Design studies on SSR1_SSR2 power couplers - simulation challenges and issues.

S. Kazakov / FNAL

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- India/DAE
- Italy/INFN
- UK/UKRI-STFC
- France/CEA, CNRS/IN2P3
- Poland/WUST

For better understanding of current designs of 325 and 650 MHz couplers we will consider the history of design, building and testing of PIP-II couplers.

Design of couplers was started about 10 years ago. PIP-II had the maiden name “Project-X” at that time. Superconducting part of accelerator includes three frequency, 325MHz, 650 MHz and 1.3 GHz, and 5 types of superconductive cavities, SSR1 and SSR2, 325mhZ, 650 MHz LB and HB elliptical cell cavities and 1.3 GHz “Tesla” type cavities. One of the accelerator options was 5mA, CW accelerator with future possible upgrade to 10mA current.
So project required rather powerful coupler: 325MHz coupler ~ 30 kW, CW and 650 MHz coupler ~ 100 kW.

First deign of coupler was made based on several principals:

Universality – 325 and 650 MHz couplers should share common parts and technology (price, reliability);
Simplicity (reliability, price);
Air cooling (no water, reliability);
HV bias for multipactor suppression (relabel operation, low time of conditioning);

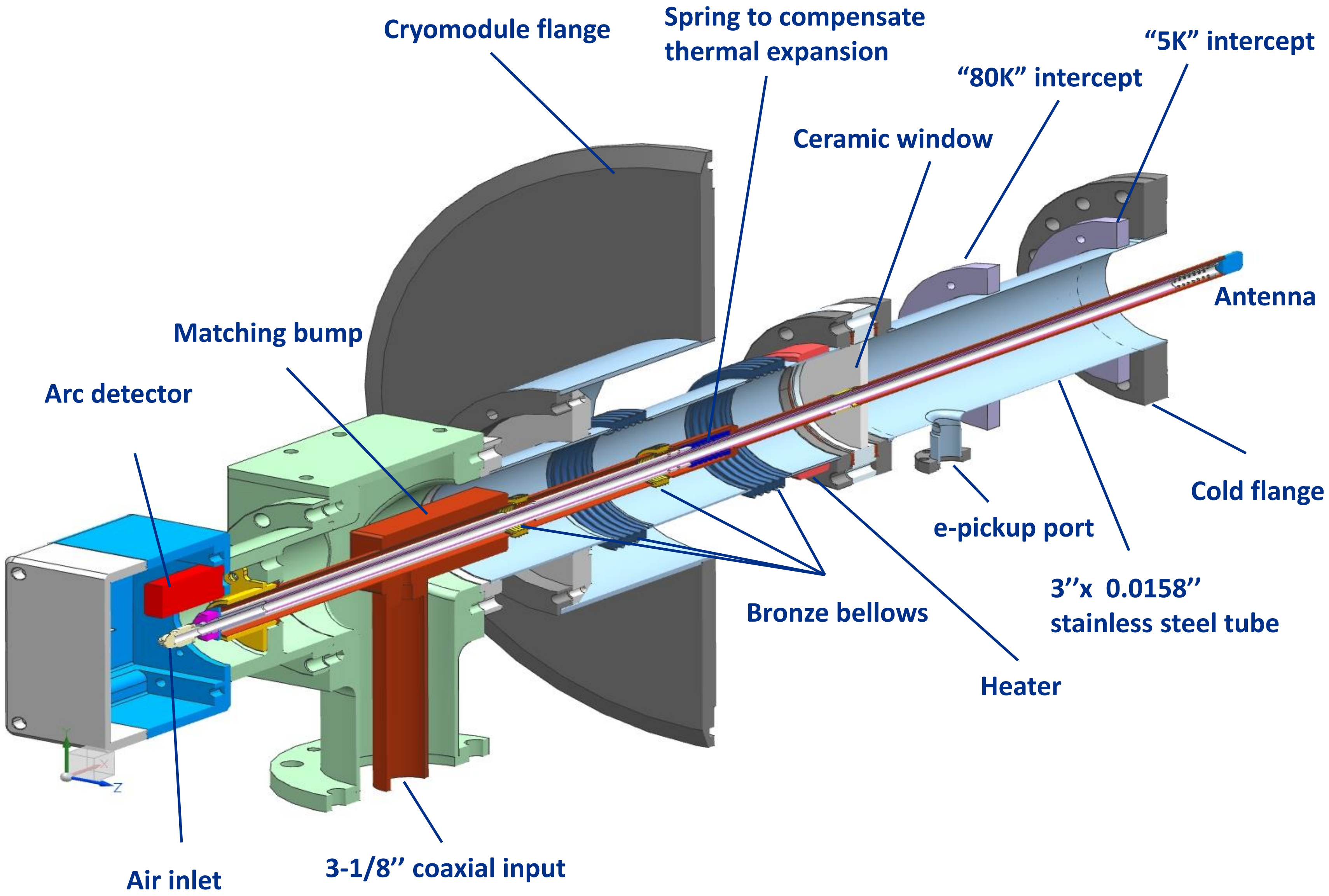
High power:
Hing power requires antenna cooling. Single window configuration was chosen to avoid complex vacuum joint cooled antenna near cold window.

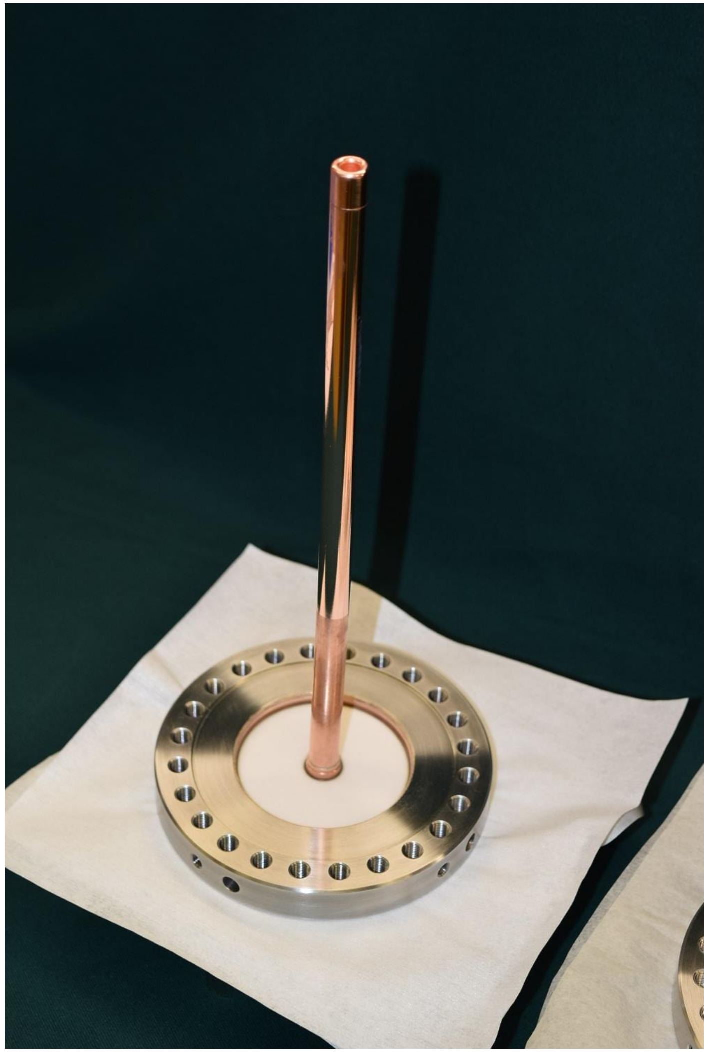
Simplicity:
Fixed coupling, no moving parts, no bellows in vacuum part of coupler, no copper coating if possible, single wall outer conductor

SSR1 cavity was build before couplers design was started. Cavity has about 3 inch input port. ~3 inch diameter (73 mm – standard SS tube) was chosen as diameter of vacuum outer conductor. Outer diameter ceramic diameter was chosen 73mm as well.

Diameter of inner conductor we decided to chose a small enough comparatively with “standard” 50 or 75 Ohm coaxial. Smaller diameters of inner conductor decrease current through outer and inner conductor (higher impedance). It reduce cryogenic loading to superconductive cavity but increase losses in antenna. **Antenna diameter was chosen as 0.5 inch (12.7mm).** It corresponds to 105 Ohm impedance. Higher impedance shifts multipactor to higher power. It is good.

As results several SSR1 couplers as presented at picture were designed, built and tested.





It was supposed that 650 MHz coupler would have similar vacuum part. But outer conductor should be copper coated and air cooling of antenna has to be more intensive.

17 SSR1 couplers were tested at room temperature test stand, CW, full reflection, 4 phase points (90 dgr shift).

10 kW: tested - 17, no broken.

20 kW: tested – 5, one broken (not good ceramics and not enough cooling for this ceramics.

30 kW: tested - 2, no broken.

47 kW: tested - 2, one broken. Not full test (it was not 4 phase points). May be it was not enough air flow rate for this power level.

Lessons learned:

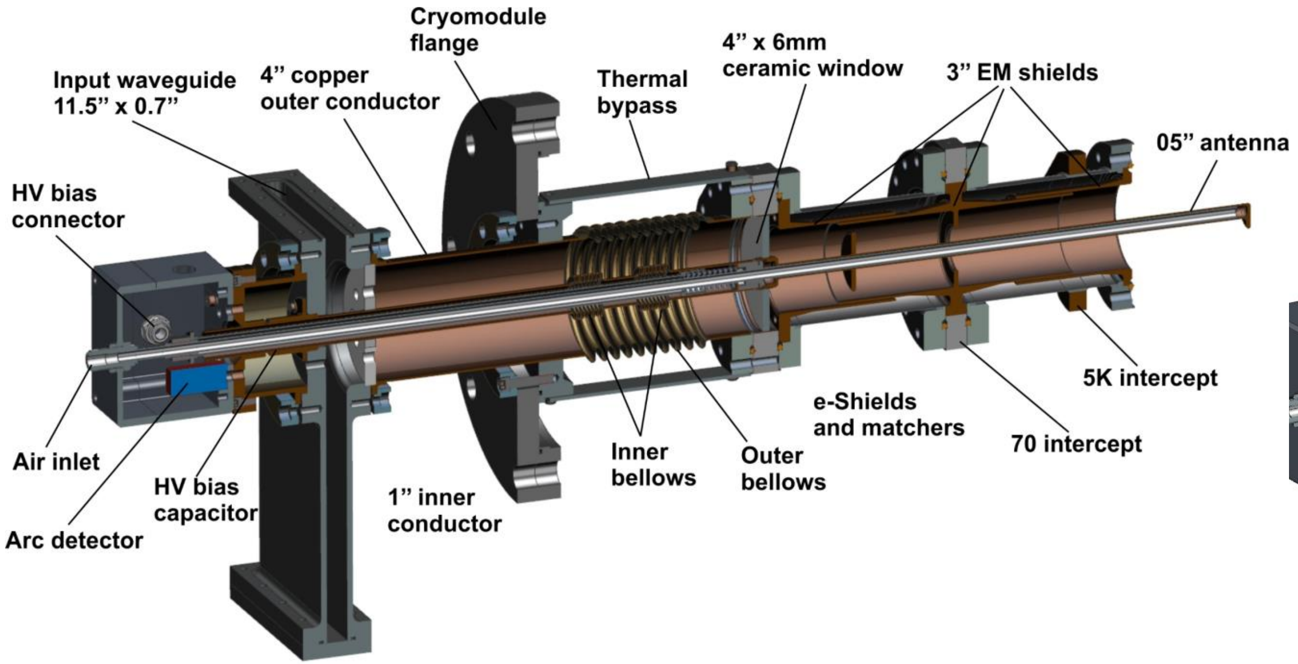
It was not easer to braze ceramic windows. Only CPI manages to do it with good quality. Possible reason is rather short copper sleeves brazed to ceramics.

This design of window may be is not powerful enough for 650 MHz coupler.

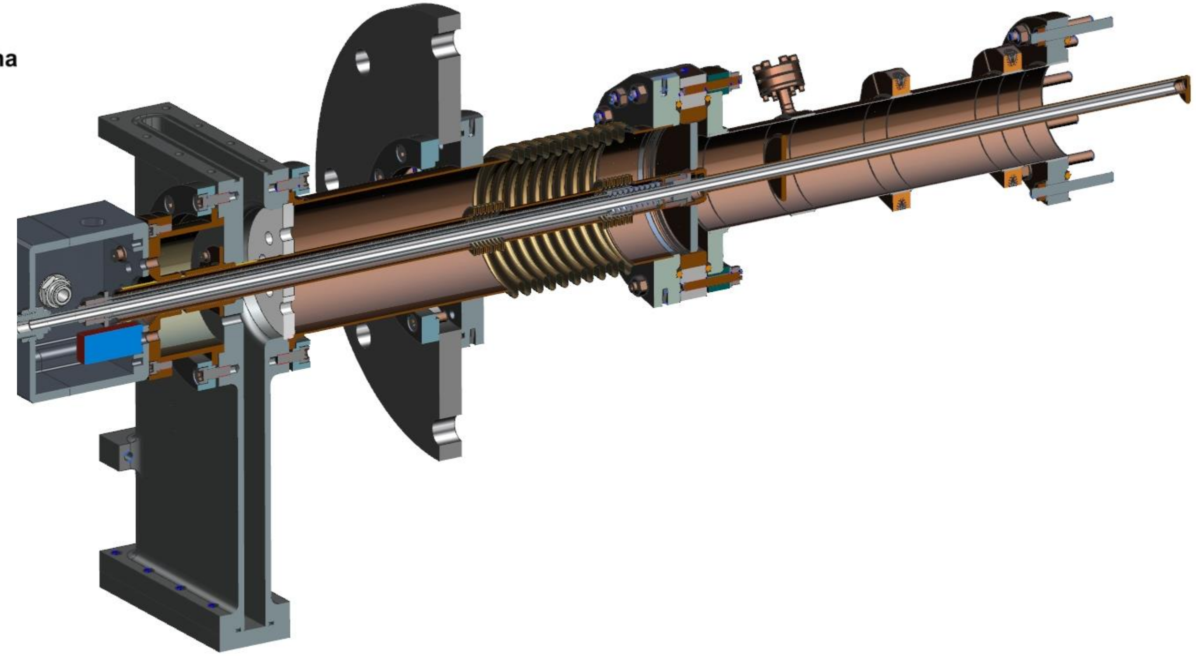
We decided to re-design 650 MHz coupler.

650 MHz coupler was re-designed with 4-inch ceramics window and two types of outer conductors, with copper coating and with electromagnetic shields without copper coating.

650 MHz without copper coating, with electromagnetic shields.



650 MHz with copper coating.



Both type of couplers prototypes where built (2 +2) and **successfully tested** at room temperature test stand up to **50kW, CW full reflection.**

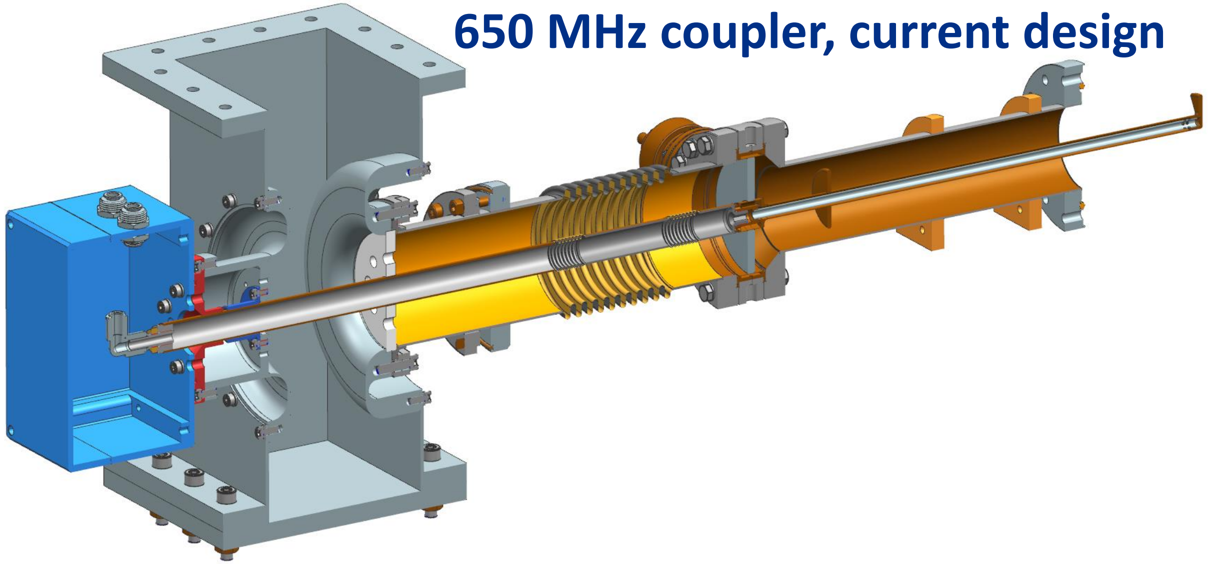
Lessons learned from 650 MHz coupler tests:

Narrow aluminum waveguide become a rather hot at 50 kW full reflection level. It requires addition water cooling. Hot waveguide heats an air in common volume, and it increases the temperature of ceramic window and reduce possible power limit of window.

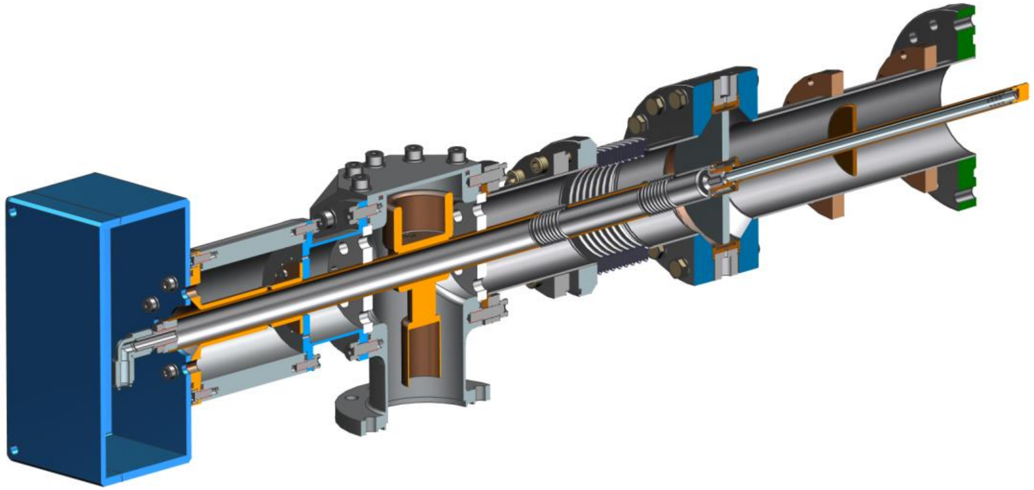
We decided to change design and use wide waveguide with "doorknob" matching elements.
"Dimond" seal window flanges were replaced by conflat flanges. Conflat flanges has smaller diameter and this 4-inch window with conflat flange can be used in 325 MHz coupler without changing outside dimensions.

We decided to follow "Universality" rule and use 4-inch window in new design of 325 MHz coupler. It will guaranty a reliability of coupler at high power.

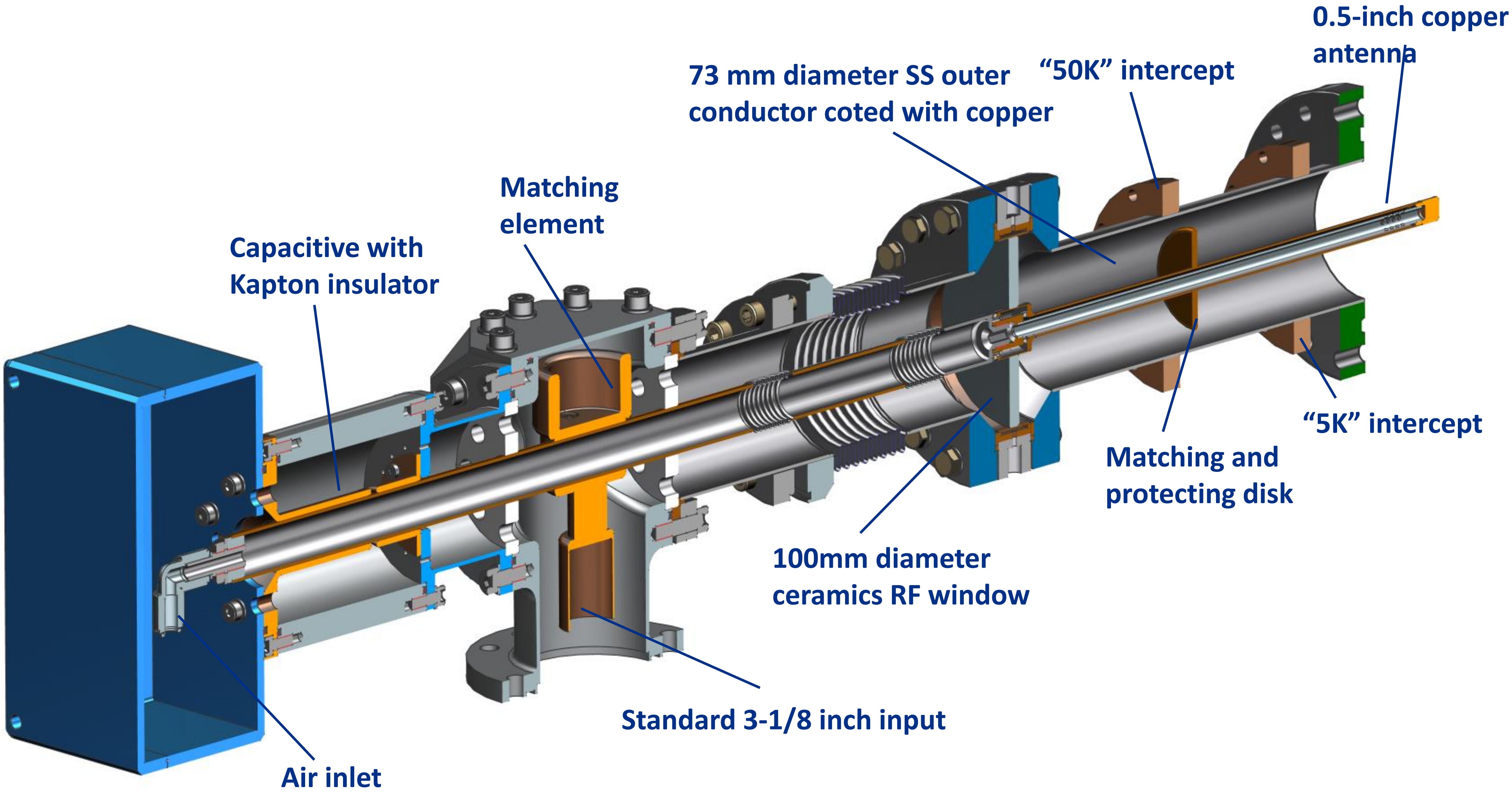
650 MHz coupler, current design



325 MHz coupler, current design



Couplers have the same windows, air cooling system, similar antennas and outer conductors.


0.5-inch copper antenna
"50K" intercept
73 mm diameter SS outer conductor coted with copper
Matching element
Capacitive with Kapton insulator
"5K" intercept
Matching and protecting disk
100mm diameter ceramics RF window
Standard 3-1/8 inch input
Air inlet

Functional Requirement Specification and fulfillment of them.

Electromagnetic parameter	Value	Y/N
Frequency, MHz	325	**325**
Bandwidth(S_{11}<0.1), MHz	> 1	**39.8**
Average nominal operating power, kW (CW, @20% reflection)	11	**Y**
Design and Acceptance Testing power, kW (CW, full reflection, any phase)	12	**Y**
Loaded Q	5.05E+6 ± 25%	**Y**
Maximum HV bias, kV	± 5	**Y**
Ceramic window dielectric loss constant	< 1E-4	**Y**

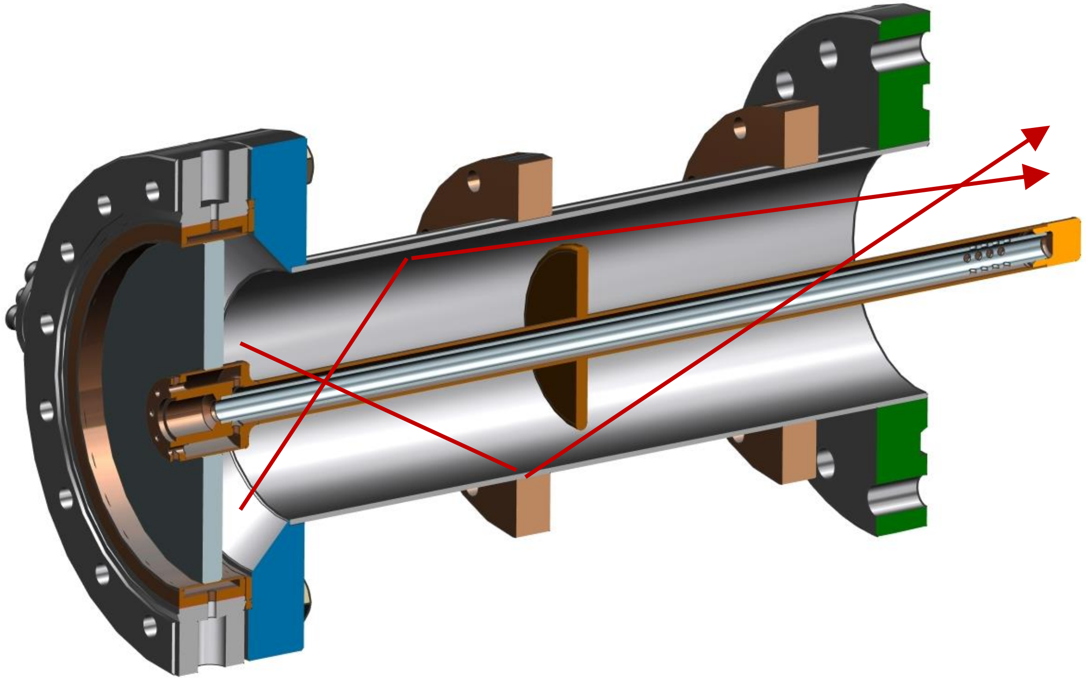
Mechanical Parameter	Value	Y/N
Input coaxial line aperture, mm	76.9	**76.9**
Input coaxial line impedance, Ω	50	**50**
Output coaxial line aperture, mm	72.9	**72.9**
RF window	Single, RT	**Y**

Thermal parameter	Value	Y/N
Thermal intercepts (nominal), K	5 and 50	**Y**
Temperature at 5 K intercept, K	< 15	**Y**
Temperature at 35-50 K intercept, K	< 80	**Y**
Maximum 2K heat load, W	< 1.0	**0.9**
Maximum 5K heat load, W	< 3.5	**2.54**
Maximum 35-50K heat load, W	< 15	**13.5**
Maximum ceramic flange temperature, K	< 325	**Y**
Antenna cooling media	Dry Air	**Y**
Air flow rate, g/s	< 3	**Y**
Max cooling air pressure drop, bar	< 1	**<0.1**
Air output temperature, K	< 323	**< 313**

Diagnostic		Y/N
Temperature sensors (per each coupler)	see description above	**Y**
E-probe current monitor	1	**Y**
Vacuum pressure gauge in proximity of the ceramic windows	1	**Y**
Bias current monitor	1	**Y**
Bias voltage monitor	1	**Y**
Air output flow monitor	1	**Y**

Problems with simulations.

- We think we can simulate accurately RF properties: EM-fields, bandwidth, losses, multiapctor.
- We can simulate accurate enough mechanical stresses.
- We can simulate accurate thermal properties except thermal radiations from room temperature window.

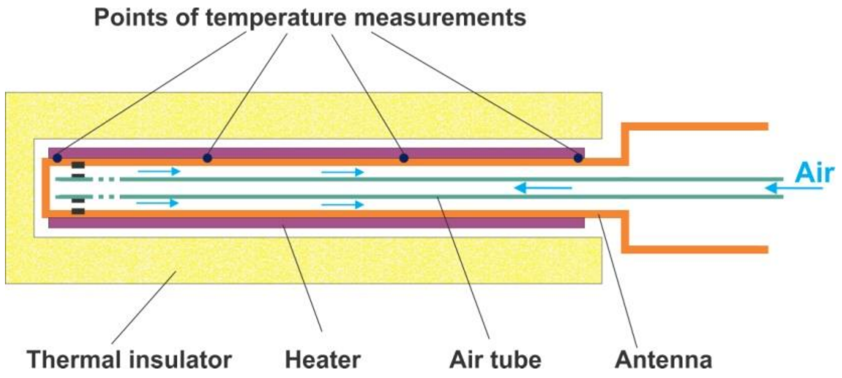


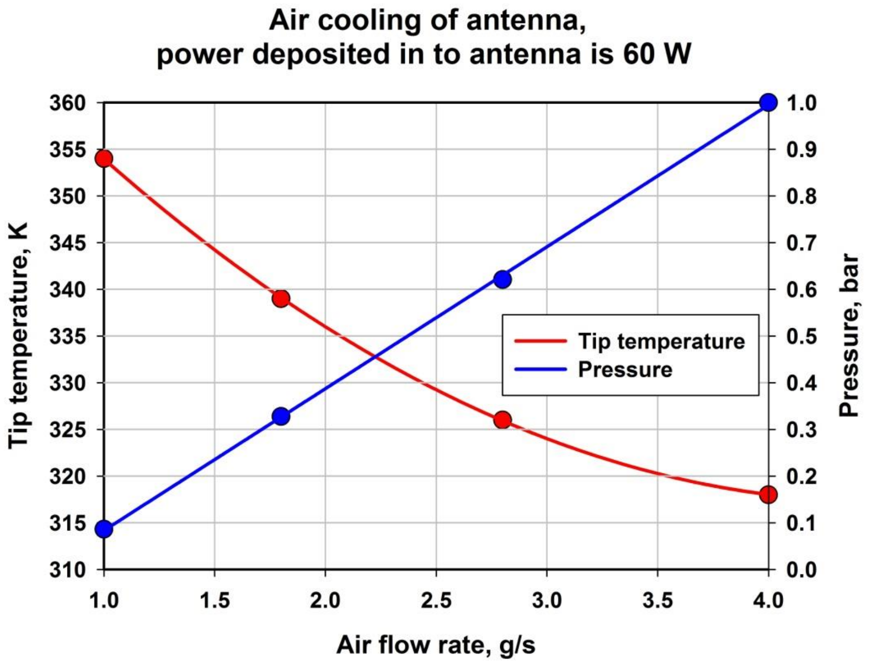
We need to know emissivity of ceramics, reflection from wall and simulate multiple reflection.
We take upper estimation as ~ 0.6W. **One of the purpose of matching disk is to reduce a thermal radiation from windows – emissivity of polish copper < 0.05.**

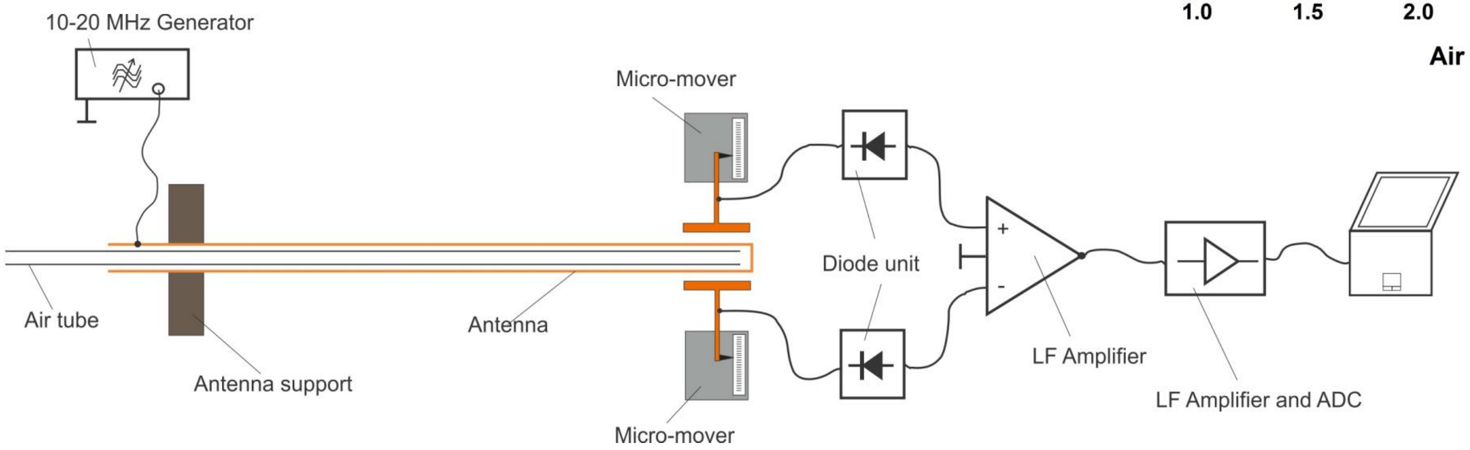
- Another unknown item is possible acoustic vibration due to air cooling. We suppose to do experiment to measure vibration and convection coefficient. Especially it is important for 650 MHz coupler because of high air rate flow. Prototypes did not show vibration, but air-cooling configuration was changed.

Measurements of cooling and vibration, 2013.

"Air cooling performance were checked. Measurements show that an air cooling provides good antenna cooling at RF power level ~ 100kW. Presser drops and air flow rate are moderate, no whistle".







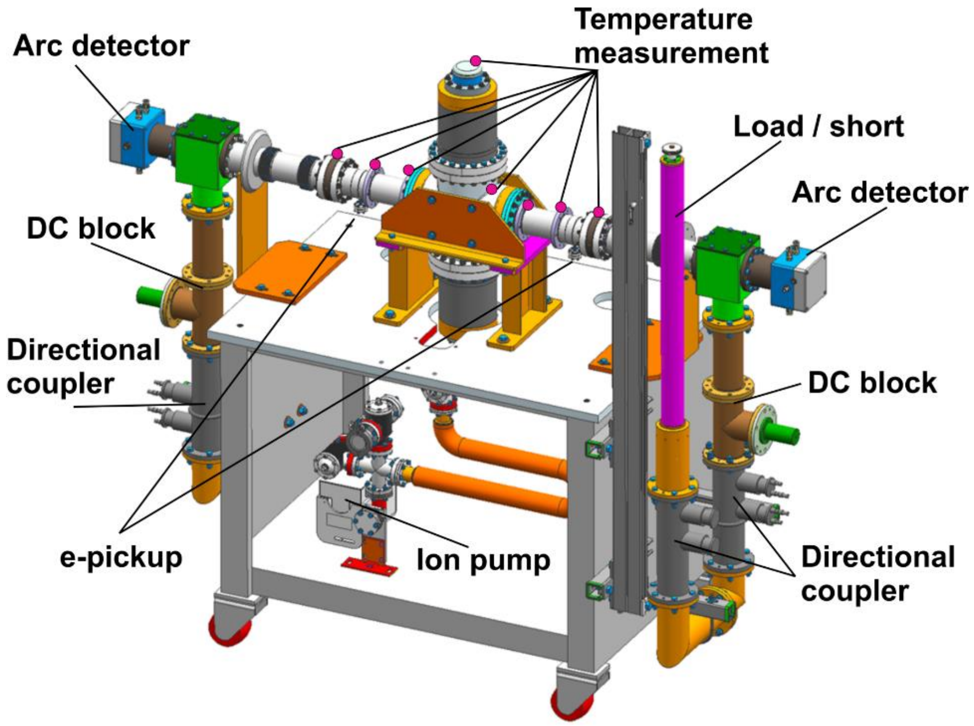
Estimated antenna vibration caused by cooling air flow is ≤ 3E-3 mm

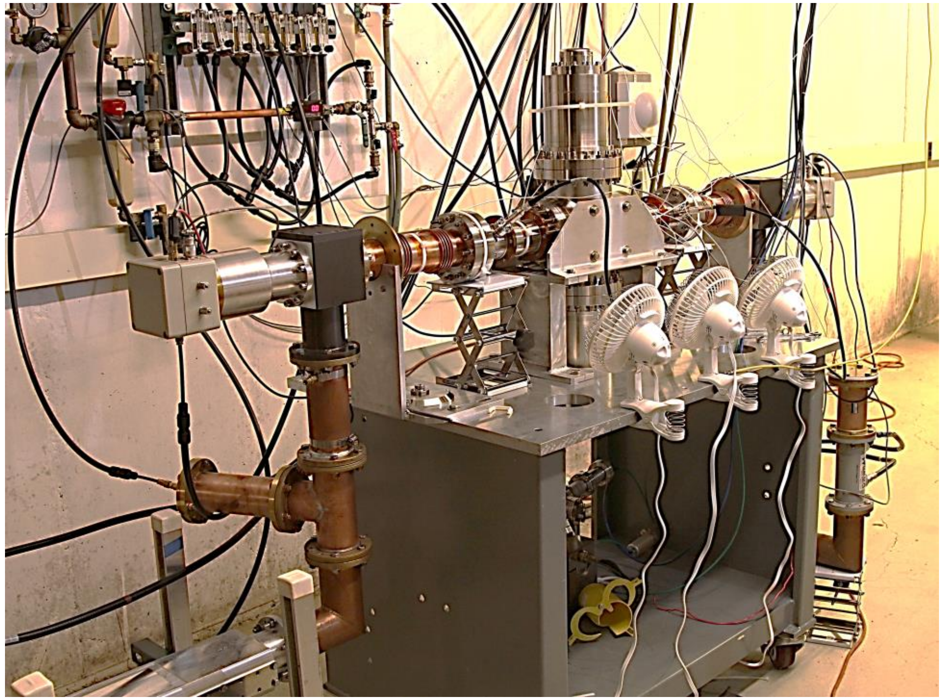
We have to repeat these measurements for new configuration.

Current status:

Four coupler will be produced by CPi, four coupler will be produced by French colleagues.
All couplers are supposed to pass trough high power acceptance test at room temperature test stand.
Acceptance criterium is successful operation at power level 12 kW, CW, full reflection.
"Successful operation" is to stay at each reflected phase point (4-8 pints) for 1-2 hour (to reach a thermal equilibrium).

325 MHz coupler room temperature test stand.





Thank you.