Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali del Sud

# Update on the RF Pulse Compressor

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# General objectives

## WP2: FLASH beam delivery

**C-band RF Pulse Compressor for the VHEE LINAC**

1. Design (RF, thermal, mechanical)
2. Prototype Manufacturing and “cold” test (low-power, no-beam)

Overview on **SLED WP2 Deliverables**

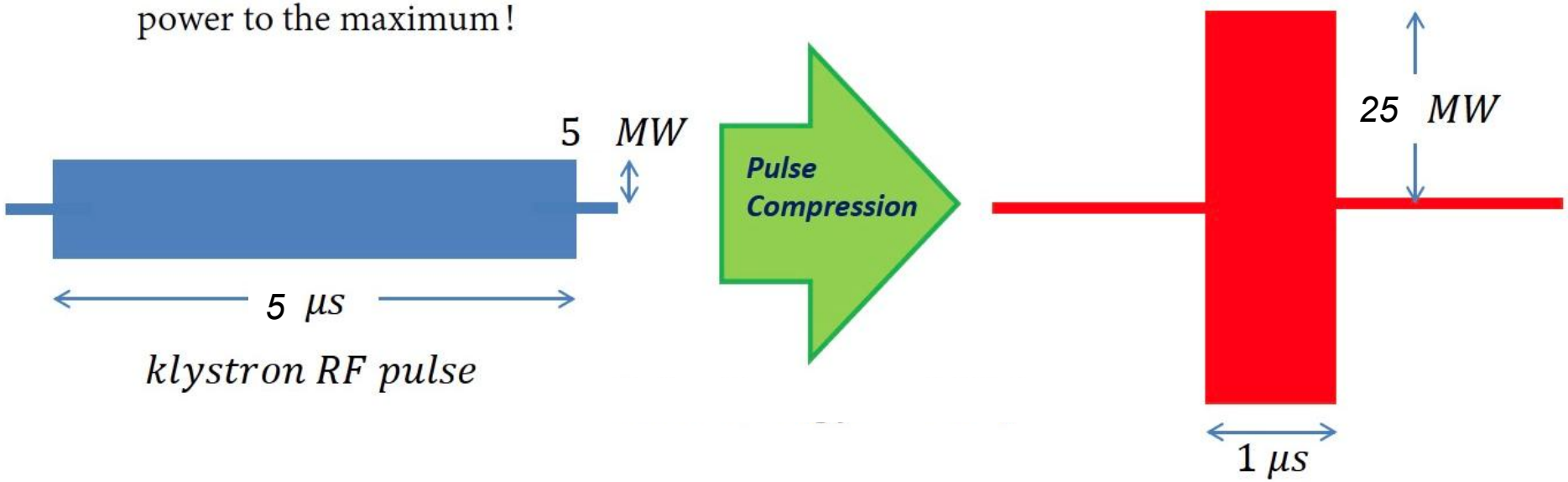
| | | | | |
|---|---|---|---|---|
| D2.1.2 | RF accelerating structure design | Design of the high gradient accelerating structure prototype | 18 | |
| D2.2.1 | RF compr. design | Design of the SLED RF pulse compressor. | 18 | COMPLETE |
| D2.1.3 | RF accel. structure manufacturing | Manufacturing high gradient accelerating prototype | 24 | |
| D2.2.2 | RF compressor manufacturing | Manufacturing of the pulse compressor prototype | 24 | COMPLETE |
| D2.1.4 | RF accelerating structure test | Low power RF tests of accelerating prototype | 36 | |
| D2.2.3 | RF compr. test | Low power RF tests of the SLED prototype | 36 | 90% COMPLETE |

# Motivation

1. Increasing the **Available Peak Power *P***
2. High Accelerating Gradients ***E*** require very high RF power **($E \propto \sqrt{P}$)**
3. RF peak power available from klystrons is typically limited
4. Duration of the **klystron RF pulsed (≈ few µs)** largely exceeds the typical filling time of **an accelerating structures (< 1 µs)**

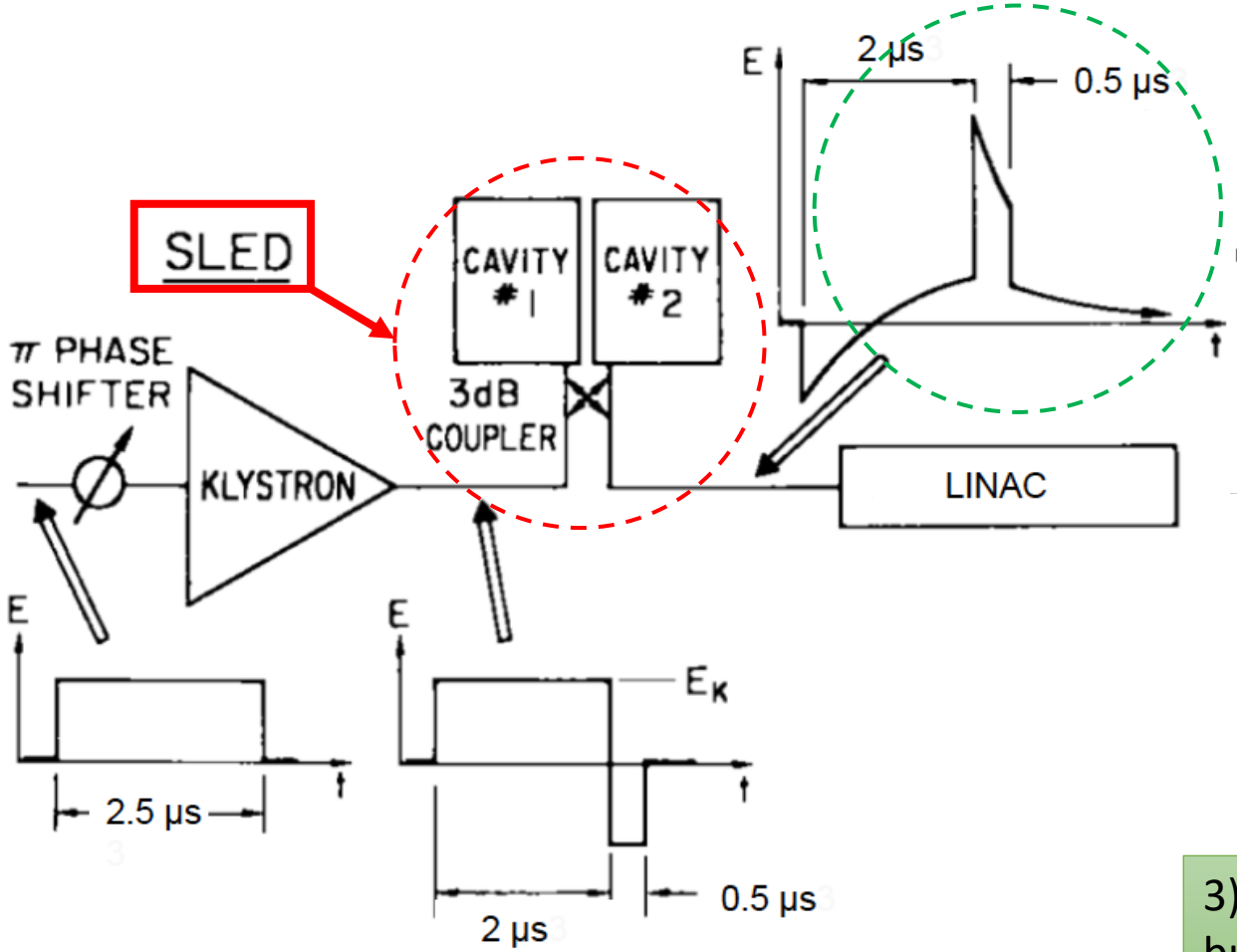
## The Idea: SLED (Stanford Linac Energy Doubler)

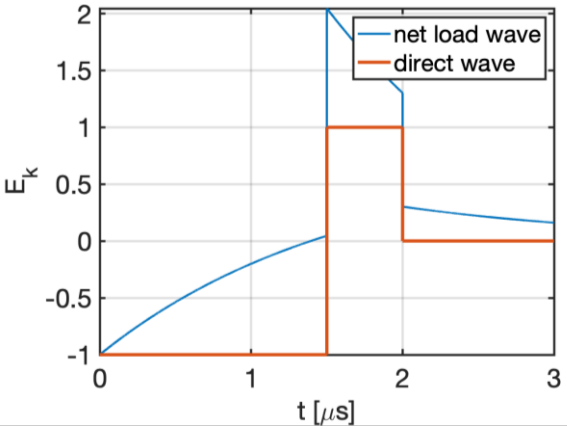
- Let's compress the energy of the RF pulse in about 1 filling time to increase the peak power to the maximum!



# Working principle

SLED (Stanford Linac Energy Doubler) is a passive power-amplifier composed of **3-dB hybrid power divider** and **high-Q RF resonant cavities**.




1) Energy from the klystron builds up in two high quality cavities.

2) Later extracted by reversing input pulse in shorter time interval

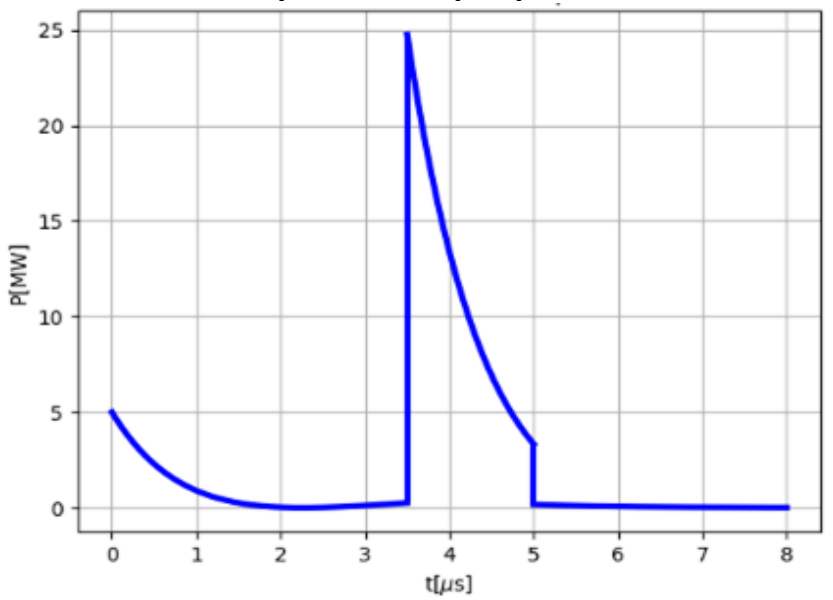
3) Amplitude is much higher, but decaying exponentially

[1] Farkas et al. - SLED A method of doubling SLAC energy

# Relevant parameters

**Relevant parameters:**
waveguide-cavity **coupling factor** and cavity **quality factor**

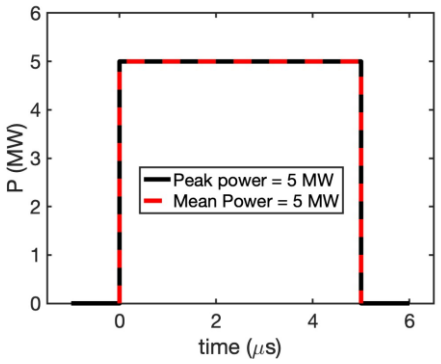
**Pulse Compressor output power from 5 MW Klystron input**

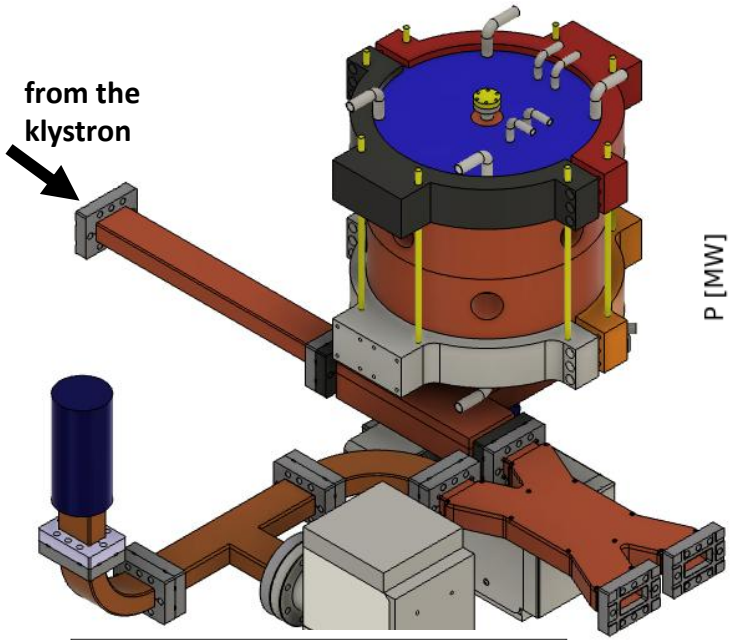



| | |
|---|---|
| **Coupling factor β**<br>(Optimization of RF design) | **3** |
| **Unl. quality factor Q**<br>(Fixed by C-band) | **134000** |
| **Pulse duration Δt**<br>(Low power level control) | **1.5 μs** |

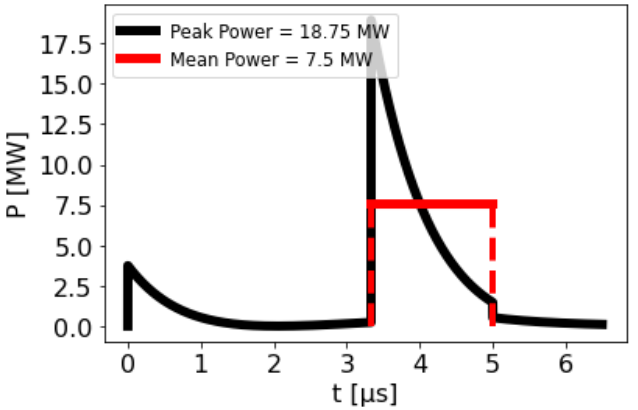
Courtesy of S. Farina

# Pulse compressor setup

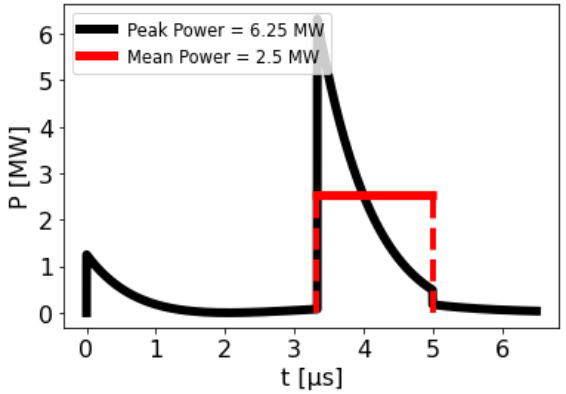



Courtesy of A. Curcio, G. Torrisi, A. Mostacci




**towards the TW section**




**towards the standing wave section**

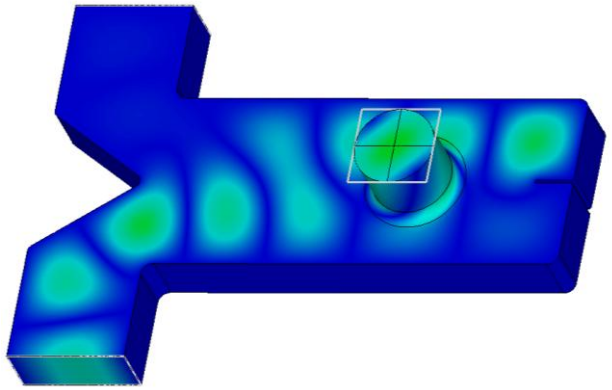
**FAT final step in 03/26**
**Expected delivery in 05/26**
**Expected test @LNF in 06/26**

L. Giuliano et al., *A compact C-band FLASH electron linear accelerator protoype for the VHEE SAFEST project*, **Frontiers**, March 2025

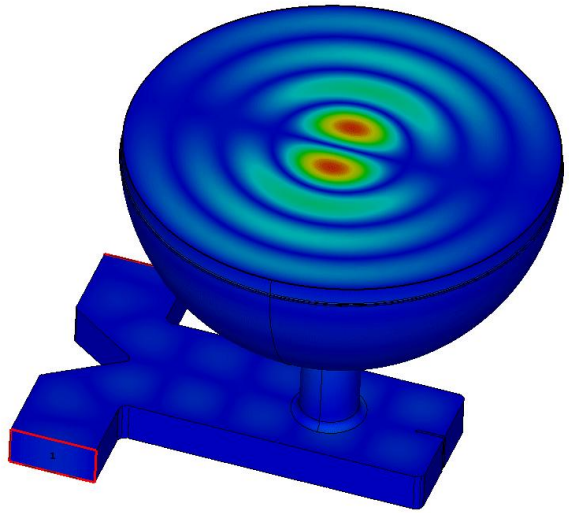
# Pulse compressor

- Each rectangular waveguide mode excite a $TE_{11}$ mode
  - Excitation in quadrature produces quasi circularly polarized wave
- $TE_{11}$ modes excite degenerate $TE_{114}$ modes of spherical resonator
  - $TE_{20}$ and $TE_{10}$ emitted/reflected from the cavity cancel at input port

**RF** dual-mode **polarizer coupler**



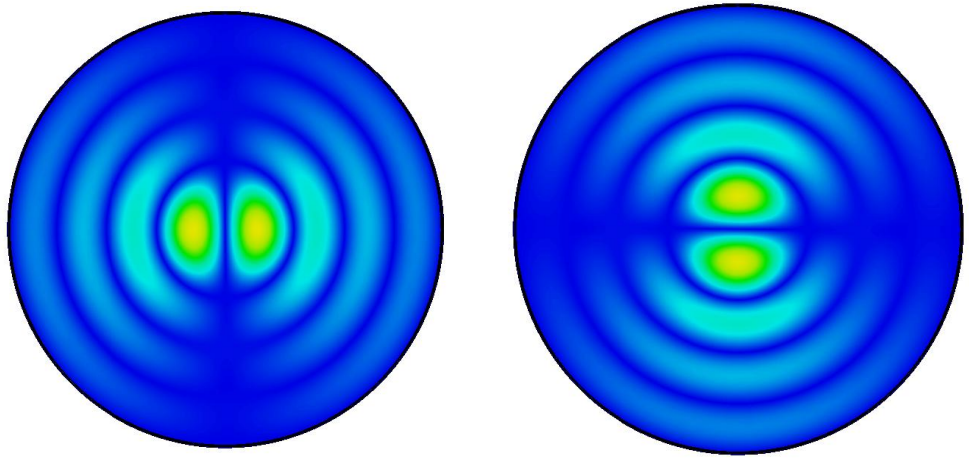
**single High-Q spherical resonator SLED**



**Relevant parameters:**
waveguide-cavity **coupling factor** and cavity **quality factor**

# Spherical cavity design

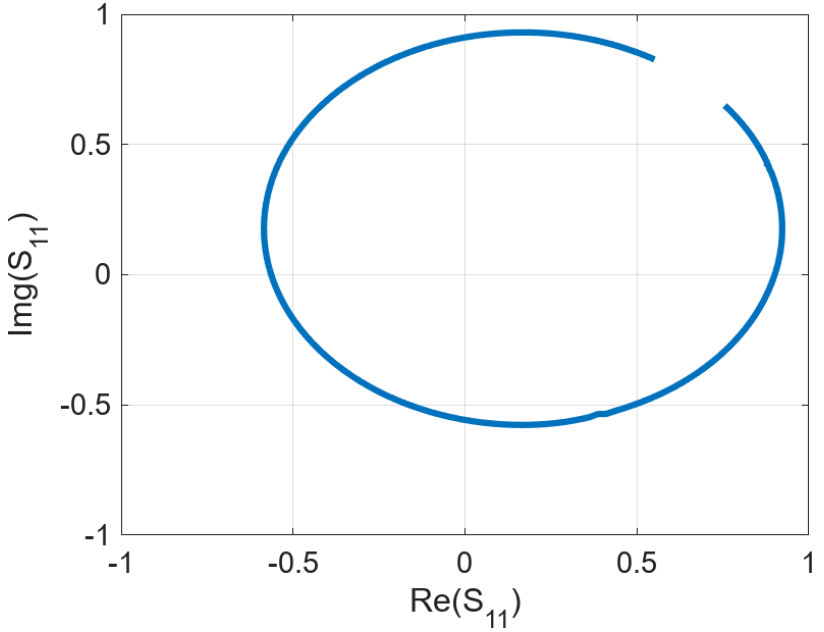
- Overcoupled cavity, $\beta_c = (1+|\Gamma|)/(1-|\Gamma|) = 3$

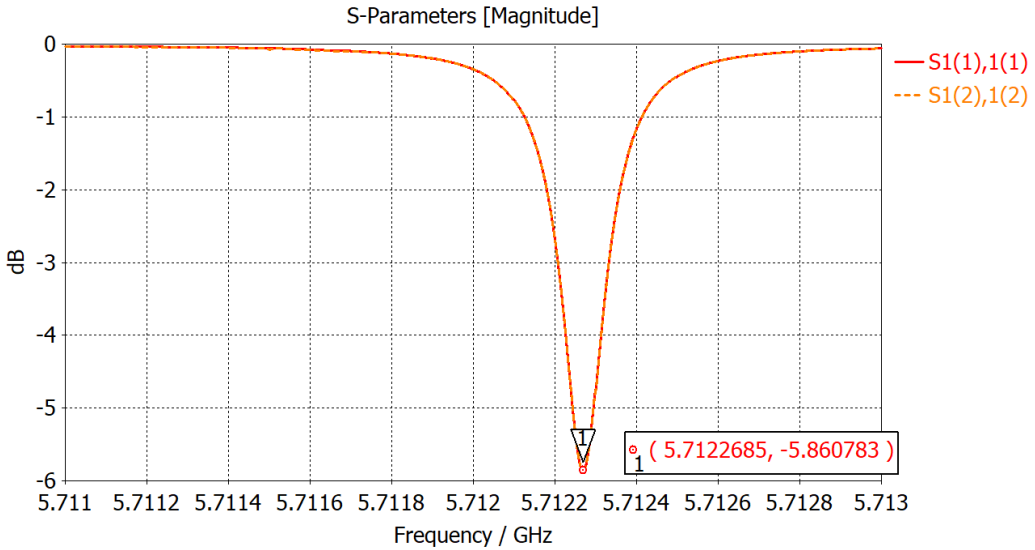


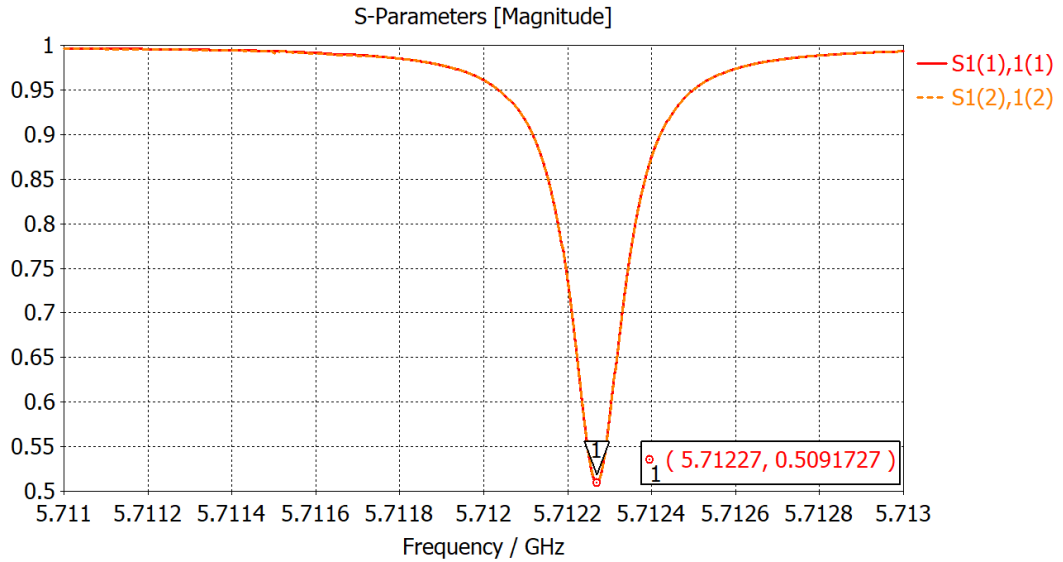
TE114, mode 1



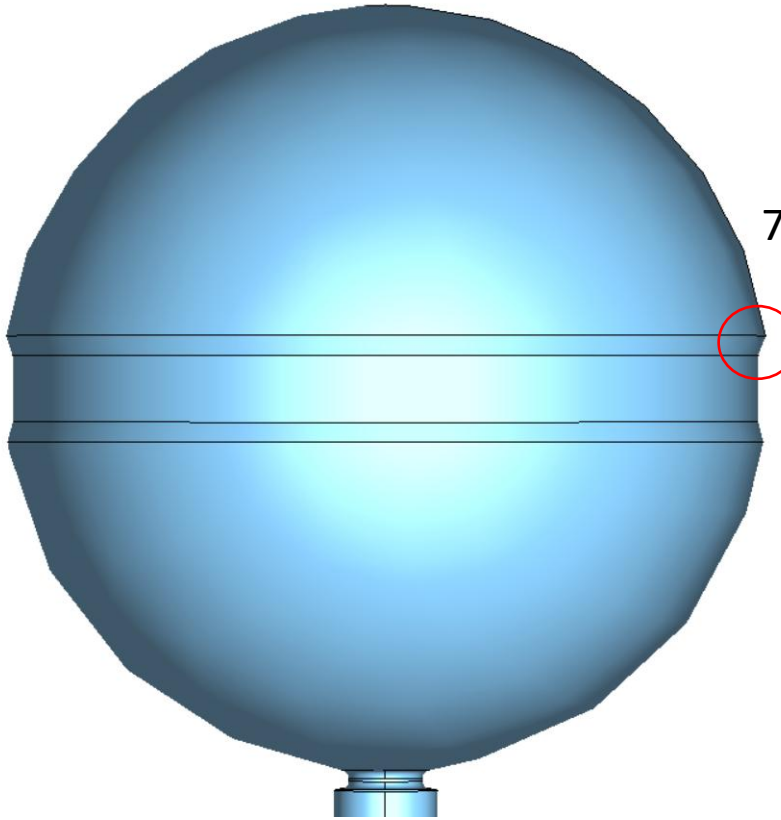
TE114, mode 2

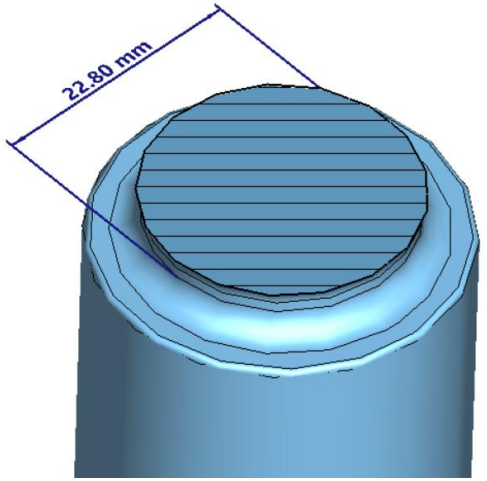


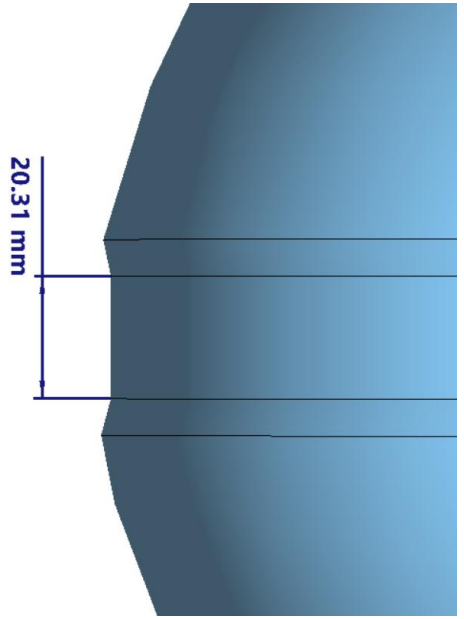



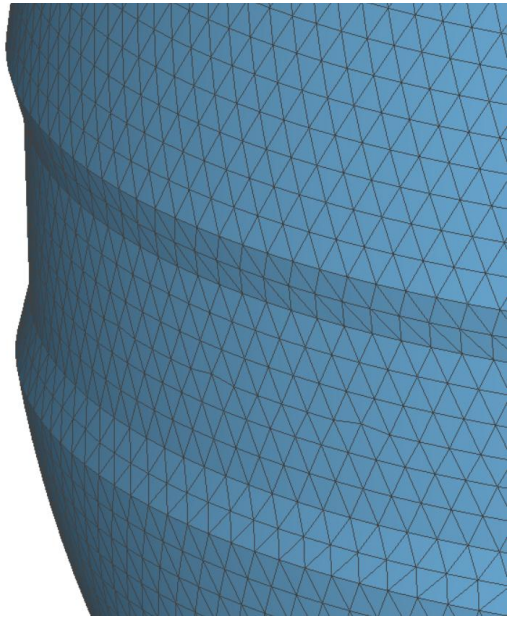



# Spherical cavity design



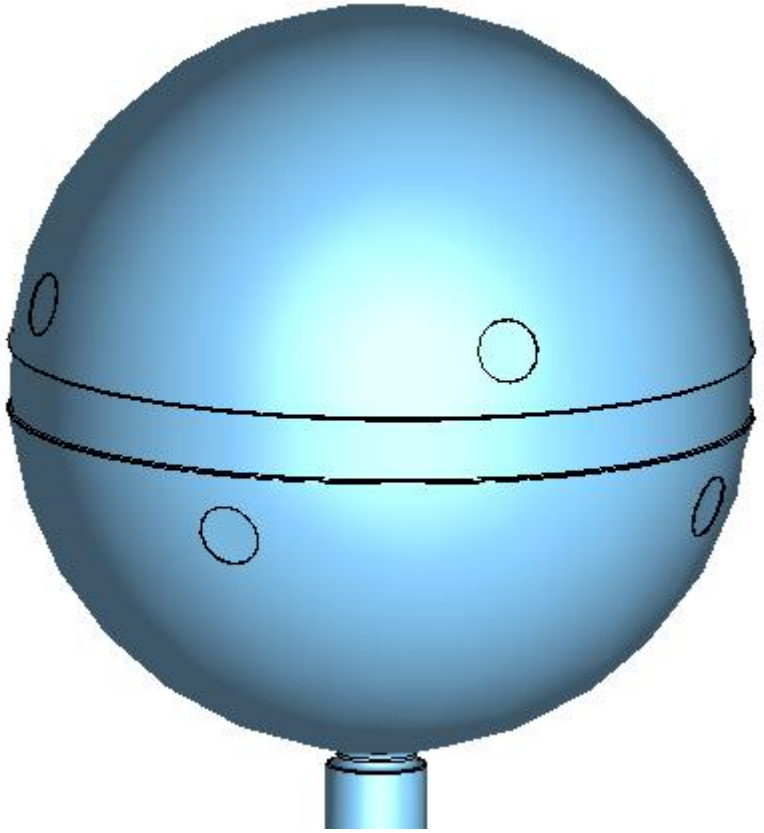



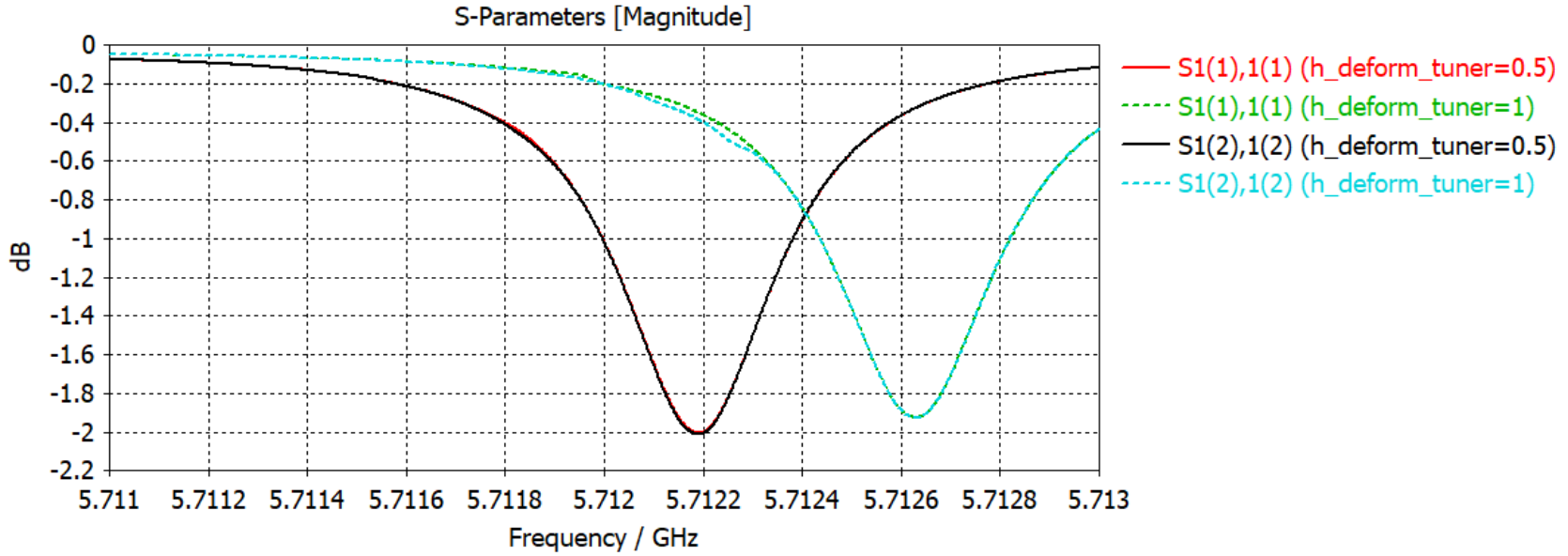



- $R_{cav}$ = 117.578 mm

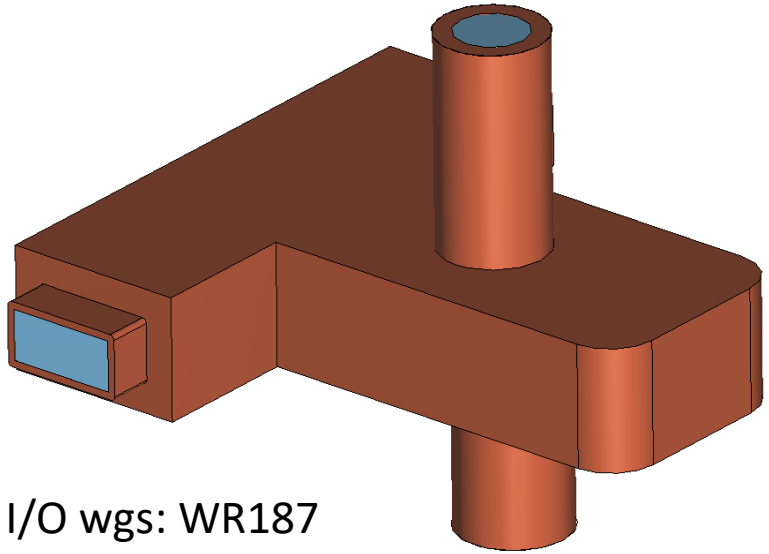
# Plastic deformation tuners

- The cavity is equipped with n.8 plastic deformation tuners.
- The effect of these has been simulated by employing cylinders with radius r = 1.75 mm.
- The simultaneous tuners insertion of the quantity l = 0.5 mm correspond to $\Delta f \approx +0.4$ MHz.

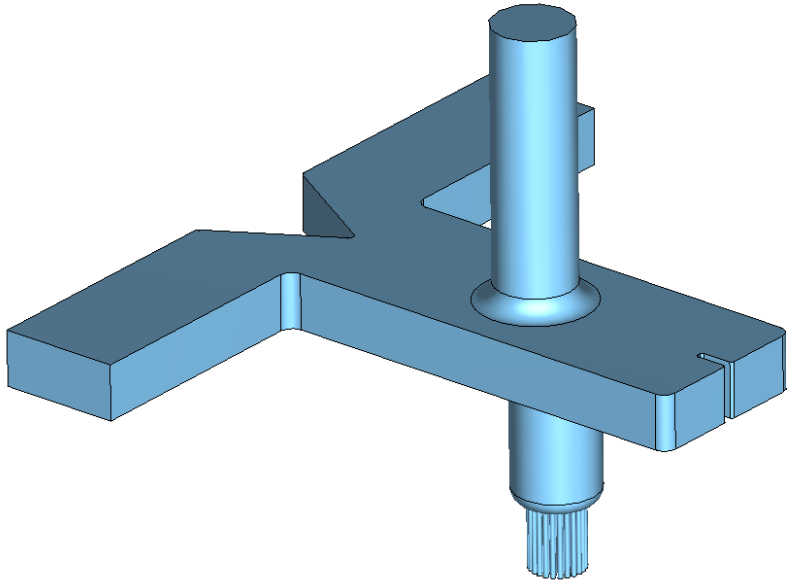


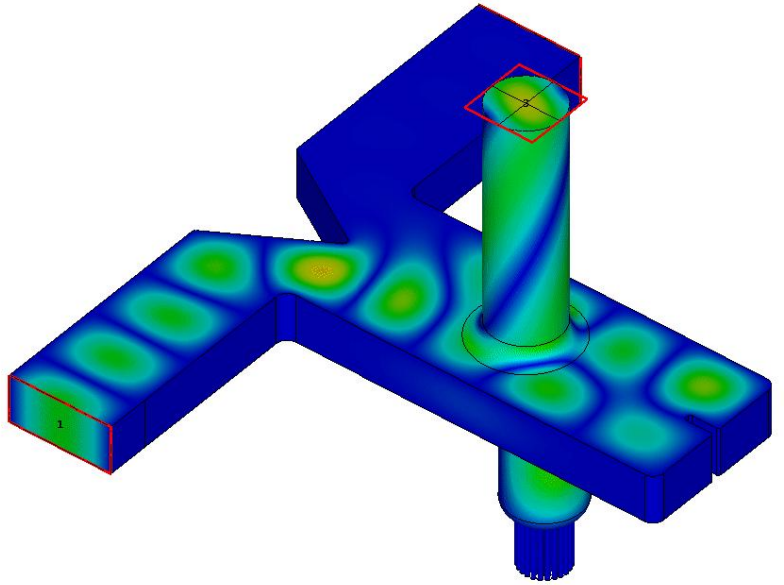


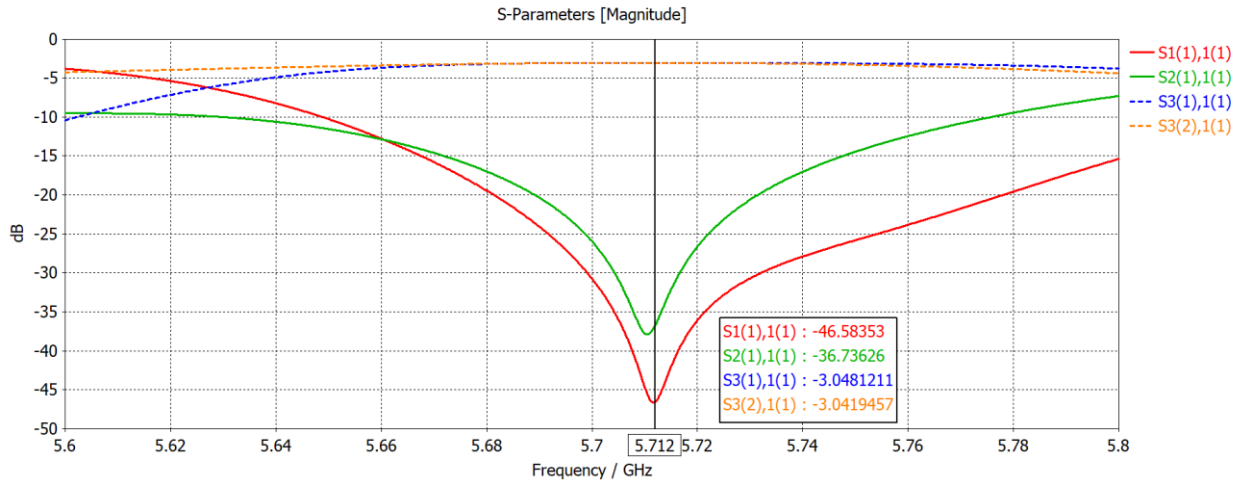
# 3 dB hybrid/polarizer

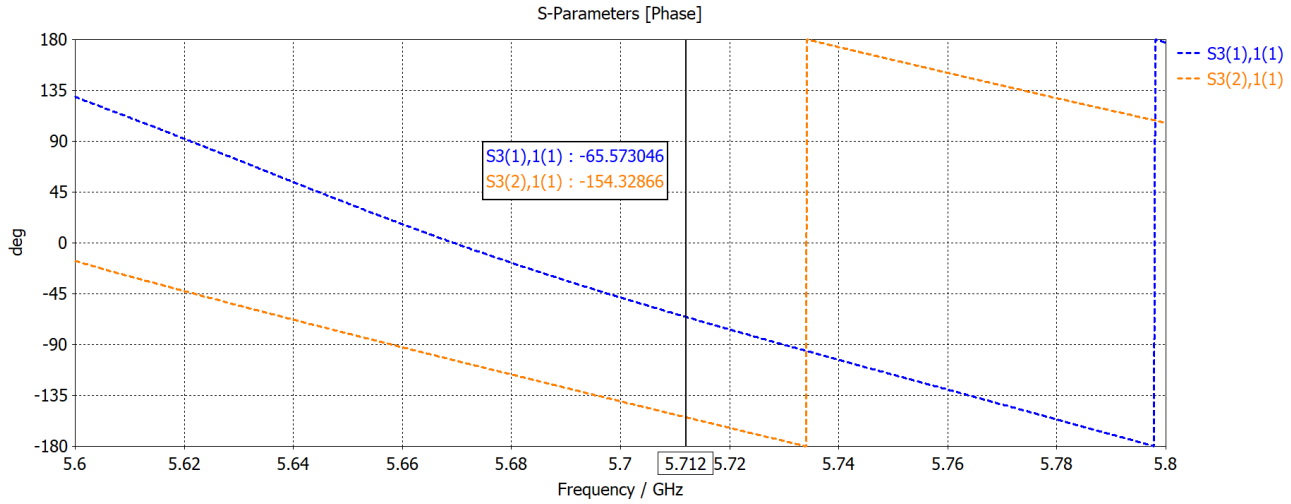


I/O wgs: WR187

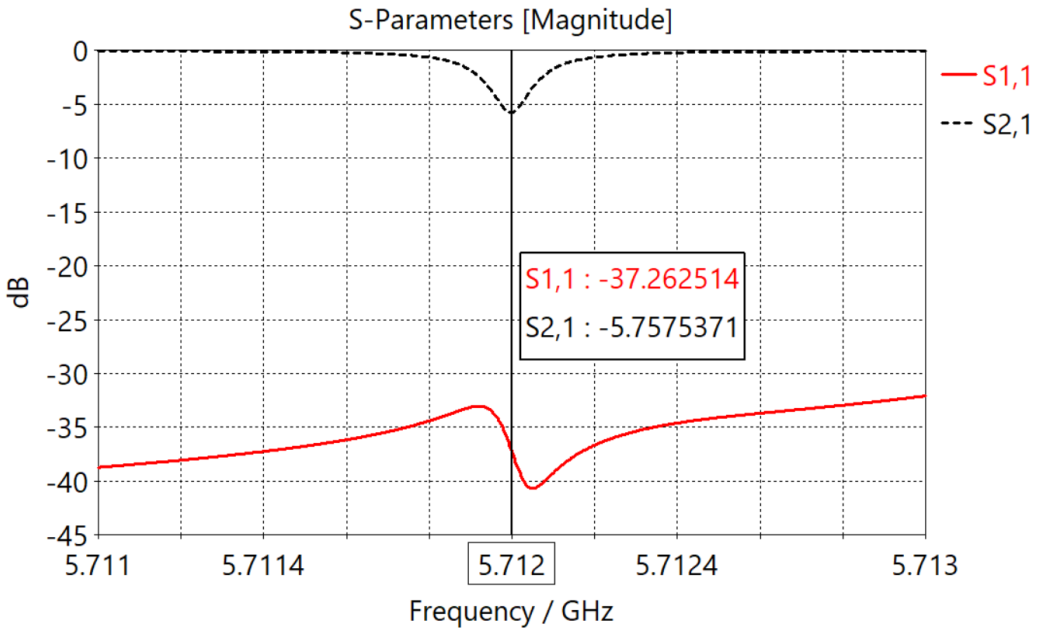


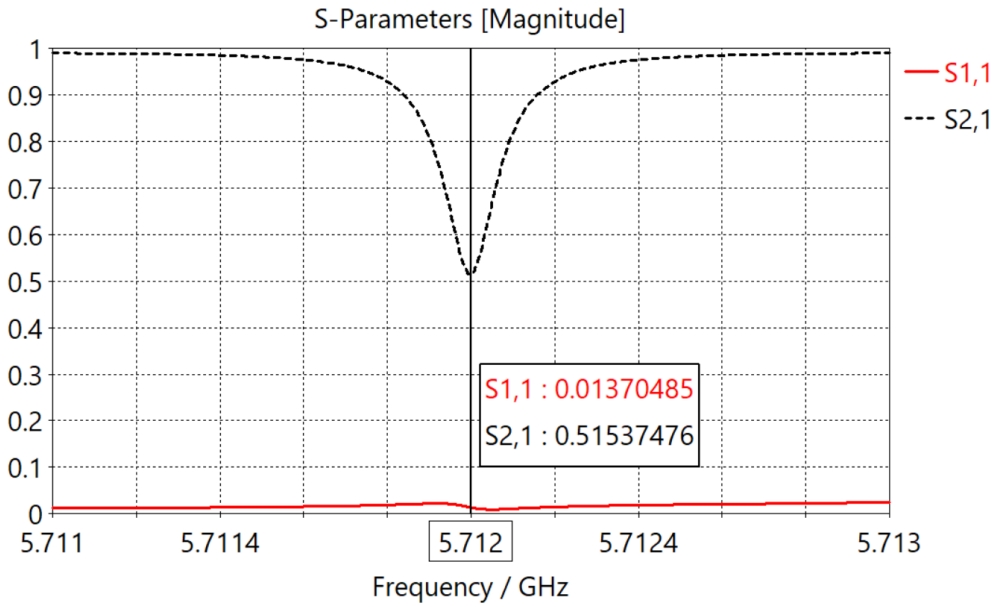


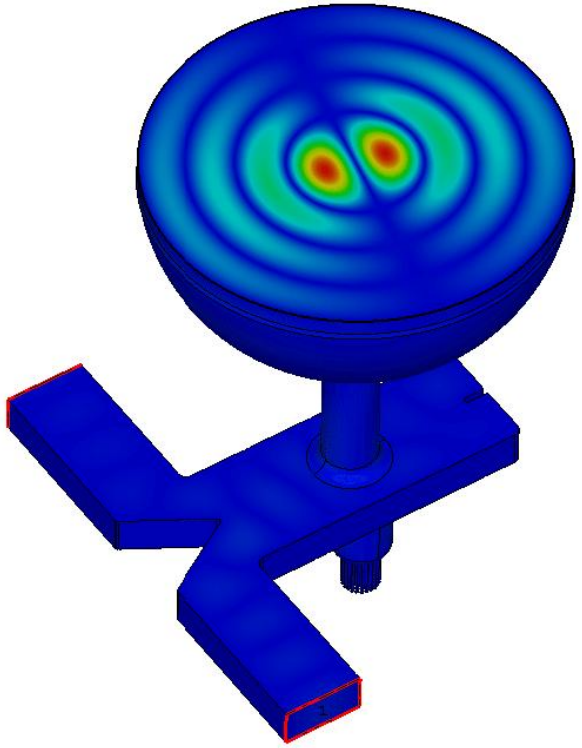


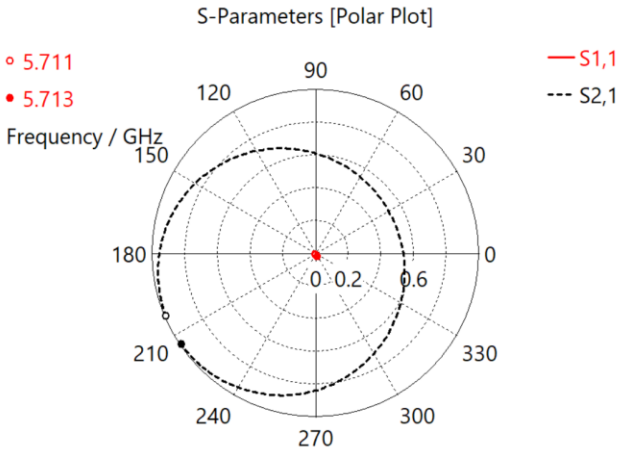



# Pulse compressor – full structure

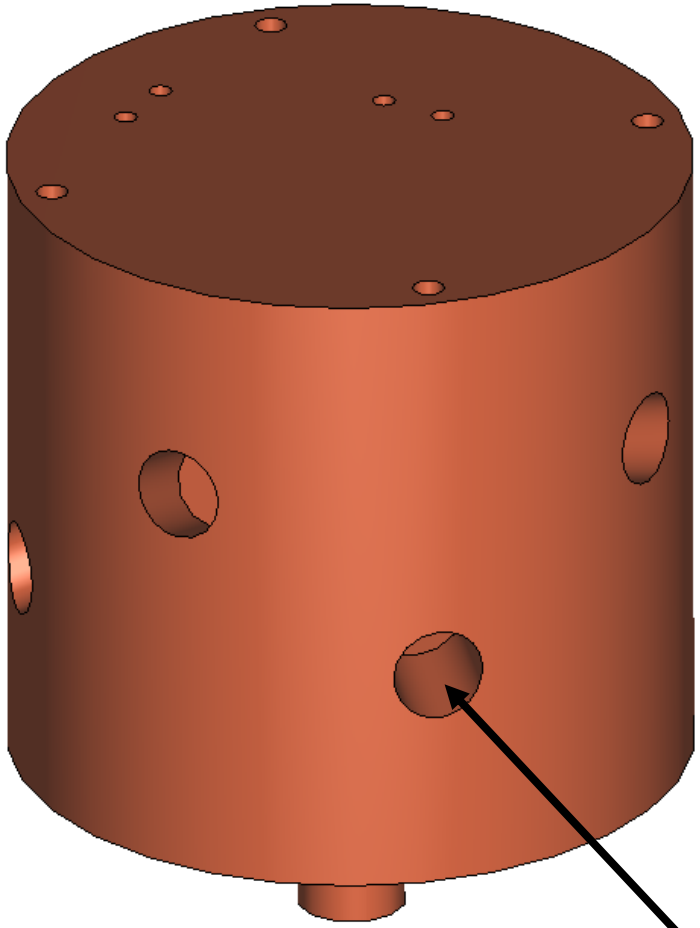


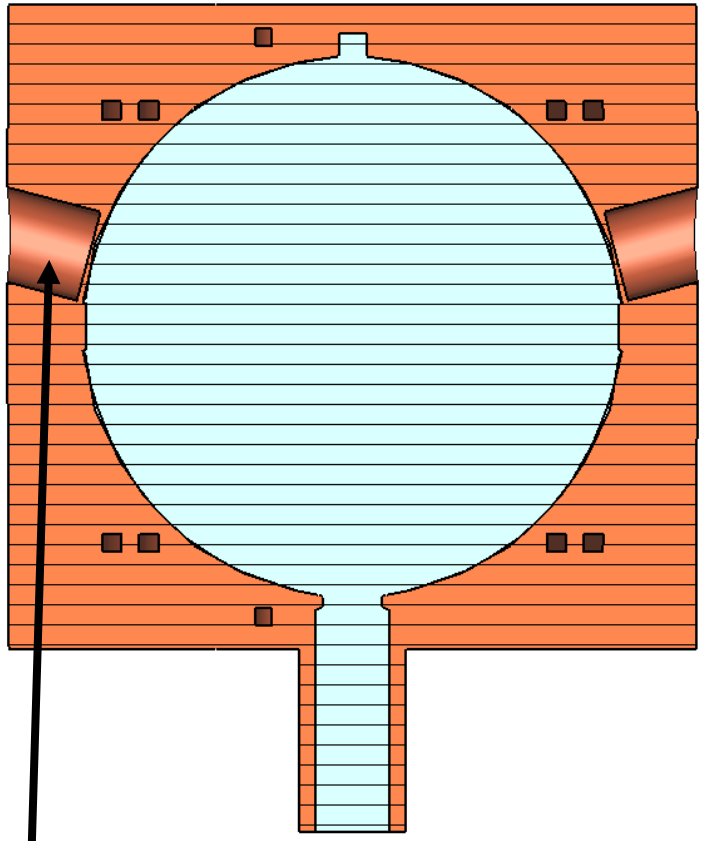



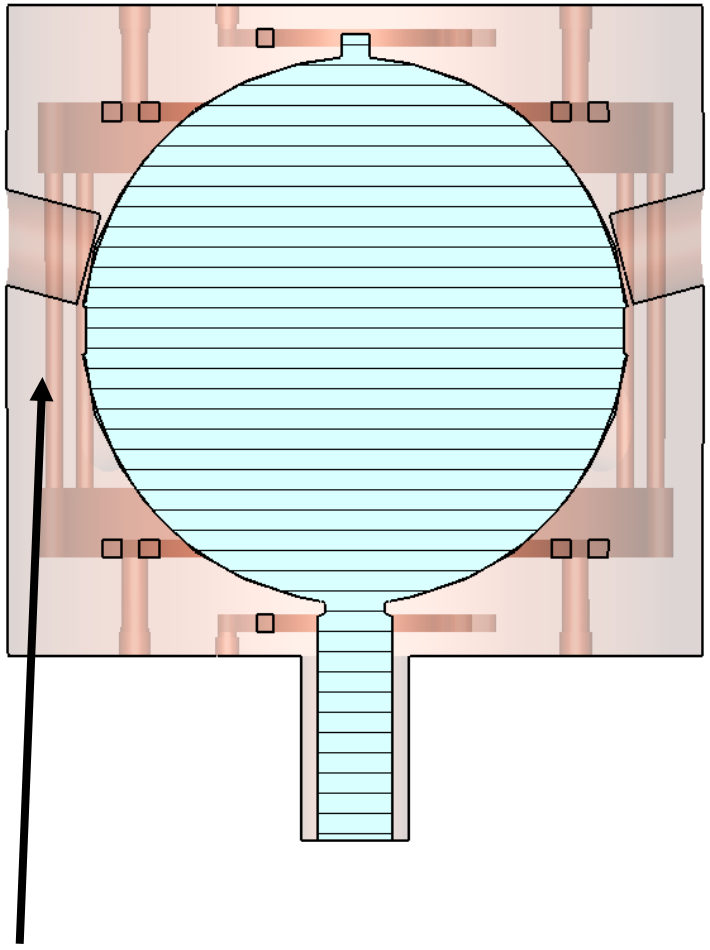





# Spherical cavity – simplified mechanical model



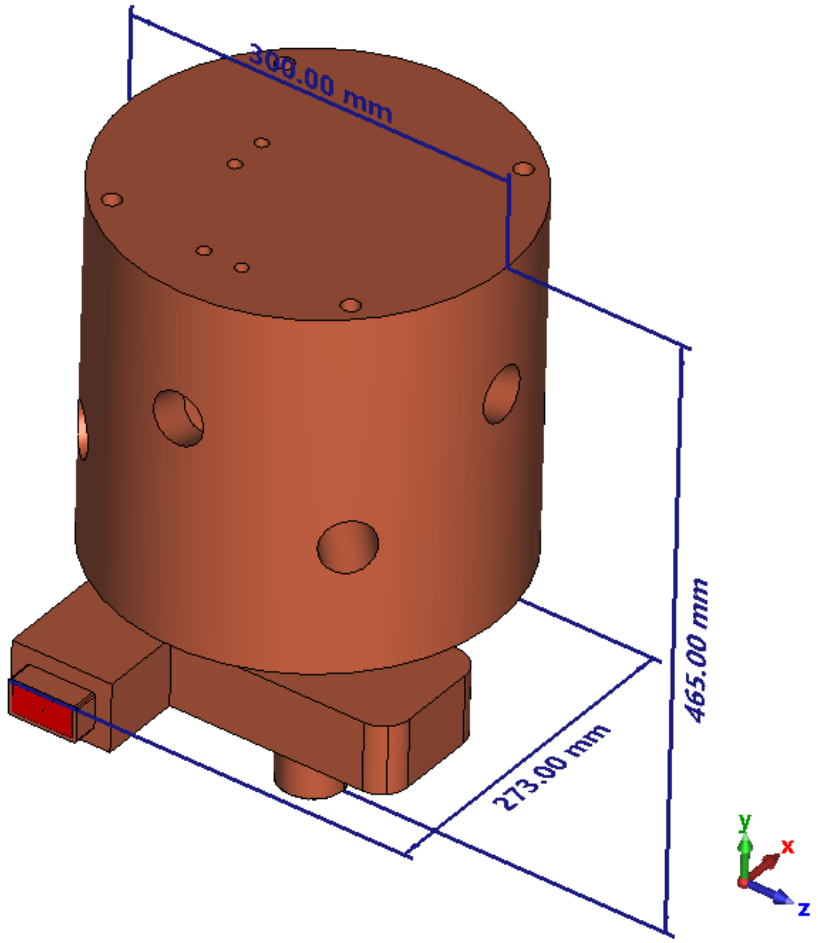


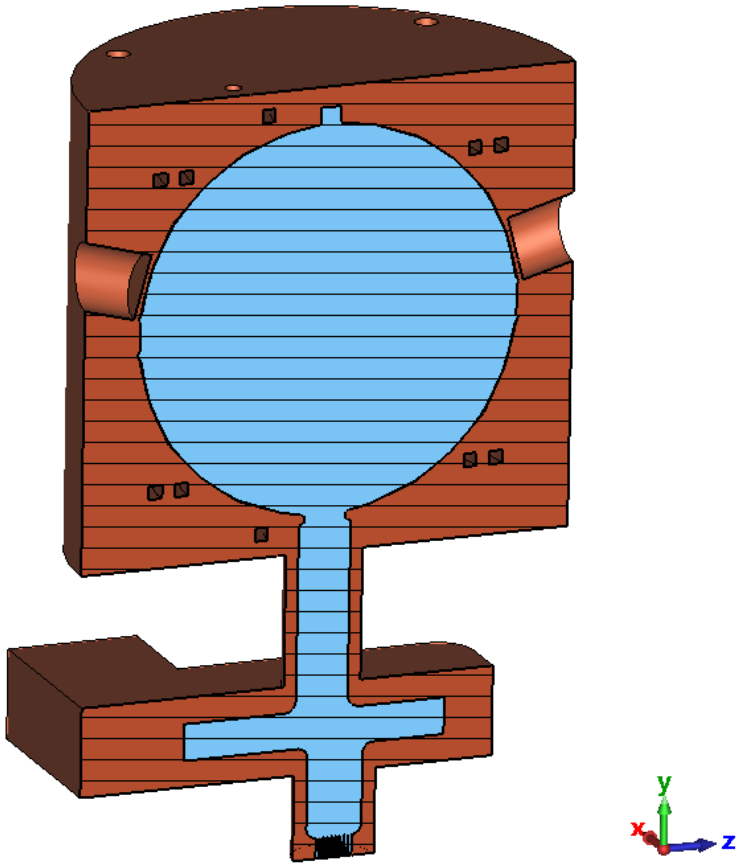


Slots for eight plastic deformation tuners

Water cooling channels

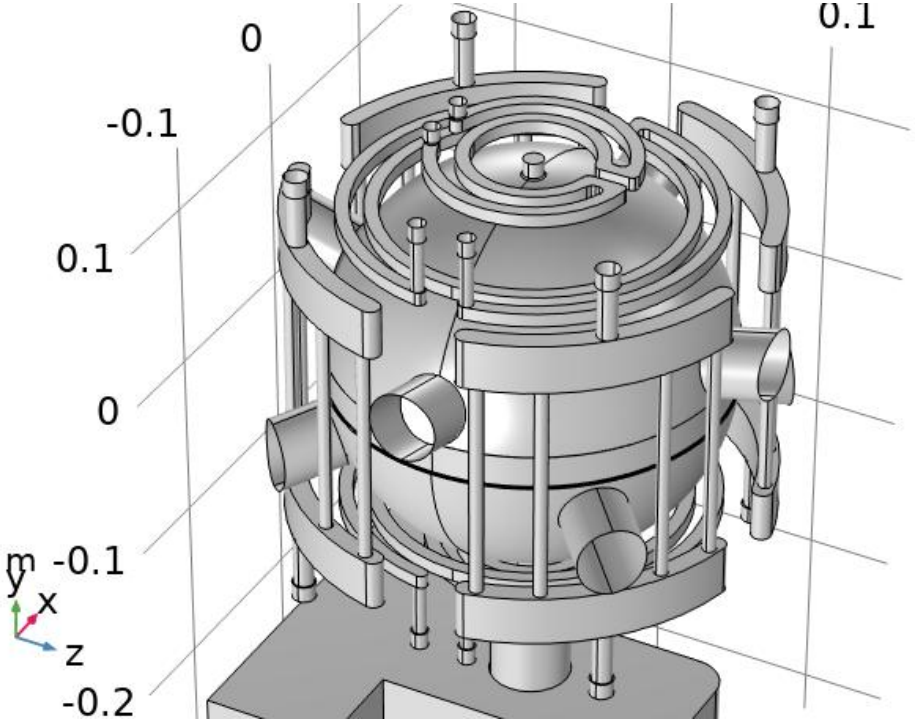
# Pulse compressor: final mechanical model



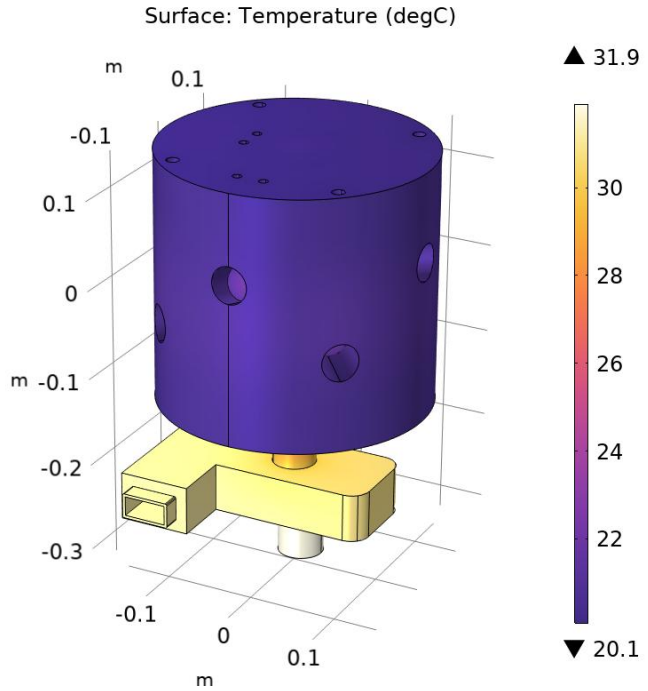



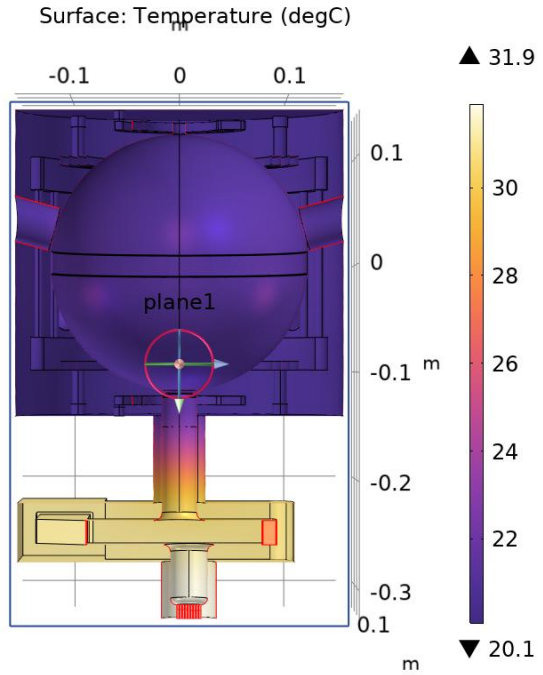
# COMSOL thermo-structural analysis

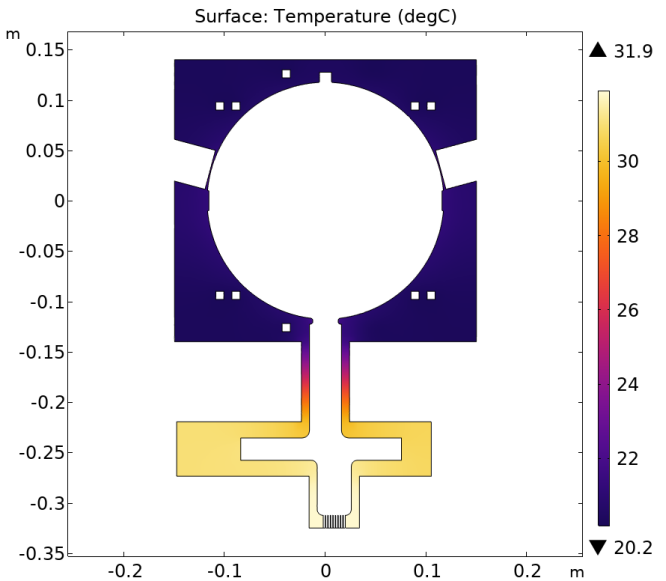
- Water temperature **T = 20°C,** water flux **$F_w$ = 20 l/m.**
- For the simulation, different heat transfer coefficients were calculated, depending on the section of the cooling tube (we have different sections).
- Ambient temperature **$T_a$ = 20°C.**
- Average input power **$P_{avg}$ = 4 kW.**

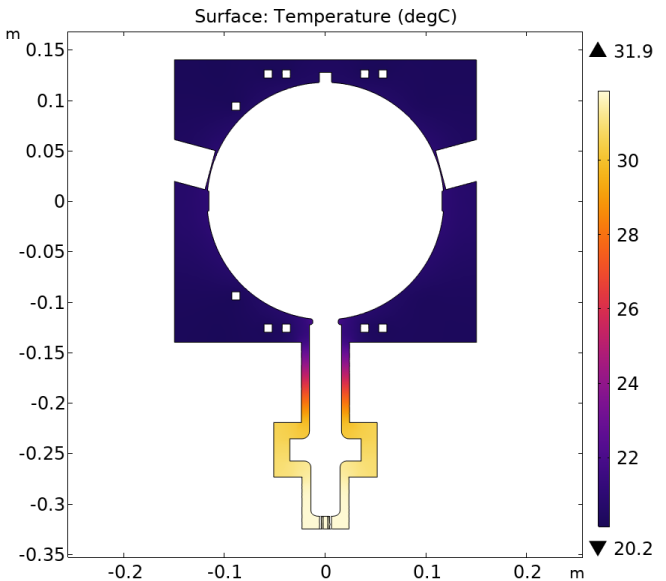


# COMSOL thermo-structural analysis



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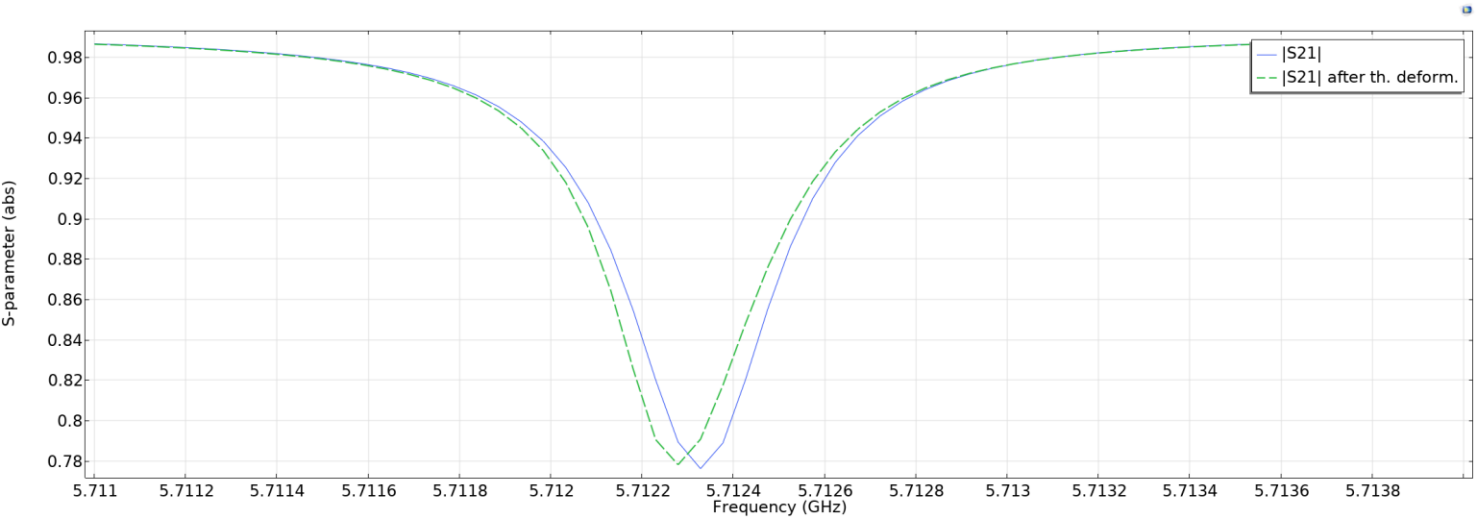
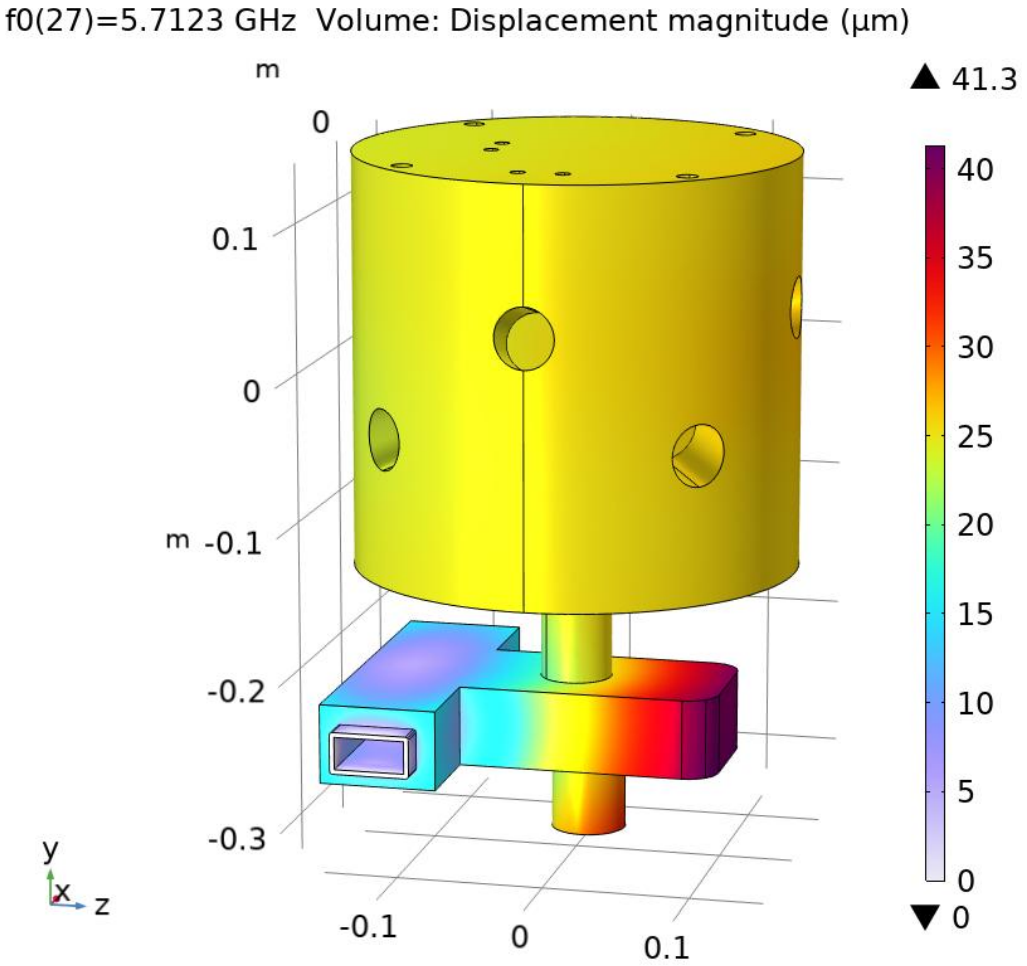
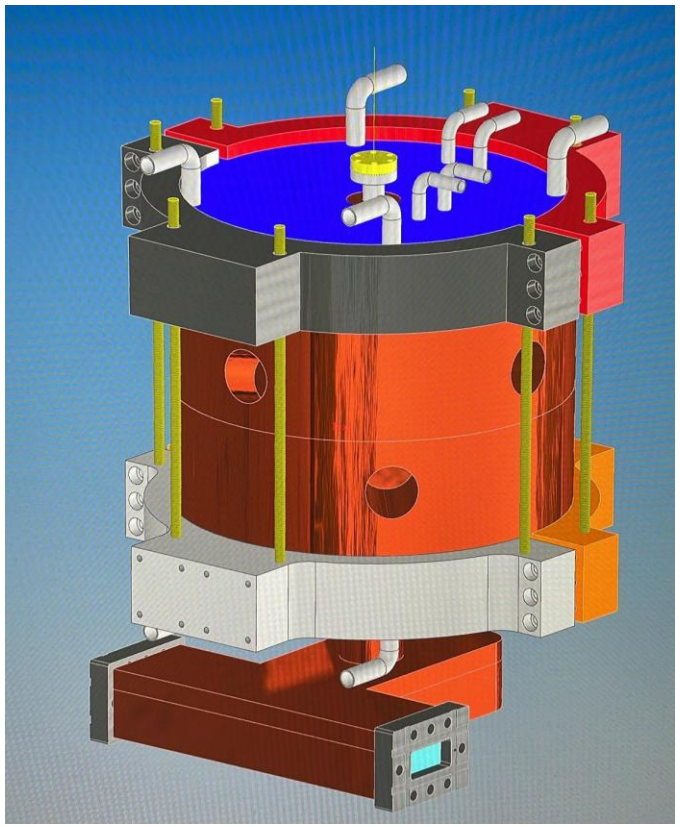
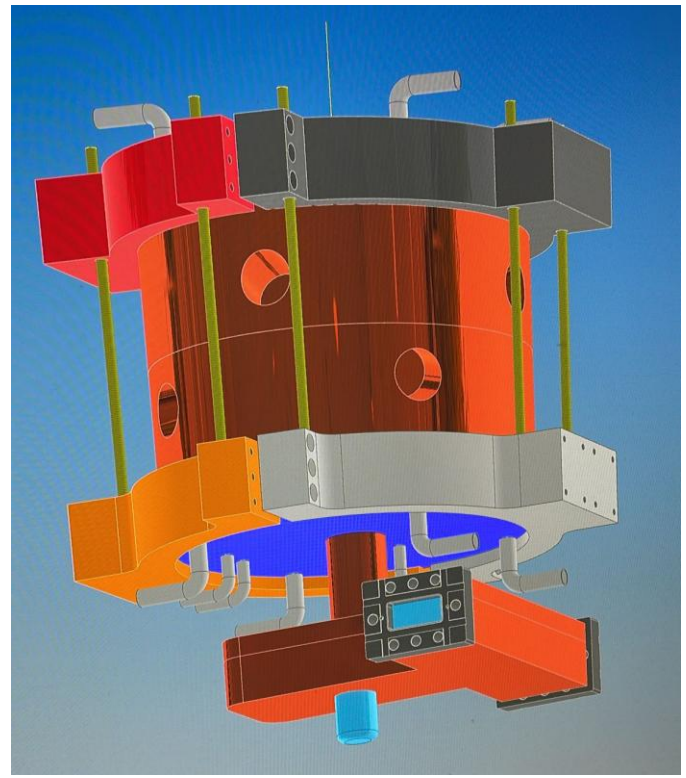


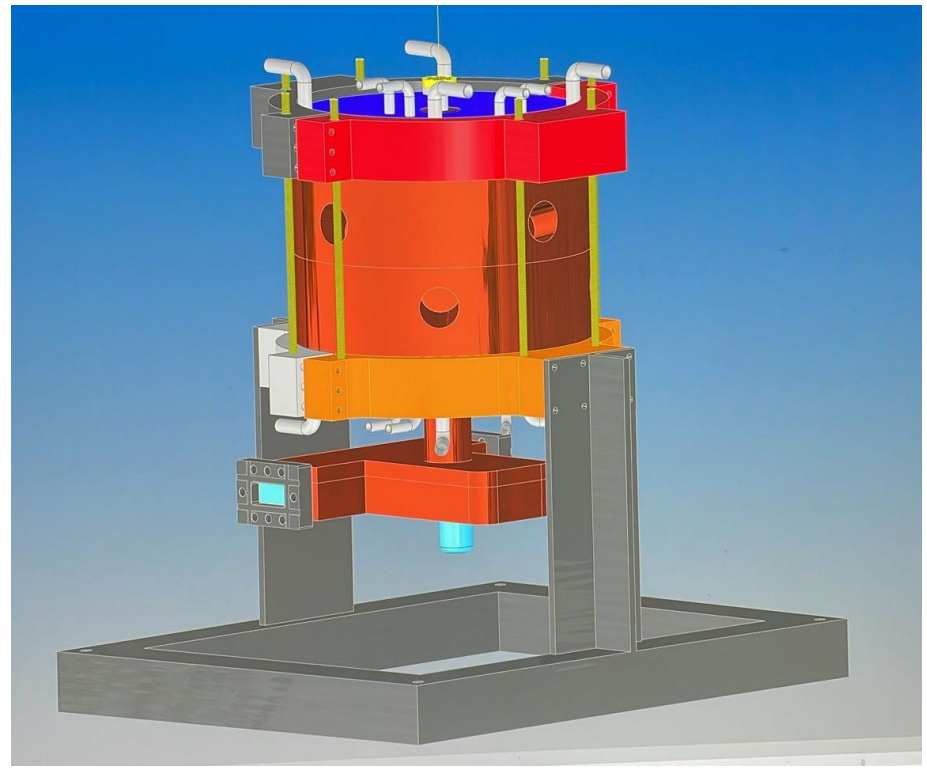

S21 shift due to thermal deformation ≤ 0.1 MHz

Simulation time ~ 36 h

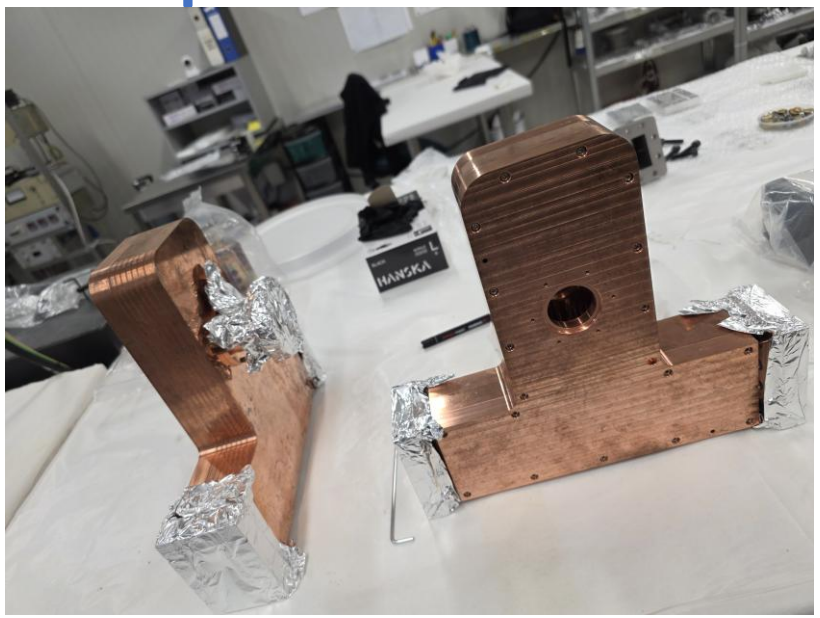
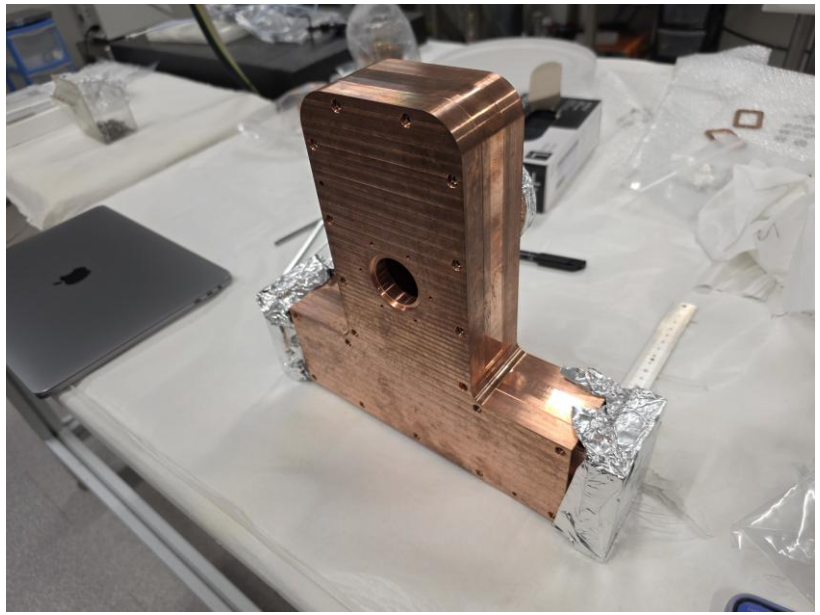
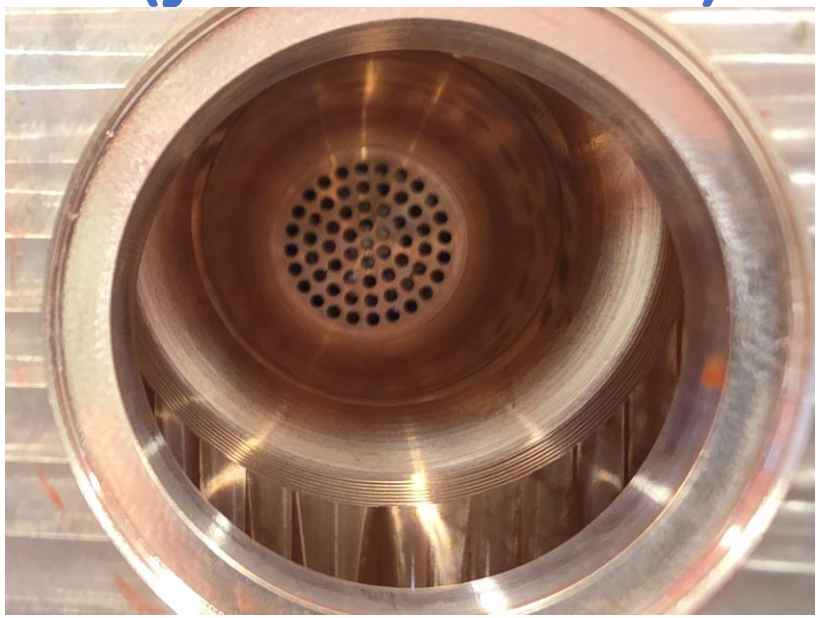
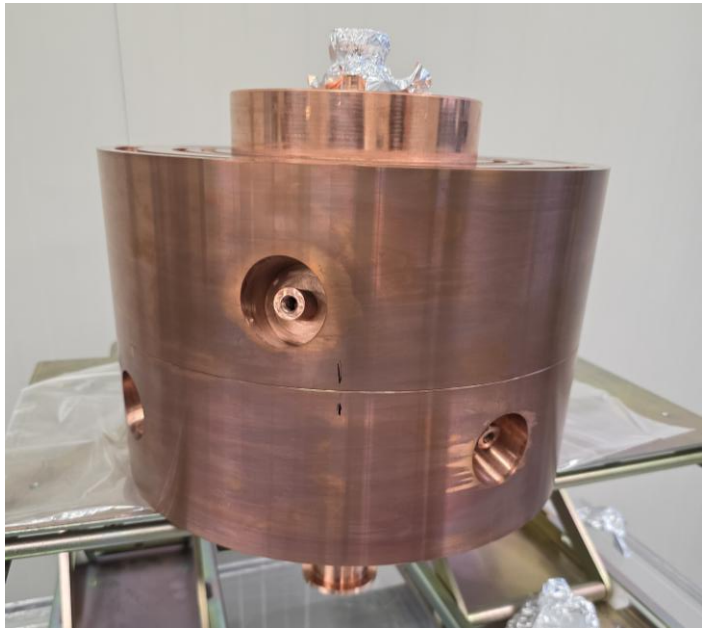
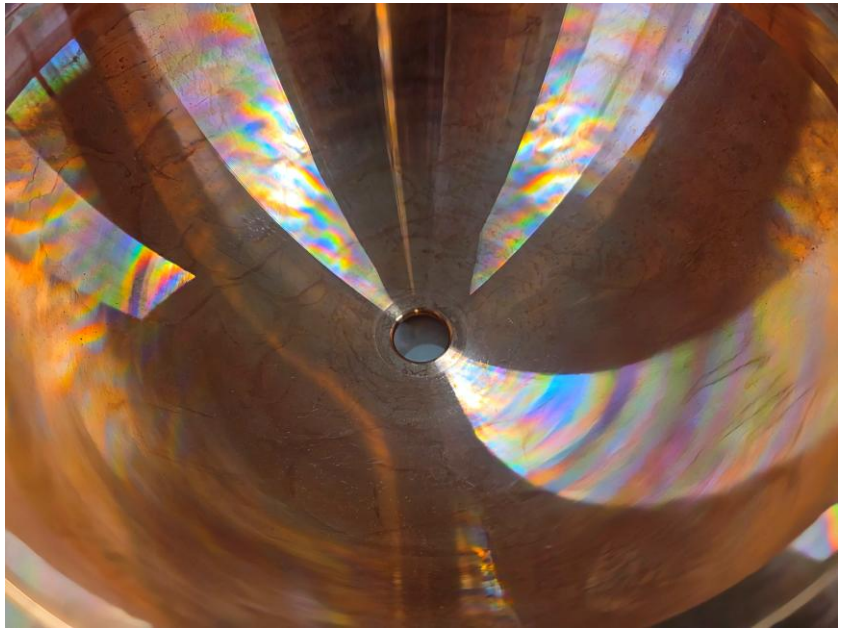
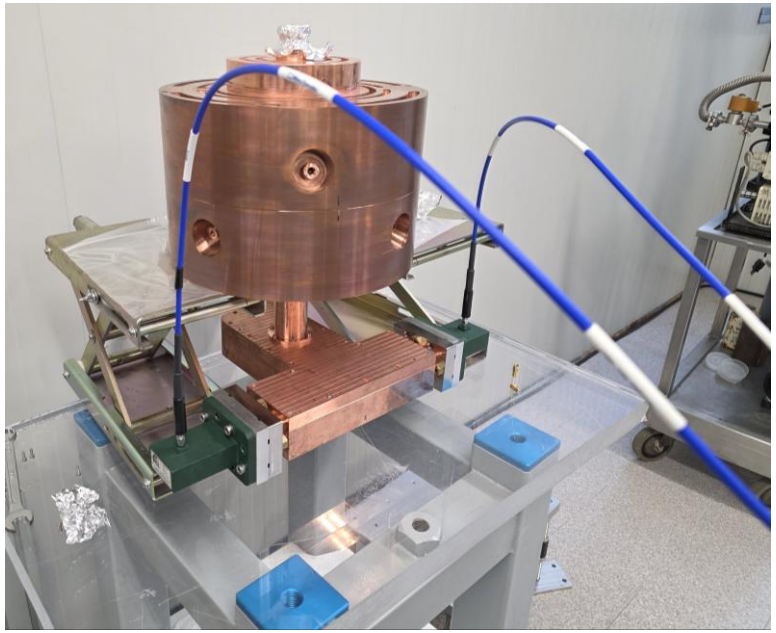








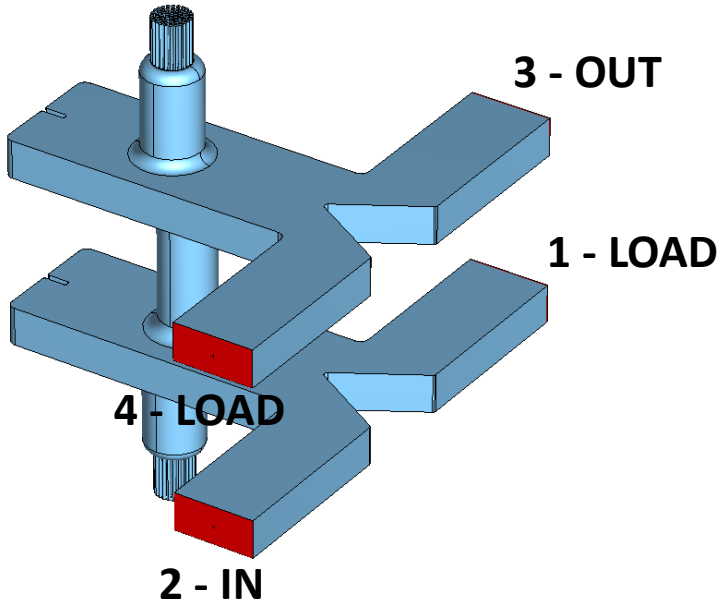
# Experimental characterization @ COMEB (jan-feb 2026)

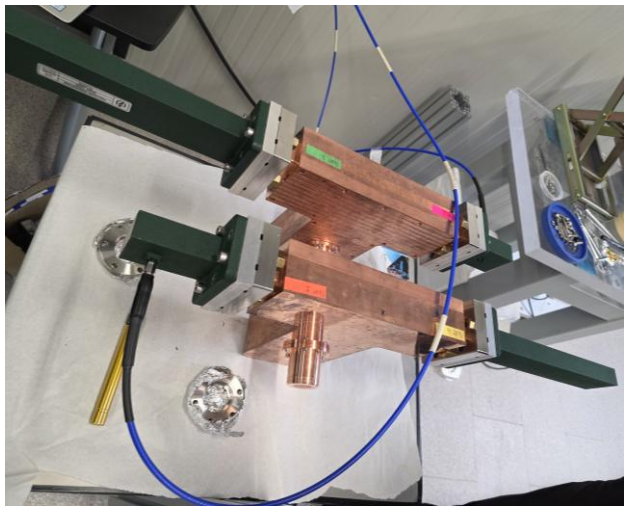







Thanks to L. Giuliano, S. Farina, R. Boldrini, A. Mostacci, Sapienza University of Rome for the support on exp. characterization.

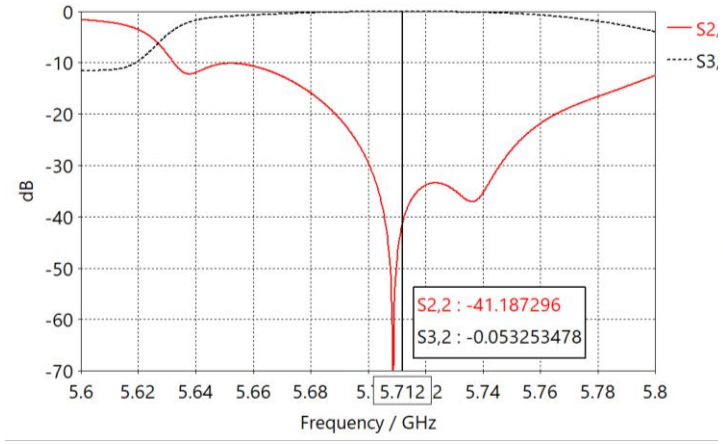
# Back-to-back polarizer measurements

- Two copper polarizer have been realized and connected for b2b characterization.
- VNA has been connected to ports 2, 3 and |S22|, |S32| have been measured.

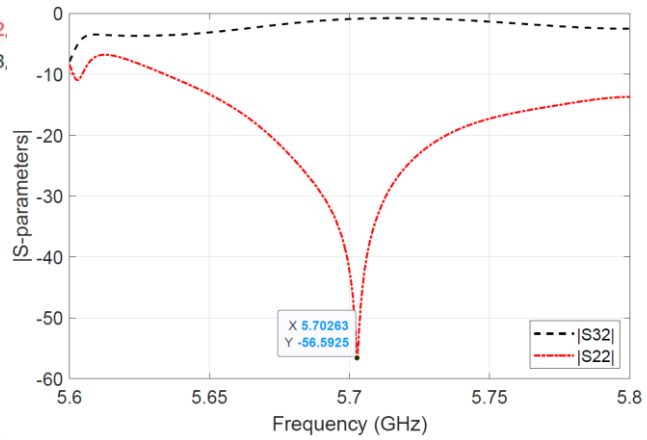


Simulation



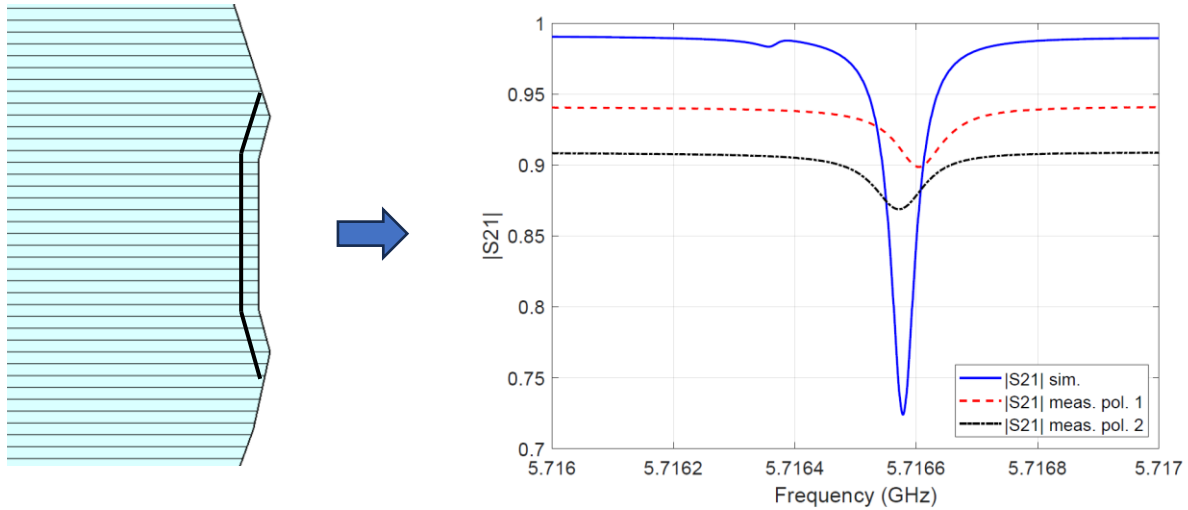

Measurement




- Measurements are in line with the simulations.
- Differences in terms of R/T are due to the missing brazing process.

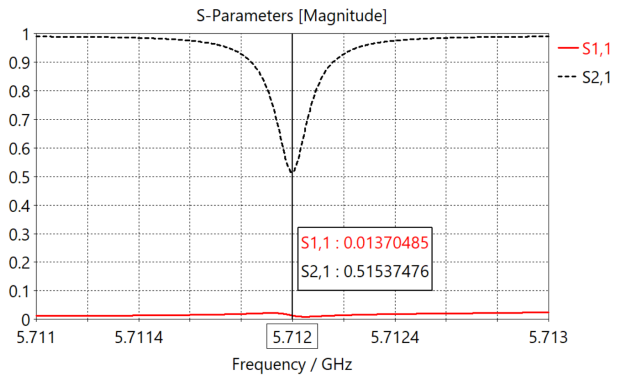
# Pulse compressor measurements

- The full structure has been characterized in air (without brazing).
- For this measurement, a safety thickness of about 1 mm has been kept along the surface of the entire azimuthal tuner (less cavity internal volume).
- This leads to higher $f_0$ and different coupling factor with respect to nominals.





Exp. characterization in air successfully completed




Next steps (march 2026):

- Re-working of the azimuthal tuning band to get the correct operating frequency ($f_0$ = 5.712 GHz).
- Full structure brazing and final cold measurements in vacuum (including $Q_0$).

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# Update on the RF Pulse Compressor

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THANK YOU