RF Power Coupler Working Group: Summary

Hassen JENHANI / CEA

PIP-II Technical Workshop

December 4th, 2020

A Partnership of:

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

RF Power Coupler Working Group: Agenda Overview

RF POWER COUPLERS WORKING GROUP
Tuesday 01/12/20
Topic 1: Design studies on high power couplers - Simulation challenges and issues
Topic 2: Comparative analysis of Power Coupler designs used in different facilities worldwide
Wednesday 02/12/20
Topic 3: Manufacturing of high power couplers - Key technologies and challenges
Topic 4: Testing, qualification, transportation and storage of Couplers - Experiences and best practices
Topic 5: Room temperature RF test stand and HTS testing of Couplers - Processing, clean room and RF Power system
Thursday 03/12/20
Topic 6: Development of key technologies for Power Coupler manufacturing experiences and challenges
Topic 7: Experiences with large scale power coupler manufacturing

40 Registrants (24 to 30 participants all the time)

abhay kumar	BARC	Guler Hayg	IJCLab
Alok Ghosh	BARC	Sandry Wallon	IJCLab
Jitendra Mishra	BARC	Walid Kaabi	IJCLab
Mentes Jose	BARC	Ashish Tiwari	RRCAT
Rajesh Kumar	BARC	Deodatta Baxy	RRCAT
Sonal Sharma	BARC	Dheeraj Sharma	RRCAT
Srinivas Krishnagopal	BARC	Kunver singh	RRCAT
Christian Arcambal	CEA	Mahendra Lad	RRCAT
Claude Marchand	CEA	Nita Kulkarni	RRCAT
Hassen Jenhani	CEA	PRASANTA KUMAR JANA	RRCAT
Olivier Piquet	CEA	Praveen Mohania	RRCAT
Sergey Arsenyev	CEA	RAHUL GAUR	RRCAT
Denis Kostin	DESY	Rajiv Kumar Arora	RRCAT
Ben Freemire	Euclid Techlabs	Ram Prakash	RRCAT
Andrei Lunin	FNAL	Ramesh Kumar	RRCAT
James Steimel	FNAL	Rinky Dhingra	RRCAT
Kenneth S Premo	FNAL	Urmila Singh	RRCAT
Nikolay A Solyak	FNAL	Vinit Kumar	RRCAT
Oleg V. Pronitchev	FNAL	Keith Dumbell	STFC
Sergey Kazakov	FNAL	Petter Corlett	STFC

+ Hot Topics (open discussion)

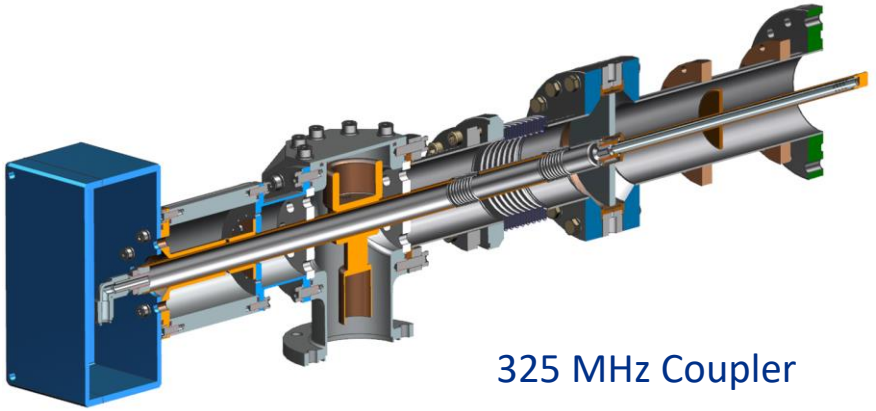
Session 1: Discussion Highlights (1)

- **Topic 1: Design studies on high power couplers - Simulation challenges and issues (2 talks : S Kazakov (FNAL))**

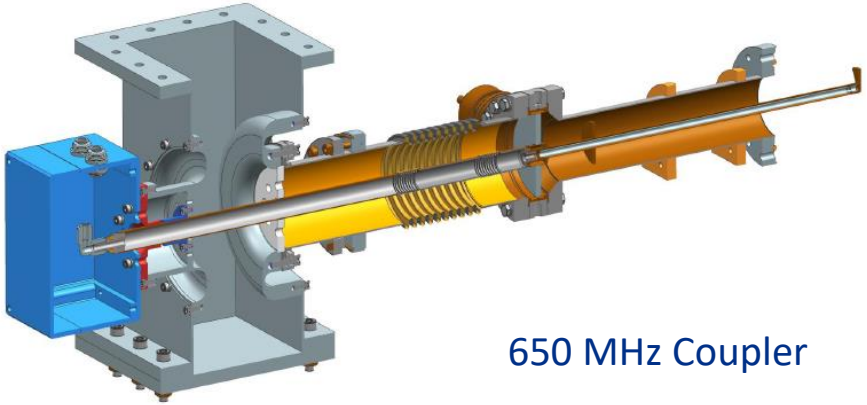
  - 10 years of developments starting with project X.
  - Current design of 325 MHz and 650MHz couplers is a combination of lessons learned from both of their prototyping experiences.
  - Simulation tools allow to obtain accurate RF, thermal and mechanical stress results. However, antenna vibration due to the air cooling flow is determined experimentally. Experimental measurements set-up will be used for that purpose.
  - The current temperature measurement on cold tests needs to be improved.

- **Topic 2: Comparative analysis of Power Coupler designs used in different facilities worldwide (2 talks: S Kazakov (FNAL) & O Pronitchev)**

  - A wide range of design choices adopted by SRF projects were presented. The Pros and Cons were developed.

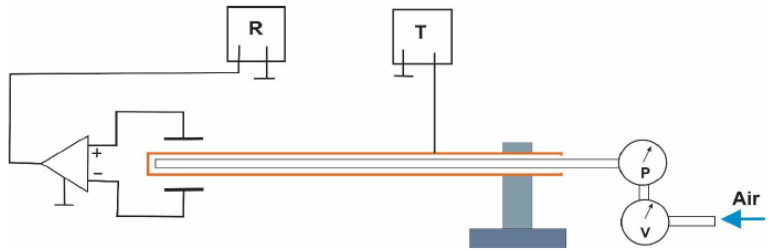


325 MHz Coupler



650 MHz Coupler

Scheme of vibration test:



Session 1: Discussion Highlights (2)

- Several design attempts were made to avoid copper plating on coupler RF surfaces, in order to reduce the related risks. Finally, this adds other manufacturing complication and reduced the possibility for upgrading RF power.

- Both EM shielded coupler design and the conventional copper plated design were **tested successfully**. Despite the lower calculated heat load of the first design, the second design more standard and more easy to clean was adopted.

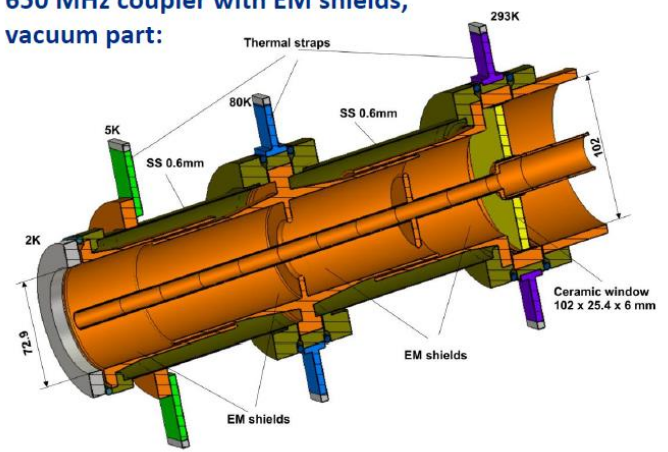
- Differences between ceramic TiN coating behavior, specification and characteristics were highlighted. Bad experience with excessive increase of the a TiN coated ceramic conductivity during RF power test was reported. Fermilab coupler group is investigating the need for TiN coating on ceramics.

- LCLS-2/TTF-III like couplers experience feedback was very beneficial to organize the assembly procedures for PIP II.

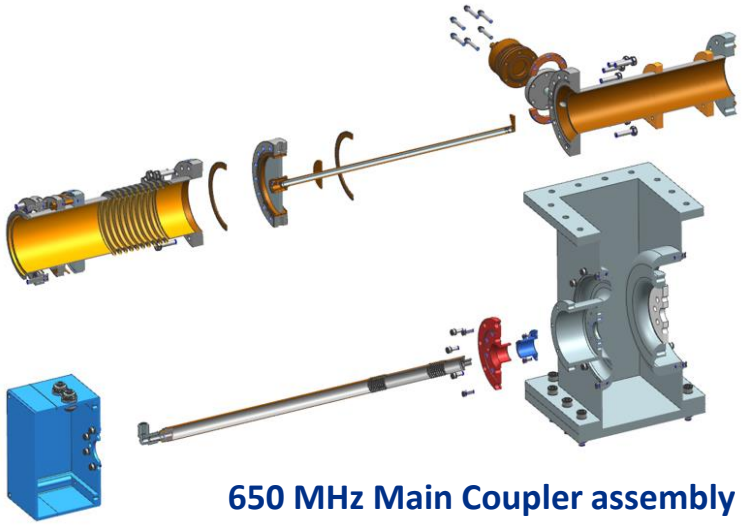
- DESY feedback about the choice of vacuum gaskets for the coupler's RF window was helpful and allowed to have a better solution.

- The global assembly procedure of 650 MHz coupler was presented. Nevertheless, more refinement of some integration and assembly operations is needed. The tooling design is not yet complete but under process.

650 MHz coupler with EM shields, vacuum part:



Tested up to 50 KW, CW, full reflection.



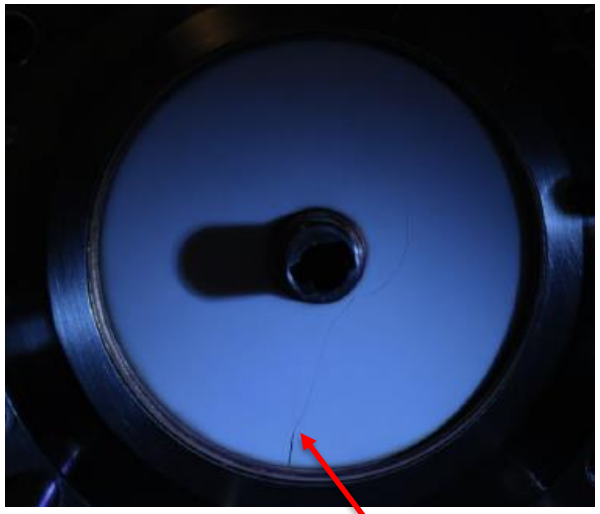
650 MHz Main Coupler assembly

Session 2: Discussion Highlights (1)

❑ Topic 3: Manufacturing of high power couplers - Key technologies and challenges (2 talks : S Kazakov, K Premo (FNAL))

- Experience and reliability of vendors is extremely important for coupler fabrication.
- Validation of the ceramic brazing needs specific knowhow. In fact, several windows with “poor” brazing were successfully tested. Reliable criteria and validation technics are needed during the vendor capability validation stage and the production stage as well. Non destructive techniques as CT Scan and ultrasonic analysis are investigated. The use of that last technique is currently explored by IJCLab with a French coupler vendor. Information exchange with Fermilab is expected.
- Quality of each ceramic disks, especially RF losses, should be checked before use in coupler production.
- We need a better understanding of how TiN coating works and how accurate characterization on samples can be performed. Not appropriate TiN coating is problematic for coupler operation.
- Surface finishing good and bad practices were also discussed.

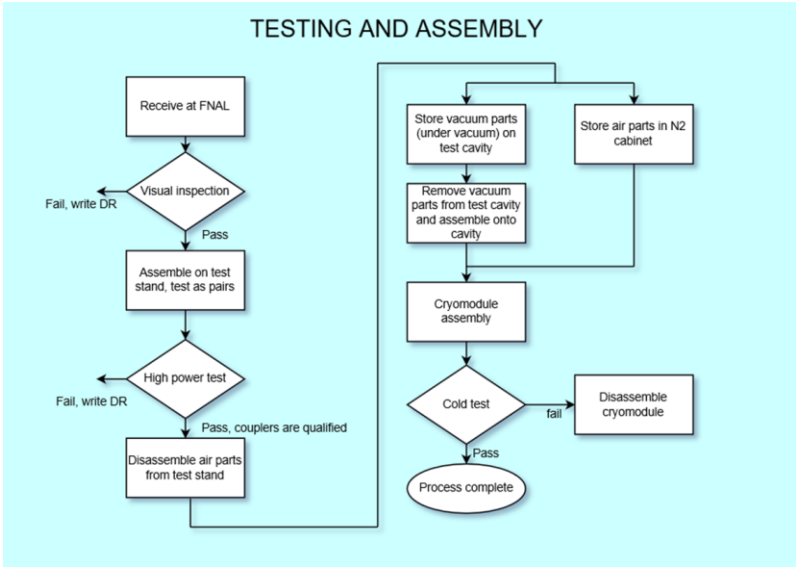
SSR1 ceramic brazing looking bad but passes the RF power test!



SSR1 ceramic cracking during RF power test (probably over heating)

Session 2: Discussion Highlights (2)

- **Topic 4: Testing, qualification, transportation and storage of Couplers - Experiences and best practices challenges (1 talks : K Premo (FNAL))**



- Incoming inspection will be governed by a Vector traveler which will be developed prior to receipt of PIP-II couplers. Currently, production follow up by travelling to the manufacturer premises (Japan) is not possible due to Covid 19.
- Adopted QA/QC plan is similar to LCLS-II
- The storage scenarios were discussed. However, the choice is not yet made.

- **Topic 5: Room temperature RF test stand and HTS testing of Couplers - Processing, clean room and RF Power system (2 talks: H Guler (IJCLab) and N Solyak (FNAL))**

- Detailed cleaning procedure was explained by IJCLab presentation and induced a big interest of the participants, especially, from DAE
- Explanation of the RF conditioning process was given and examples of coupler behavior and diagnostics signals based on the XFEL experience were presented.

Session 2: Discussion Highlights (3)

- We learned from XFEL experience that controlled storage of the couplers is very important. Re-conditioning them on the cryomodule will take only few hours. Moreover, we always need to perform warm RF conditioning of couplers on cryomodule before cold conditioning to not contaminate the cavity after cooling.

- Fermilab reported the experience of the PIP-II Couplers RF processing:

  - ✓ SSR1 CM under testing @PIP2IT

  - ✓ Four SSR2 couplers will be produced by CPI and four others will be produced by IJCLab (Procurement awarded)

  - ✓ Both 650 MHz couplers designs (shielded and conventional) were qualified at 50kW full reflection at arbitrary reflection phases.

  - ✓ **HP processing without bias was successfully demonstrated** (~30hrs for all phases) on 650 MHz coupler with EM-shielded design.

SSR1 Cryomodule

650 MHz couplers test stand

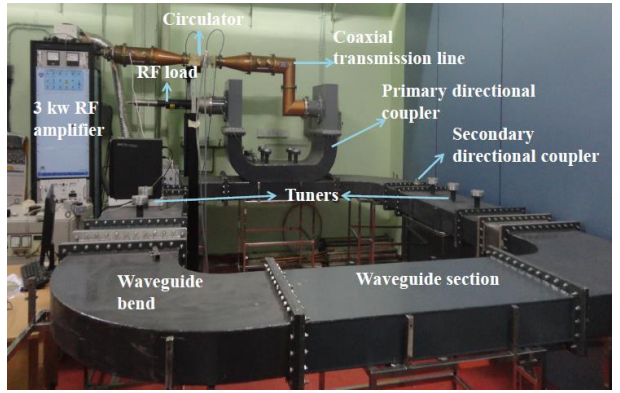
Session 3: Discussion Highlights (1)

- **Topic 6: Development of key technologies for Power Coupler manufacturing experiences and challenges (3 talks: R Kumar (BARC), D Kostin (DESY), B Freemire (Euclid))**

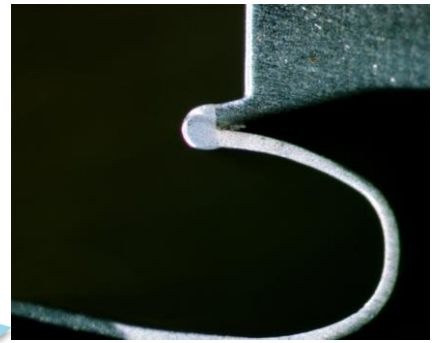
- Development status of 325 MHz and 650 MHz Power couplers for IIFC was presented and several qualification tests are on going. Ceramic brazing caused some difficulties which are currently being analyzed. Some procurement difficulties are encountered and could potentially be solved thanks to the collaboration.

- A 325 MHz testing bench based on travelling wave resonant ring is developed and successfully tested allowing at least 10 dB gain. The design principle can be applied to 650 MHz frequency.

- Very detailed report of DESY experience feedback based on TTF-III like couplers development was presented:
  - ✓ materials choices
  - ✓ assembly technics (Brazing, welding : EB, TiG, Laser ,..),
  - ✓ copper plating, TiN coating, qualification…
  - ✓ tooling
  - ✓ …end several lessons to learn reported later in this presentation



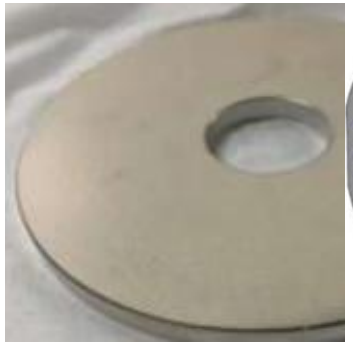
Travelling wave resonant ring



Laser wilding for thin parts

Session 3: Discussion Highlights (2)

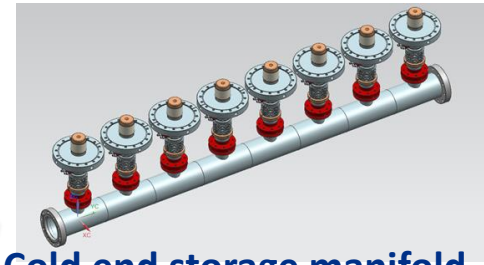
- A report on development progresses on the conductive MgTi ceramic developed by Euclid Techlabs : good RF properties were obtained and brazing solution was developed. A first high power test of conductive ceramic couplers will take place at Fermilab then JLAB in 2020-2021.



MgTi Conductive ceramic

❑ Topic 7: Experiences with large scale power coupler manufacturing (K Premo (FNAL), W Kaabi (IJCLab))

- LCLS-II manufacturing experience was detailed: No major issues thanks to the long experience feedback of the XFEL project allowing to the evolved vendors to have the needed knowhow.



Cold end storage manifold.

- The different manufacturing processes were mastered and the shipment conditions were generally secure.

- However some problems of parts storage was encountered. Cold-end storage manifold is found to be a practical storage solution for coupler cold parts.

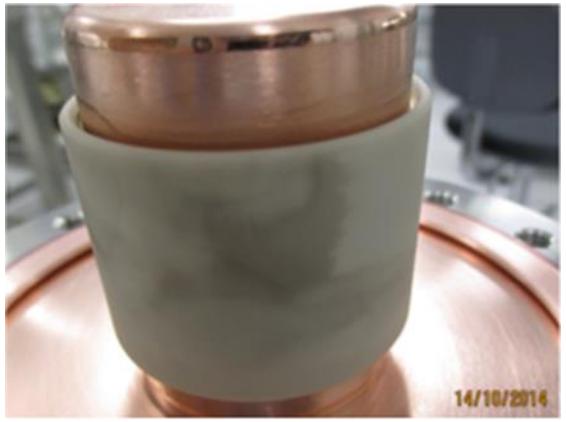
- Furthermore, the manufacturing follow-up of the large scale coupler production for XFEL was detailed :
  - ✓ Copper coating : process, characterization, inspection and defects definition

Visual control of copper plating quality

Session 3: Discussion Highlights (3)

- ✓ Brazing control
- ✓ TiN coating control

- Examples of problems encountered during the production of XFEL couplers were presented and discussed as well.



Main defect discovered during the final inspection: Dark layer in cold ceramic window

❑ Hot Topics open discussion (ALL)

- TiN coating on ceramics
- Copper plating
- High Power RF Processing

The most important outcomes of this discussion is integrated in the lessons to learn and open issues in the following parts of this presentation.

Lessons Learned (1)

- Successful FPC design uses modular approach, standard materials, standard sizes and standard manufacturing techniques.
- Close collaboration with the company is necessary with the investigation of problems on samples. Investigation tooling is also needed to allow inspection of hidden surfaces and defects.
- New fabrication methods emerge and may be effectively applied. Classic well known techniques are being developed as well – with some of them sometimes needing re-inventing – copper plating is an example.
- Deep investigations during the qualification of the process is highly recommended:
  - Destructive tests on real parts.
  - Several analysis methods (even sophisticated one and complicate to be set up).
- Once the process parameters are optimised and validated, it needs to be replace by simple, fast and reliable control methods.
- Vendor oversight is important: regular meetings and site visits to monitor vendor processes are needed.
- Catch small problems before they become big

Lessons Learned (2)

- Copper plating is by far the most critical process:
  - ✓ Need to be monitored closely to avoid process drift and react fast.
  - ✓ Classification of defects and acceptance criteria have to be set in accordance with the supplier

- Parts in circulation strategy has to be studied:
  - ✓ Try to match deliveries with usage
  - ✓ Plan for storage of couplers if they are not used immediately. Example : Cold end storage manifolds, N2 cabinets

- The parts cleanliness is not only a matter of final cleaning in cleanroom, special care is needed for handling operations in workshop.

- Importance of each cleaning step should be coupled with :
  - ✓ Proper check procedures
  - ✓ Proper cure/solution procedures
  - ✓ Proper improvement procedures

- Cleaning and assembly procedures need to be carefully followed, if not a direct impact on RF conditioning is seen.

- Safe RF conditioning means proper set of diagnostics coupled with adapted interlock system

Lessons Learned (3)

- For mass production, having 2 suppliers is always recommended to minimise risks, but also bring twice the work to be performed
- The end of the mass production could be as critical as the ramp-up phase:
    - Suppliers try to recover the defected parts and ovoid to order new materials.

    ➔ This has to be taken into account in the global project schedule.

From Hot Topics Discussion:

- Ceramic loss tangent varies marginally with coating thickness
- Optimal TiN thickness value seems to be 5-20 nm. Color seems to be a good indication of thickness.
- XFEL and LCLS-II have good experience with copper plating, this knowhow should be used as reference for the other projects
- RF Power Coupler conditioning starting with short pulses and preceded by in-situ baking seems to be the most efficient way.
- CEA, IJCLab and DESY experience consider the use of the HV Bias as an option in case of a problem during operation and not as a baseline solution for operation. Fermilab is investigating the two cases.
- Already conditioned coupler need reprocessing on cryomodule for typically few hours if coupler is stored in good condition

Open Issues

- Ceramic brazing: What are best (or optimum) non-distractive control techniques?

- TiN and TiO coatings characterization :
  - ✓ Reasons of measurements discrepancies between some laboratories need to be investigated
  - ✓ Coating Stoichiometry need to be known.

- Mitigation of the risk related to not using TiN vs risks related to have “bad” TiN coating?

- What the effective role of the TiN for draining charges on ceramic?
  - ➔ Experiments should be planned to measure this aspect.

RF Power Coupler Working Group: Conclusions

- PIP-II RF Coupler Group showed a great capacity to evolve their design and to learn from the prototyping experience and the collaboration exchanges.
- LCLSII and XFEL experience offer a very important feedback based on mass production and long coupler development programs.
- Collaboration between US, European and Indian institutes is a big opportunity to take advantage from all the experiences and skills in order to make the coupler program and the hole project successful.
- Open issues listed previously are discussed since several years. Dedicated **R&D** programs is probably the best solution to get the answers.
- This workshop offered a very good chance to discuss technical details and share experiences.

Thank you for having organized this event!

I would like to thank the speakers for their excellent work and their clear presentations.

Many thanks to all the participants in the RF Power Coupler Working Group for the productive discussions.

I would like to acknowledge the help of Rajesh KUMAR (Co-chair) and Sergey ARSENYEV and Mentes JOSE (Note Takers) with the organization and the reporting work.