Polarization Modulator Unit: angular accuracy and wobbling calibration

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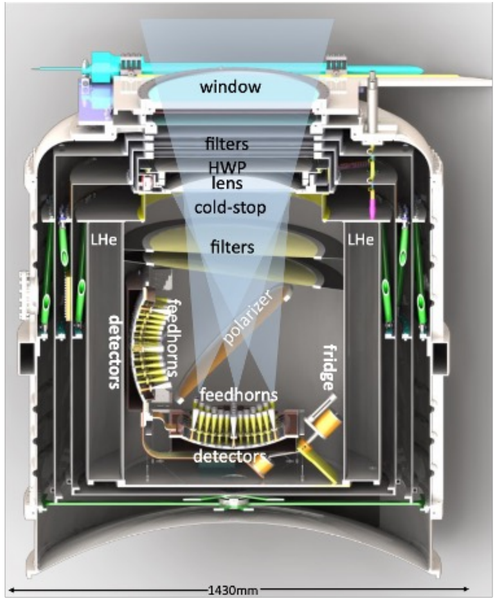
07/11/2024
CMB-CAL 2024

Missions' Requirements

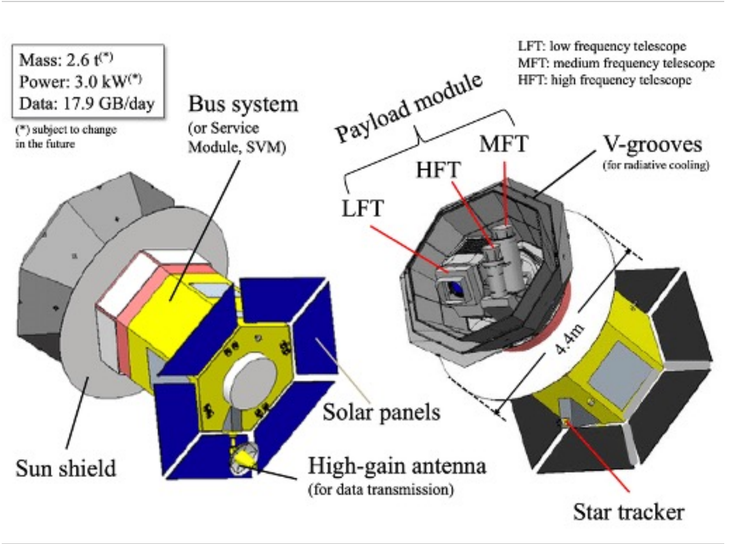
LSPE/SWIPE

- Balloon-borne mission
- 3 bands, 120 – 250 GHz
- 326 TES bolometers
- + LSPE/Strip



LiteBIRD

- Satellite
- 15 bands, 40 – 400 GHz
- 3 telescopes



	SWIPE	MFT	HFT
Angular Accuracy	< 10'	< 1'	< 5'
Power Load	< 40mW	< 4mW	
Temperature	< 20K	< 20K	< 20K
Wobbling	< 30'	< 30'	< 30'

Missions' Requirements

	SWIPE	MFT	HFT	Systematic Effects / Issues
Angular Accuracy	< 10'	< 1'	< 5'	Reconstruct with good accuracy the HWP angle to avoid leakage from E-modes to B-modes
Power Load	< 40mW	< 4mW		Limited thermal budget Minimize the load on the detectors
Temperature	< 20K	< 20K	< 20K	Minimize spurious polarized emissions of the HWP Detectors' calibration is affected by the HWP's temperature
Wobbling	< 30'	< 30'	< 30'	Has to be monitored both for optical and mechanical issues

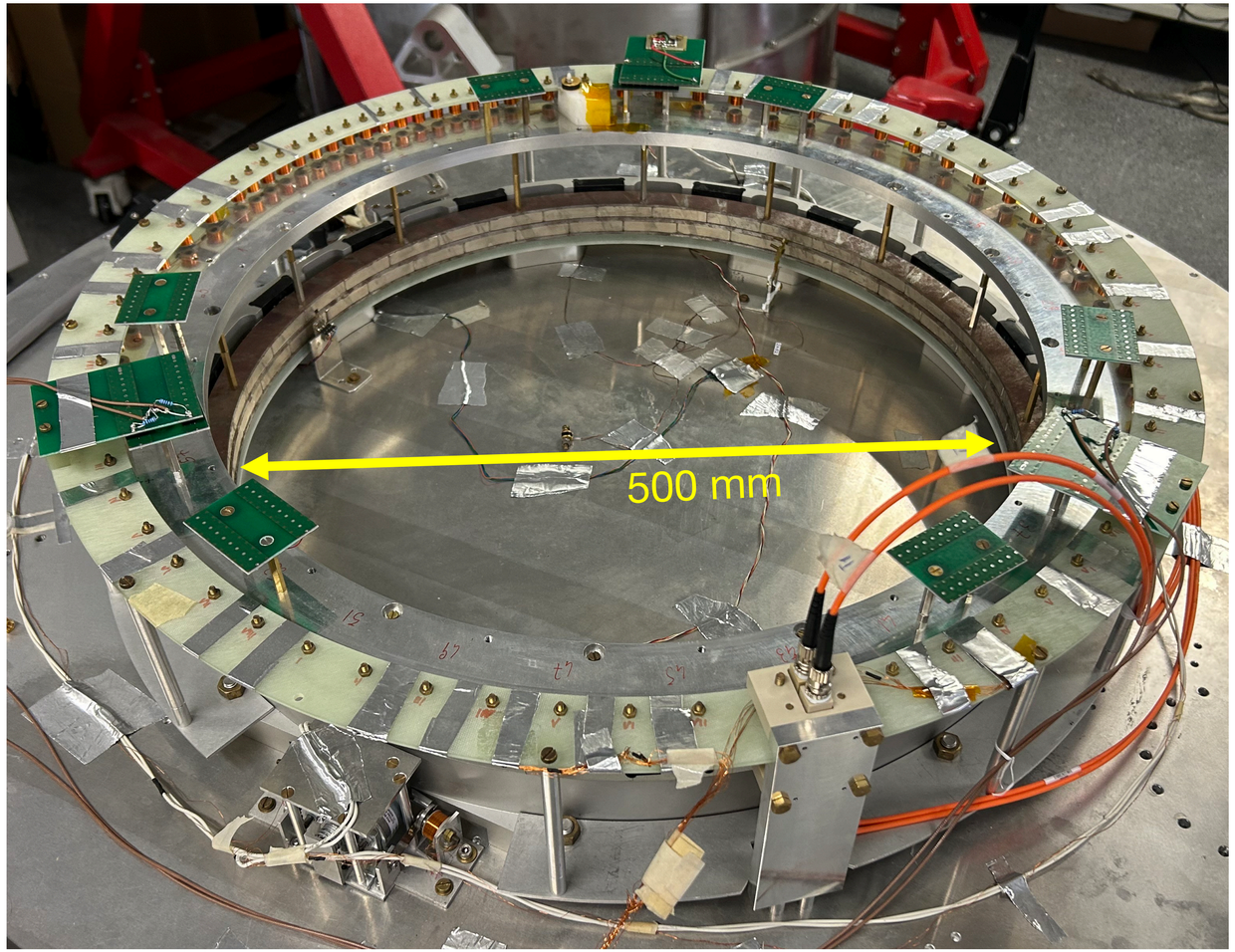
Polarization Modulator Unit

Continuously-rotating metal-mesh Half-Wave Plate (500mm diameter)

Cryogenic environment: 5K

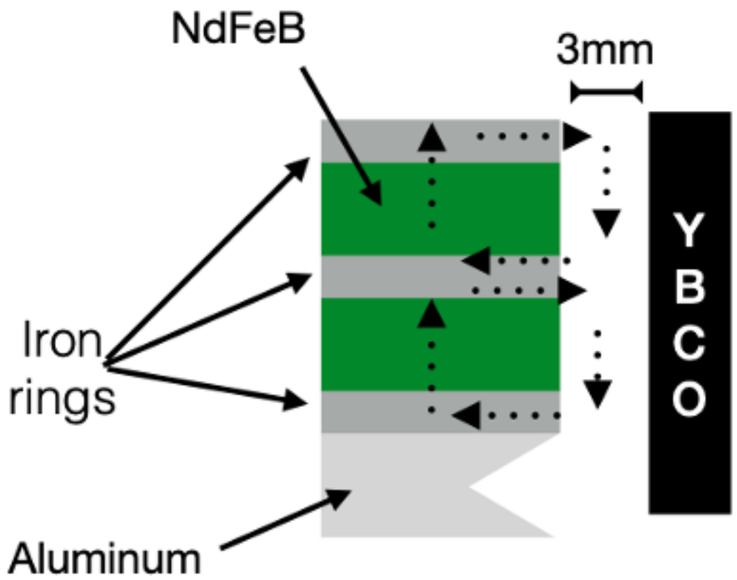
Subsystems:

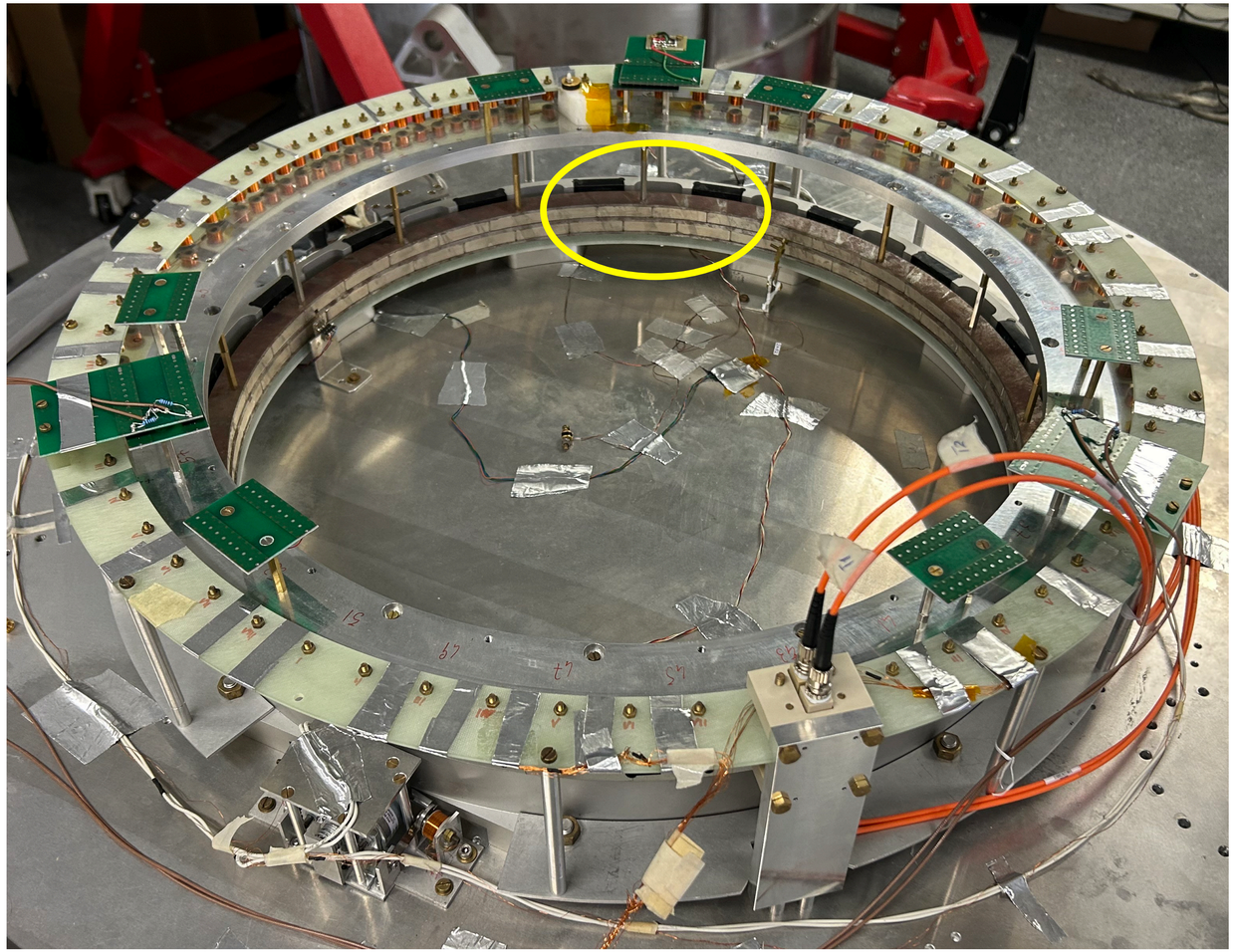
- Superconducting Magnetic Bearing
- Clamp/release system
- Electromagnetic motor
- Optical encoders
- Hall sensors
- Capacitive sensors



PMU - Superconducting Magnetic Bearing

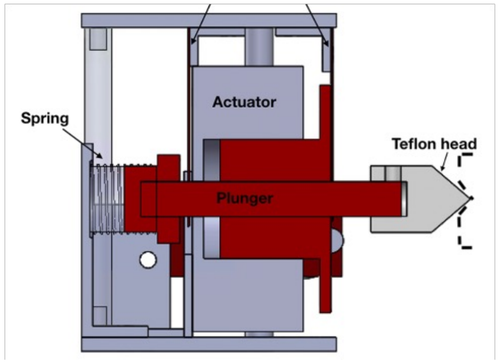
- 18 YBCO bulks
- 2 NdFeB segmented rings





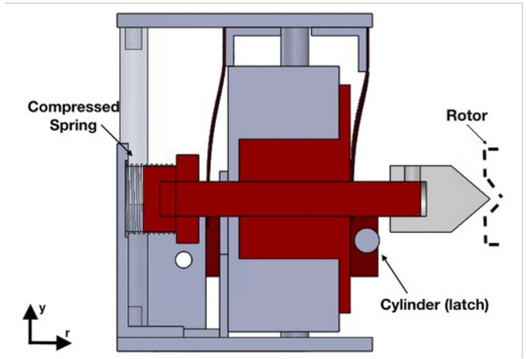
PMU - Clamp/Release system

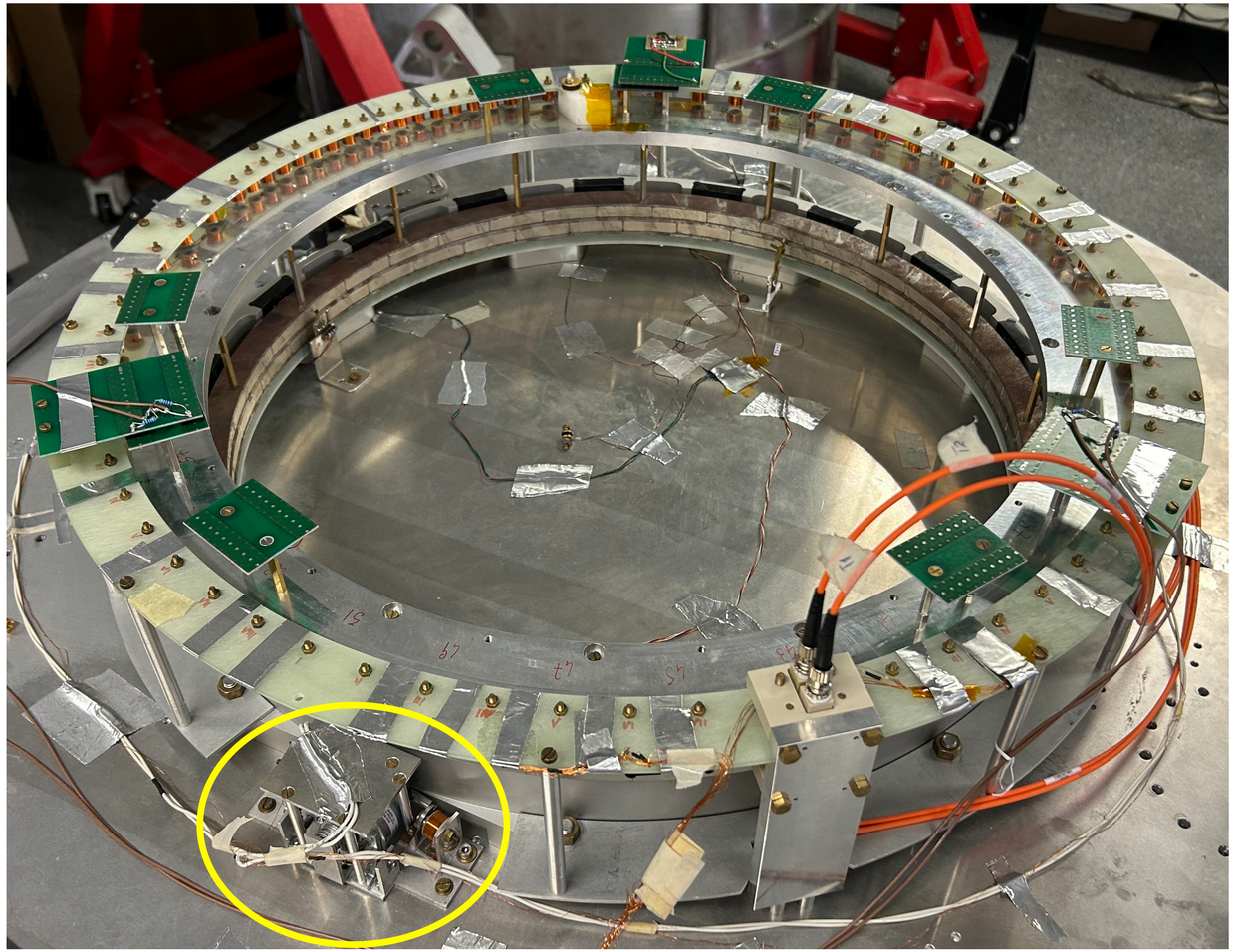
The actuator is holding the SMB rotor



The plunger is retracted in the radial direction, releasing the SMB rotor.

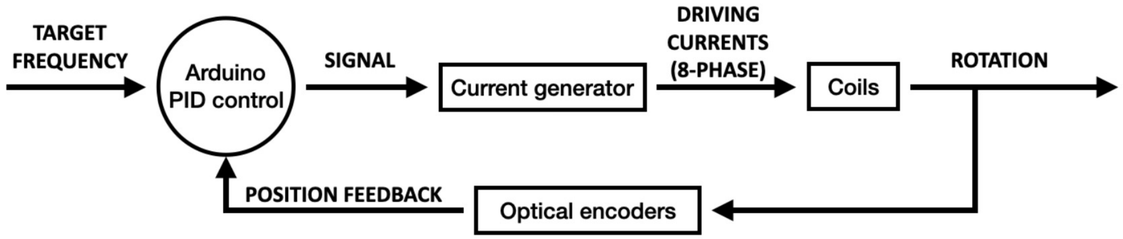
Small cylinders are inserted, latching the head in the retracted position.

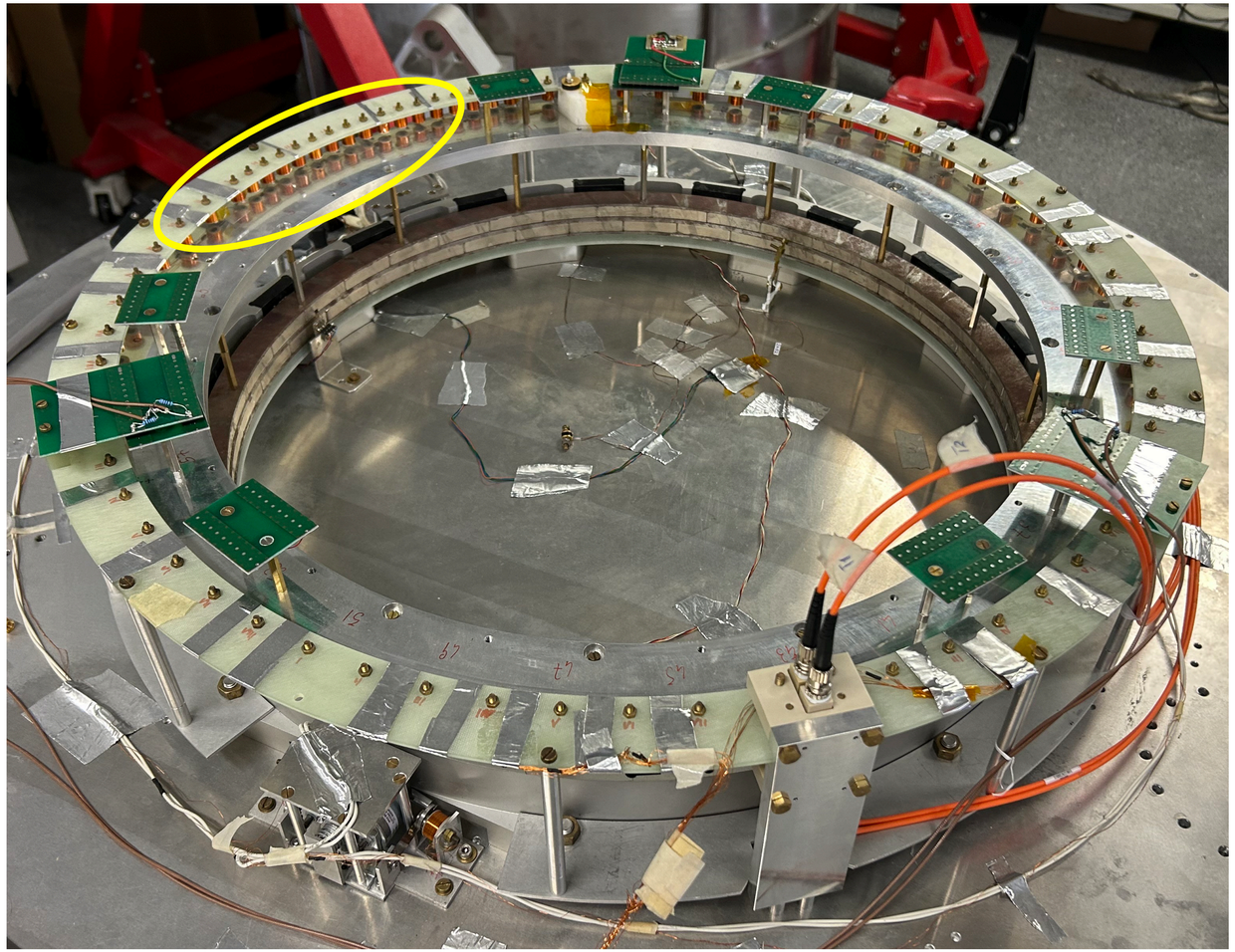




F. Columbro, P. de Bernardis, and S. Masi. “A clamp and release system for superconducting magnetic bearings”. Review of Scientific Instruments. 2018.

PMU - Electromagnetic Motor





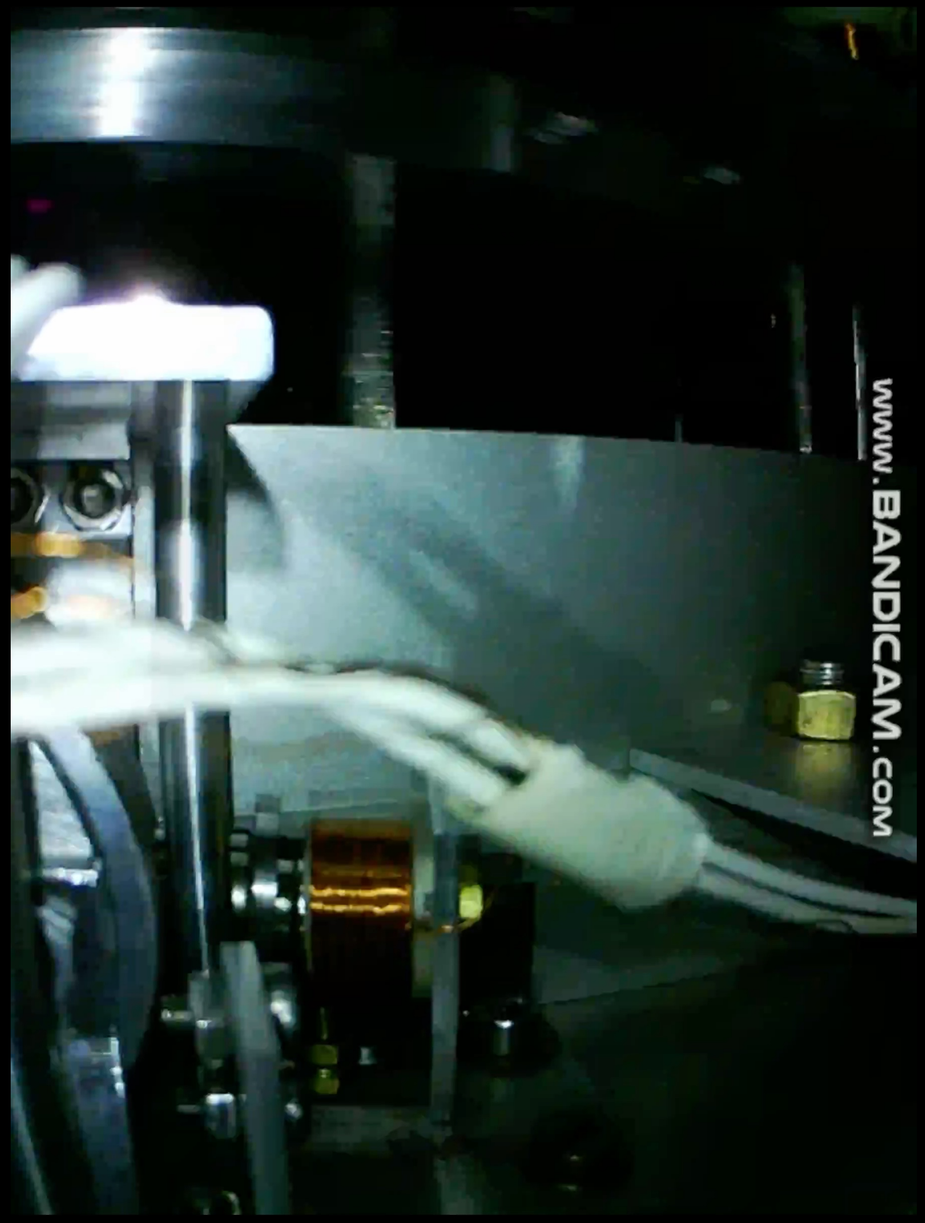
- 64 driving coils placed on the stator
- 8 small magnets (NdFeB) placed on the rotor

Current correction:

$$u(t) = K_p e(t) + K_i \int_0^t e(\tau)d\tau + K_d \frac{de(t)}{dt}$$

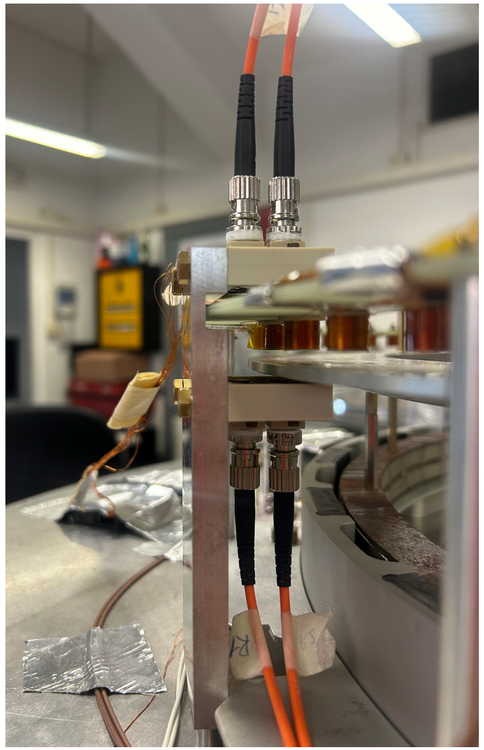
$$e(t) = r(t) - SP$$

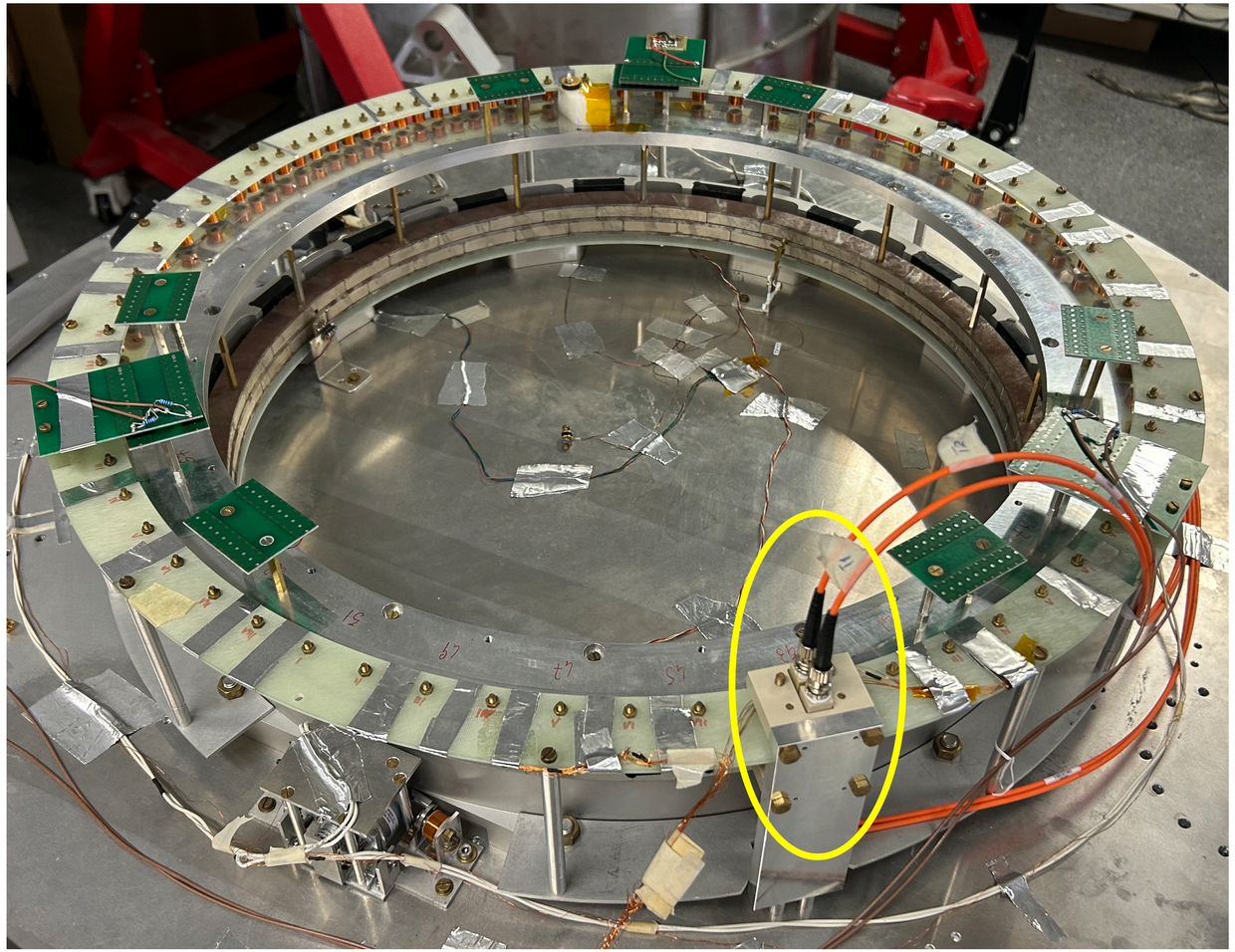
PMU - Rotation



PMU - Optical Encoder

- Absolute encoder—> single slit
- Relative encoder—> 64 evenly spaced slits





Measurements and Results

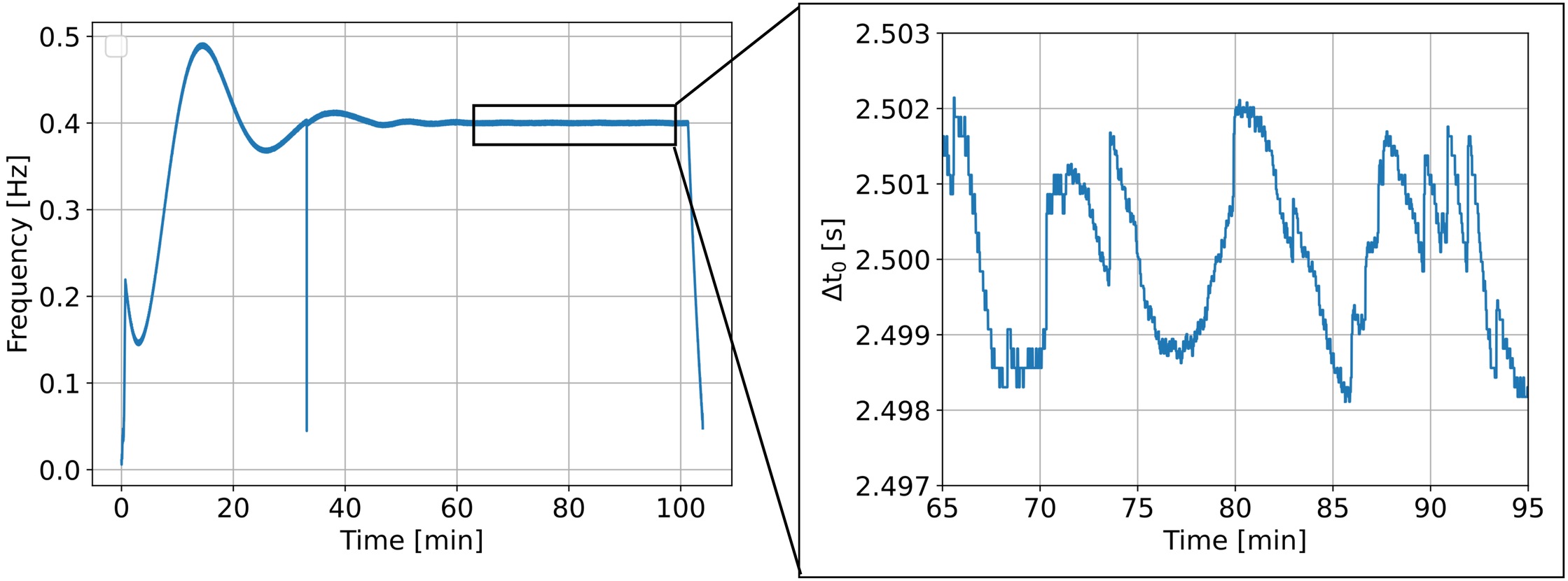
1. Stability / Angular Accuracy

2. Friction → Power Load
   → HWP temperature

3. Capacitive sensors → Distance measurements → Wobbling
   → Temperature measurements → HWP temperature

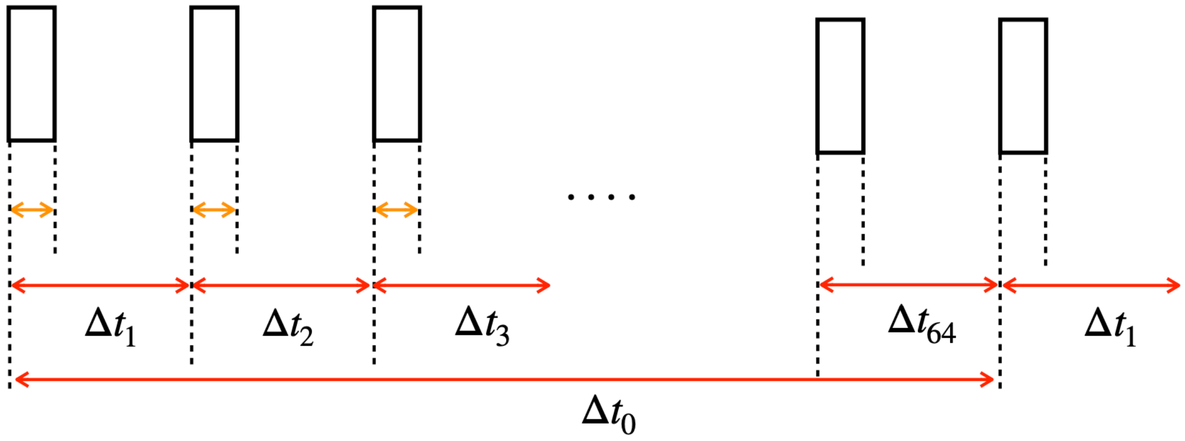
1. Stability

The PID feedback control stabilizes the rotation ⟶ Long-term **stability** < 0.1%



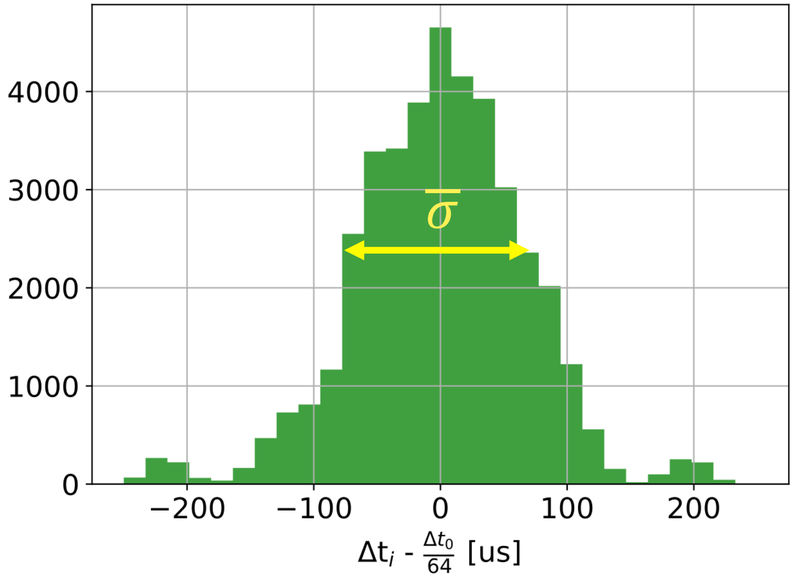
1. Angular Accuracy

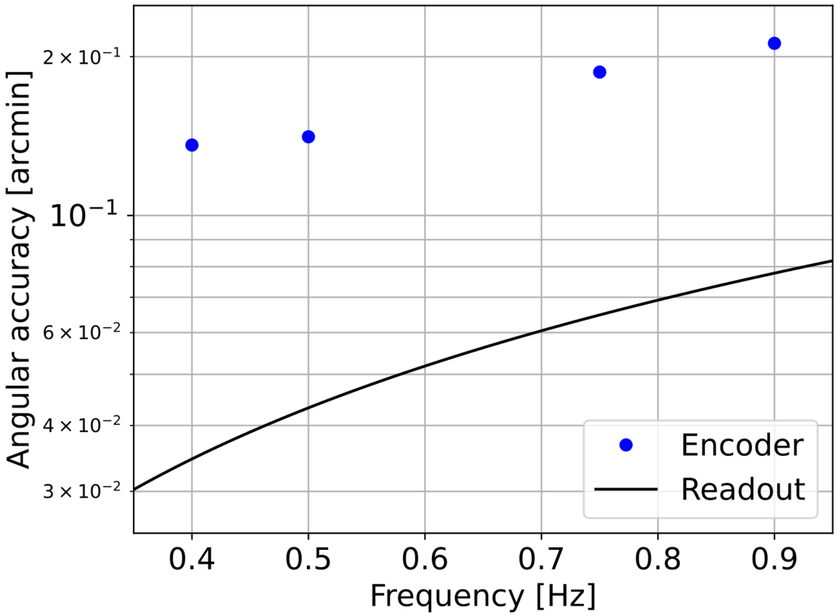
Reconstruct the HWP angle with good accuracy to minimize a leakage from E-modes to B-modes



- Absolute encoder Δt_0
- Relative encoder $\Delta t_i \ \ (i = 1, \ldots, 64)$

Angular accuracy: $\sigma_\theta = \overline{\sigma} \cdot 360 \cdot f \cdot 60$





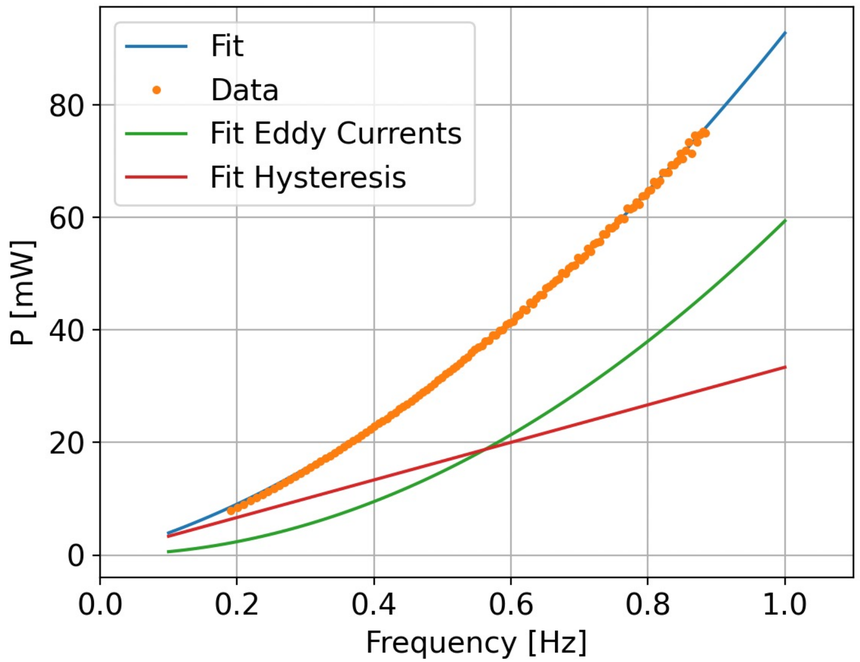
F. Columbro, P. de Bernardis et al. "A polarization modulator unit for the mid- and high-frequency telescopes of the LiteBIRD mission". Proc. SPIE 11443. 2020.

2. Friction

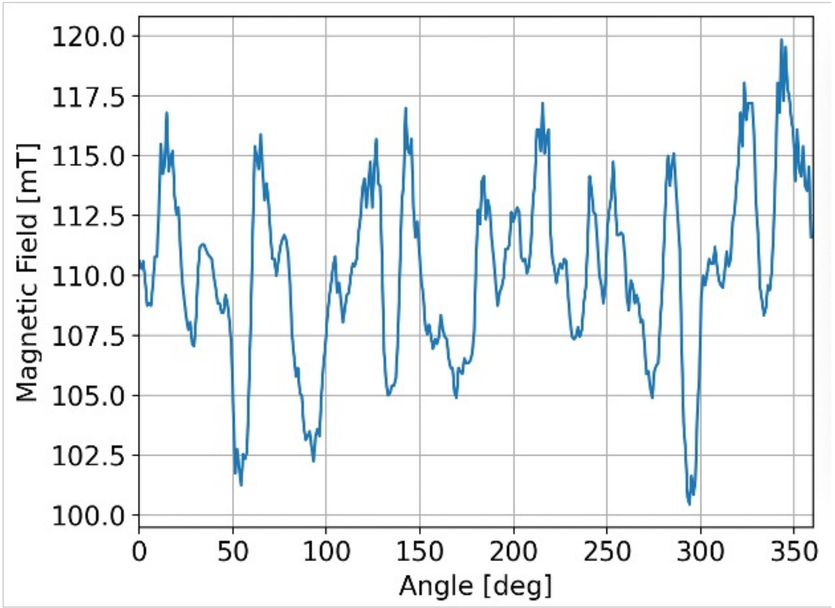
Minimize the **power dissipated** during the rotation

$$P(\omega) = \omega I \frac{d\omega}{dt} = 2\pi f I \alpha_0 + (2\pi f)^2 I \alpha_1$$

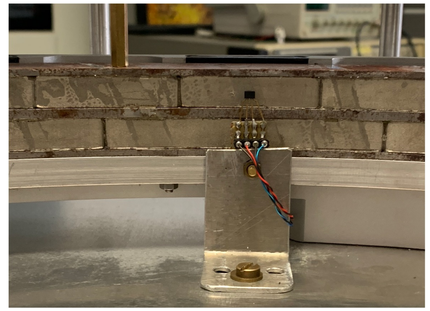
Hysteresis $\propto \Delta B$ — Eddy Currents $\propto \Delta B^2$



Magnetic field inhomogeneities: $\frac{\sigma_B}{\langle B \rangle} \sim 6\%$



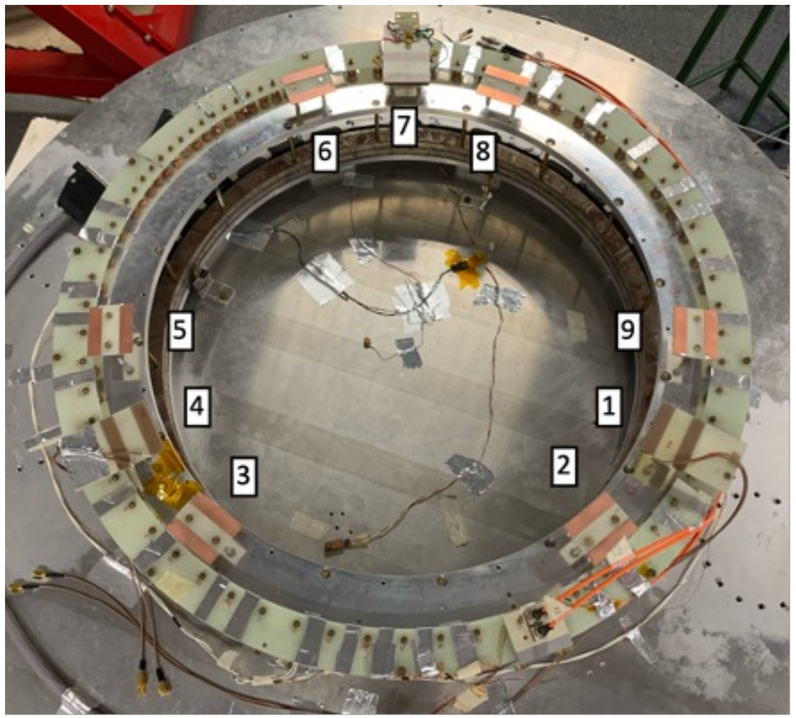
Hall sensor
HE144P from Asensor
—> 10uT resolution



3. Capacitive Sensors

Capacitors allow to monitor:

- **Levitation height** —> $V_C = AR\omega V_{in}(\epsilon_0 \frac{S}{2d} + C^*)$
- **Temperature variations** —> Thermistor: $R(T)$

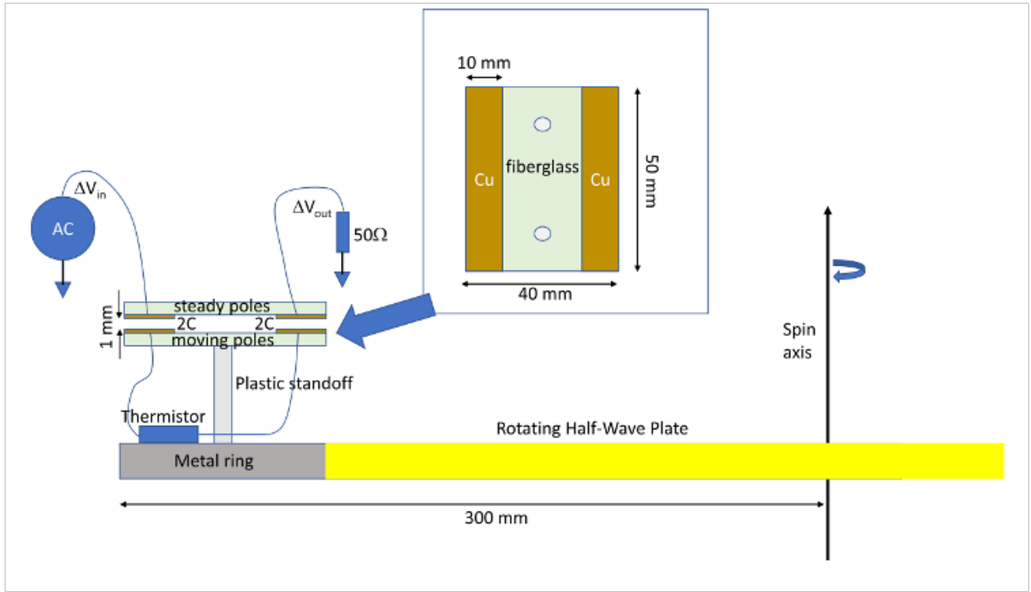


3 plates mounted on the stator:

- 2 lines with a high frequency bias (40 MHz)
- 1 line with a low frequency bias (90 kHz) and a lockin amplifier

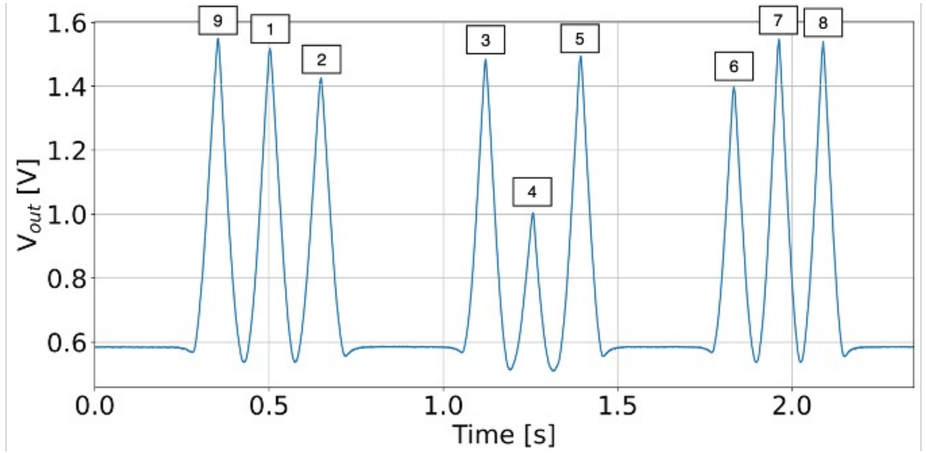
9 plates on the rotor:

- 8 monitor the levitation height
- 1 coupled with thermistor monitors temperature (#4)

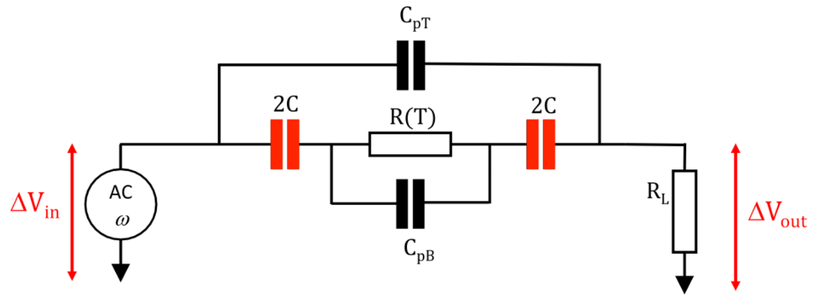


P. de Bernardis, F. Columbro et al. “A simple method to measure the temperature and levitation height of devices rotating at cryogenic temperatures.” Rev. Sci. Instrum. 2020.

3. Distance Measurements

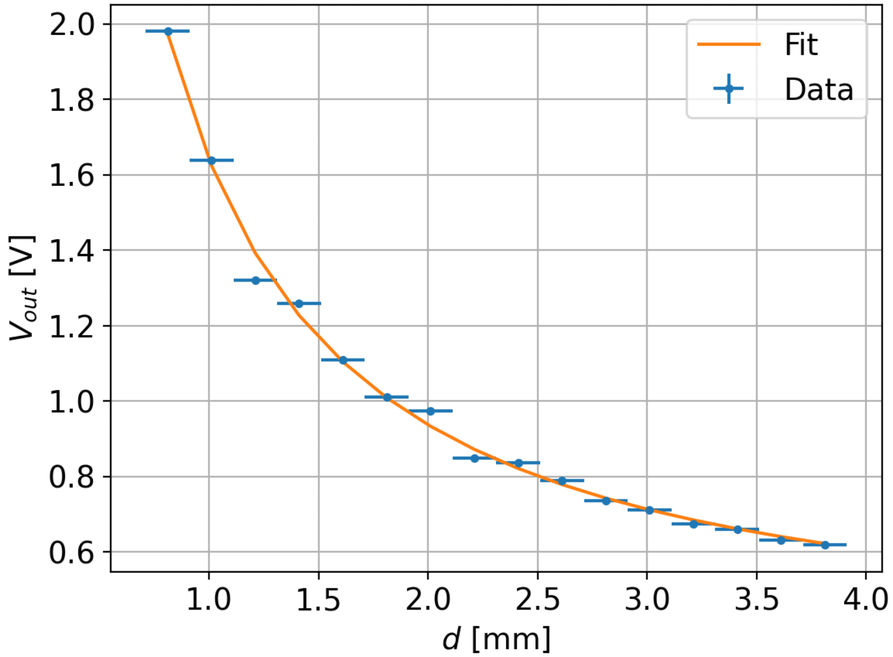


Data from 1 capacitive sensor over a 360° rotation



Schematic of the equivalent circuit of the capacitive sensors

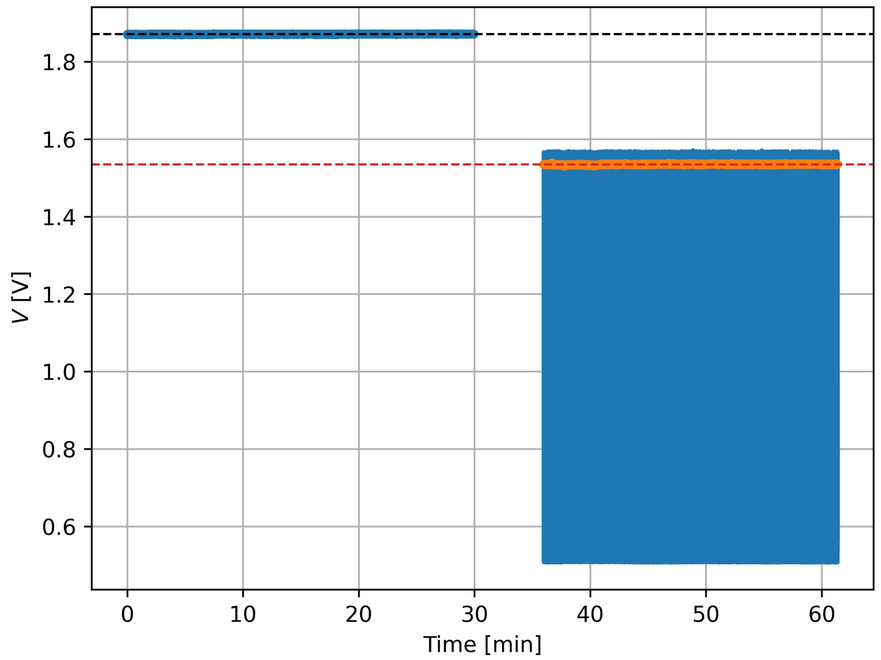
Sensor calibration



$$V_{out} = \sqrt{\left(AR\omega V_{in}(\epsilon_0 \frac{S}{2d} + C*)\right)^2 + V_{off}^2}$$

3. Distance Measurements

Rotor Release

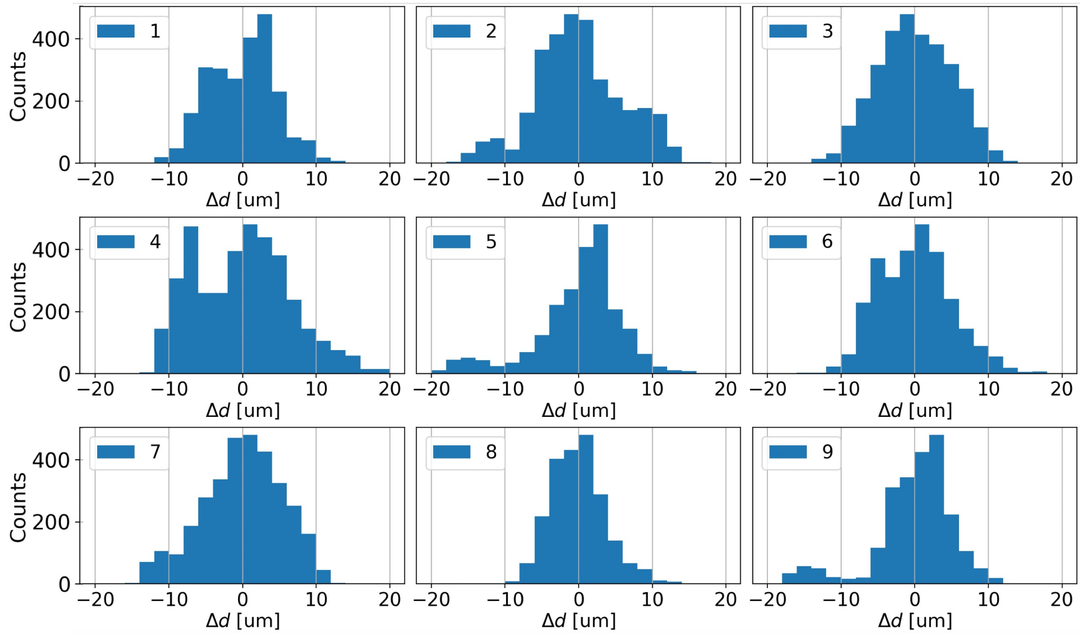


Left: rotor clamped

Right: rotor levitating and spinning at 0.6 Hz

Estimated **drop of the rotor**: $\Delta h = 0.43$ mm

Wobbling



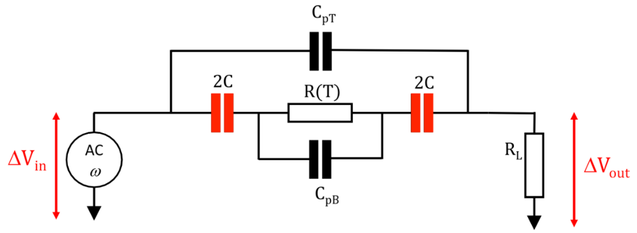
Error on the levitation height: $\sigma \sim 20\mu m$

↓

LSPE/SWIPE: **Wobbling Angle** < 20 arcsec

F. Columbro, G. Barbieri Ripamonti et al. “Capacitive sensors for the polarization modulator unit of the Mid- and High- Frequency Telescopes of LiteBIRD space mission”. Proceedings of SPIE. 2024.

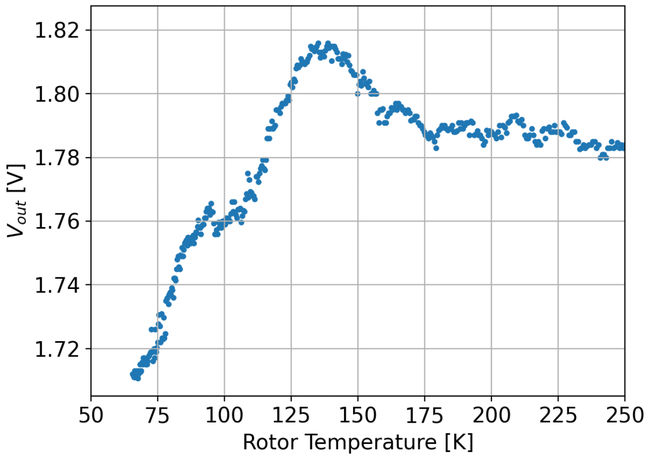
3. Temperature Measurements



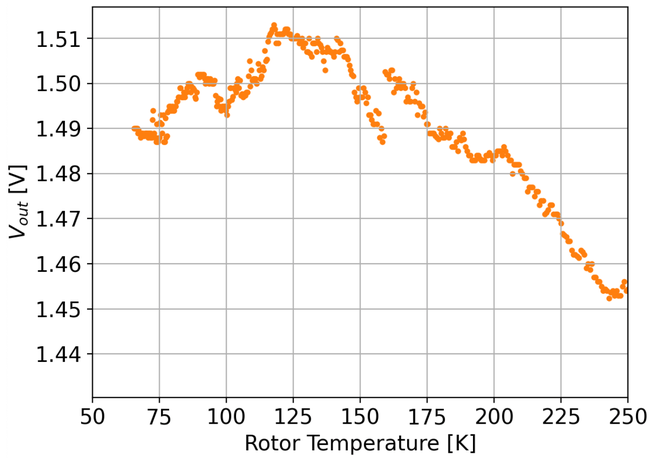
Goal: to measure **rotor's temperature variations** during the rotation

—> The thermistor on the rotor has a resistance change very small with respect to the impedance of the readout circuit

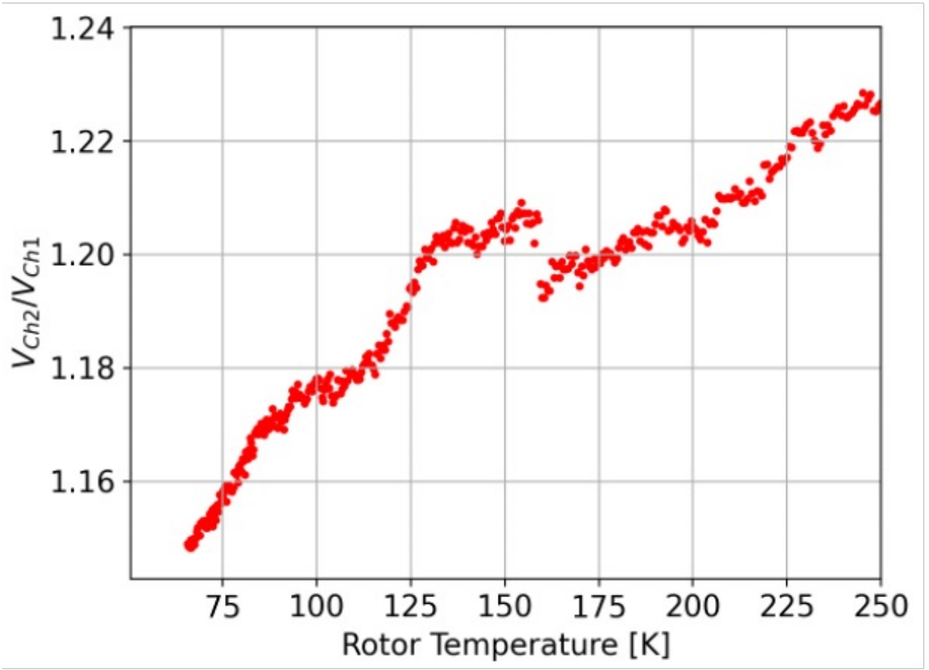
We have been able to measure the trend of the thermistor resistance due to temperature variations during the cooling down of the system



Line **with** the thermistor



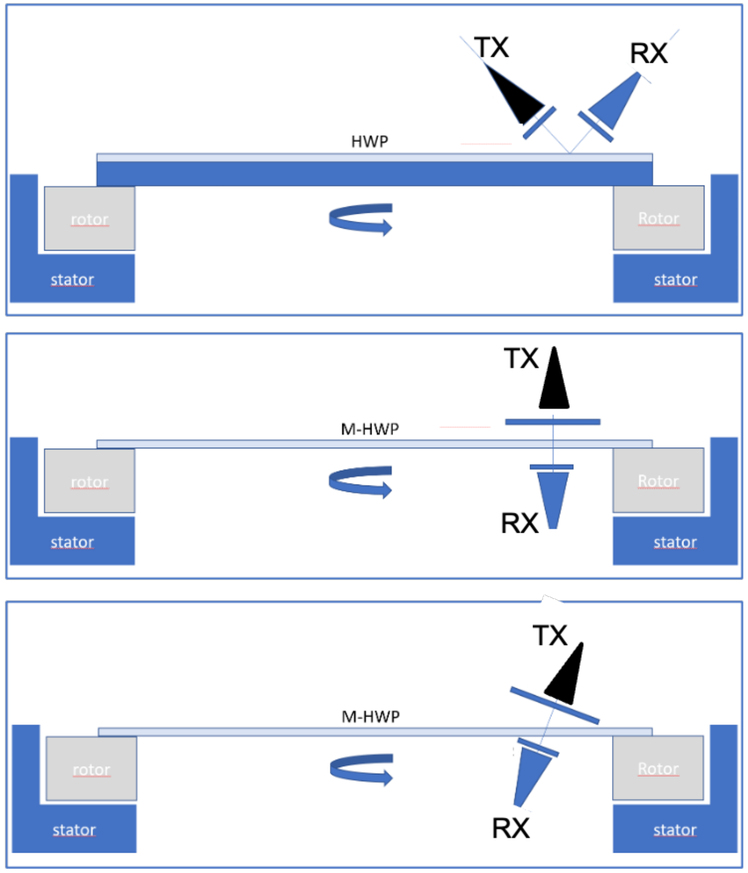
Line **without** the thermistor



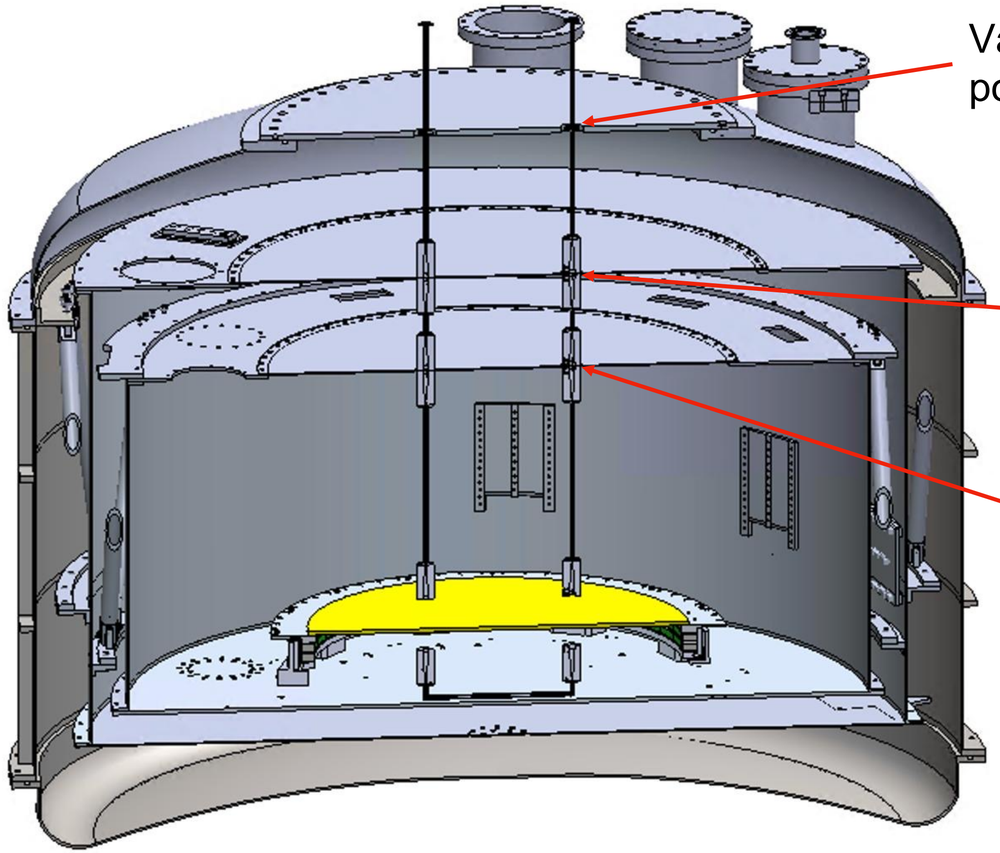
Ratio between the two signals

HWP Cryogenic Tests

Goal: to measure the **optical performance of the HWP** at cryogenic temperature—> Mueller matrix



Sketch of the measurement

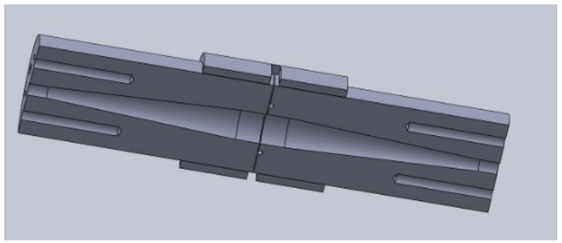


Hardware Implementation

Vacuum feedthroughs with polyethylene plugs in the waveguides

300K-40K thermal disconnection, waveguide gap

40K-4K thermal disconnection, waveguide gap



Summary and Conclusions

Angular Accuracy

The angular resolution is $\sim 0.1 - 0.2\ \mathrm{arcmin}$ between 0.3 and 1 Hz

Wobbling

The wobbling during the rotation has been measured to be $\Delta\theta < 20\ \mathrm{arcsec}$

Power Load & Temperature

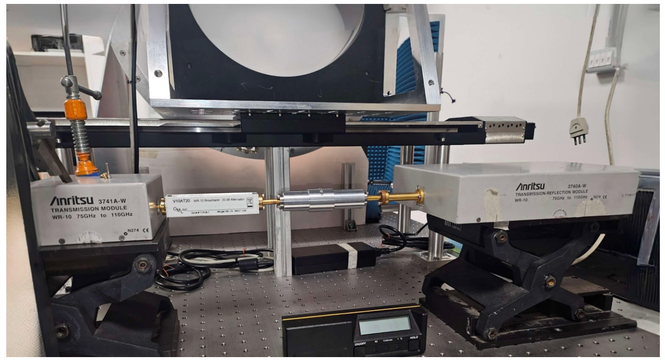
The magnet will be replaced to reduce friction

Rotor's temperature measurement is under development and promising

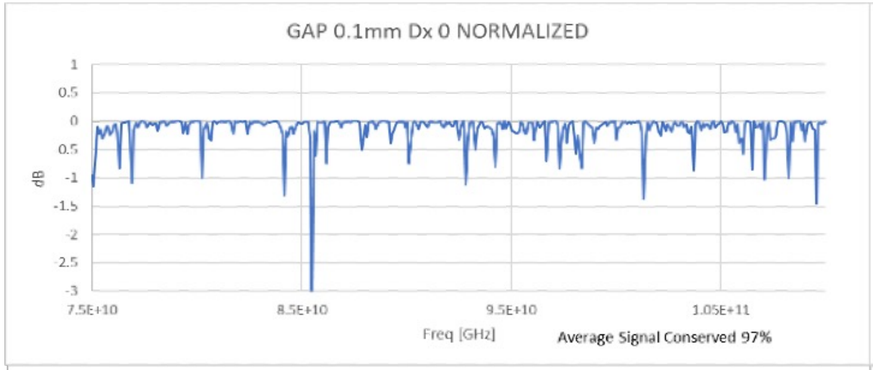
Future Goal

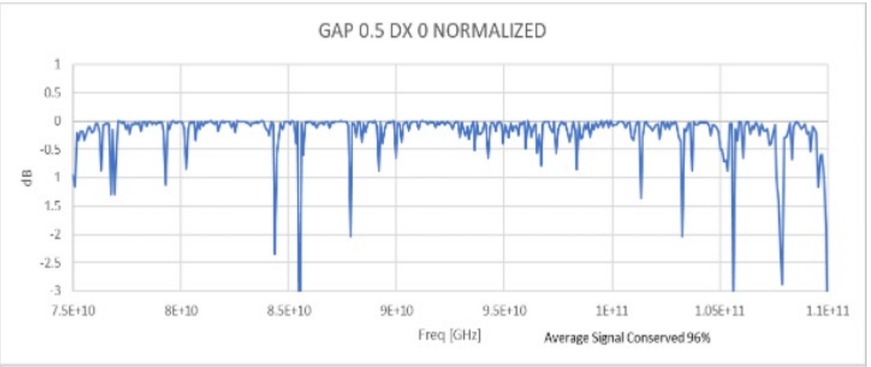
Cryogenic optical tests of the HWP will be carried out in the near future

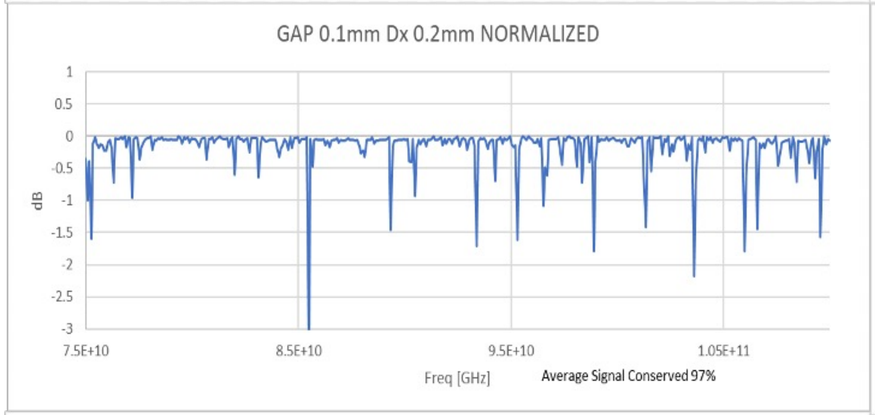
Waveguides - Preliminary Measurements

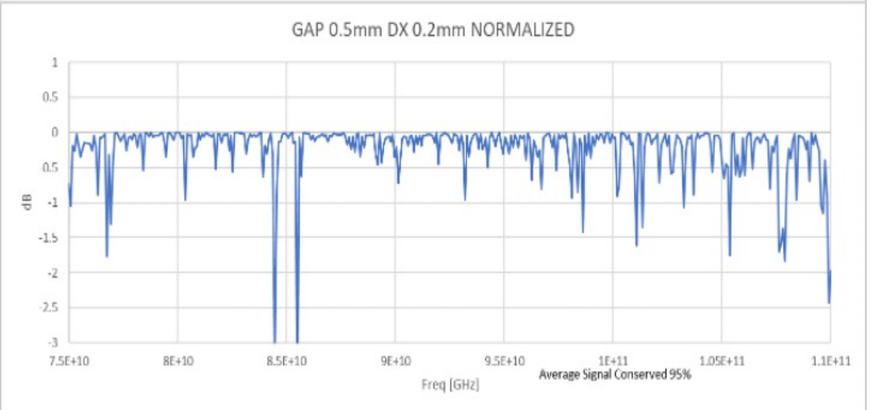


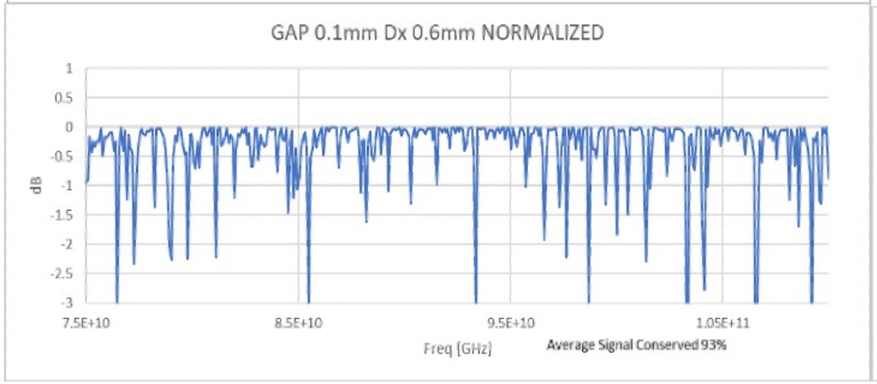
The waveguides have been designed and are currently being tested at room temperature

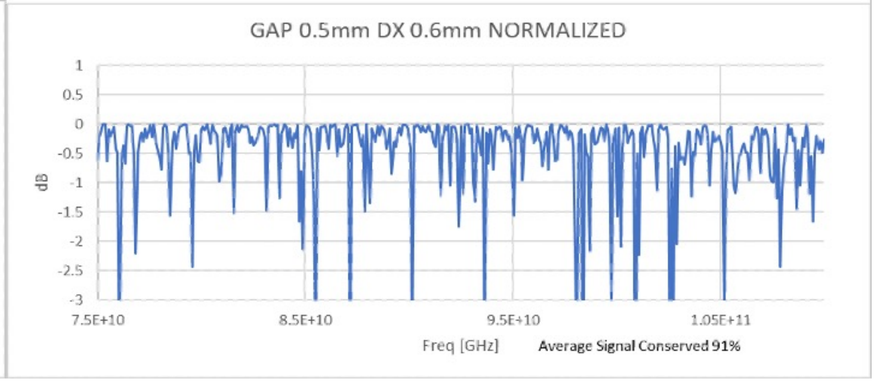








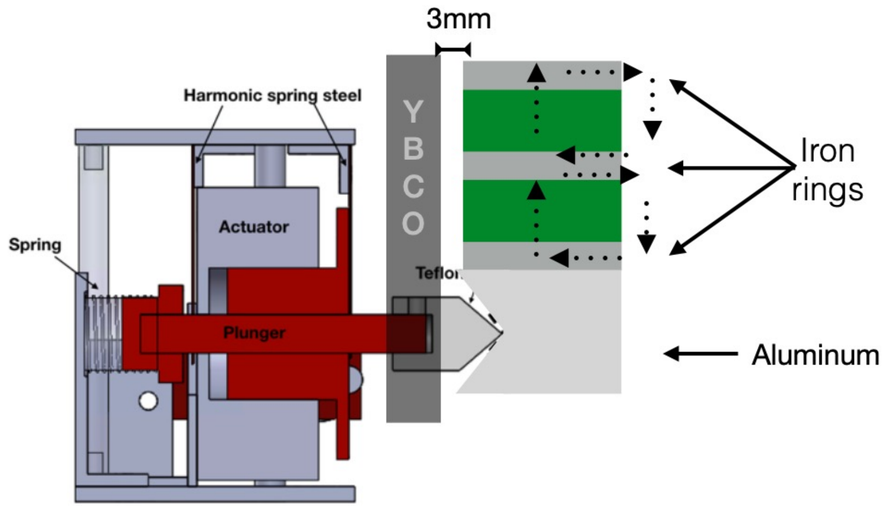




Credits: G. Gorla and G. Pisano

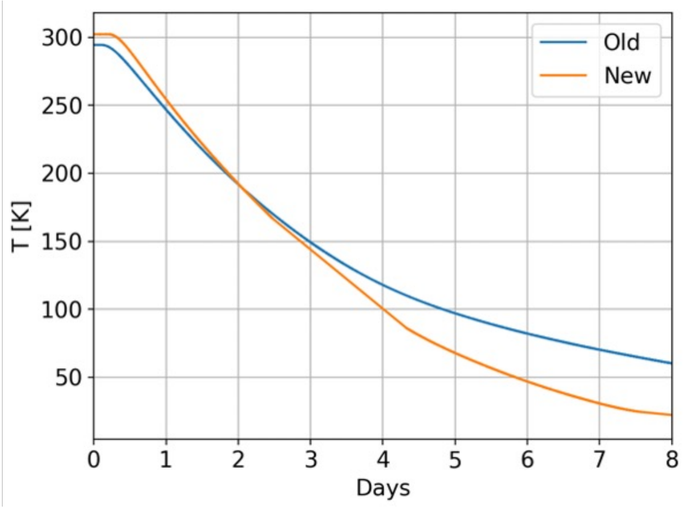
Friction and Thermal Conductivity

Groove ring: Aluminium —> **G10**
Heads: Teflon —> **Brass**

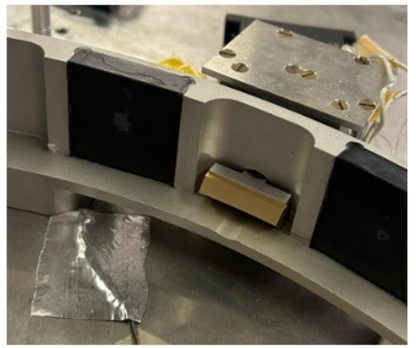


Friction should be reduced
—> test to understand the contribution from this ring

The new configuration reduces the **cooldown time**

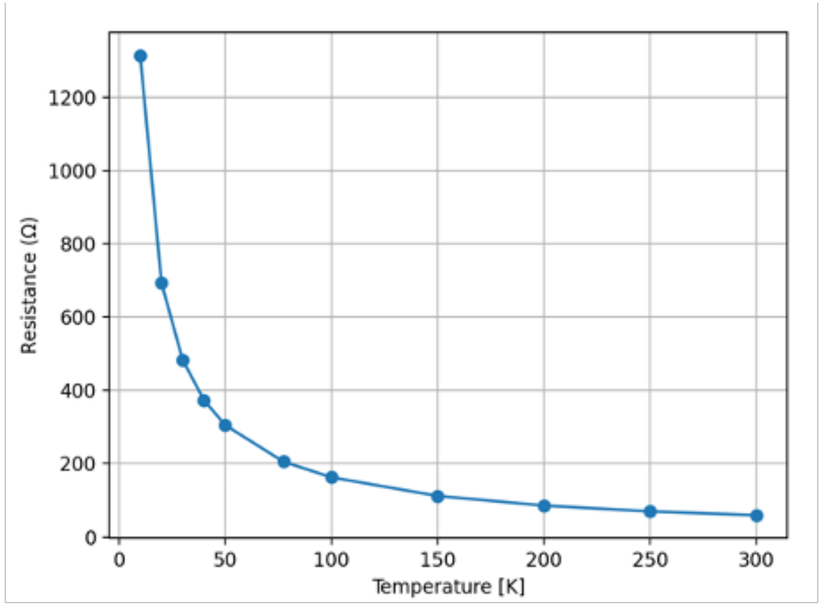


We gained a factor 2 in the **conductive** heat transfer

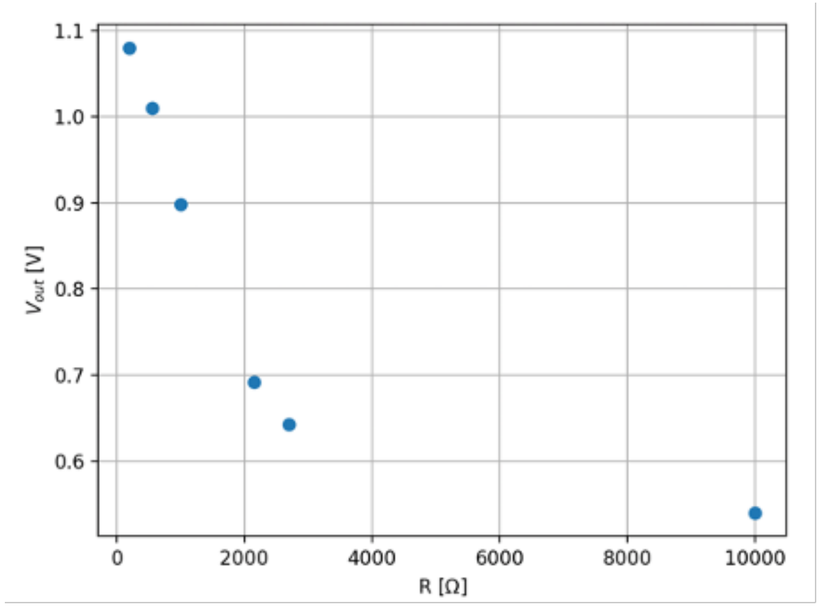


Temperature Measurements – Optimization

Resistance of the current thermistor as a function of temperature



Response of the readout circuit to different resistances



Currently: $\Delta T = (100K - 20K) \rightarrow \Delta R = (163\Omega - 693\Omega)$

New thermometer: $\Delta T = (100K - 20K) \rightarrow \Delta R = (515\Omega - 1720\Omega)$

We could gain a factor 2 in the output signal