Design studies on LB650 & HB650 power couplers - simulation challenges and issues.

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A Partnership of:
- US/DOE
- India/DAE
- Italy/INFN
- UK/UKRI-STFC
- France/CEA, CNRS/IN2P3
- Poland/WUST

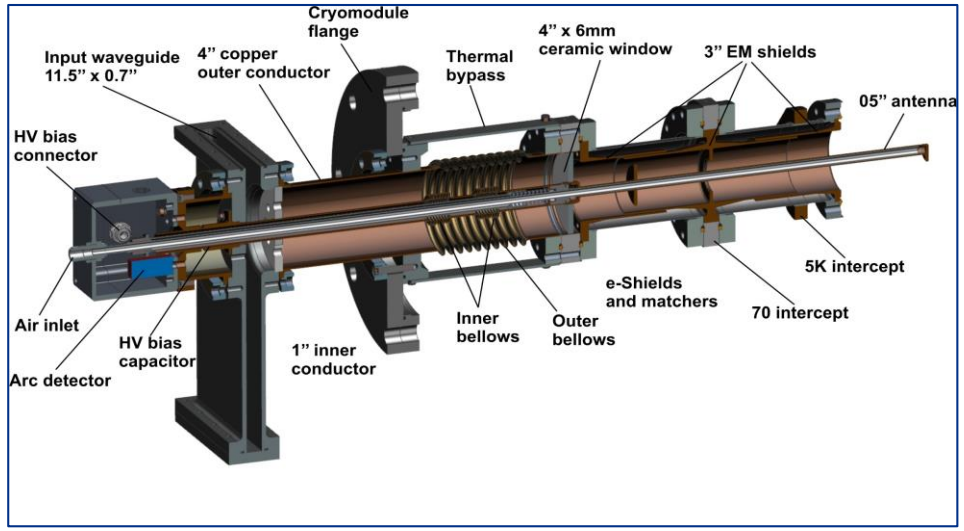
Functional Requirement specifications of 650 MHz coupler

Electromagnetic	Parameter	Value
	Frequency, MHz	650
	Pass band (S_{11}<0.1), MHz	> 2
	Maximum operating power, kW (CW, <25% reflection)	**43**
	Acceptance Testing power, kW (CW, any reflection)	**50**
	Loaded Q	9.8E+6 ± 20%
	HV bias for DC Block, kV	± 5
	Ceramic window dielectric loss constant	<1E-4
Mechanical		
	Input waveguide	WR-1150
	Output coaxial line aperture, mm	72.9
	Output coaxial line impedance, Ω	105
	RF window	Single, RT
	Cavity flange relative displacement, mm	± 3
	Antenna tip centering, mm	< ± 1.5
	Antenna tip vibration (by air cooling), mm	< ± 0.1
	Vacuum leak tightness, mbar.L/sec	< 2E-10
	Transportation shock, vertical, g	3
	Transportation shock, transverse, g	1.5
	Transportation shock, longitudinal, g	5

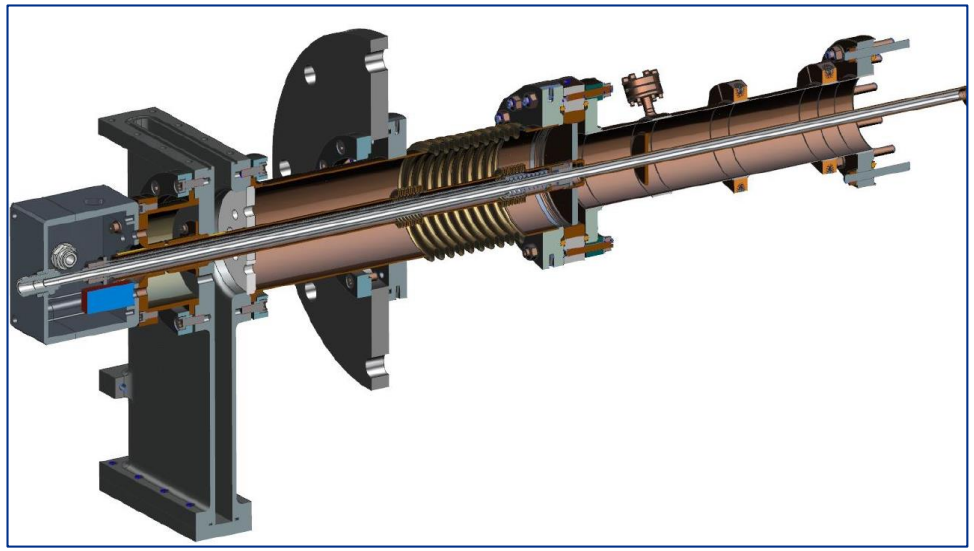
Thermal (at maximum operating condition)		
	Thermal intercepts (nominal), K	5 and 50
	Temperature at 5 K intercept, K	< 15
	Temperature at 50 K intercept, K	< 125
	Maximum 2 K heat load, W	**< 1.6**
	Maximum 5 K heat load, W	**< 3.5**
	Maximum 35-50 K heat load, W	**< 10**
	Maximum antenna tip temperature, K	< 350
	Antenna cooling media (if needed)	**Air**
	Air flow rate, g/s	< 5
	Max cooling air pressure drop, bar	< 1.5
	Air output temperature, K	< 340

Two type of prototypes were designed and built based on experiences of testing 325 MHz couplers.

650 MHz coupler without copper coatings (with EM shields):



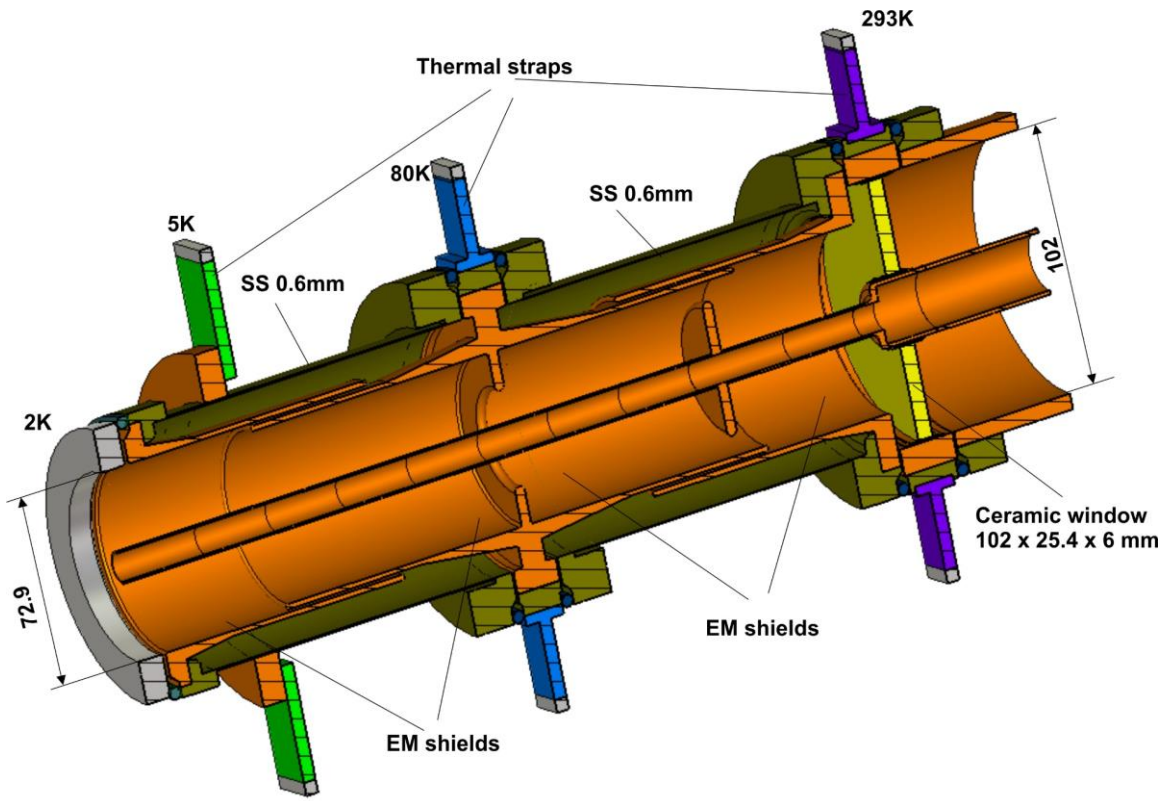
650 MHz coupler with copper coatings



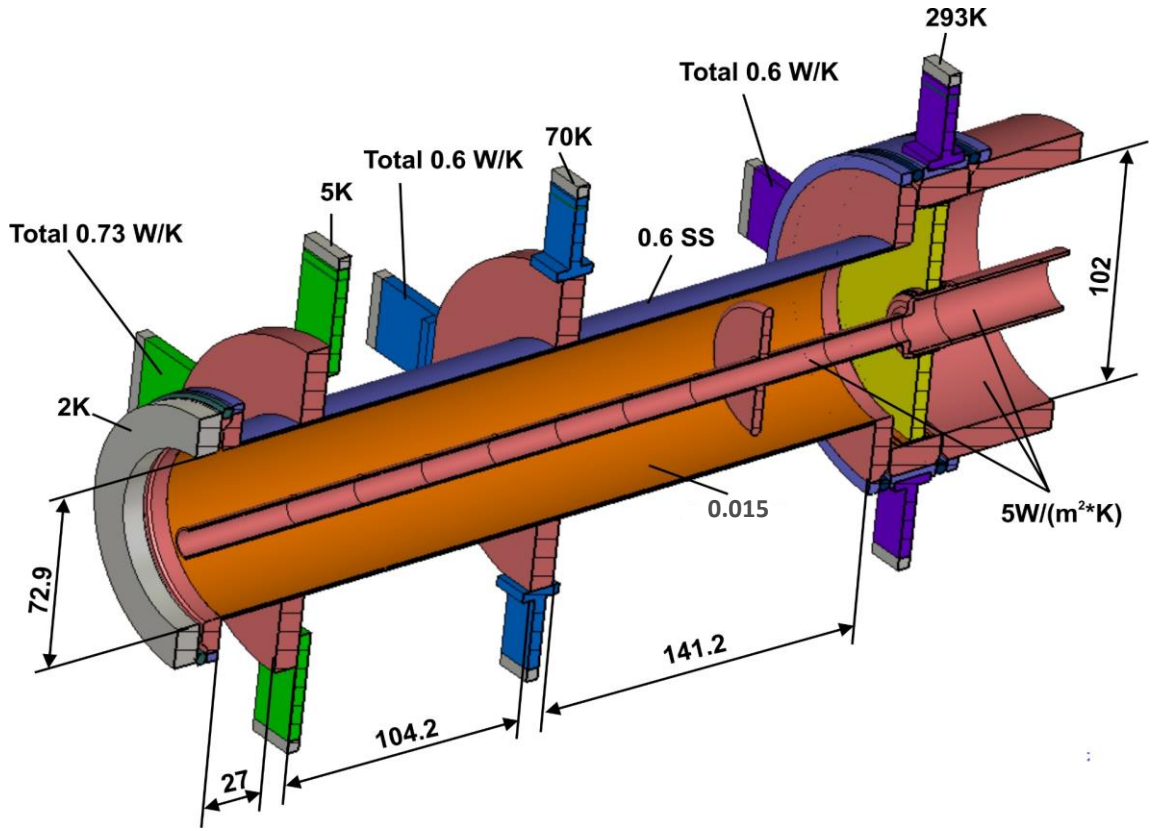
Vacuum parts of couplers:

a) copper coated
b) with EM shields

Configuration with EM shields

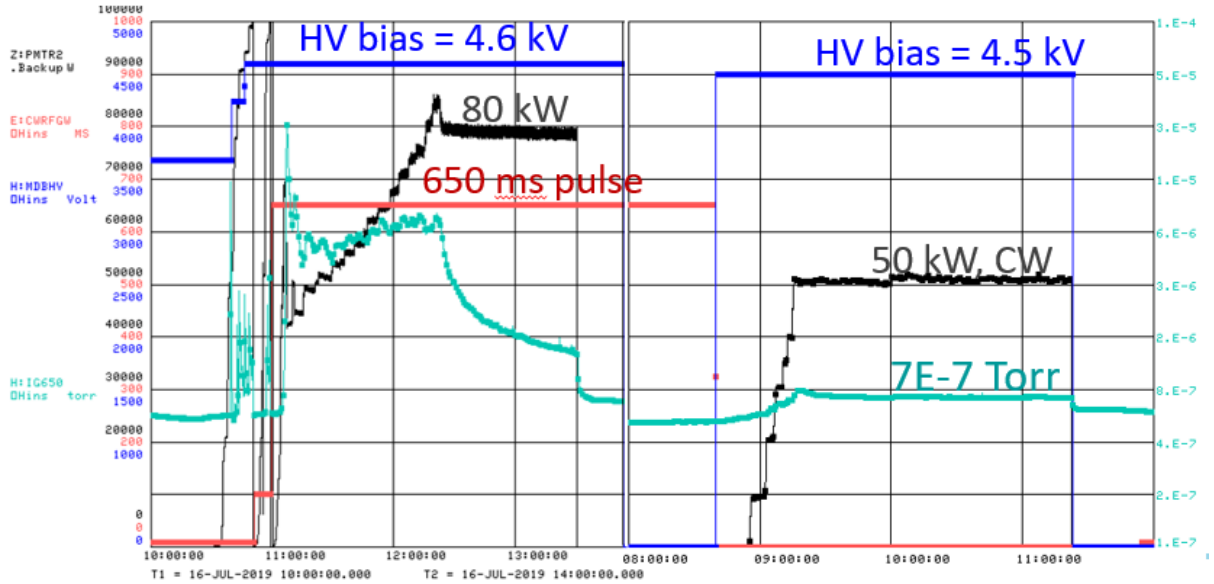


Configuration with copper coating



Both types of couplers were successfully tested at room temperature test stand up to 50 kW, CW, full reflection. Successful test: 4 phase reflected points (step 90 dgr) and 1.5-2 hours at each points of 50 kW input power, CW.

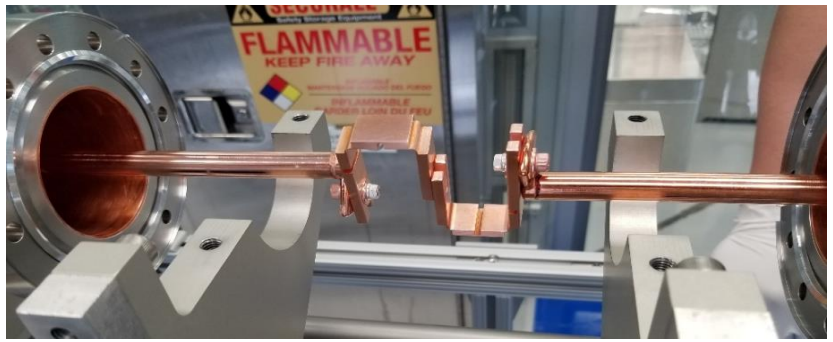
Examples of signals during room temperature high power test:



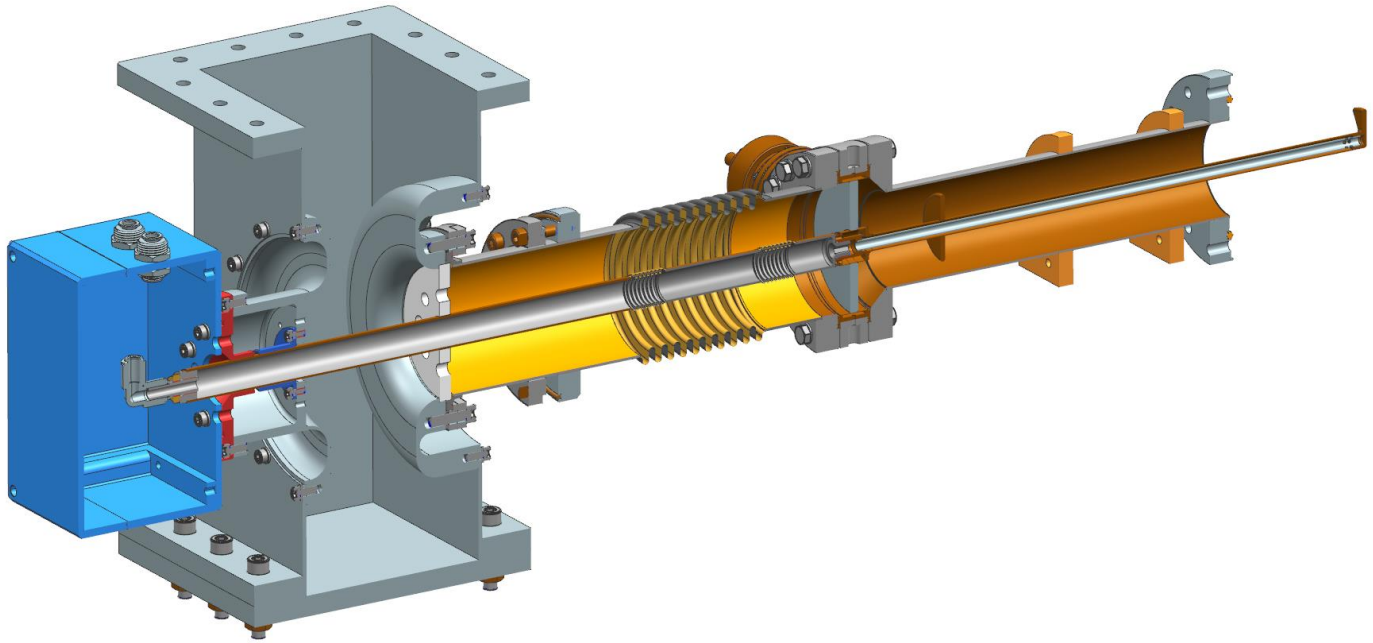
Lessons of high-power tests of 650 MHz couplers:

- Narrow waveguide does not fit good a 50-kW power level with full reflection. It becomes hot and heats up the window trough common air volume. Waveguide cooling should be improved, or height of waveguide should be increased.
- It was a not good idea to use mechanical joint of couplers antennas. It simplifiers configuration, but temperate of bridge is high during the test. There was a deposition of materials of fasteners (because of multipactor?) at antennas tips after tests. Test chamber should be re-designed.
- High voltage bias suppresses multipactor successfully even for uncoated ceramics (no TiN).

Mechanical joint of couplers antennas:



New improved design:



Main differences from previous version:

- Standard size input waveguide with matching elements to reduce losses and temperature.
- Air cooling tube is brazed inside antenna to reduce probability of vibration due to cooling air flow.
- Vacuum gage added for diagnostic.

"Conventional" configuration with copper coating was chosen for next bunch of 650 MHz coupler.
Both approaches (copper coted and with EM shields) have pros and cons.

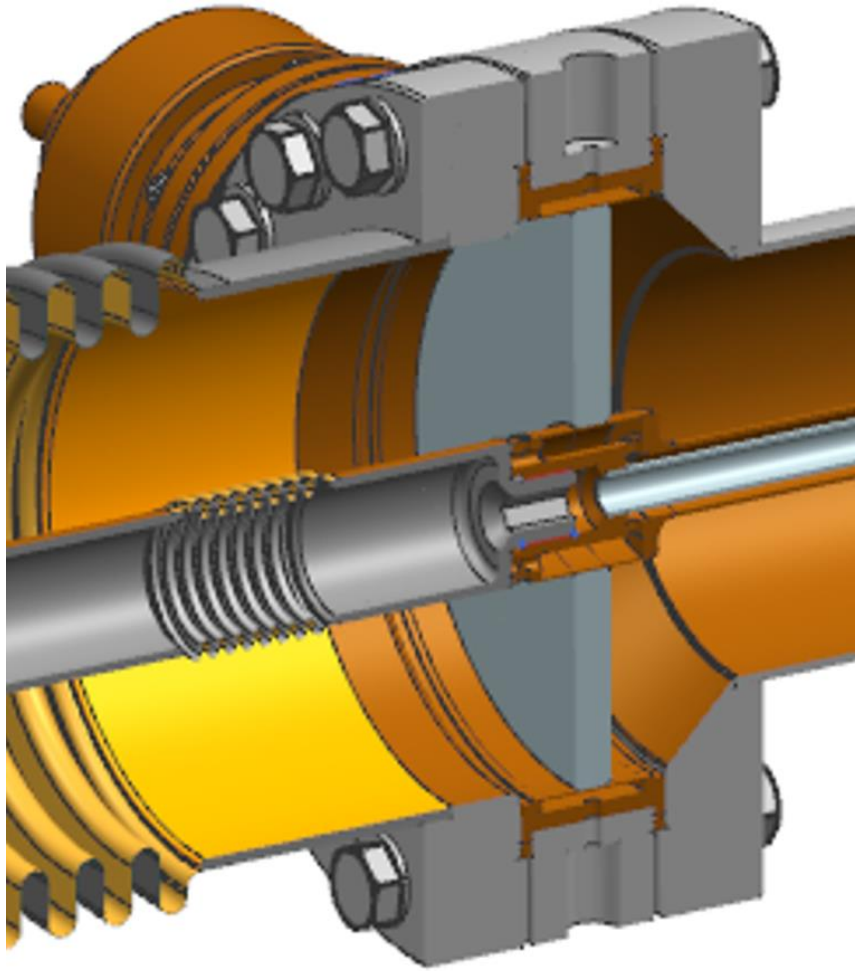
EM shields: Pros: no copper coating, no possible flakes, more reliable, less cryogenic loadings.
Cons: bigger sizes, heavier, additional vacuum joints, probably more expensive.

Copper coatings: Pros: smaller sizes, lighter, less vacuum joints, probably less expensive.
Cons: sensitive technology, possible flakes, less reliable, higher cryogenic loadings.

Key element of coupler - ceramic window.

Ceramic sizes:

D_out 100mm, D_in 25.4mm, Tickness x 7mm.

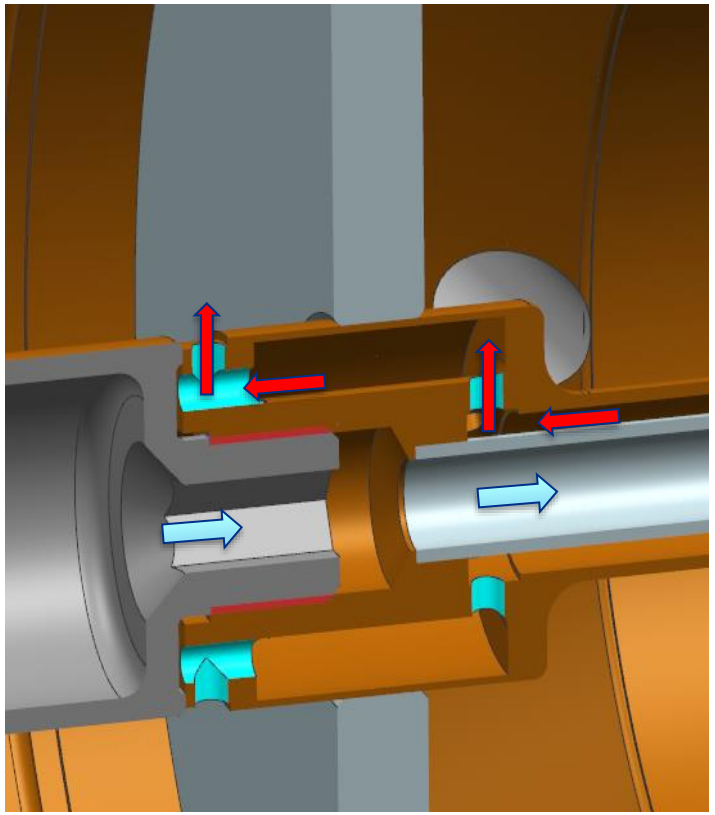


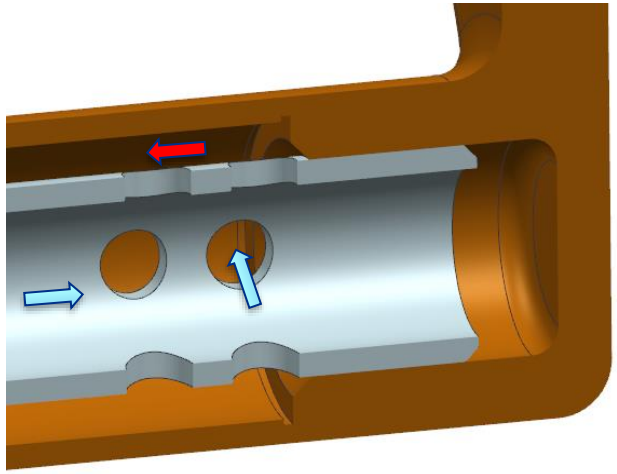
Air cooling of antenna and window:

Air flow rate:

~ 4-5 g/s during operation (43 kW, 25% reflection)

~6-7 g/s during room-T test (50 KW, full reflection)





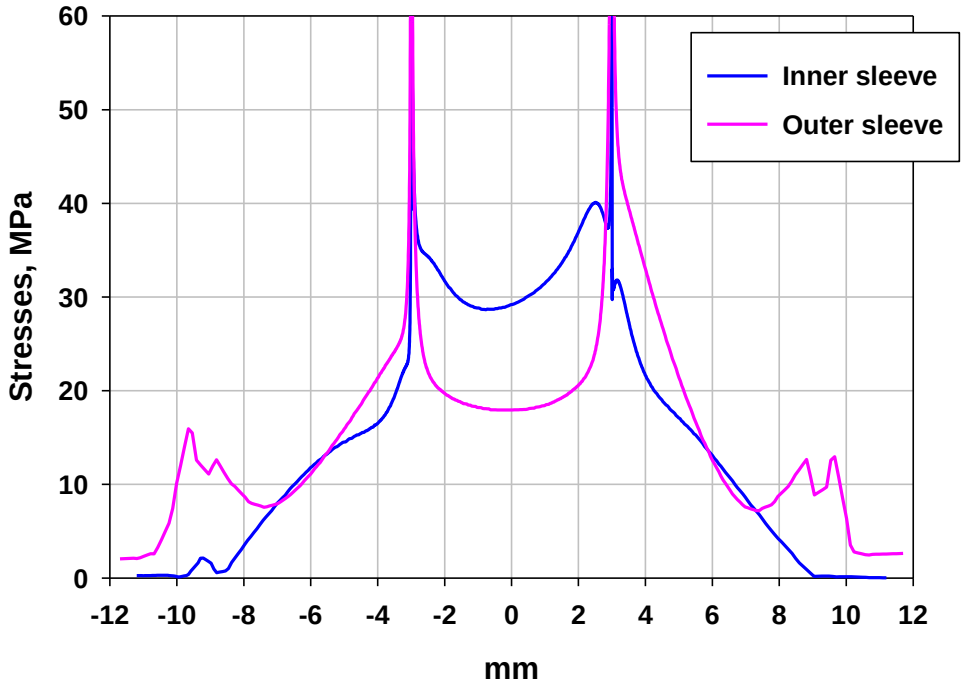
Main criterium of design:

To provide acceptable mechanical stresses at operating power level and, as result, provide necessary long lifetime (~ 1e+5 On/Off cycles)

20 years, 1 trip per hour = 1.7E+5 On/Off RF power

Stresses should not excide ~ 80 MPa.

Stresses from 1 bar pressure to window + 50kW, 20% refl., 305drg refl., 1e-4 loss tng., 4g/s air



Stresses ~ 50 MPa at operating conditions.

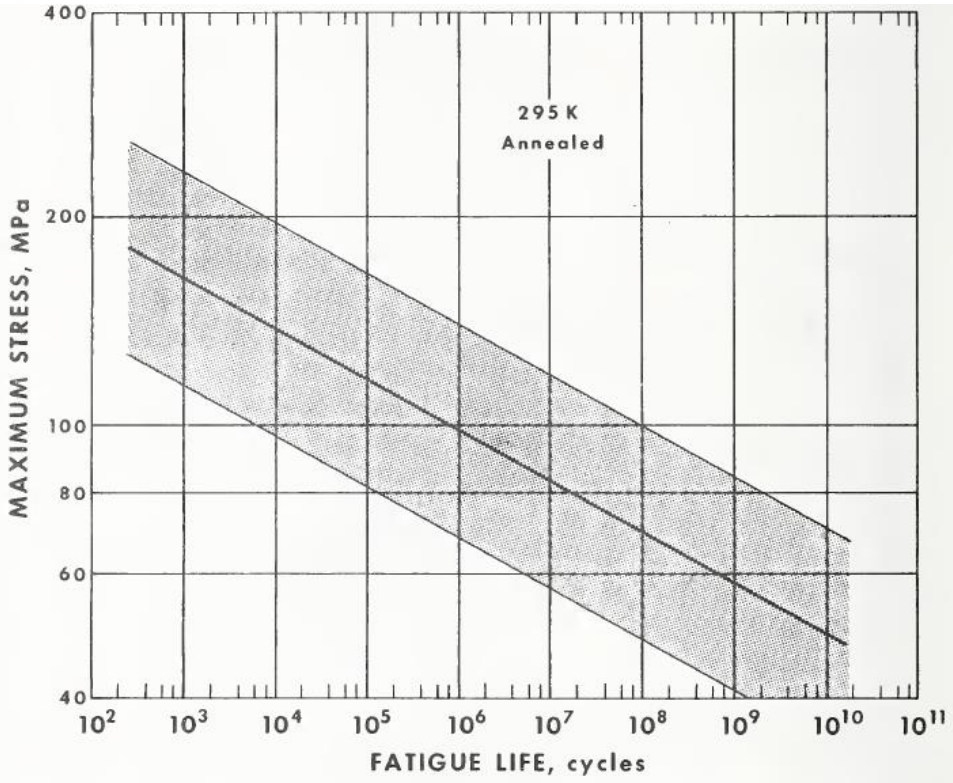


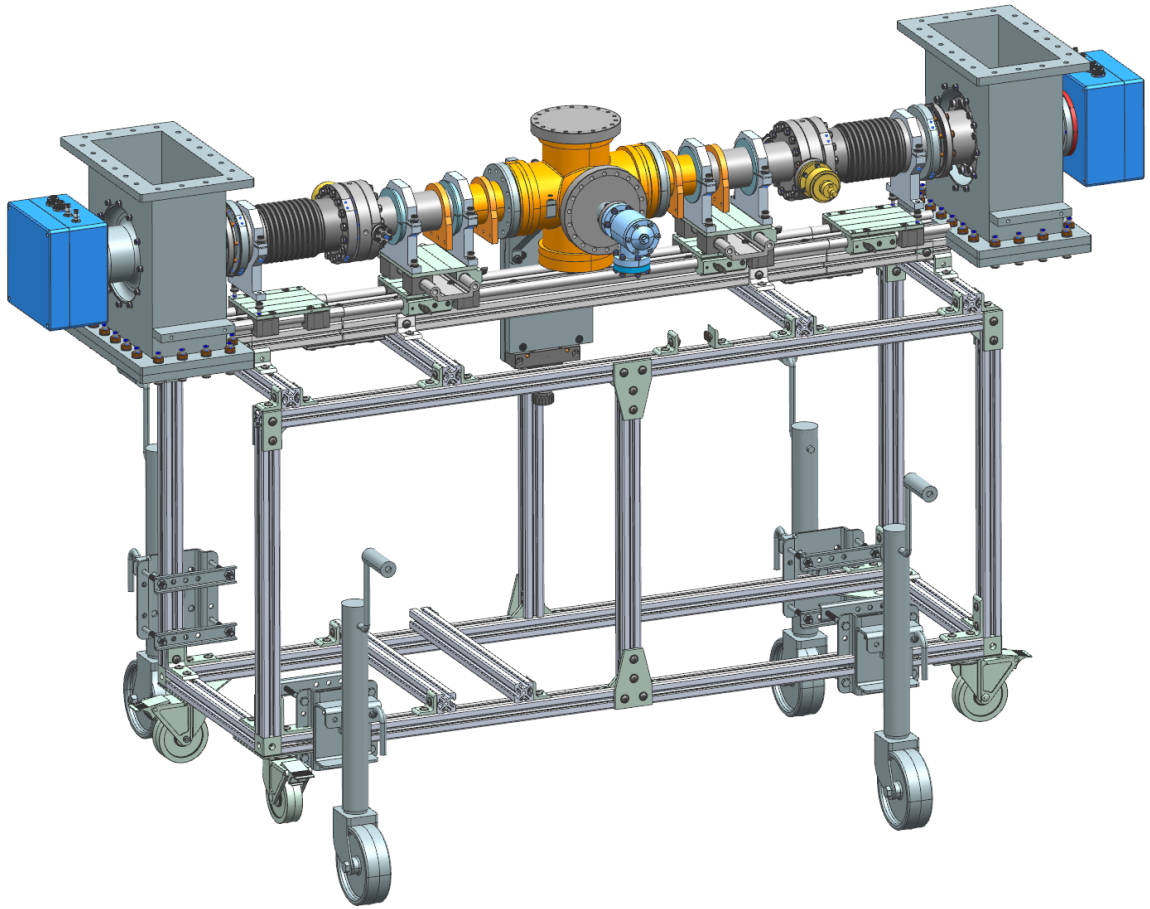
Figure 4.2. Dependence of maximum stress at 295 K upon number of cycles to failure. The scatter band represents two standard deviations about a linear regression equation based upon 148 measurements. The regression equation is

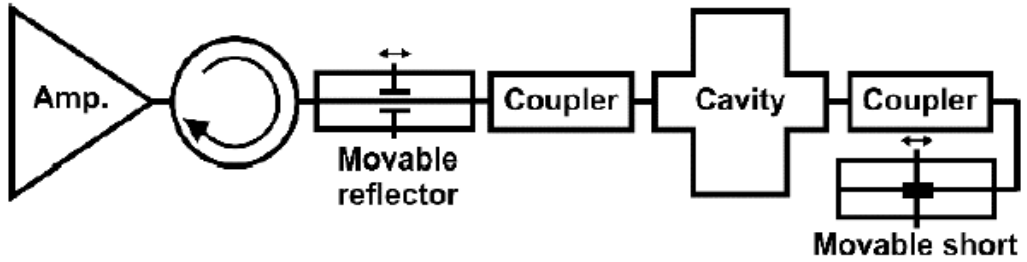
$$\sigma_m(\text{MPa}) = 271\, N^{-0.074}.$$

Acceptance criterium:

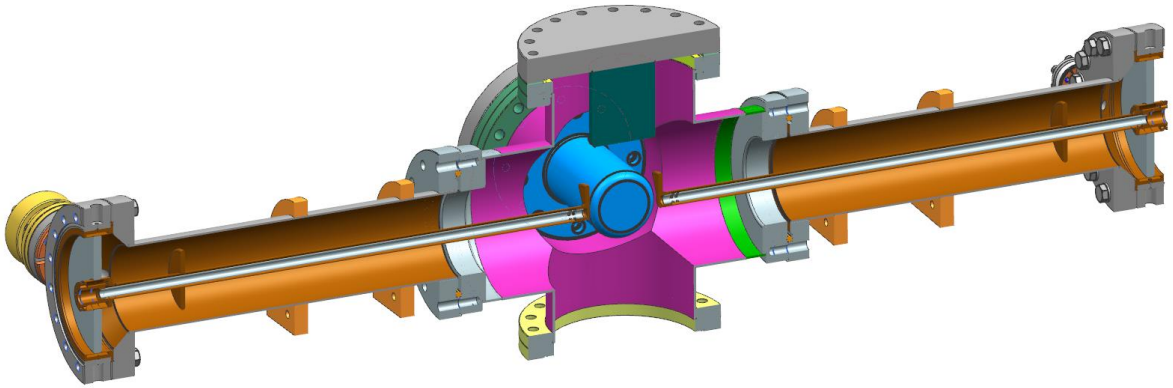
room temperature high power test at power 50kW, CW, full reflection, 4-8 points of different reflection phase. 1.5 – 2 hours at each point to reach thermal equilibrium.

Test stand with new “capacitive” vacuum chamber.



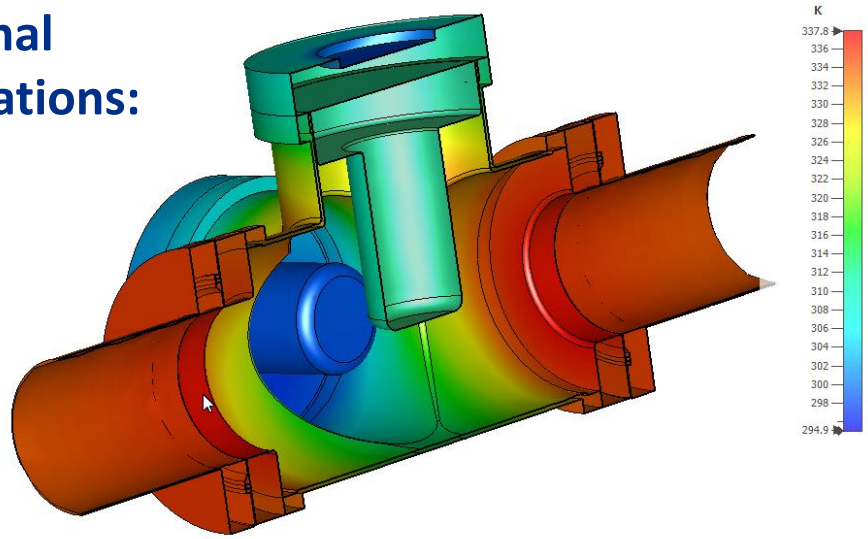


New vacuum chamber of test stand with capacitive coupling.

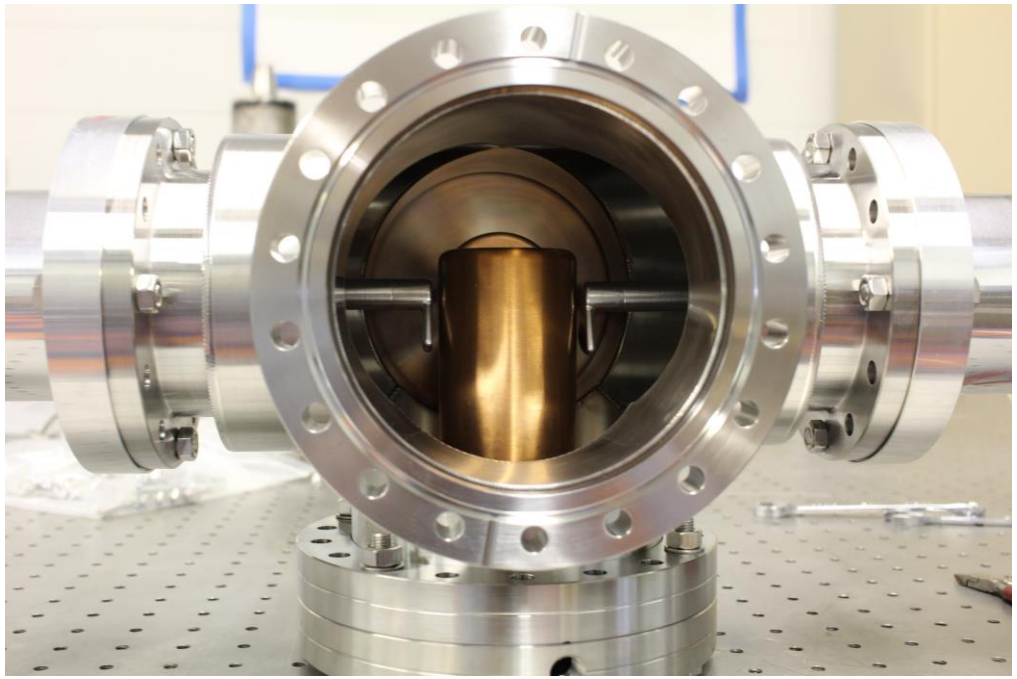


New chamber with dummy couplers:

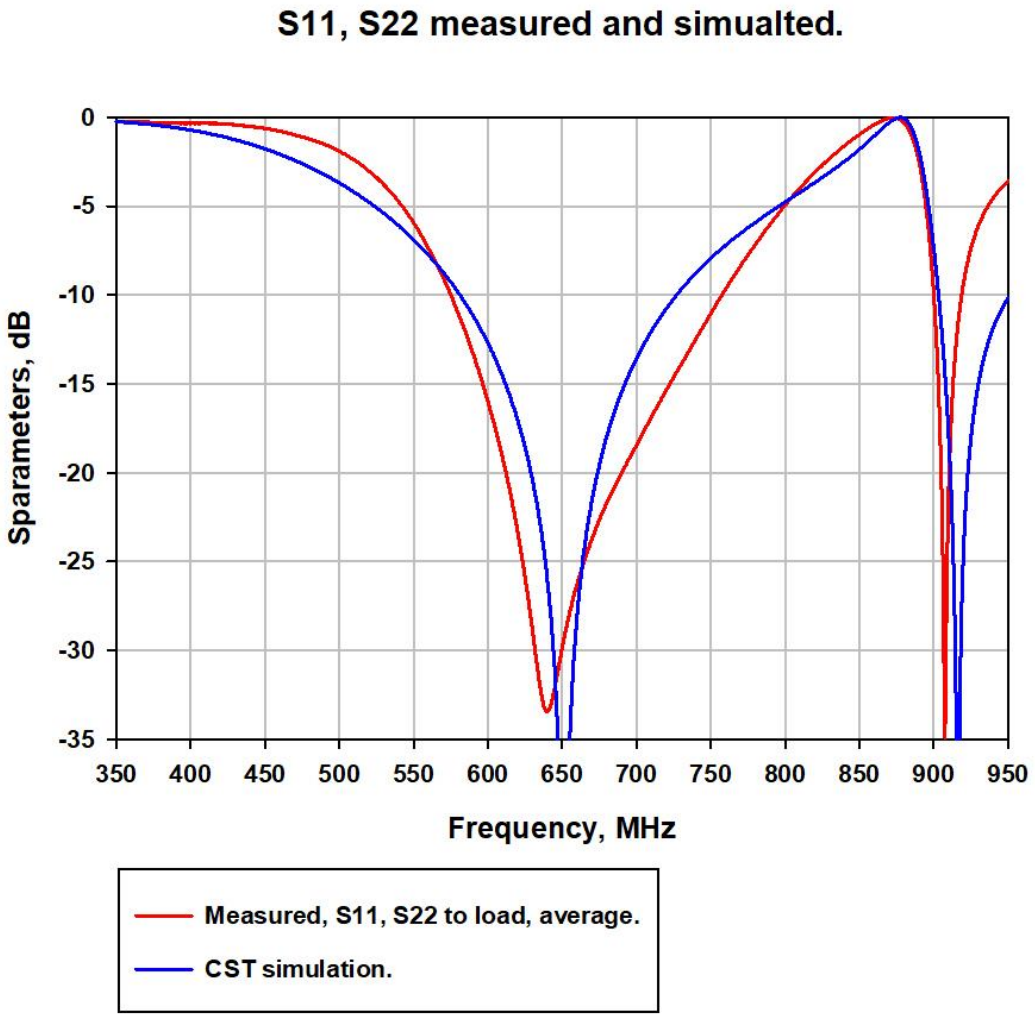
Thermal simulations:

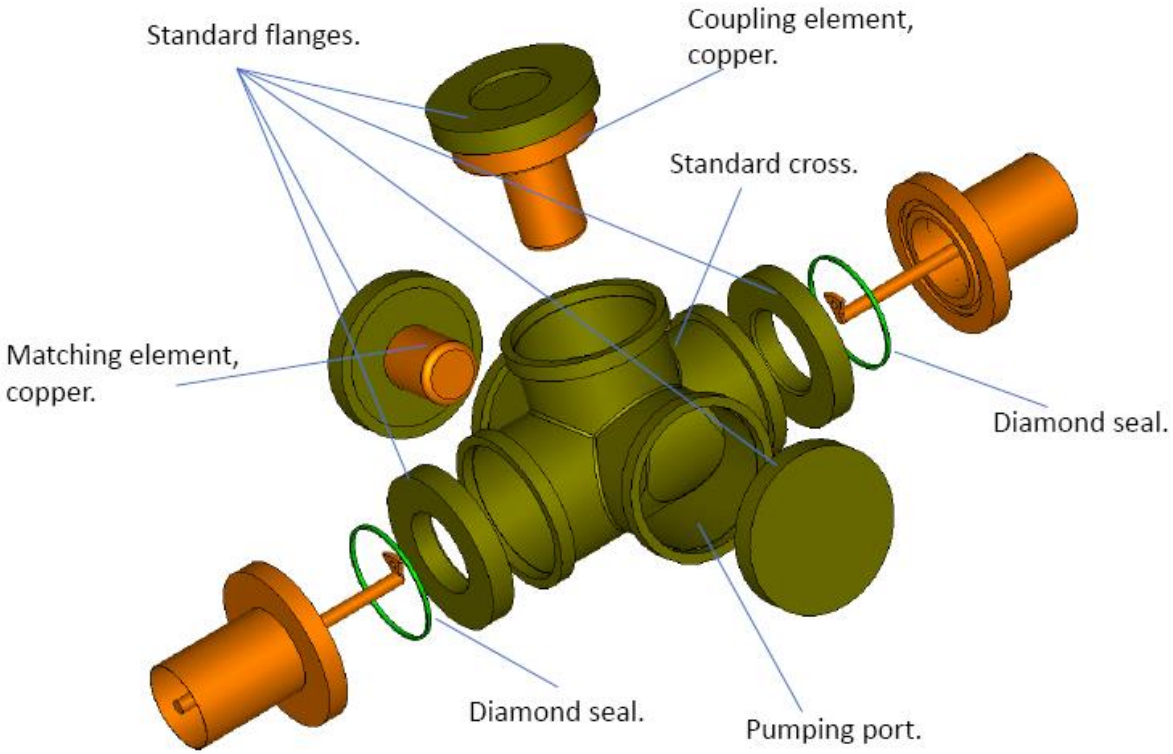


Max. T < 60C for 50 kW, CW, full reflection

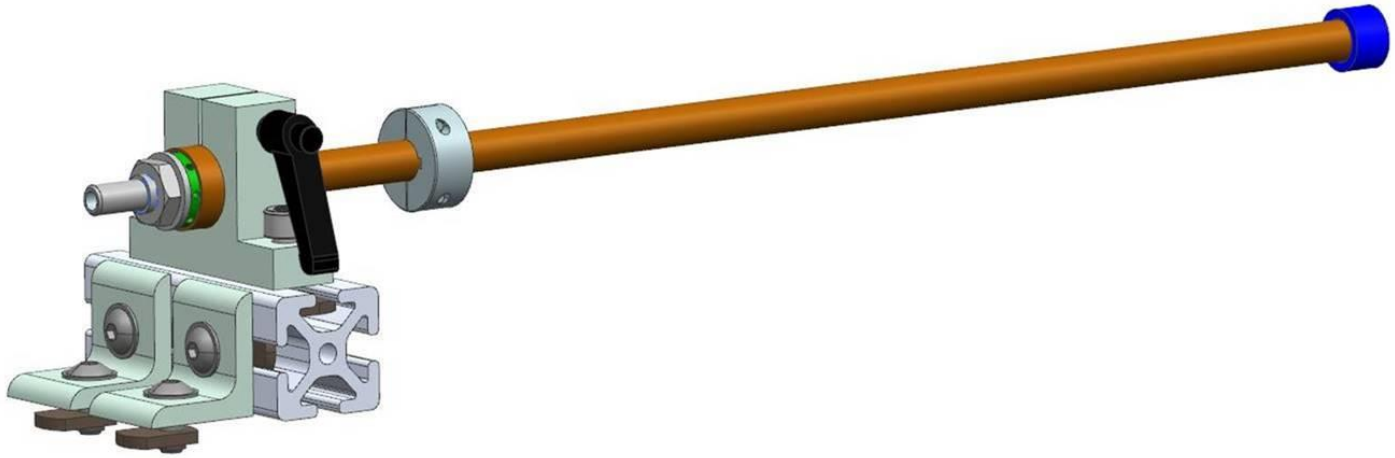


S11 and S22 of new chamber, measured and simulated.

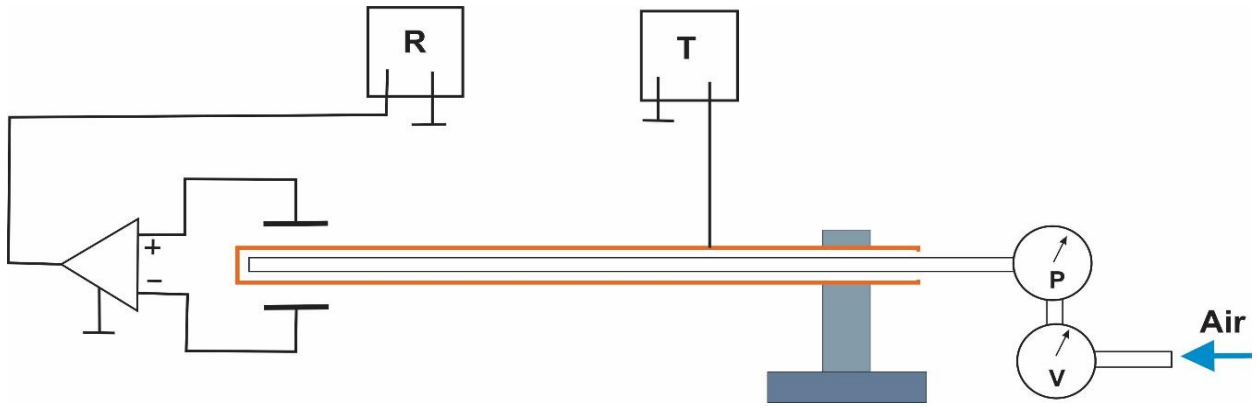




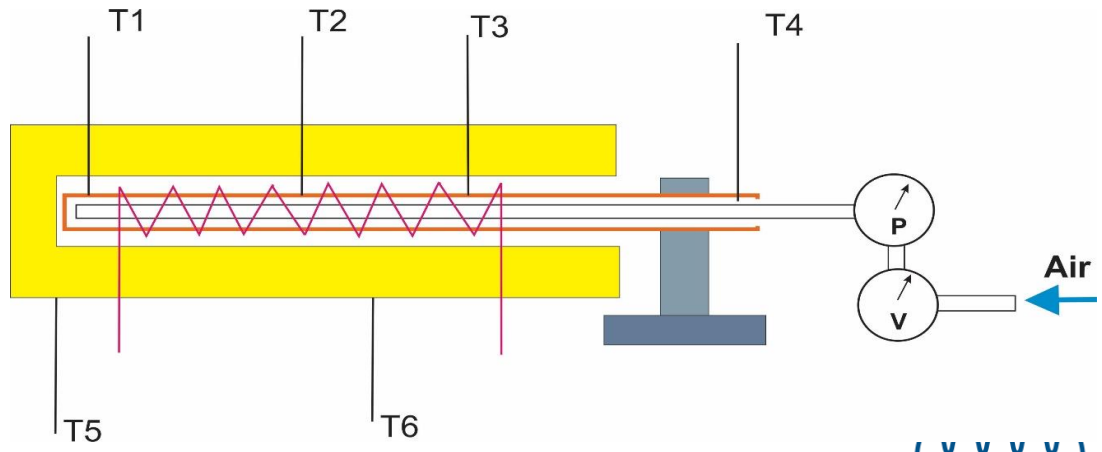
We suppose to make vibration and cooling tests to measure vibration and efficiency of cooling of antenna.



Scheme of vibration test:

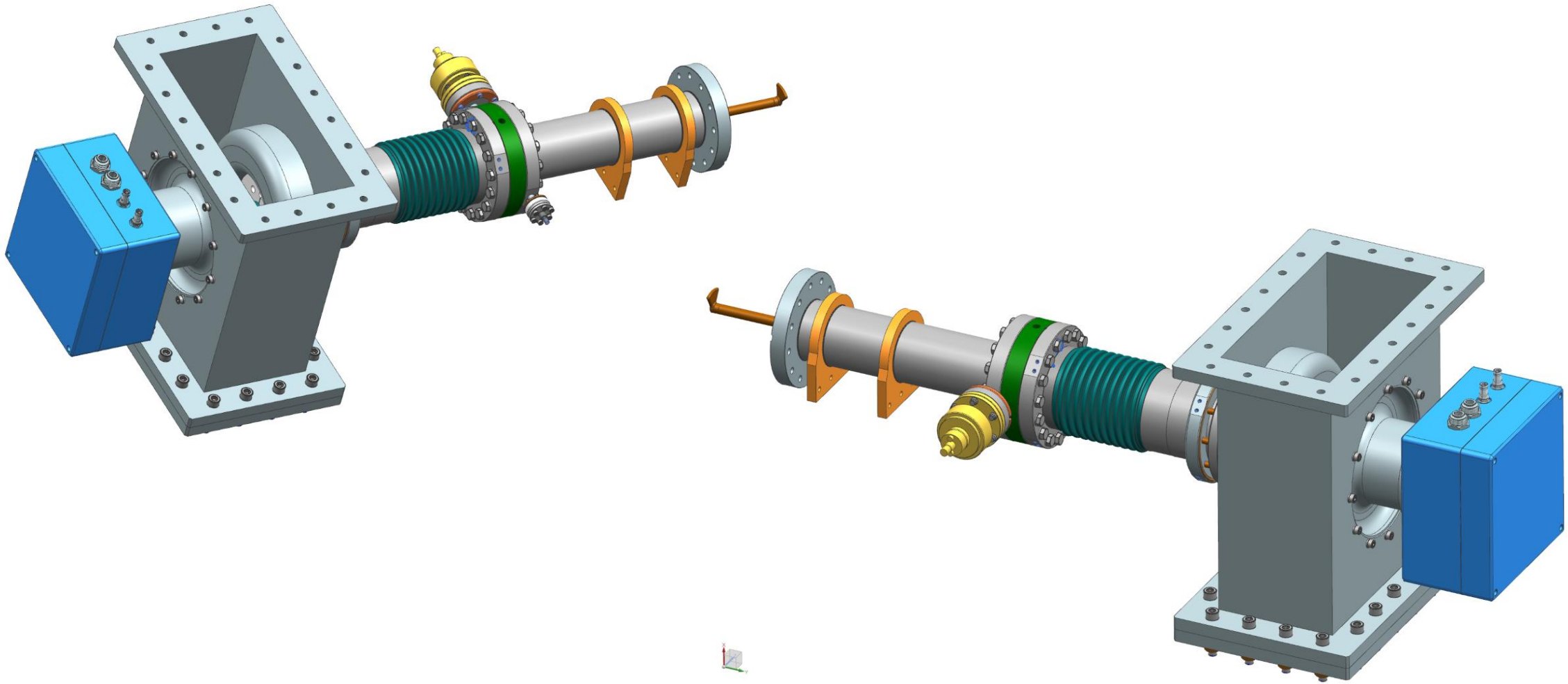


Scheme of cooling test:



Current situations:

9 couplers will be fabricated by Canon (former Toshiba)



Thank you.