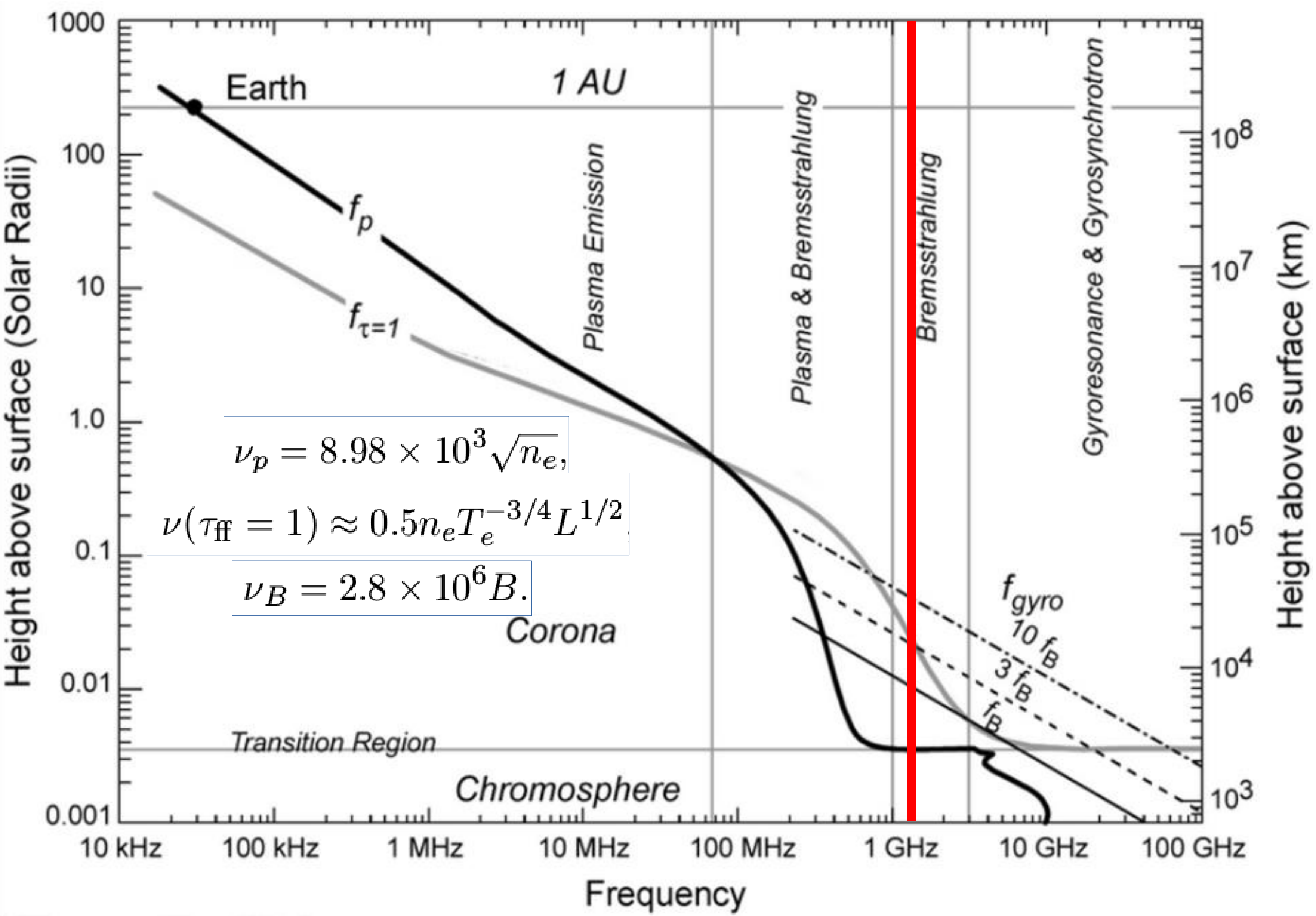

Figure 4: Characteristic Radio Frequencies for the solar atmosphere and the dominating type of emisión mechanism (Gary, 2014)

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Introduction

The **Phased Array Radio Interferometer at 21cm in the Observatorio Astronómico Nacional (PhAraON)** is a 2-element drift solar radio interferometer operating at 1.42GHz (λ=21 cm) developed as a Bachelor's Thesis in Electronics Engineering at the Department of Electric and Electronics Engineering - Universidad Nacional de Colombia in 2016 [**1**].

PhAraON is a novel prototype of radio interferometer, with Yagi-Uda antennas fabricated as printed circuit boards and deployed in a 2X2 array configuration. The antenna elements are separated 8 meters, forming the East-West baseline. Later a Sum-Difference coupler circuit working as an analog correlator, and USB dongles as signal receivers are used. This is considered as stage 1 of the ongoing project. **The current design uses these identical Yagi-Uda printed antennas at the focal point of a reflector dish, in order to enhance its directivity, hence its sensitivity.**

Previous Stage

Figure 5: 2-element drift Solar Radio Interferometer Installation. Observatorio Astronómico Nacional, Campus Building. (Hincapié Tarquino *et. al.* 2016). **Left:** Array installation. **Top, Center:** Antenna element in 2x2 Yagi-Uda antena configuration. **Top, Right:** Rat-race coupler as analog correlator. **Bottom, Right:** Data acquisition & visualization sytem.

Antenna Design

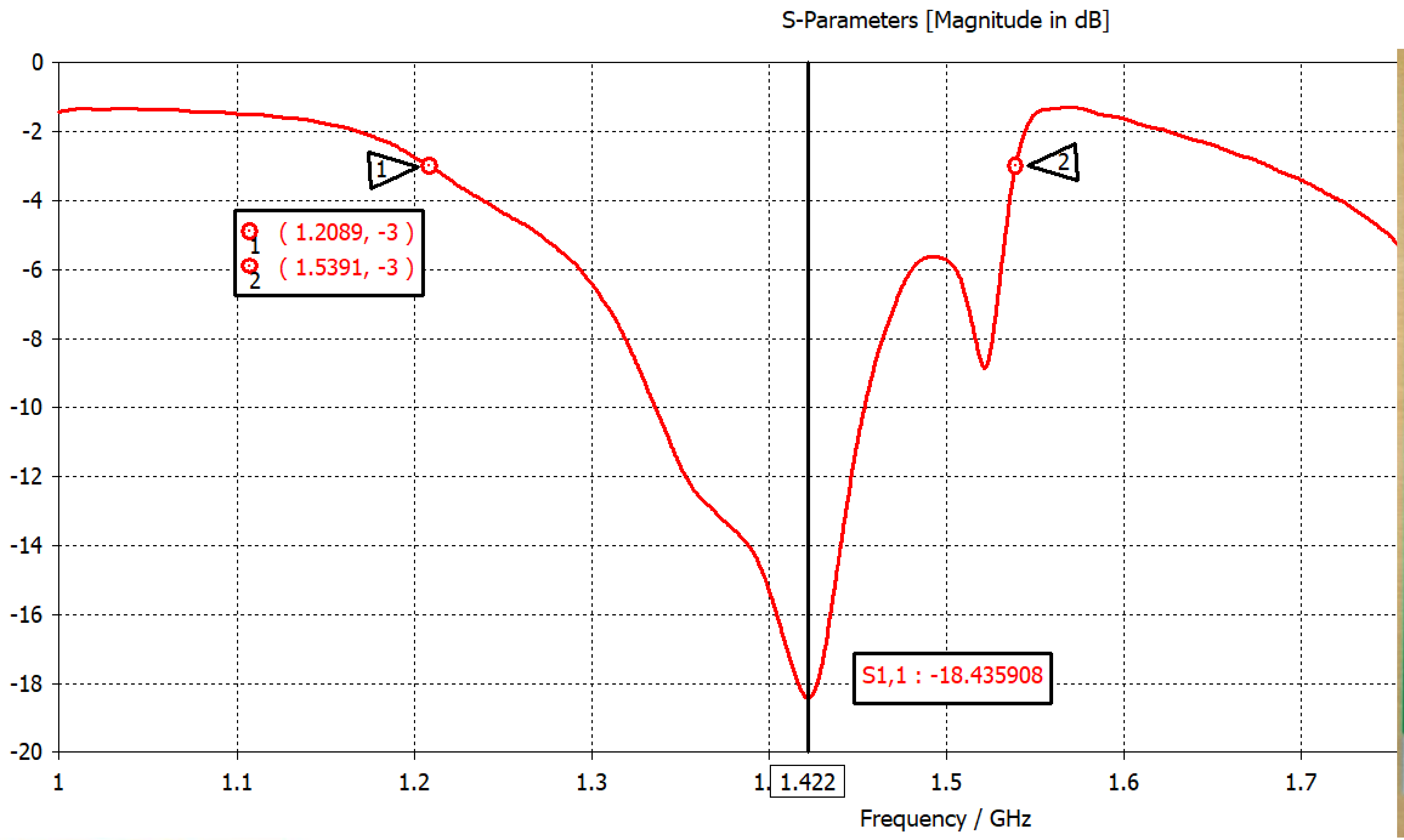


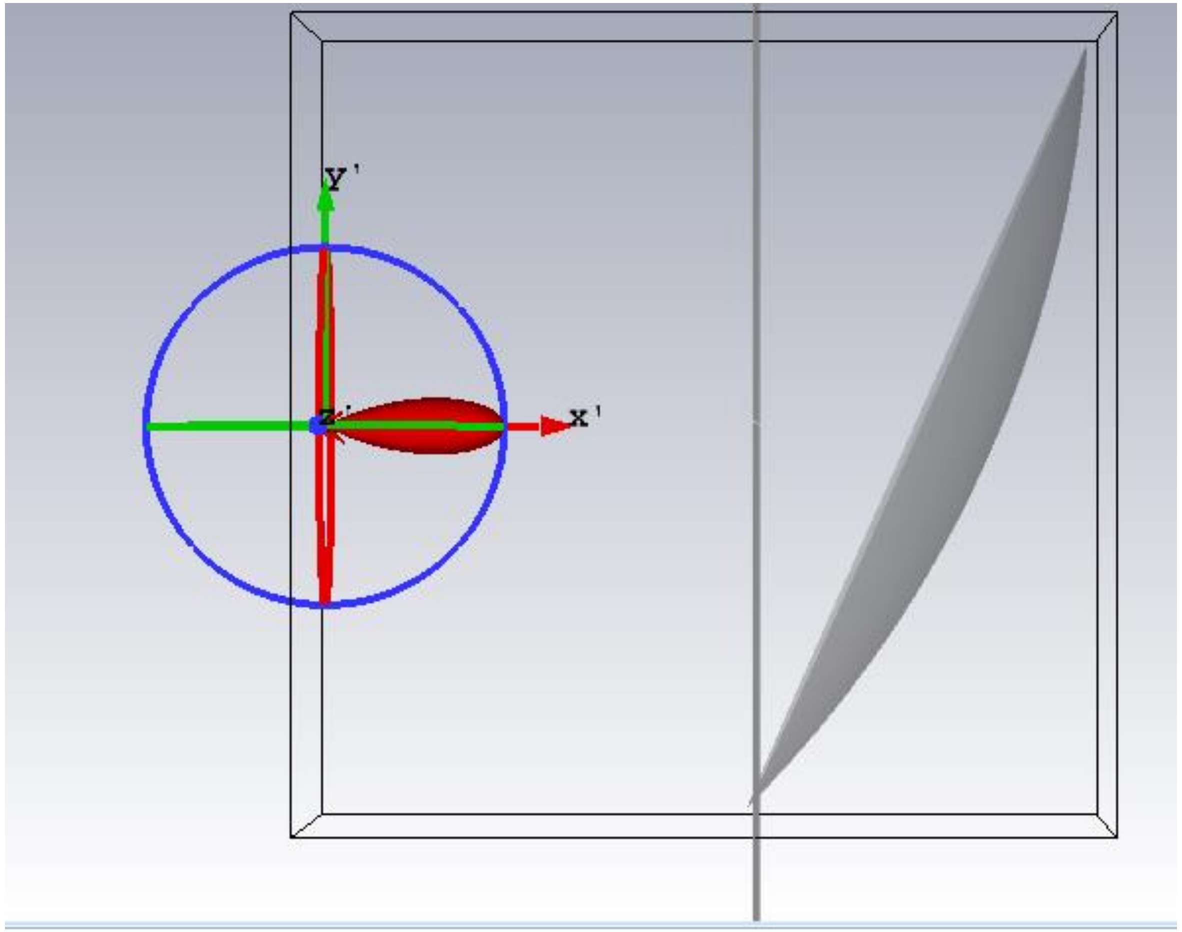
Figure 6: Antenna Simulation: S11 Parameter - Antenna Reflection Coefficient. (Hincapié Tarquino *et. al. in. prep.*)

Antenna Design

Simulations were performed in order to know the behavior of the antenna element, with the printed antenna on the focus of the parabolic reflector dish. This was done in two configurations for the feeding system: First as a single antenna (Figure 8), and then as a 2x2 array (Figure 9), as was used in the precursor drift interferometer.

Simulations results for the single antenna feed configuration yield higher gain and smaller side lobes in comparison with the 2x2 array. This means that the dish is sub-utilized with the 2x2 array. This was verified during the validation for all mechanical and RF systems, so the design chosen for the project is the single antenna configuration.
All simulations were performed in CST Microwave Studio Suite.

Antenna Design



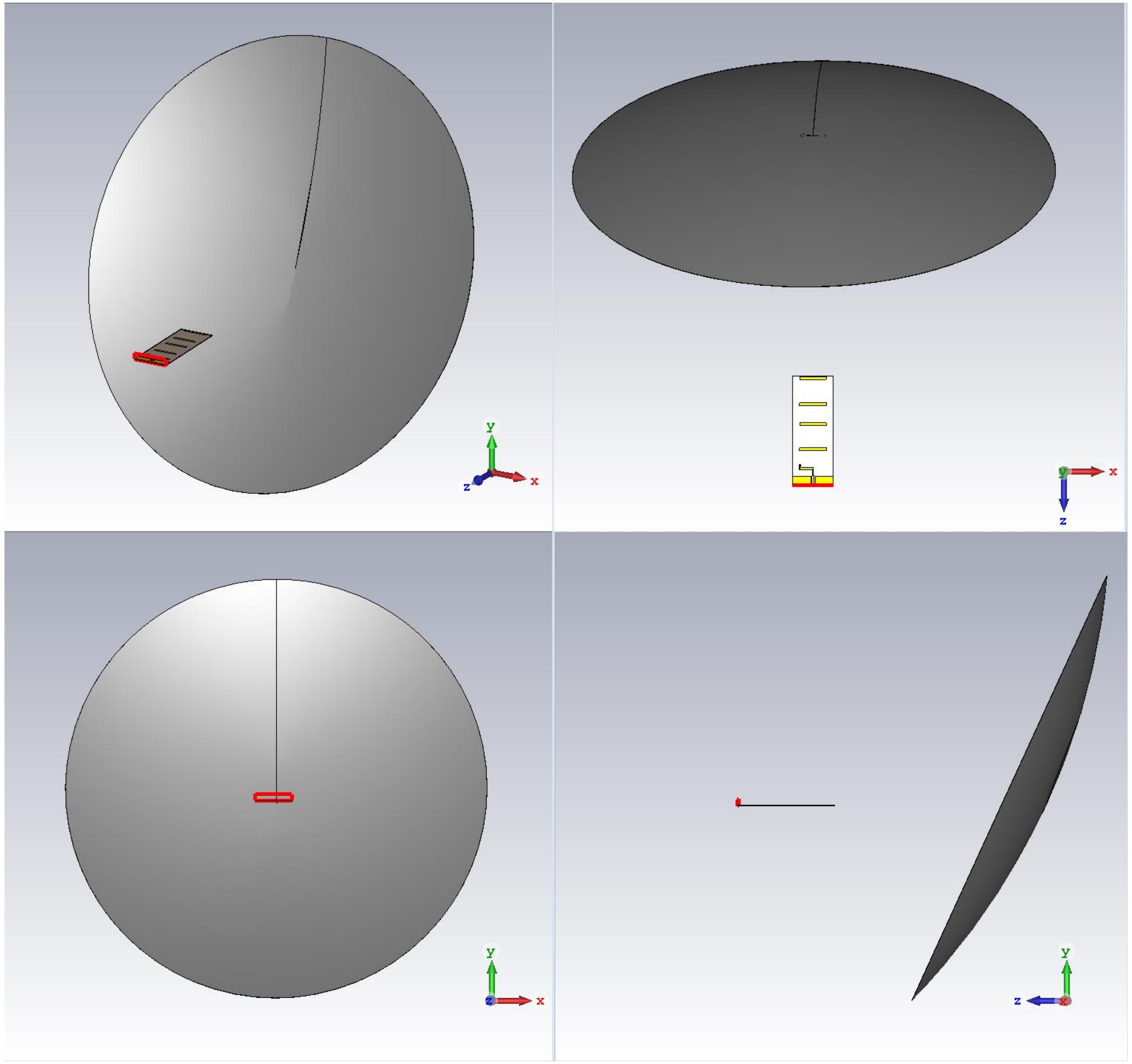


Figure 7: Antenna Element Simulation Design. Single Yagi-Uda antenna in the focus of an offset-fed reflector dish.

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Antenna Design

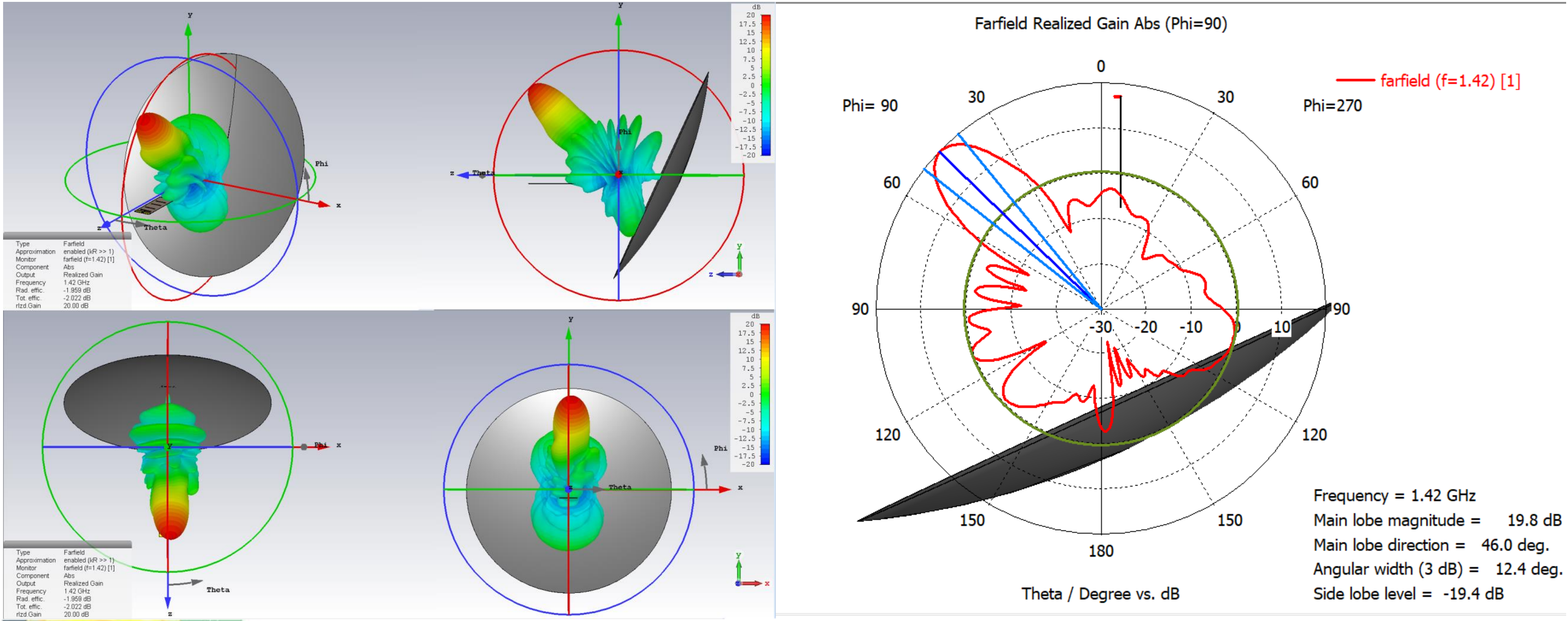

Figure 8: Antenna Simulation: 1 Antenna + Reflector. Realized Gain. (Hincapié Tarquino *et. al.* *in. prep.*)

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Antenna Design

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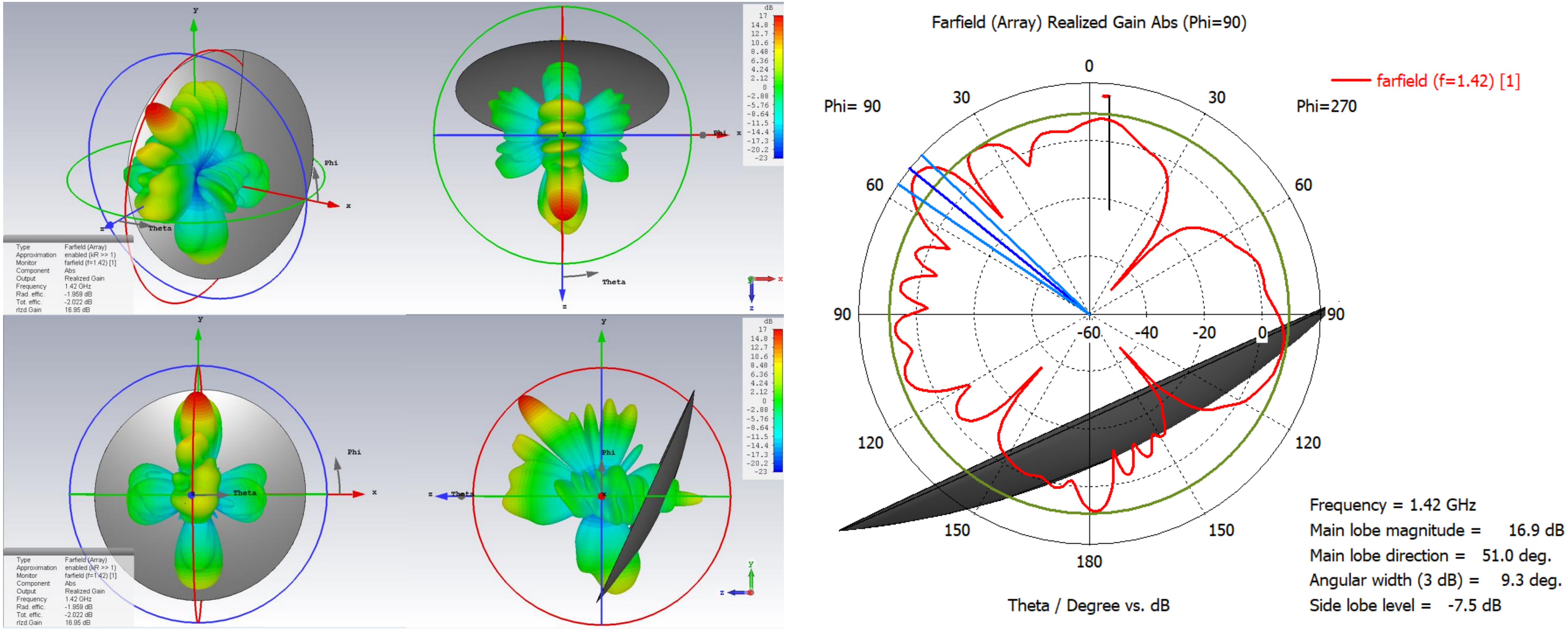

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Figure 9: Antenna Simulation: 2x2 Antenna Array + Reflector. Realized Gain. (Hincapié Tarquino *et. al. in. prep.*)

Steerable Pier: Preliminary and Final Design

Preliminary design for steerable pier consisted on a DC motor for azimuth motion and a DC actuator for elevation motion (Figure 10).

After preliminary tests were conducted for validation of RF and mechanical systems, we changed the design for a configuration of Stepper motors, each with reducer gearbox (Figure 11).

This, in order to get more torque and control for the antena motion. Additionally the actuator for elevation did not have uniform motion during the full range.

Figure 10: Steerable Pier Preliminary Design: DC motor for Azimuth & DC actuator for Elevation

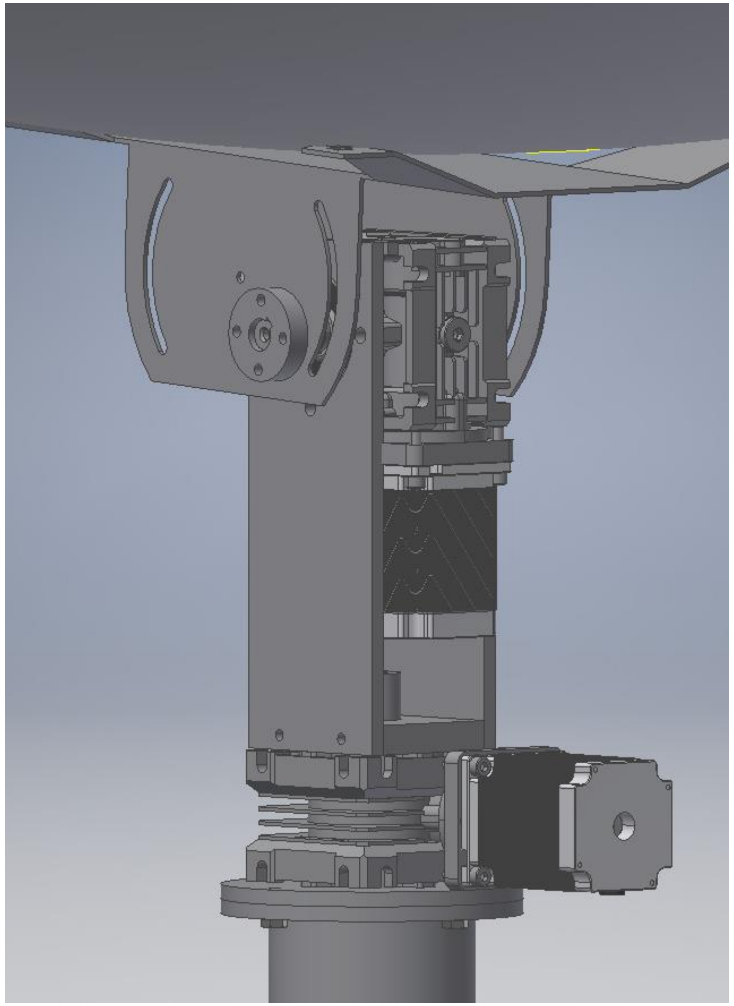

Figure 11: Steerable Pier Final Design: Stepper motor and reducer gearbox for Azimuth & Elevation motion (Hincapié Tarquino *et. al. in. prep.*)

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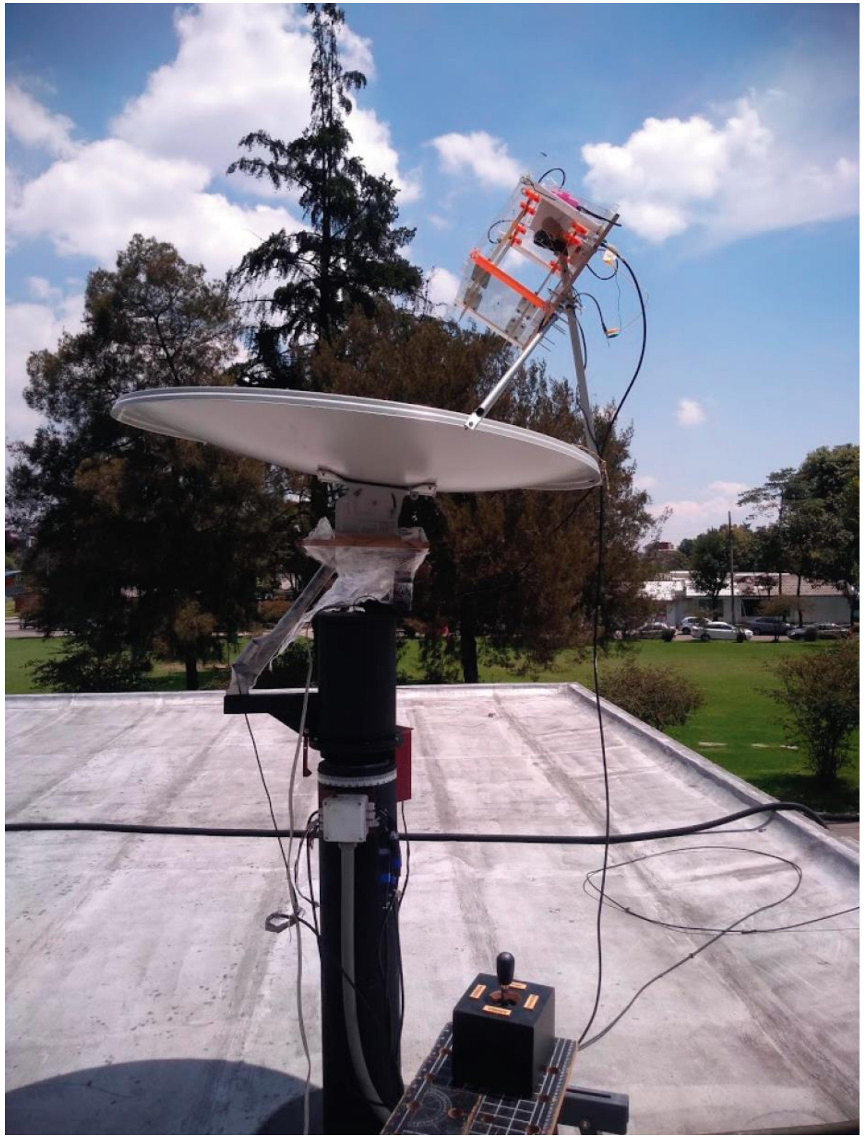
Mounting and First Testing Phase

Figure 12: First Testing Phase with 2x2 Array Feed (Hincapié Tarquino *et. al. in. prep.*)

Mounting and First Testing Phase



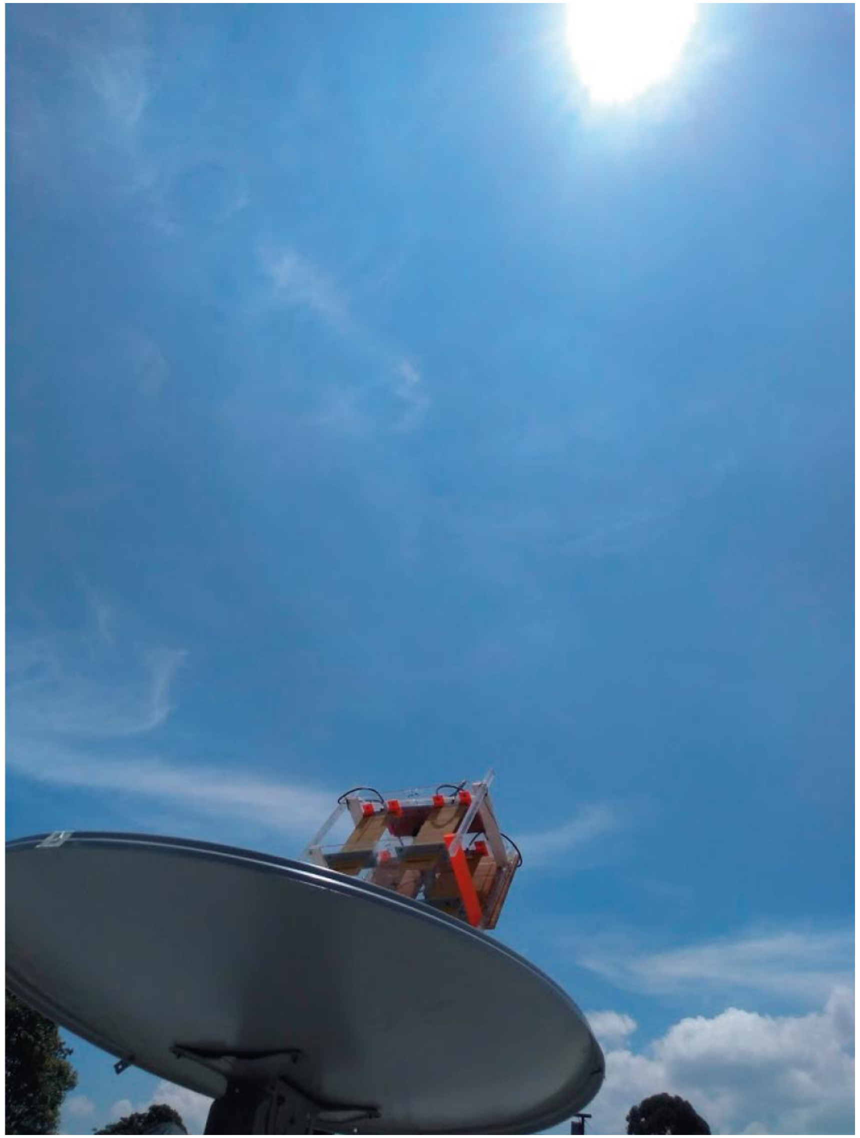


Figure 13: First Testing Phase with 2x2 Array Feed (Hincapié Tarquino *et. al. in. prep.*)

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Preliminary Results

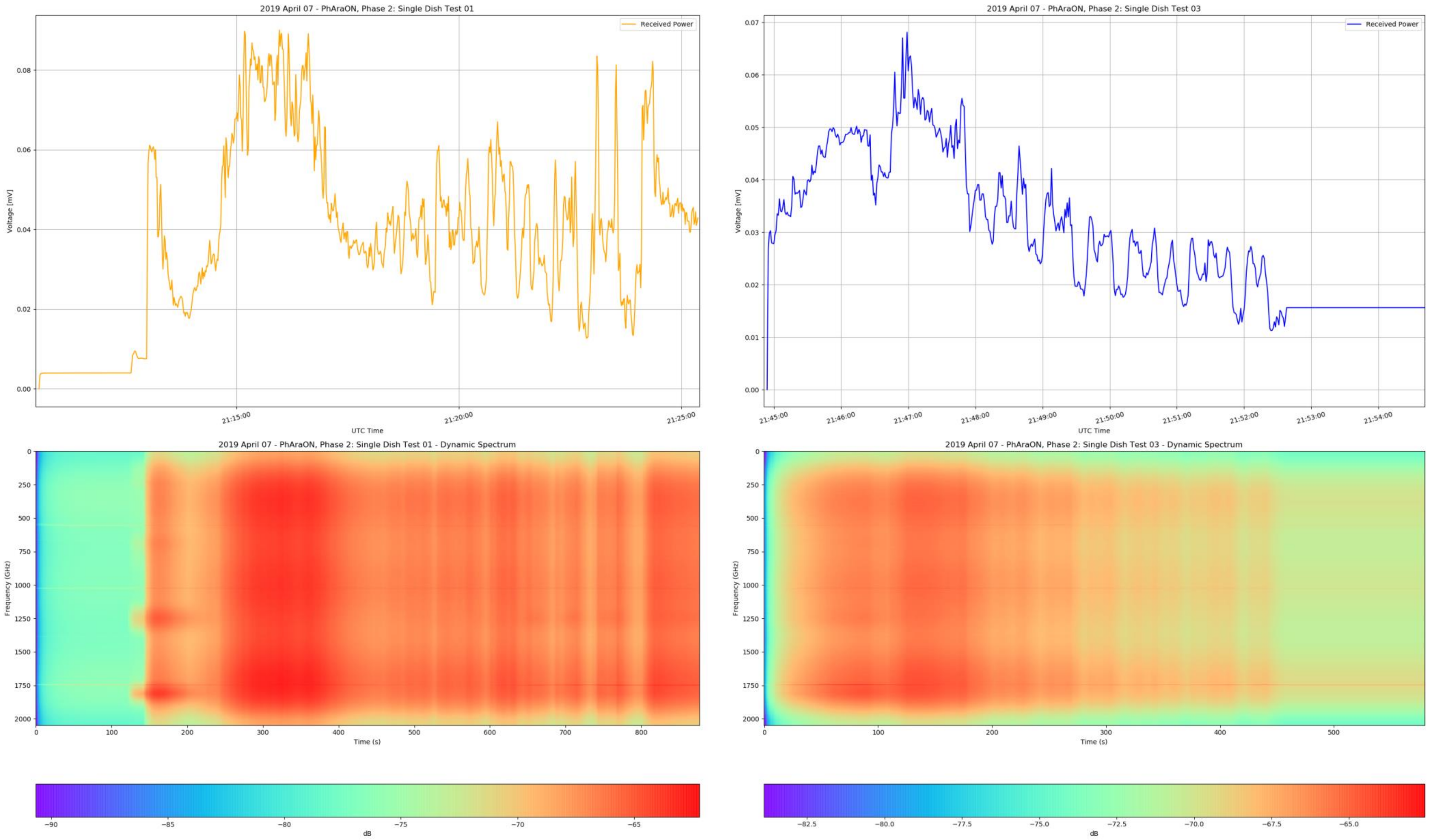

Figure 14: Preliminary Results: Solar Scan with 2x2 Array Feed

Preliminary Results

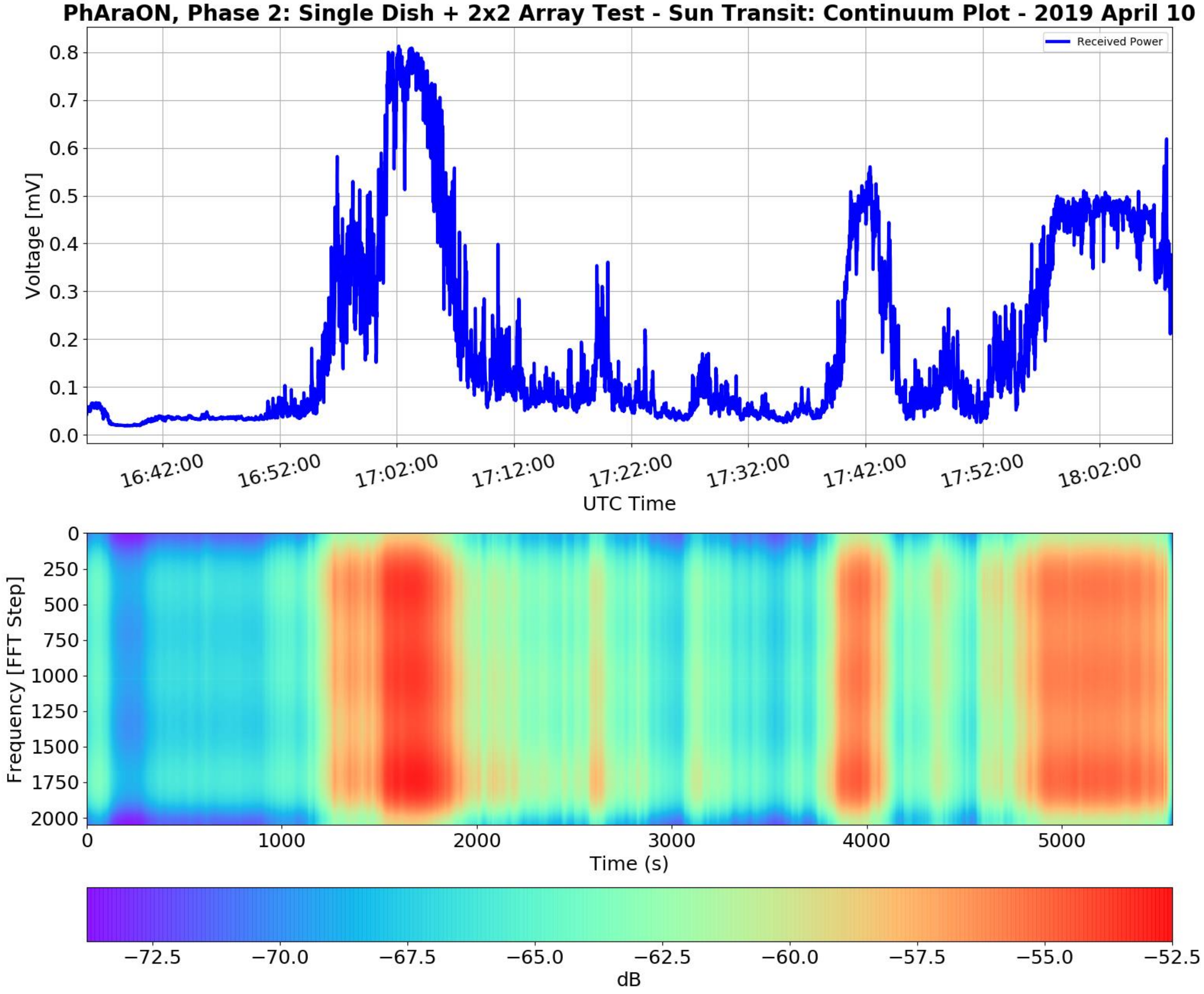

Figure 15: Preliminary Results: Solar Scan in Azimuth and Elevation (*Single Dish Result*). (Hincapié Tarquino *et. al. in. prep.*)

Preliminary Results

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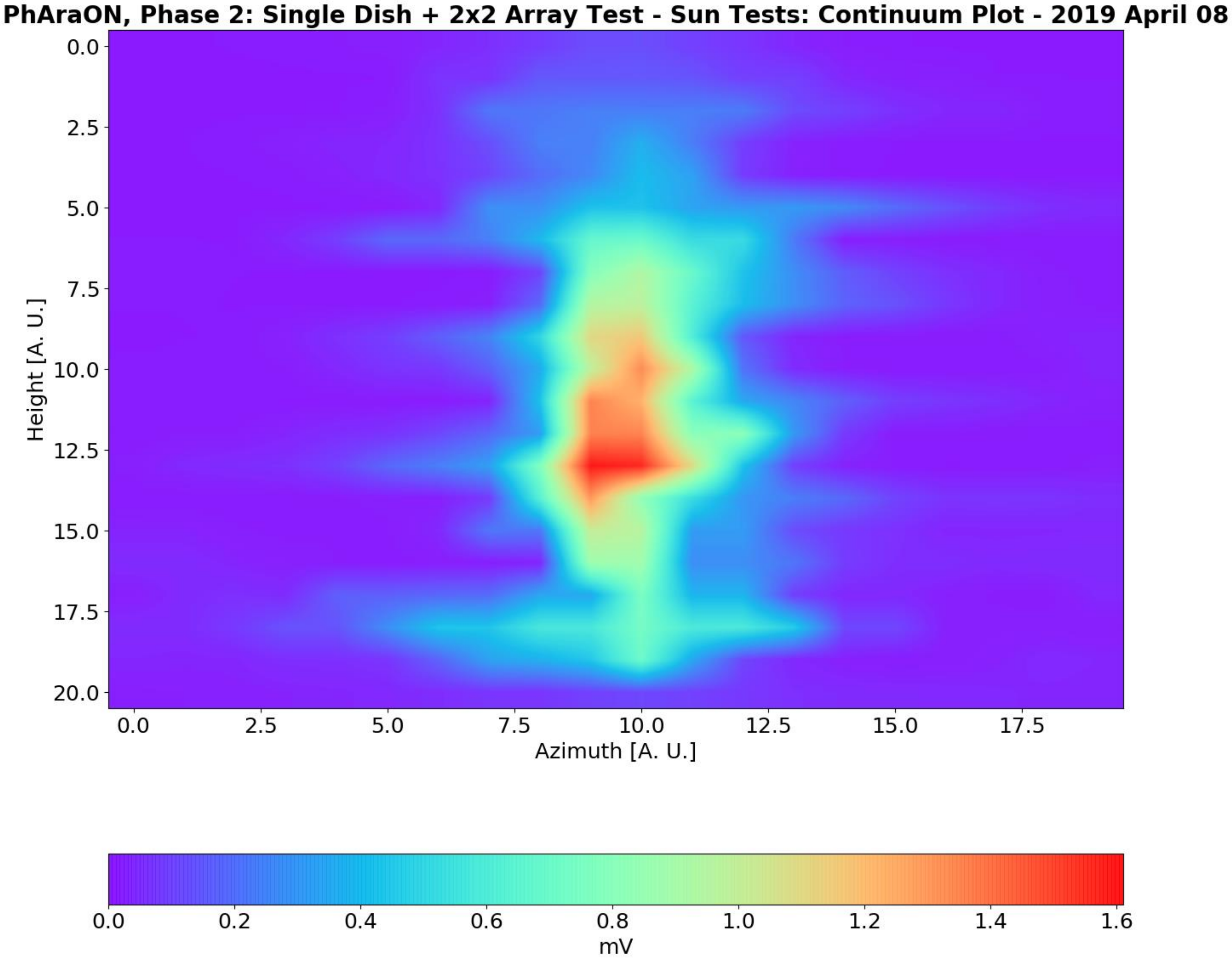

Figure 16: Preliminary Results: Solar Scan with 2x2 Array Feed. (Hincapié Tarquino *et. al. in. prep.*)

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Design: Array Implementation

Figure 17: Array Location at Observatorio Astronómico Nacional, Campus Building – Universidad Nacional de Colombia. (Hincapié Tarquino *et. al. in. prep.*)

Design: Array Implementation

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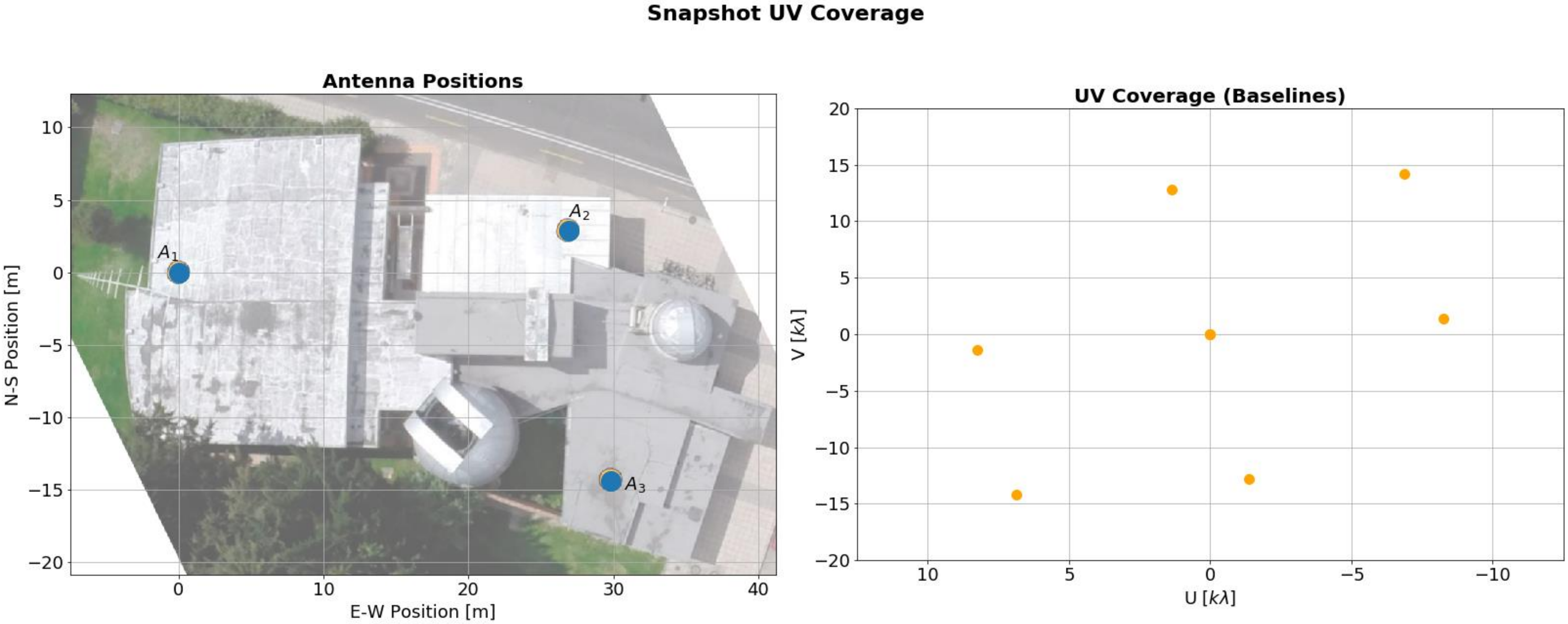

Figure 18: Snapshot UV Coverage for the interferometric array. (Hincapié Tarquino *et. al. in. prep.*)

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Design: Array Implementation

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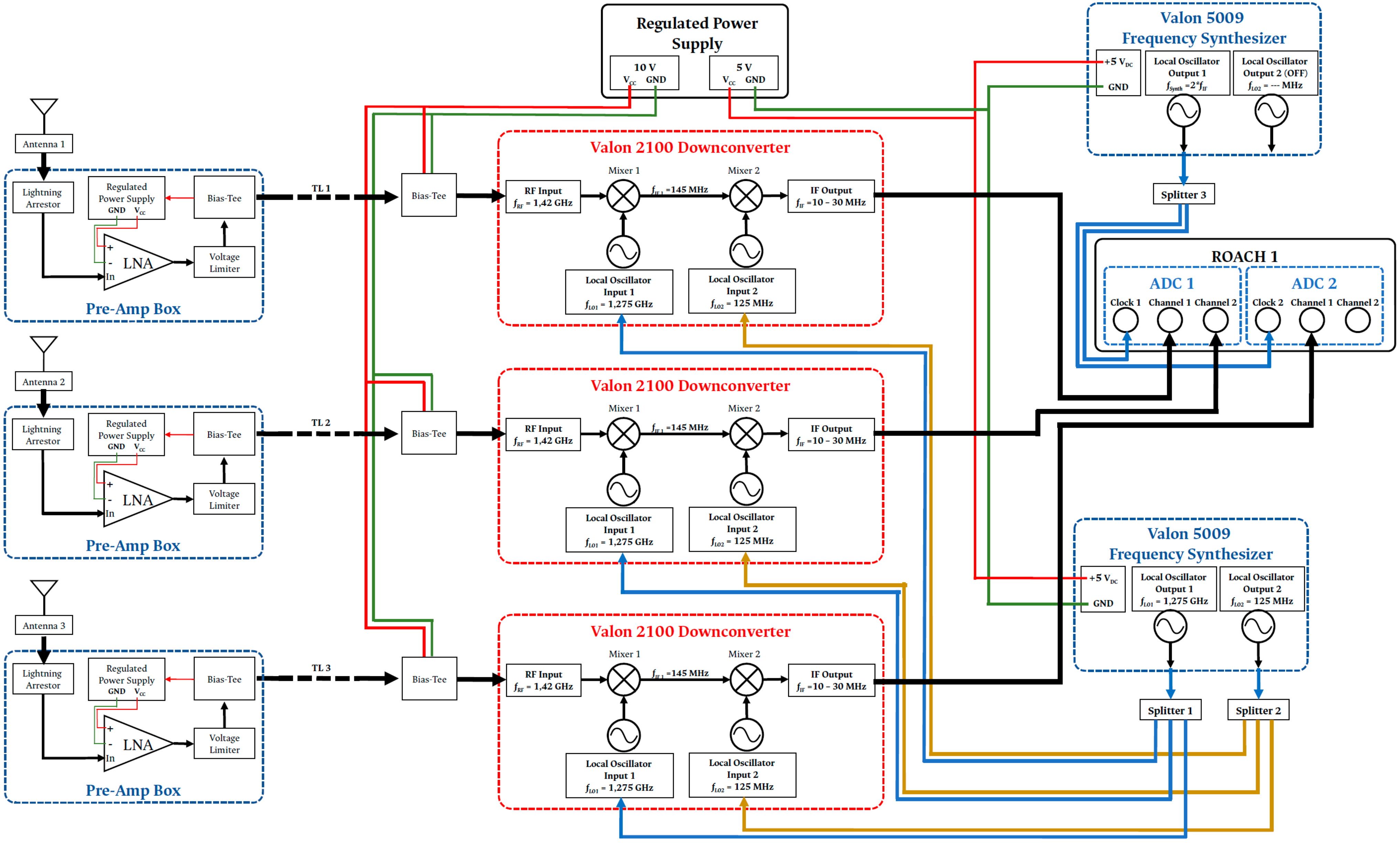

Figure 19: Block Schematics for full interferometric array. (Hincapié Tarquino *et. al. in. prep.*)

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Front-End: Pre-Amp Stage

Pre-Amplification stage is based on the amplification stage used for several systems of the e-Callisto Solar Spectrometer Network. A similar stage is also used for **FiCoRI**, an interferometer dedicated to solar observations at the Observatorio Astronómico Nacional - Campus Building (Guevara Gómez, 2017).

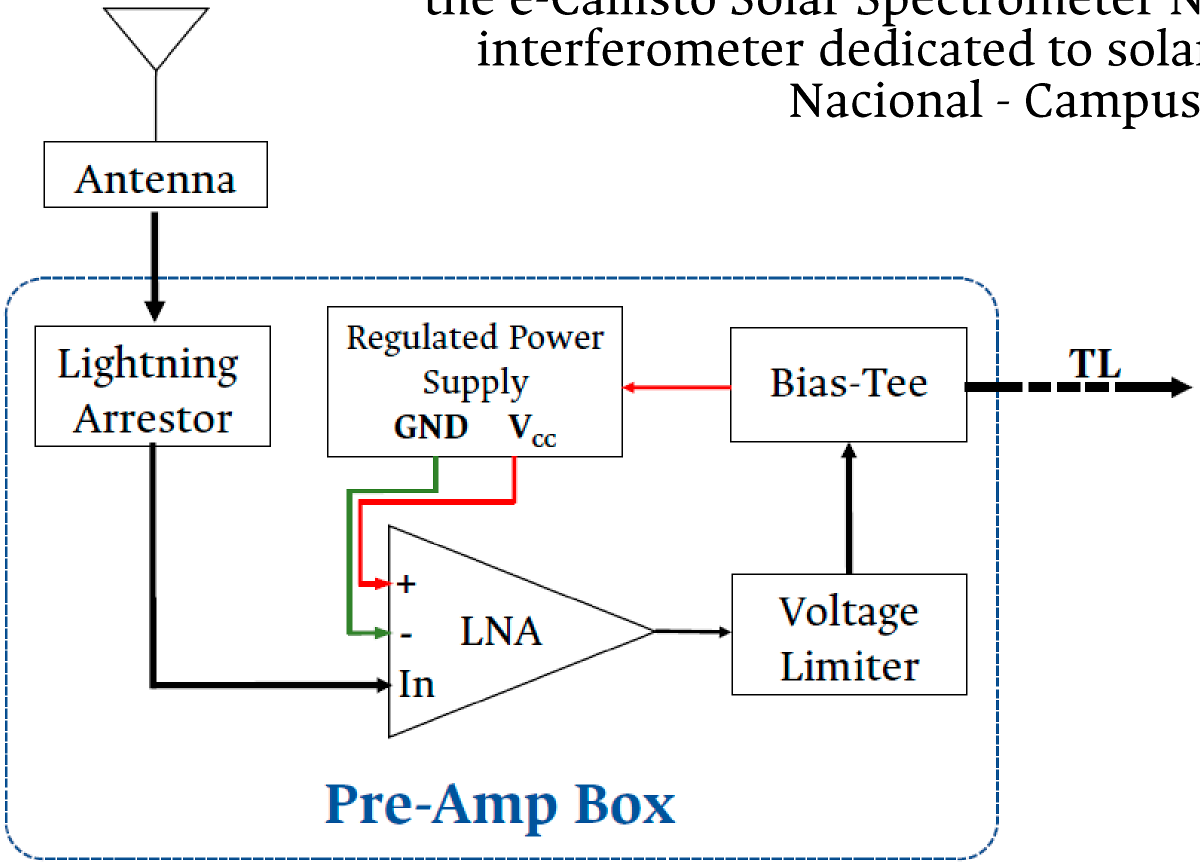

Figure 20: Block Schematics for Pre-Amp stage. (Hincapié Tarquino *et. al. in. prep.*)

Figure 21: FiCoRI Pre-Amp box (Guevara Gómez, 2017)

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Front-End: Downconversion Stage

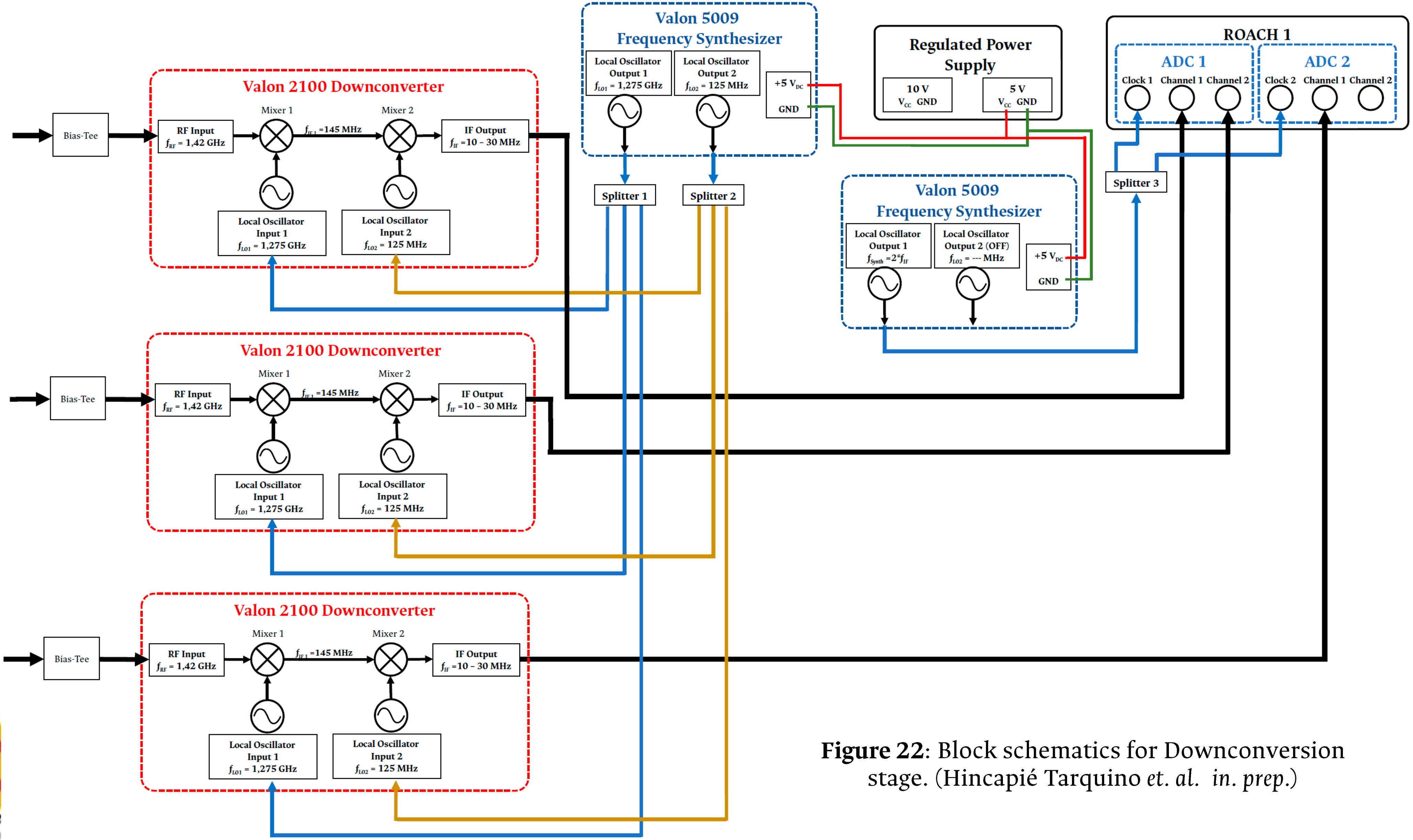

Figure 22: Block schematics for Downconversion stage. (Hincapié Tarquino *et. al. in. prep.*)

Back-End: Correlator

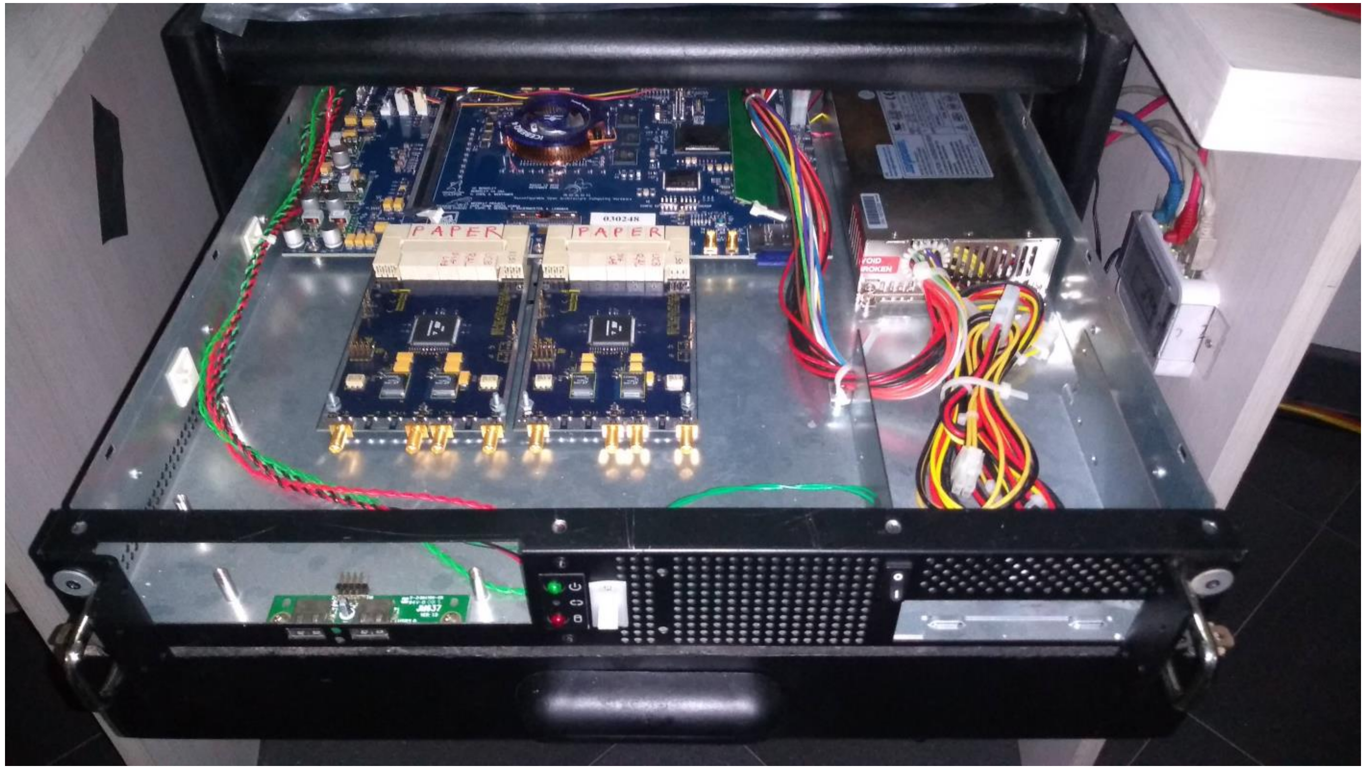

Figure 23: Correlator Implemented with ROACH-1 board. .
(Hincapié Tarquino *et. al. in. prep.*)

Steerable Pier: Motor Assembly

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Antenna Motion Control Stage is implemented using I2C protocol and Stellarium for automated control. Validation tests were already successfully performed.

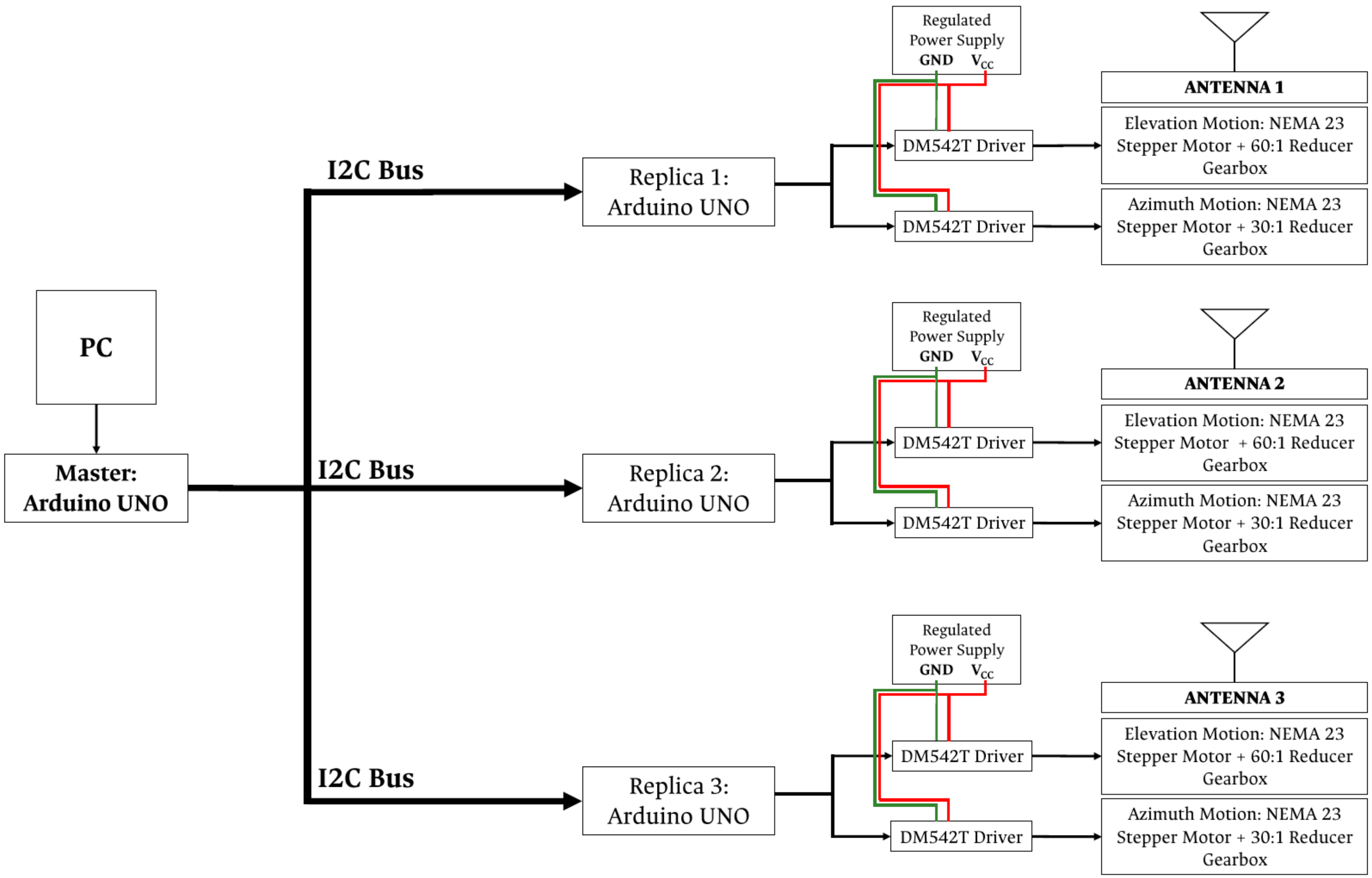

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Figure 24: Block Schematics for Antenna Motion Control Stage: Master-Replica I2C Protocol. (Hincapié Tarquino *et. al. in. prep.*)

Steerable Pier: Motor Assembly

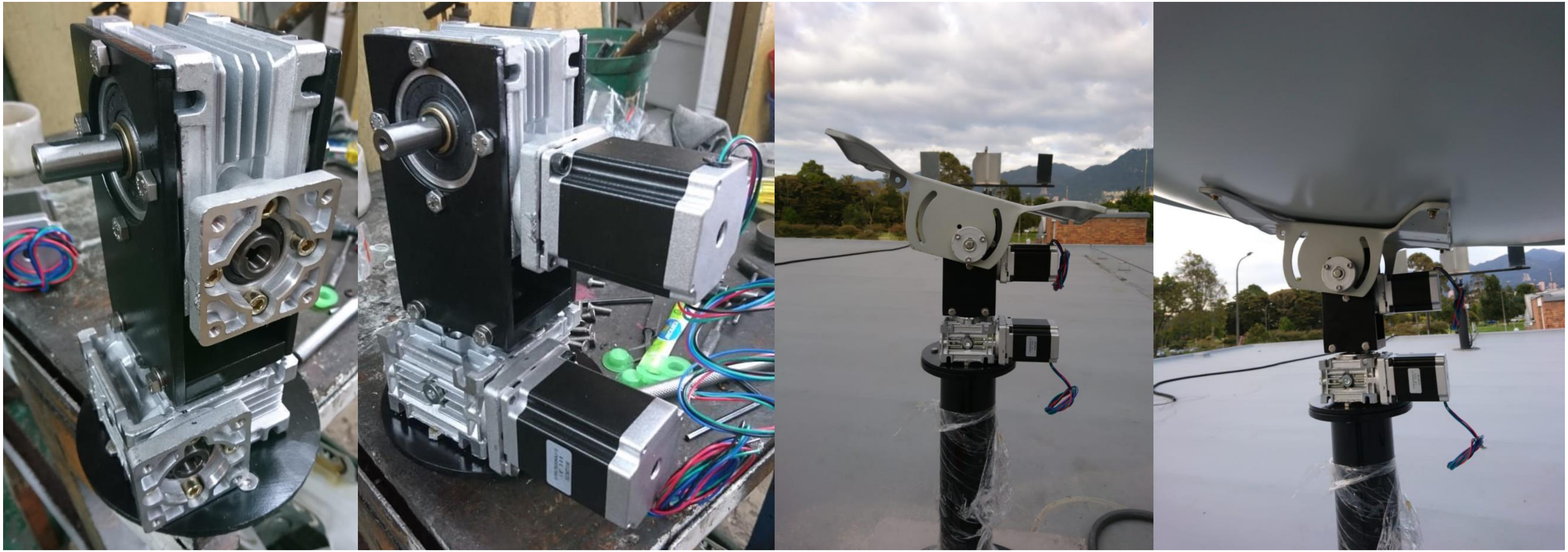

Figure 25: Steerable Pier Assembly: Stepper Motor & Reducer Gearbox for each axis in Alt-Az motion. (Hincapié Tarquino *et. al. in. prep.*)

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[1] - **HINCAPIÉ-TARQUINO, Juan Sebastián**. *"Diseño y Construcción de un Radiointerferómetro Solar de dos elementos"*. Department of Electric and Electronics Engineering, Faculty of Engineering. Universidad Nacional de Colombia. B.Eng. Thesis. 2016.
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