An S-band Polarimeter for the Determination of Spacecraft Attitude Behaviour

BY SCOTT TILLEY, VE7TIL

Summary – Practical Polarimeter

- Define Polarization
- Axial Ratio
- Stokes Parameters
- Hardware
- Software
- Calibration
- Observational Results

Polarization Defined

- POLARIZATION, property of certain electromagnetic radiations in which the direction and magnitude of the vibrating electric field are related in a specified way.
- Linear, circular, elliptical and unpolarized states are possible.

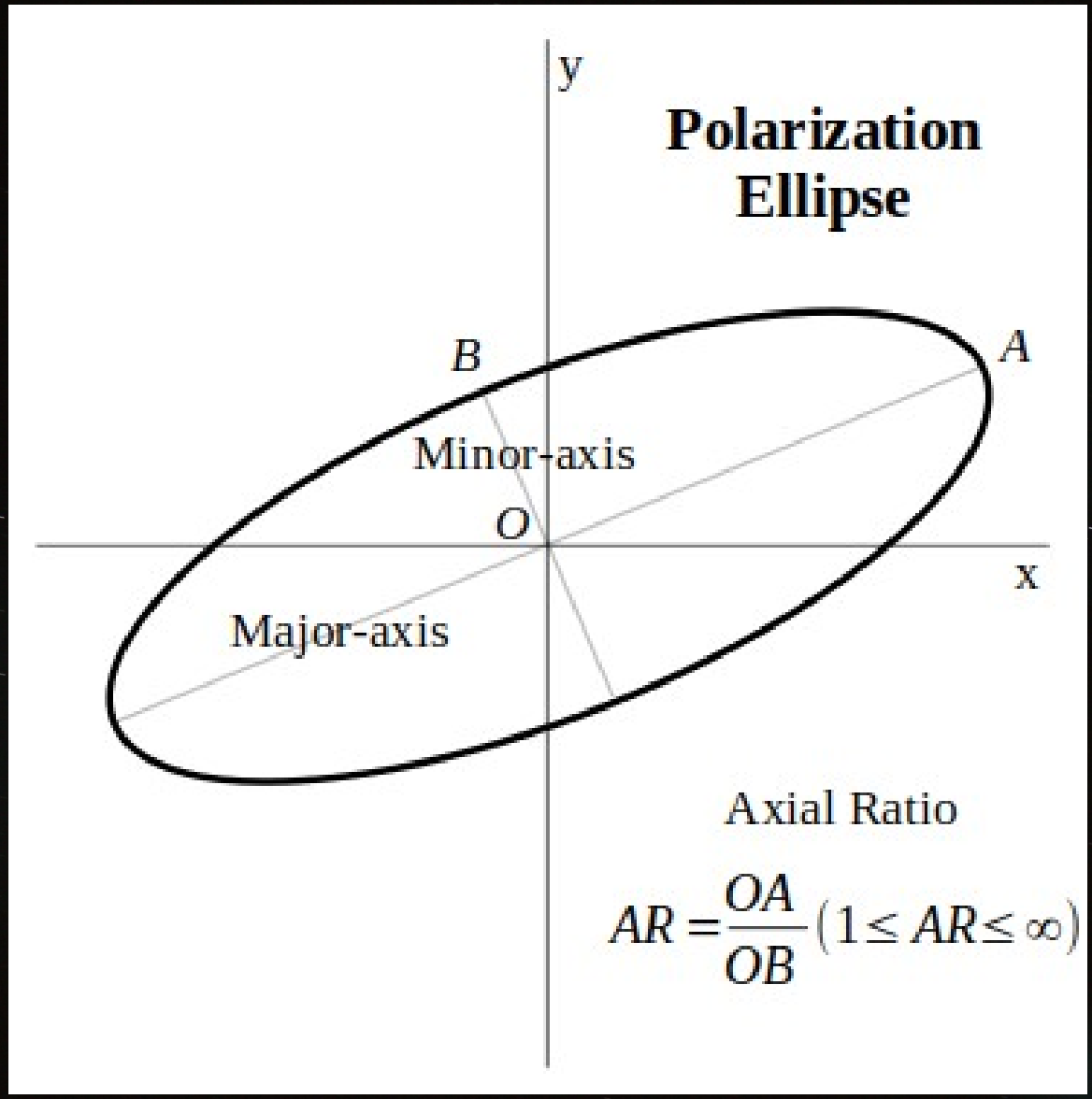
Why Quantify Polarization?

- Measure polarization properties of any emission (antenna testing).
- Determine information about spacecraft attitude.
- No need to decode and understand telemetry.
- Gain insight into uncooperative spacecraft behaviour.

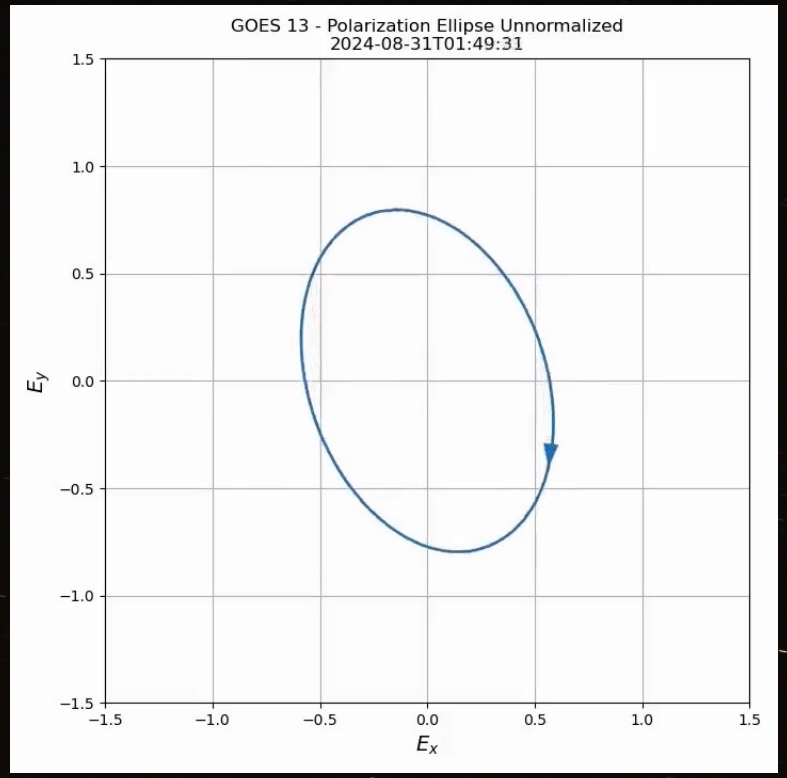
Axial Ratio

- Space communications often involves circular polarization.
- Circular polarized antennas are only REALLY circular along their bore sight
- Off bore sight we see elliptical polarization with a combination of circular and linear states.
- Changes in these states over time can produce insight into the emitting antenna’s change in attitude toward the observer.

Axial Ratio – Polarization Ellipse



Axial Ratio – Animated Example
GOES 13 wanders by…



Stokes Parameters – The Man...

- Developed by George Gabriel Stokes in 1852.
- The Stokes parameters are a set of values that completely describe the polarization state of electromagnetic radiation.
- They are related to the geometry of the **Polarization Ellipse**.

Stokes Parameters – The Math

$$I \equiv \left|E_x^2\right| + \left|E_y^{\,2}\right|,$$

$$Q \equiv \left|E_x^{\,2}\right| - \left|E_y^{\,2}\right|,$$

$$U \equiv 2\,\Re\left(E_x E_Y\right),$$

$$V \equiv -2\,\Im\left(E_x E_Y\right)$$

Stokes Parameters - Meaning

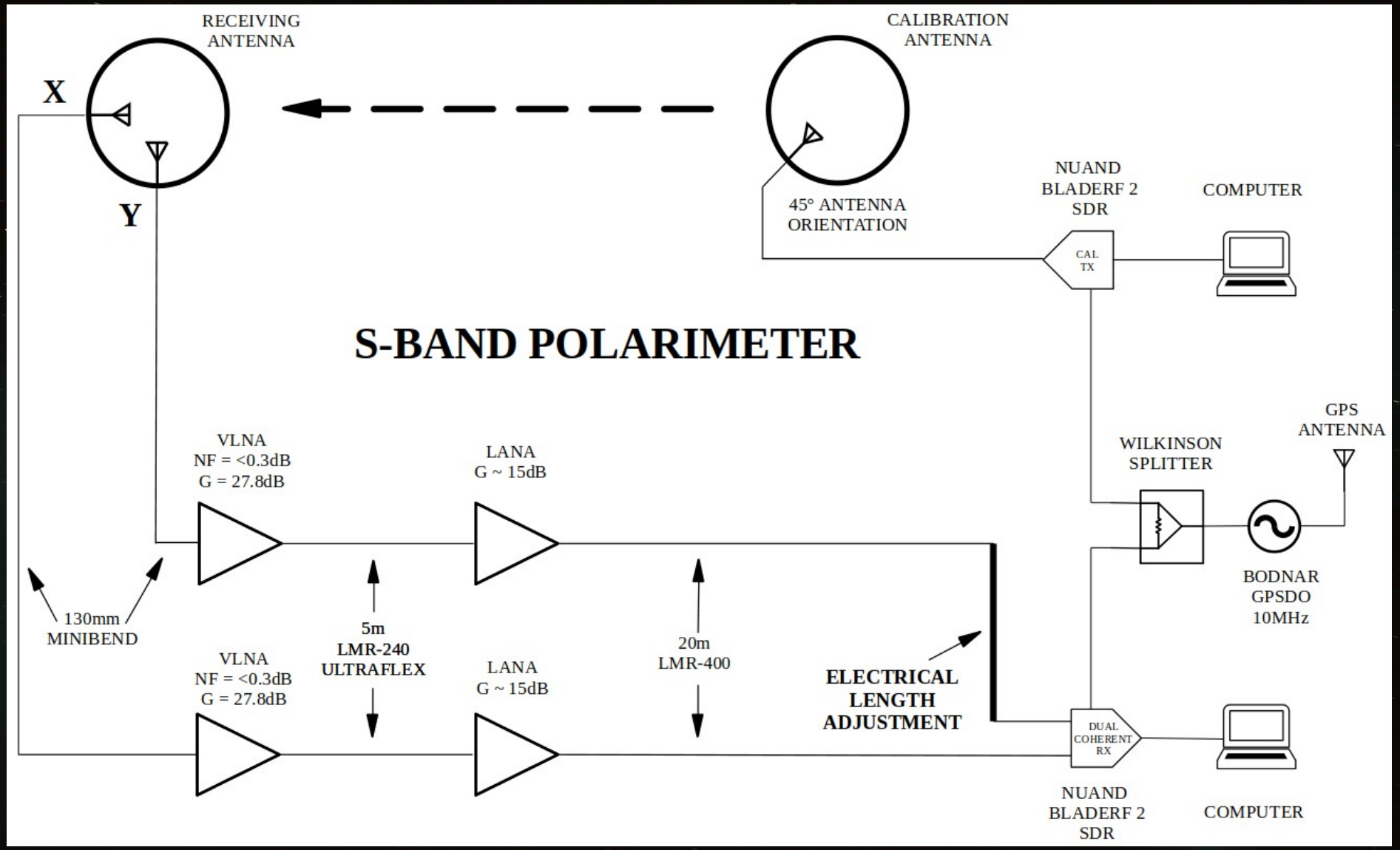
I – Sum of the Intensity of light, polarized and unpolarized.

Q – Difference between linear horizontal and vertical intensities of light. (+ Horz., - Vert.)

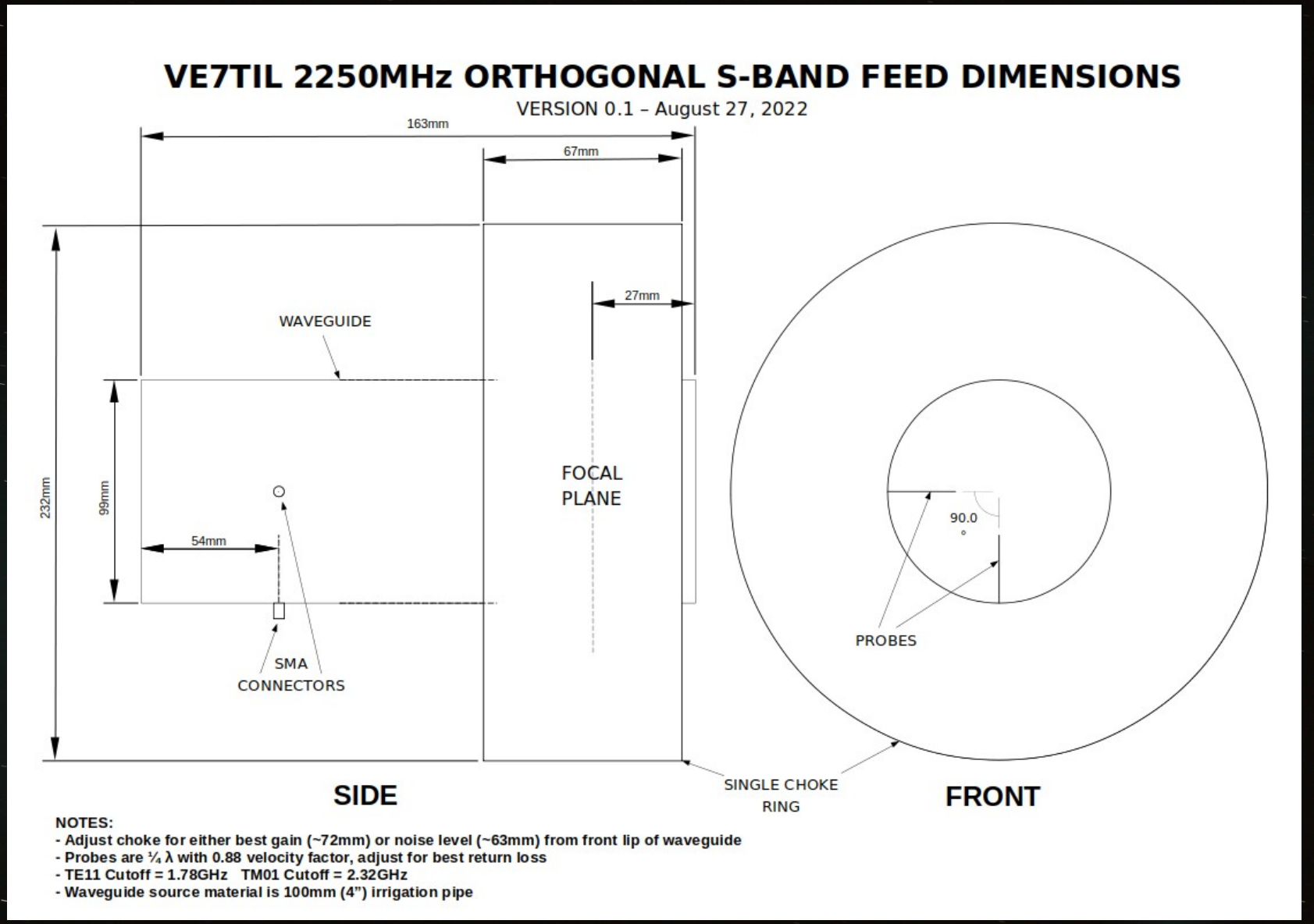
U – Difference between linear +45° and -45° intensities of light.

V – Difference in circular light intensities.
(+ RHCP, - LHCP)

Practical Polarimeter - Hardware



Practical Polarimeter - Hardware



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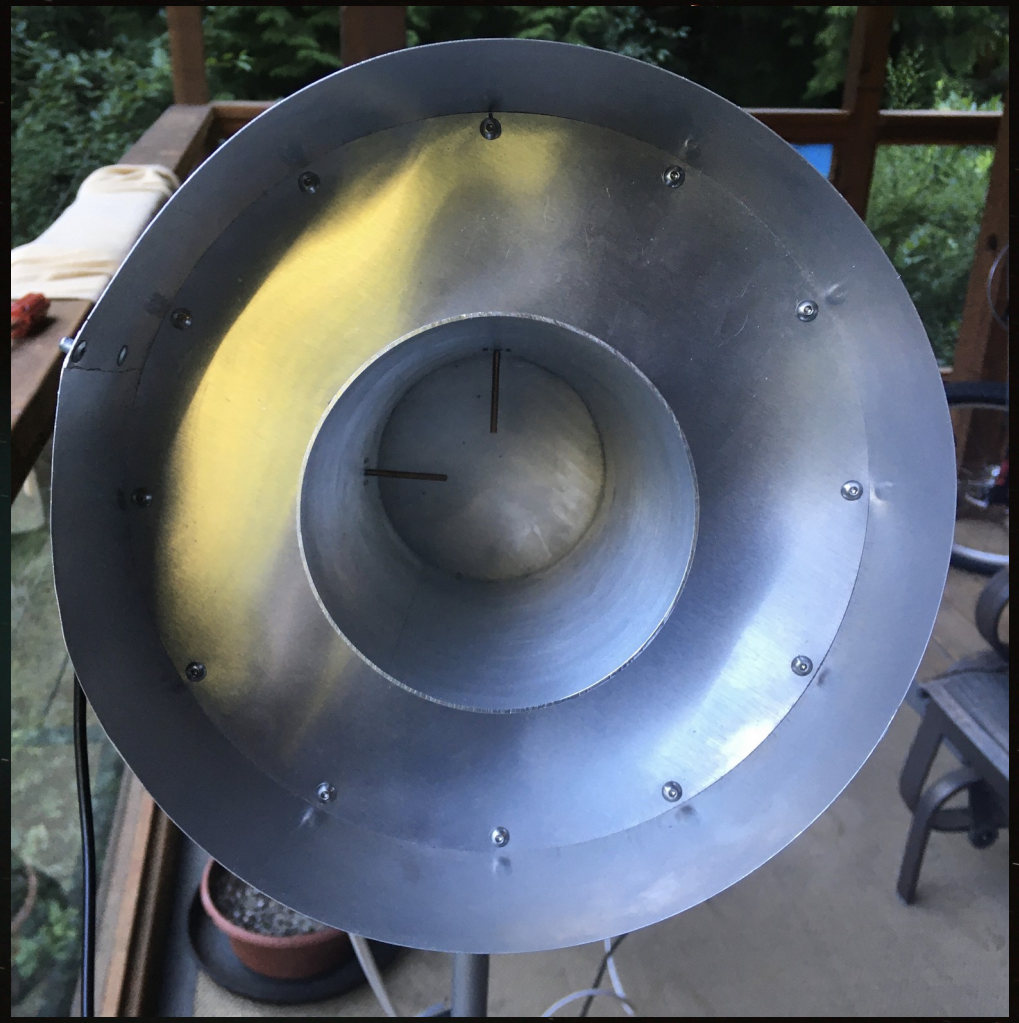

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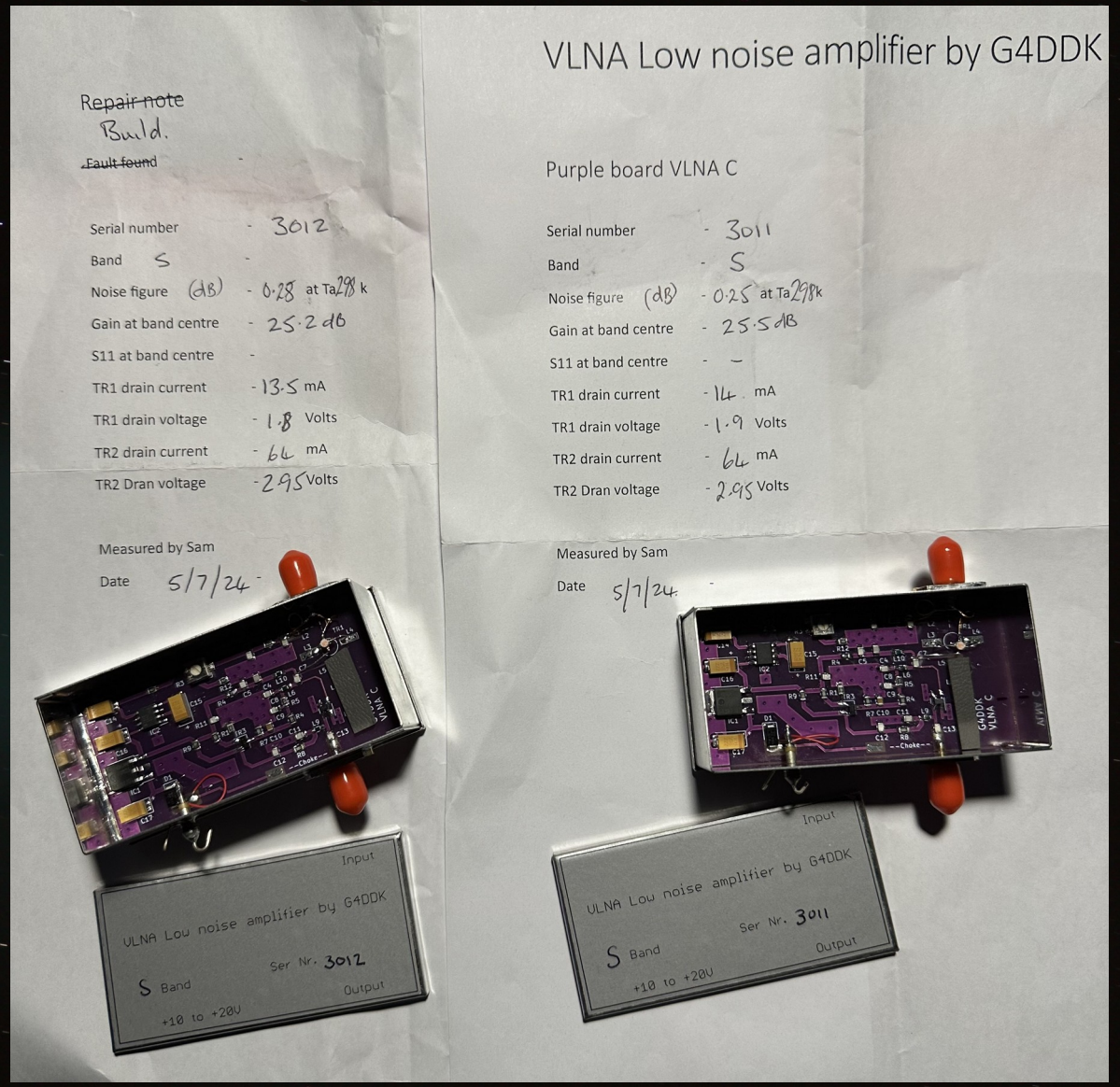
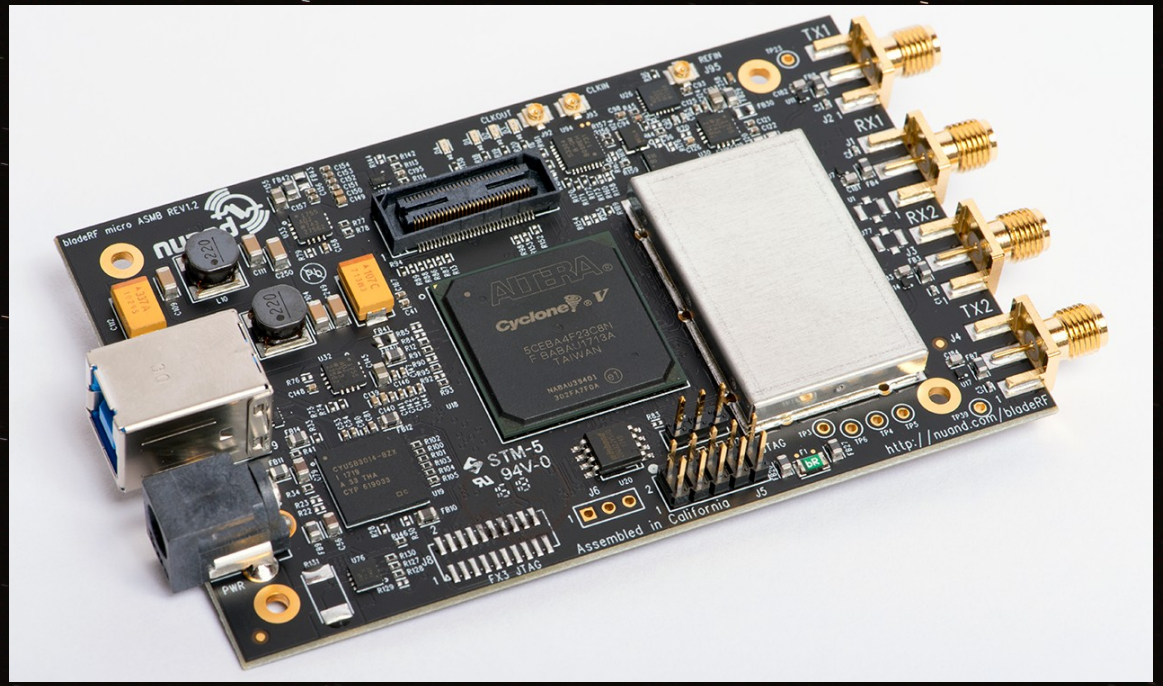
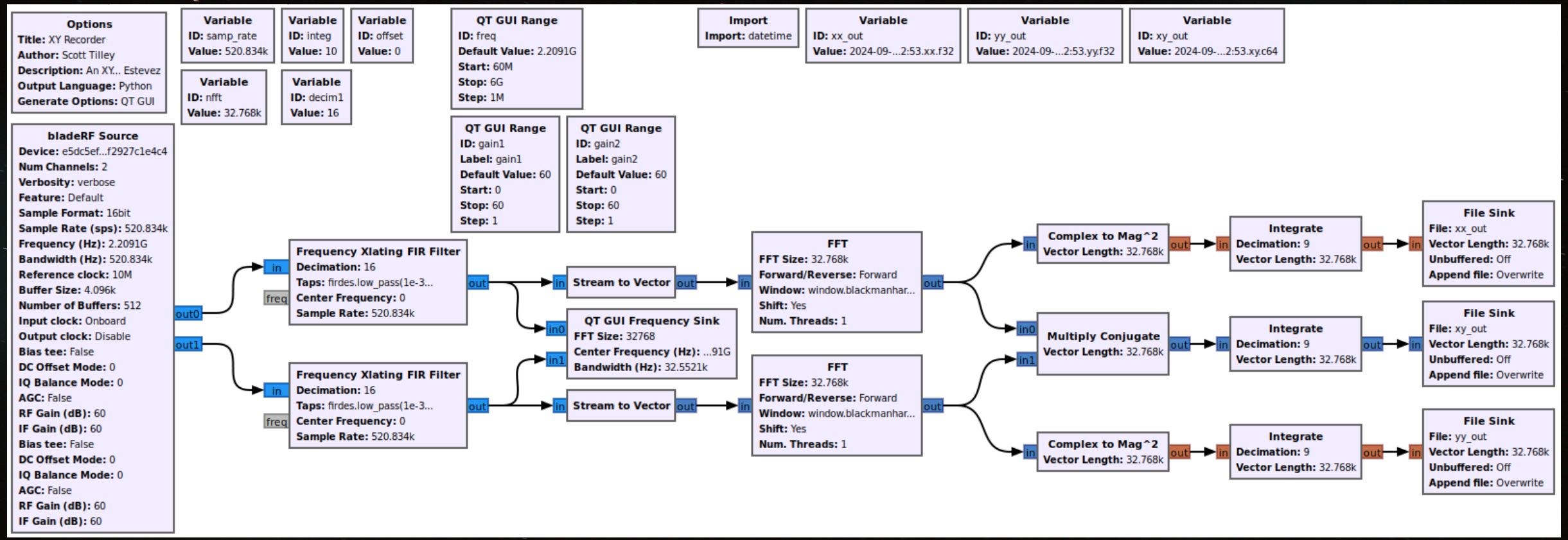




Practical Polarimeter - Software

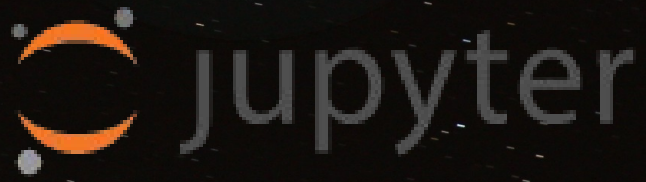
GNU Radio
THE FREE & OPEN SOFTWARE RADIO ECOSYSTEM



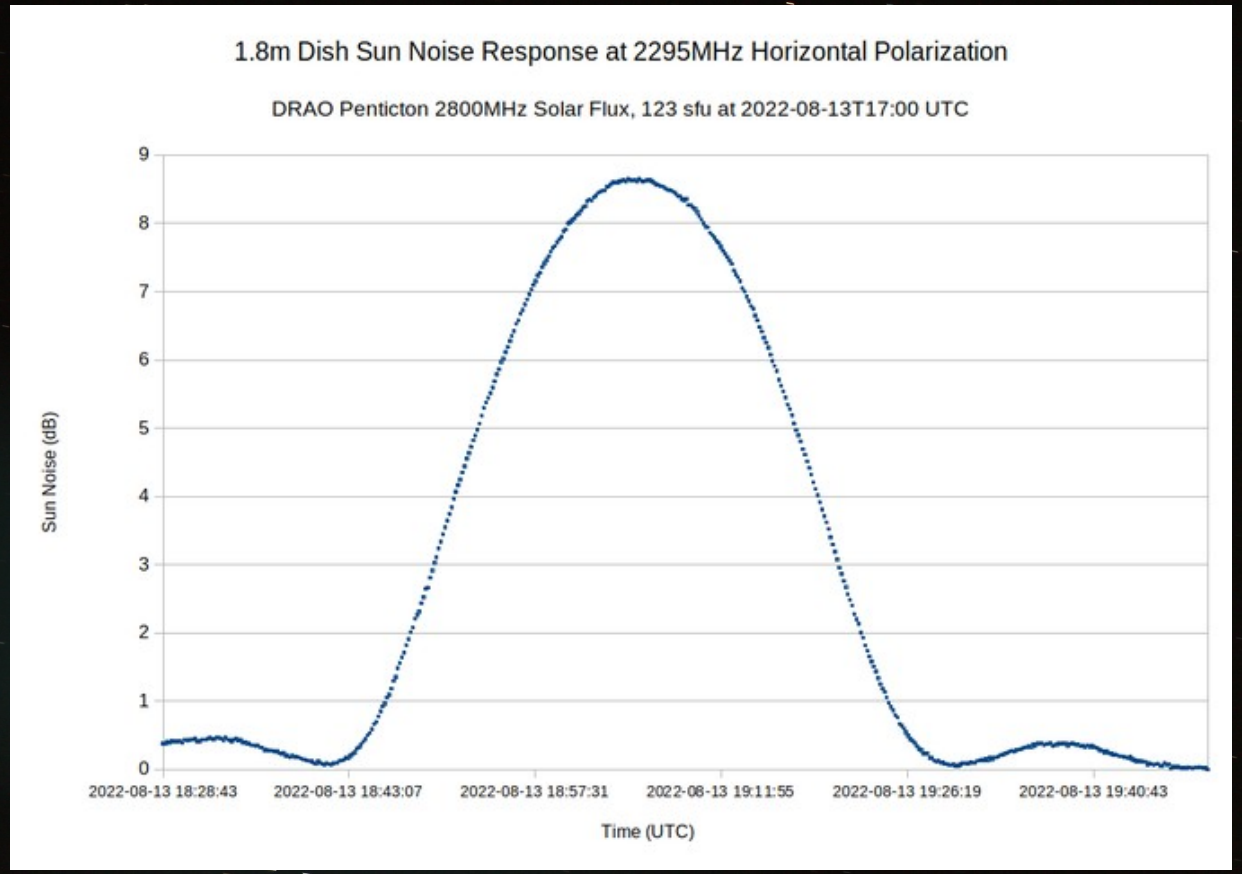
Practical Polarimeter - Software

python

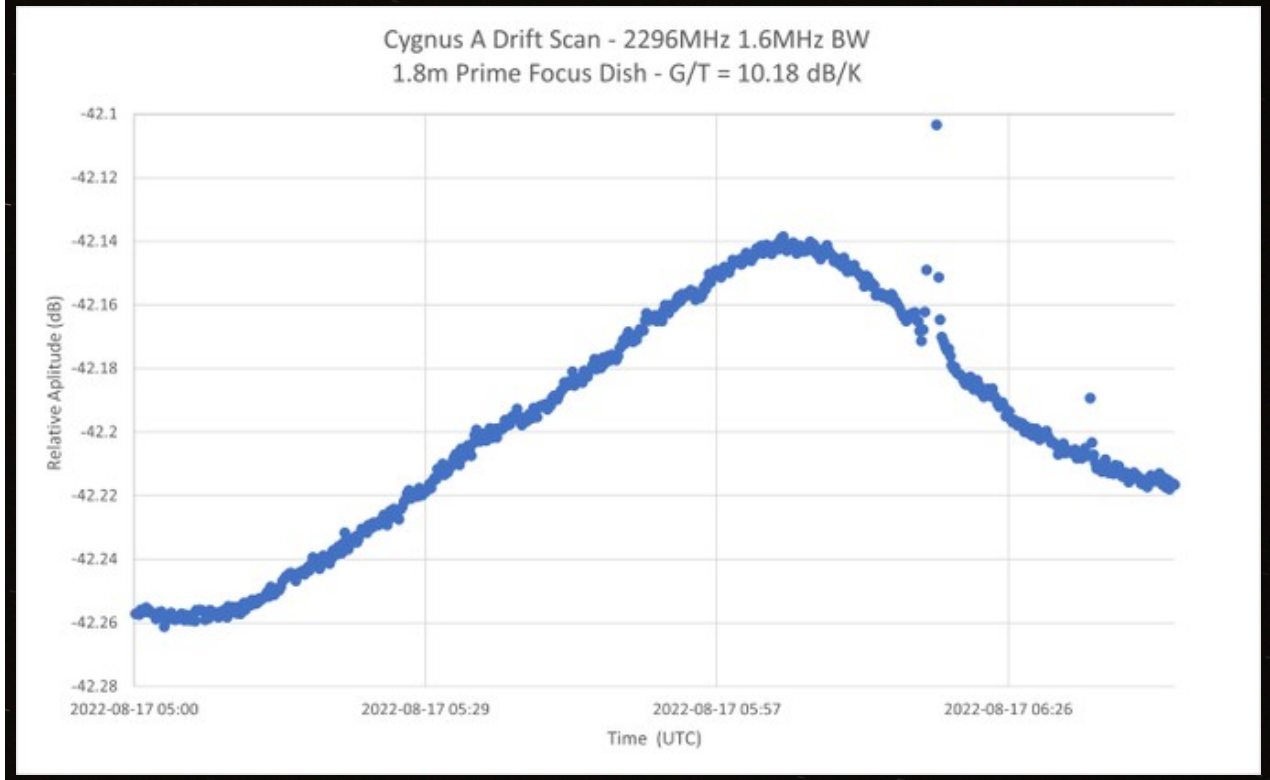
- Application of the gain offset,
- Application of the phase offset,
- Presents plots and data values to allow for determination of correct tuning and signal levels,
- Doppler and Stokes *I* plot and saves data in Sattools RF (STRF format),
- Extract peak features, adjust gains and normalize the data arrays,
- Calculates Stokes parameters and derived values,
- Plot Stokes parameters,
- Plot linear polarization and polarization angle,
- Plots other parameters based on analysis requirements.



Practical Polarimeter - Calibration



SUN NOISE



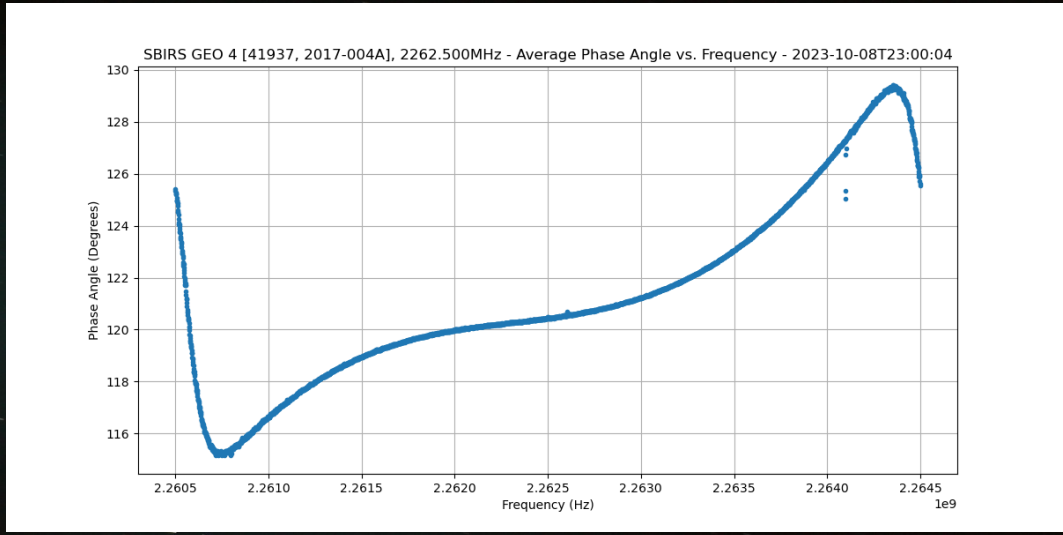
RADIO ASTRONOMY

Practical Polarimeter – Calibration

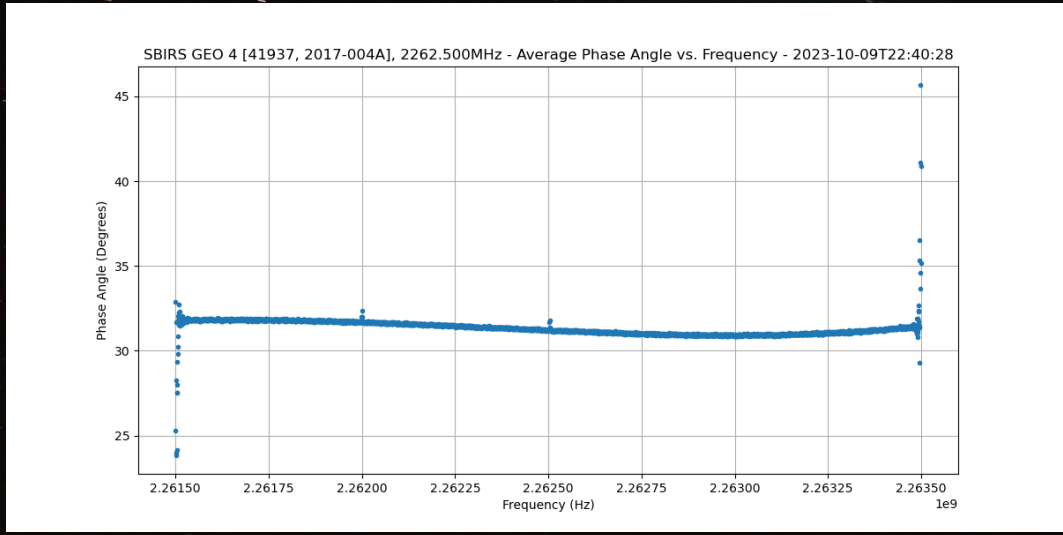
- Electrical length of the X and Y sides of the hardware system before the SDR receiver inputs,
- Gain offset at a particular frequency of observation,
- Phase offset at a particular frequency of observation.

Practical Polarimeter – Calibration

Equalize electrical length of the X and Y sides of the hardware system before the SDR receiver inputs using a satellite



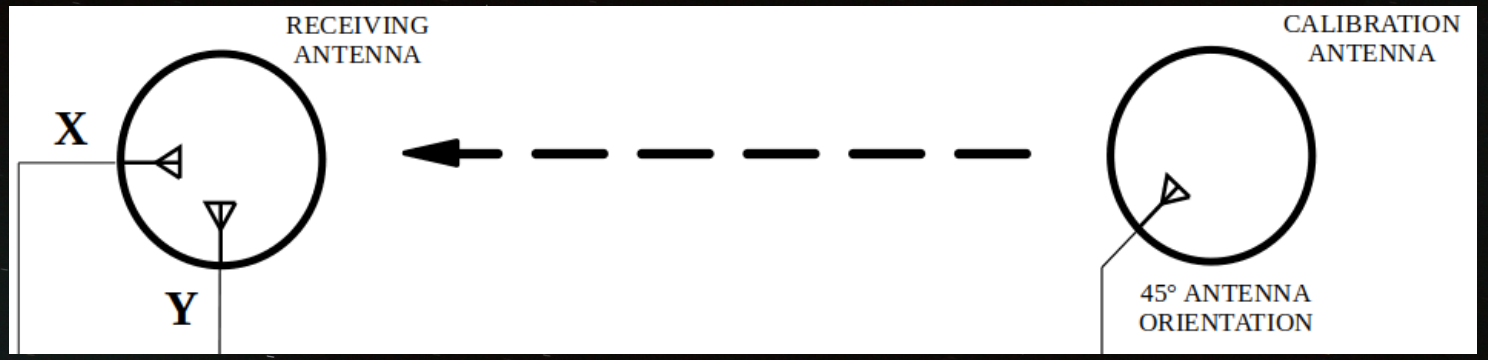
BEFORE



AFTER

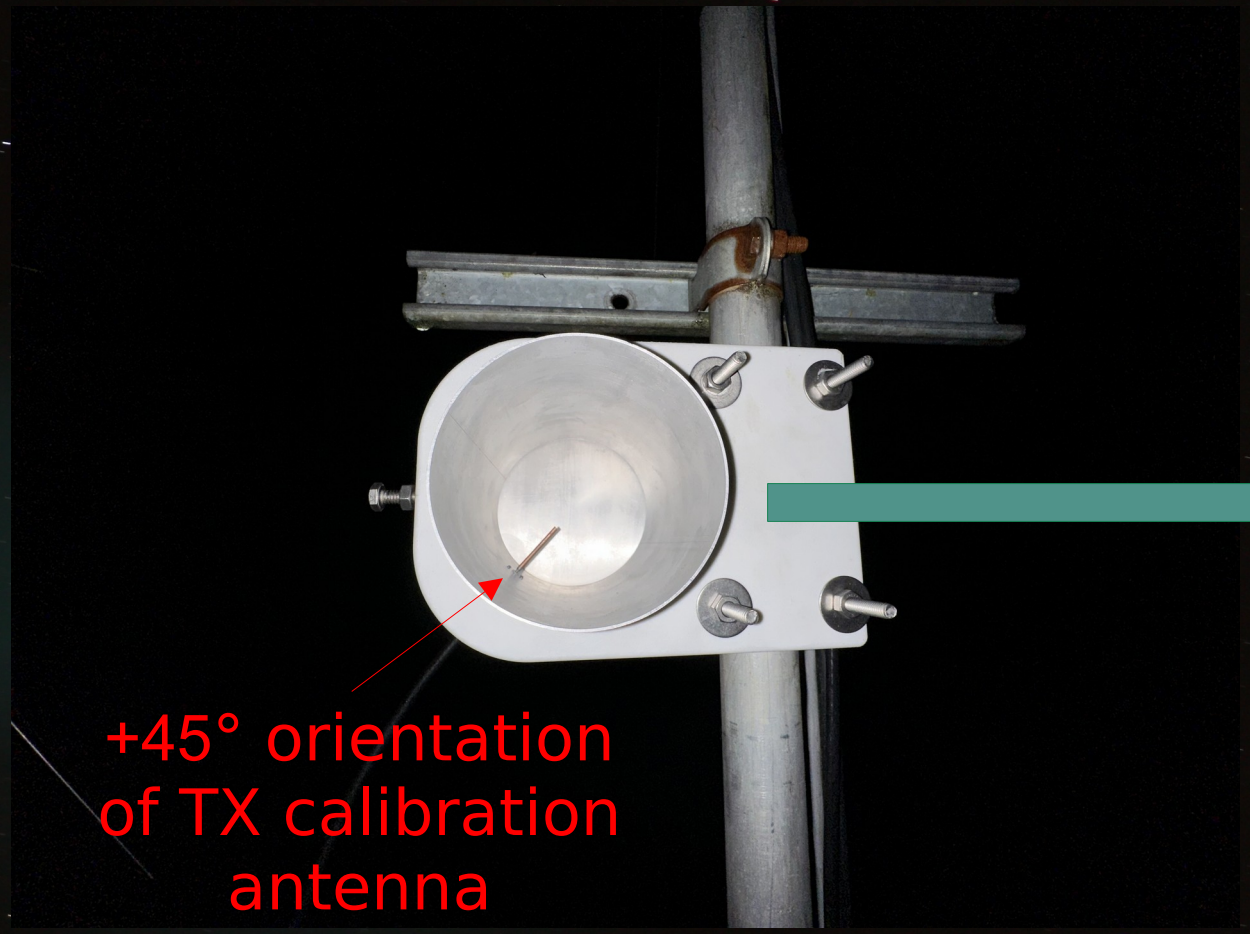
Practical Polarimeter – Calibration

WHY does this work?



- Calibration antenna is at +45°, thus no Stokes Q only U.
- Calibration antenna is linear polarized and has no circular component.

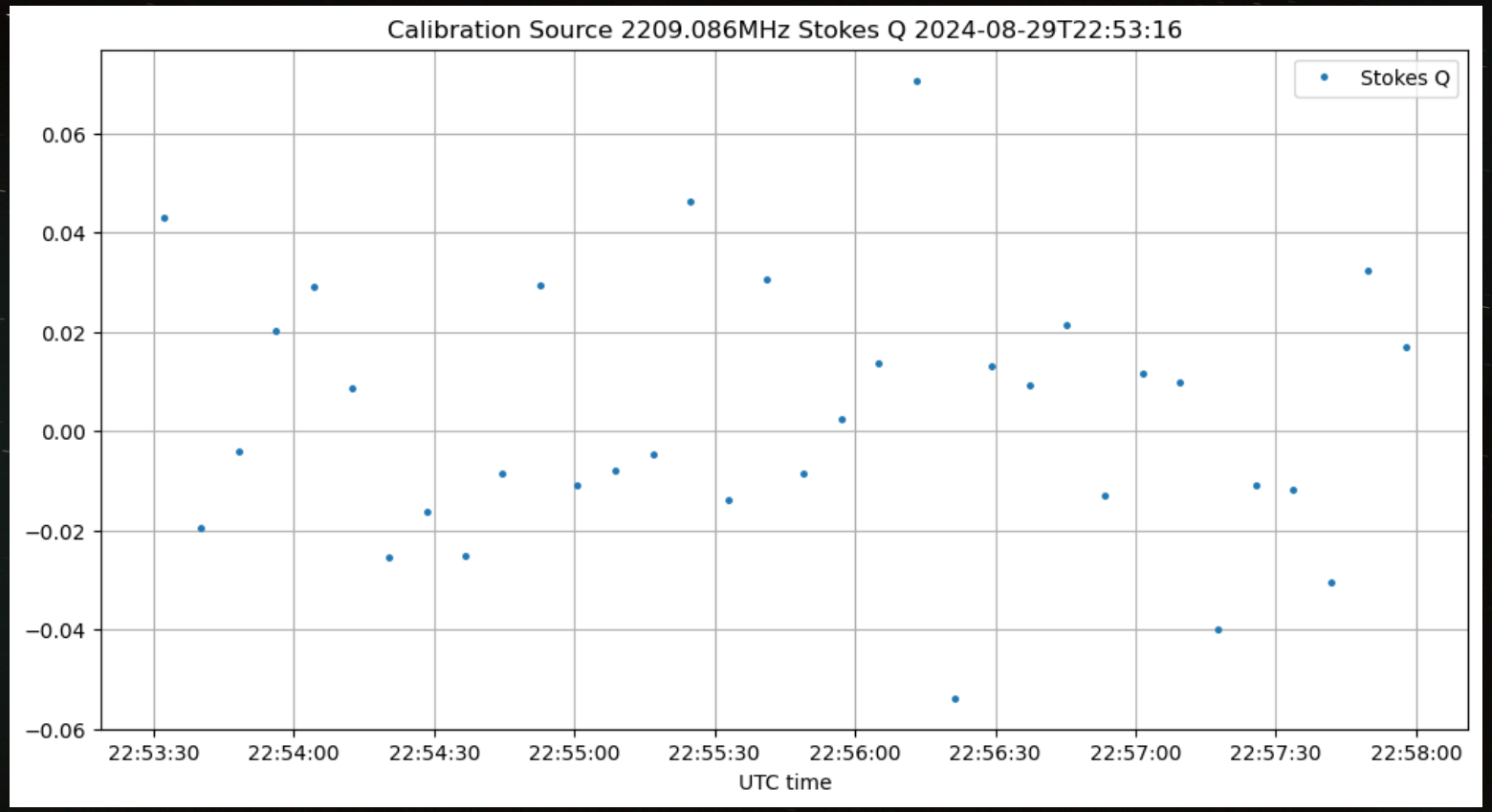
Practical Polarimeter – Calibration Setup



Orthogonal orientation of feed probes

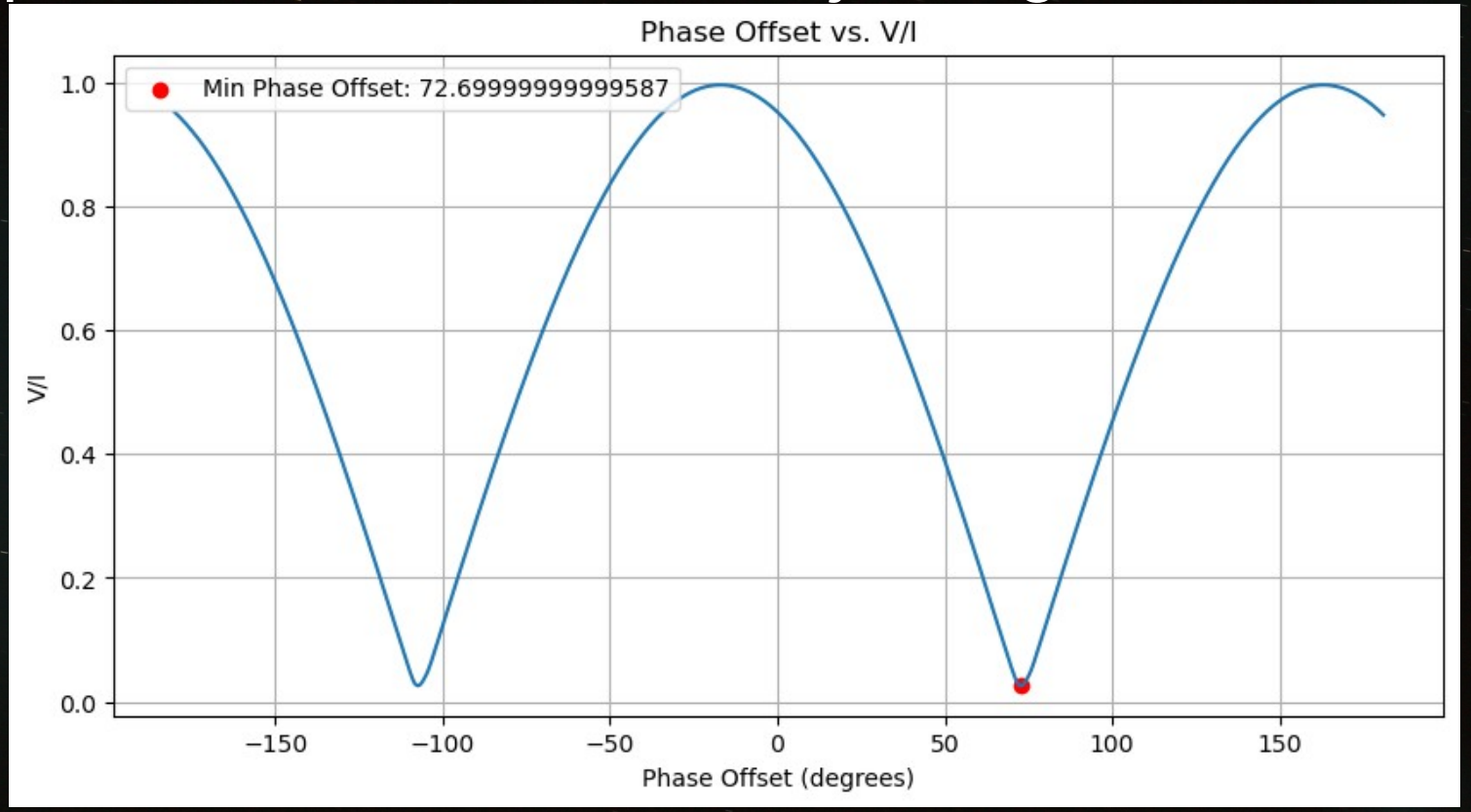
Practical Polarimeter – Calibration

Average difference in the gain for X and Y and apply offset until Stokes Q reads zero



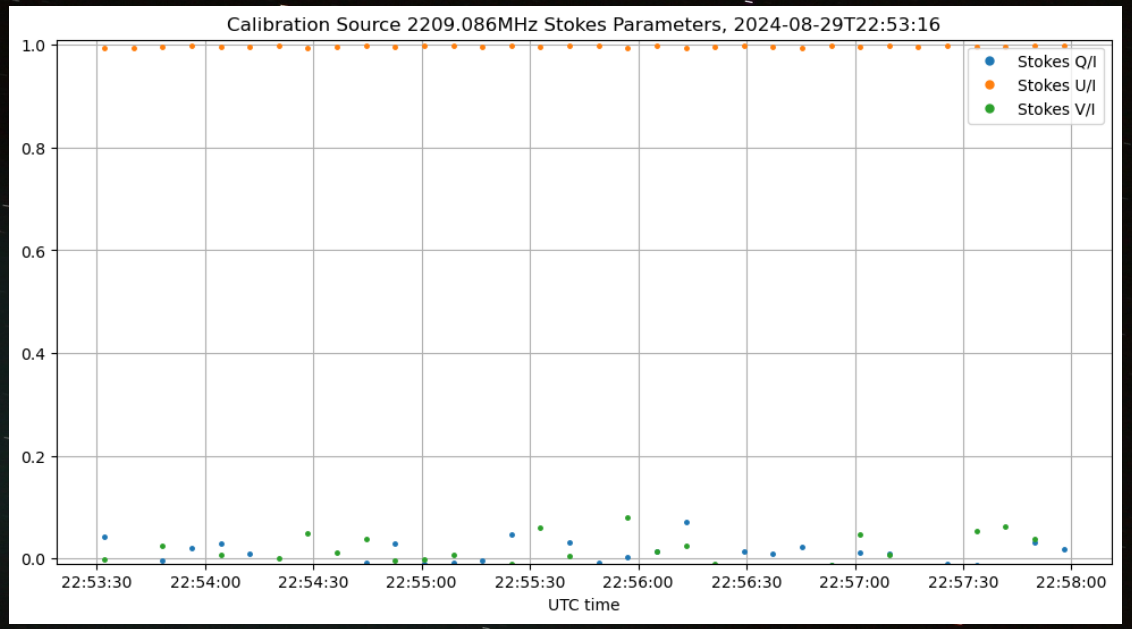
Practical Polarimeter – Calibration

Iterate the phase offset until Stokes V reads zero. Use a known emitting satellite to determine which phase value produces + RHCP and adjust sign of Stokes V

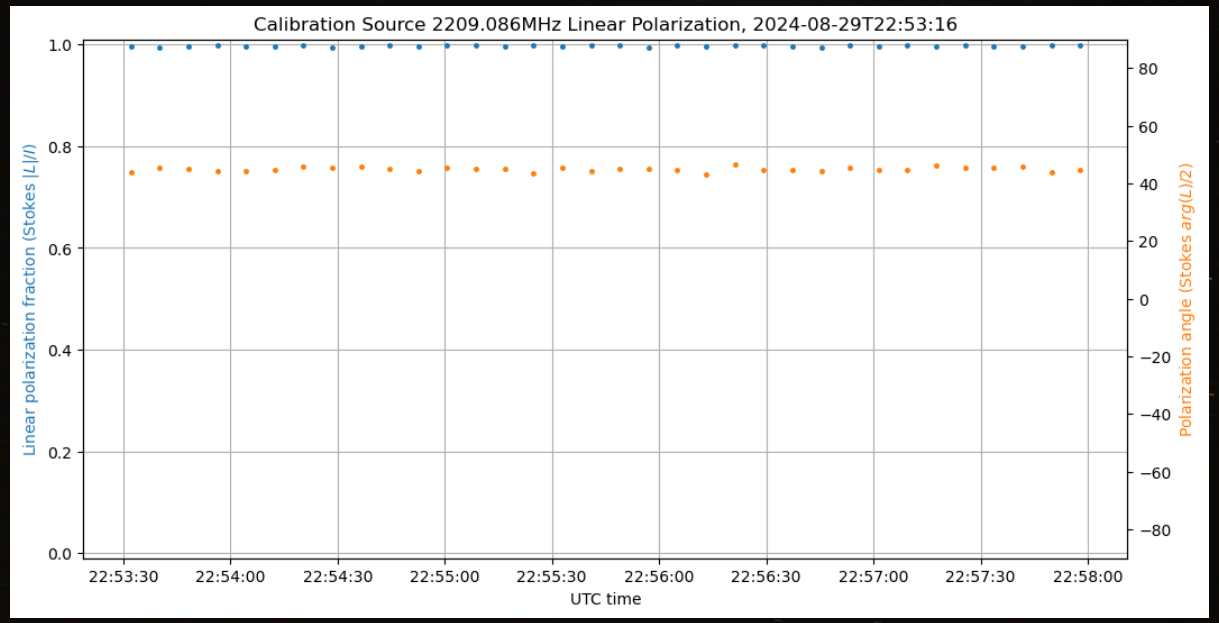


Practical Polarimeter – Calibration

Summary of completed calibration, U = 1, Q and V = 0, Polarization Fraction = 1 and polarization angle = 45°



STOKES



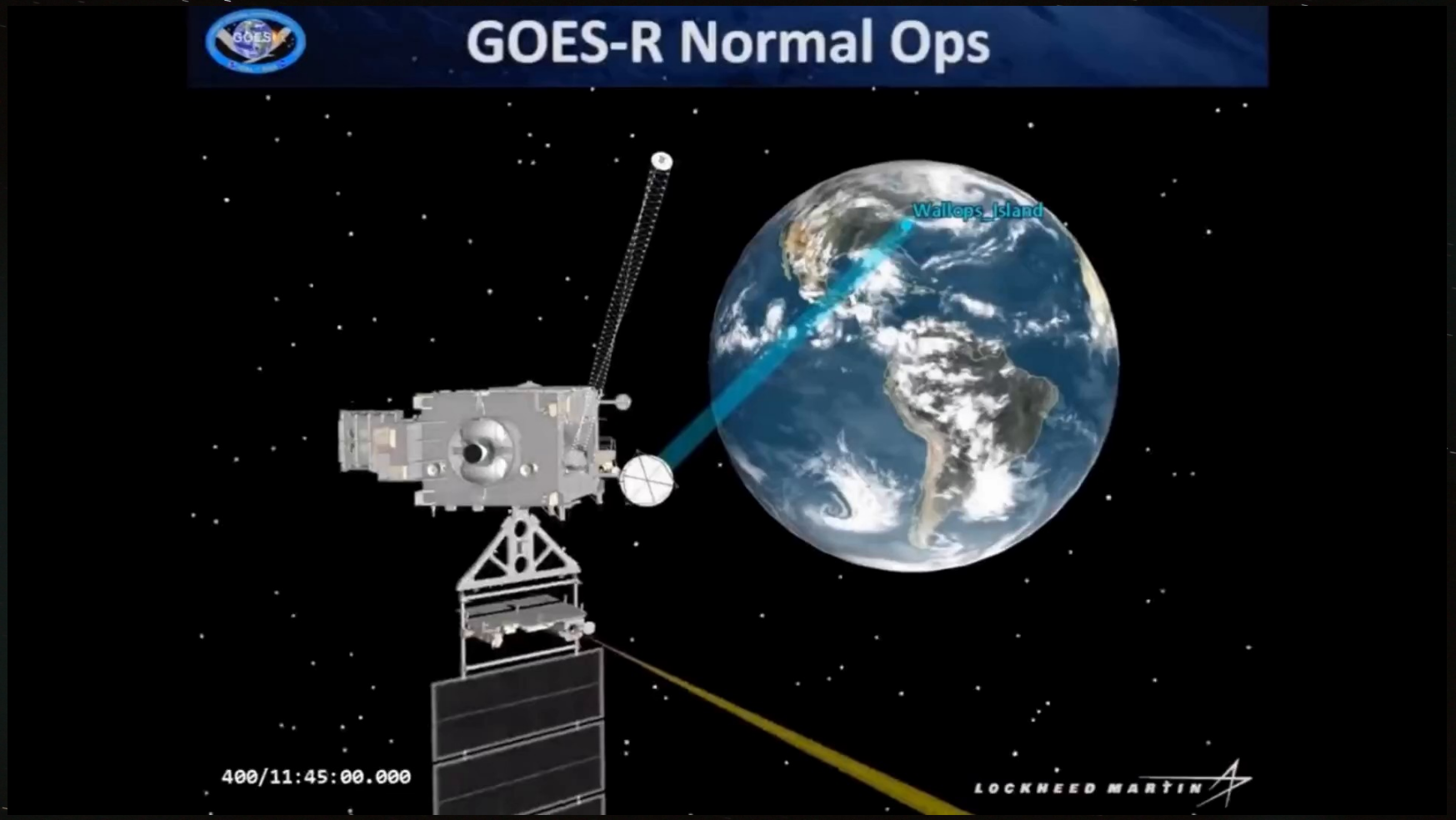
LINEAR POLARIZATION

Practical Polarimeter – Error Sources

- Not re-calibrating gain and phase offsets when you change frequency.
- Coax dielectric phase sensitivity to temperature. Most sensitive ranges between 10 and 20°C.
- Calibrator misalignment.

Practical Polarimeter – Results

GOES 17 – Storage Orbit Yaw Flip



Practical Polarimeter – Results

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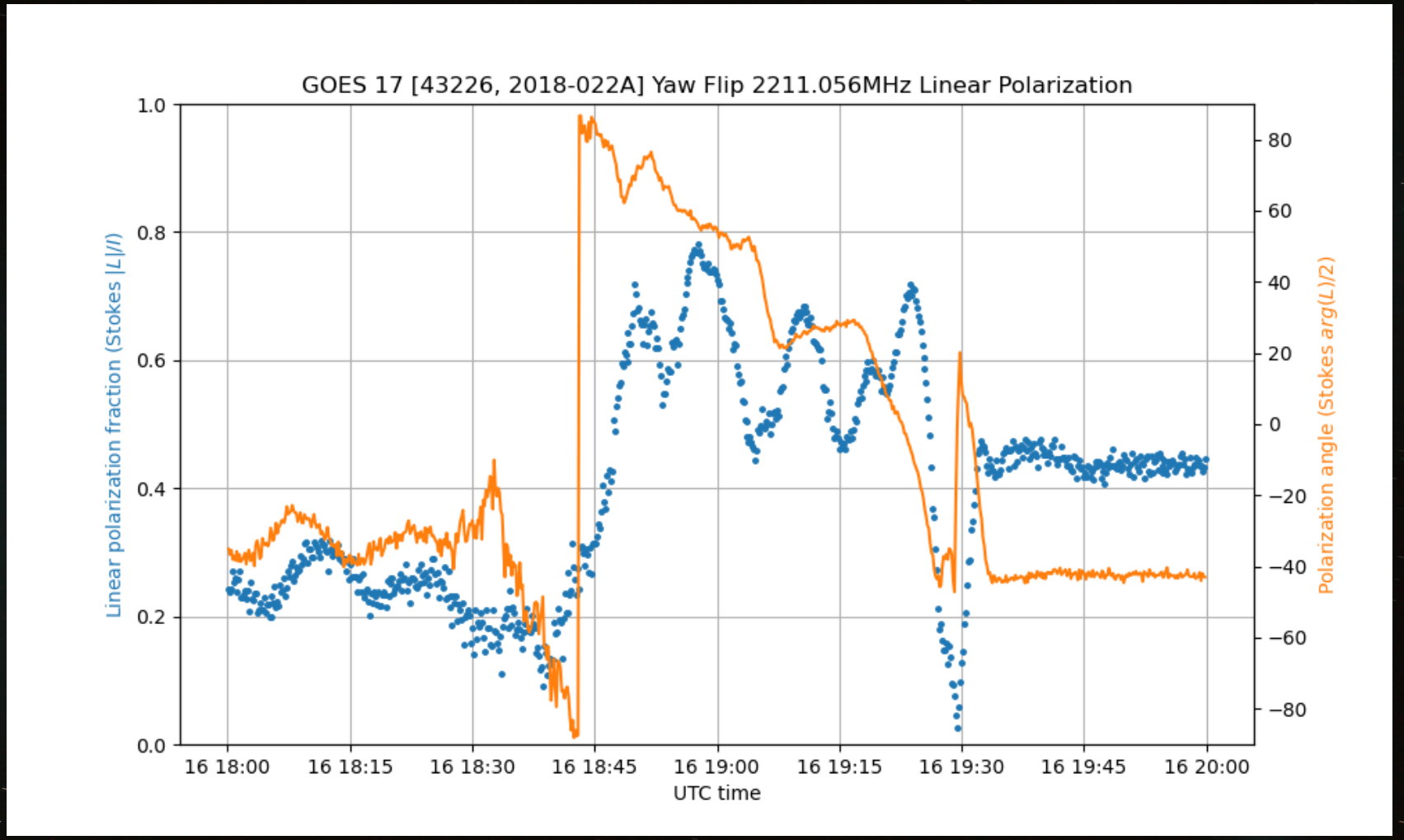
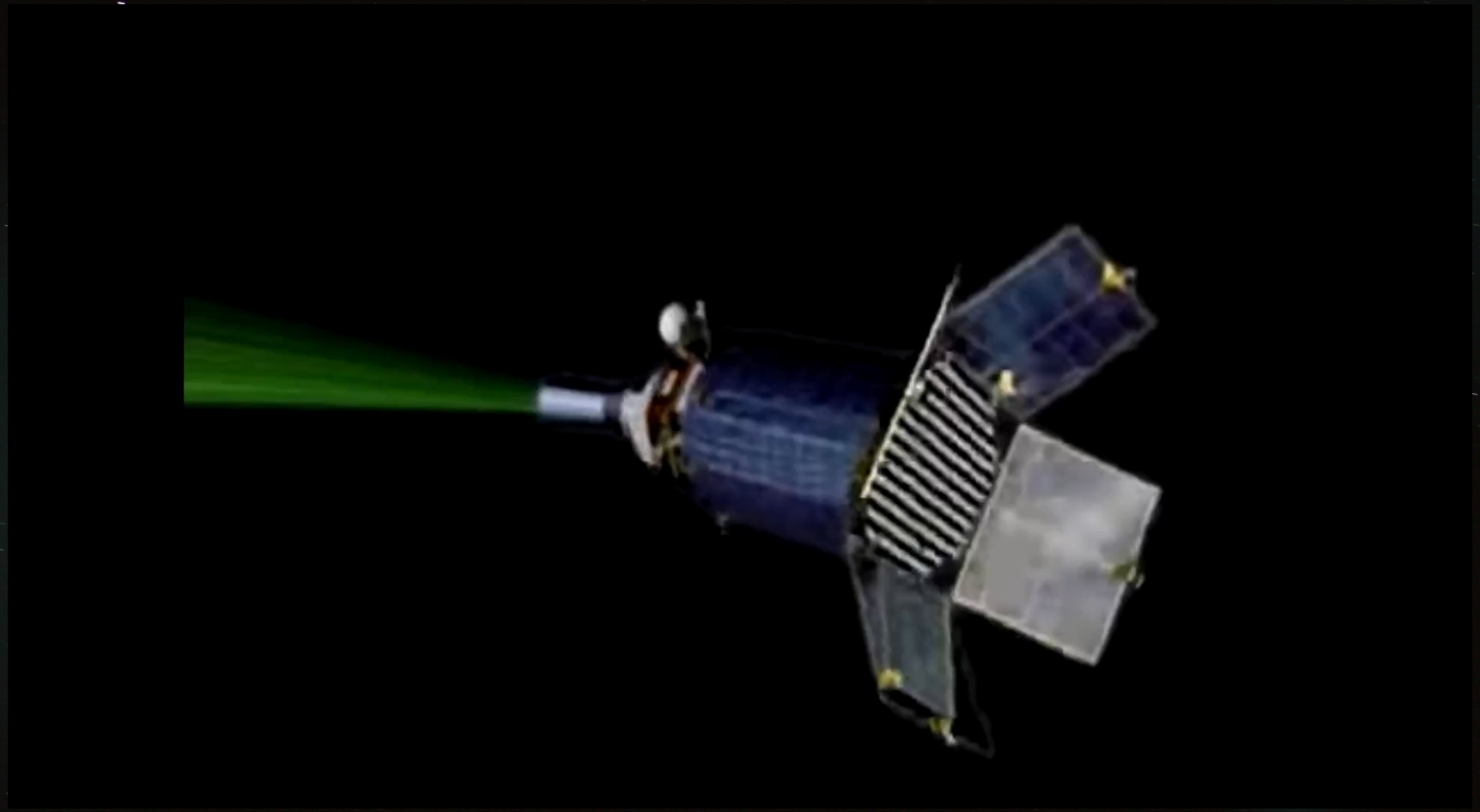


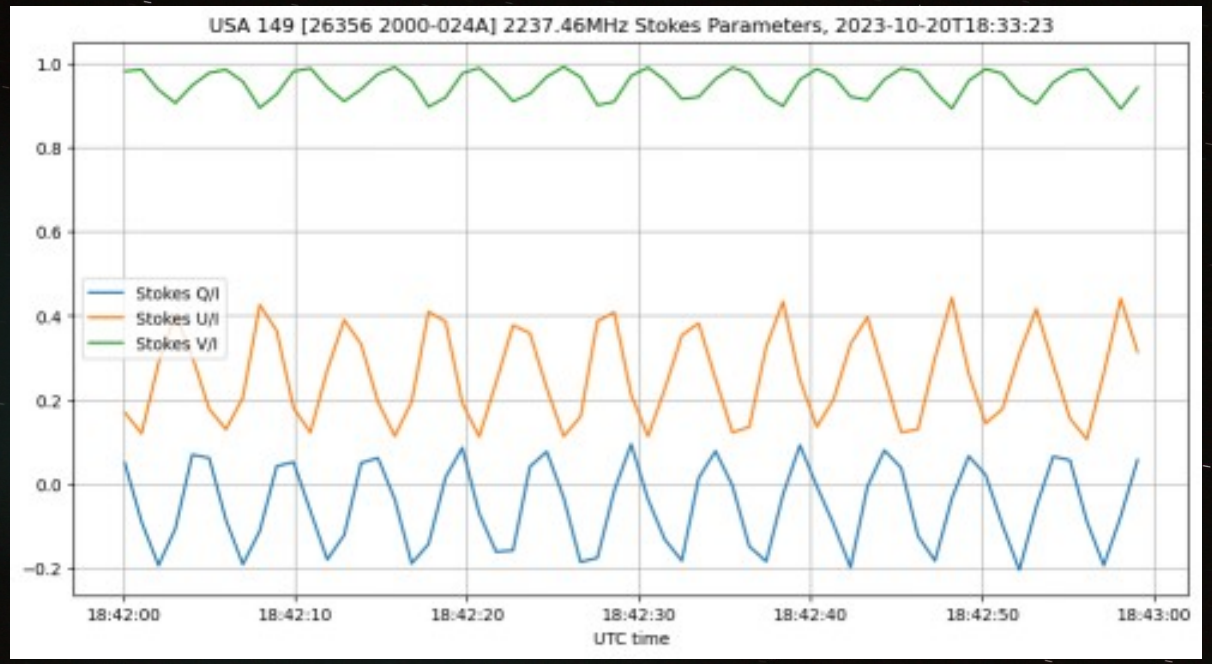
Practical Polarimeter – Results

DSP F20 – Rotating Missile Launch Detection Satellite.

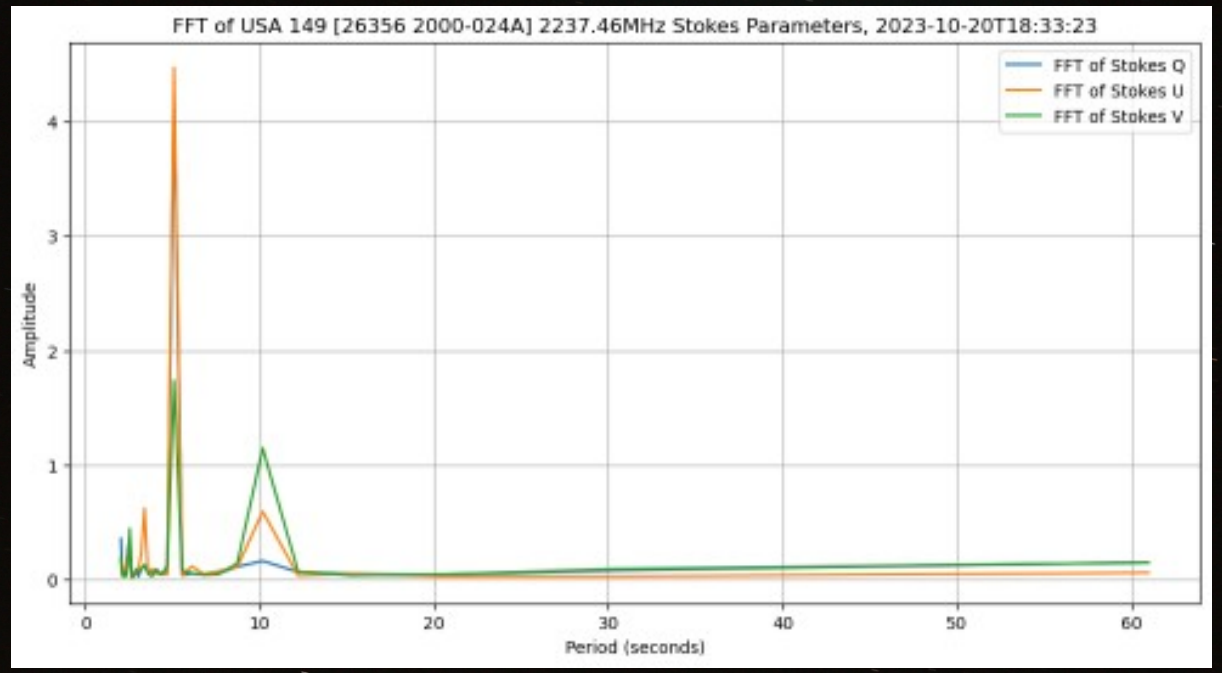


Practical Polarimeter – Results

DSP F20 – 5 and 10 second signal matches known operational spin rate of satellite.



QUADRATURE Q AND U SHOW ROTATION



FFT OF STOKES DATA REVEALS 5 AND 10 SECOND SIGNAL COMPONENTS

Practical Polarimeter – Summary

- Polarization defined.
- Concept of axial ratio and polarization ellipse was discussed as it relates to antenna attitude.
- Stokes parameters introduced for quantification of polarization of light.
- Practical hardware and software is demonstrated.
- Calibration process is demonstrated.
- Error sources highlighted.
- Results of observations to demonstrate the viability of the system.
- Insert your practical application NOW!