Indian Power couplers activities: Coupler test bench and manufacturing experience

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

Development of high Power couplers for IIFC

- Manufacturing activities related to 325 MHz and 650 MHz Couplers
- Other facilities related to coupler manufacturing
- High Power coupler (325 MHz) test bench based on traveling wave resonant ring

Manufacturing activities related to 325 MHz and 650 MHz Couplers

R&D Phase Coupler deliverables:

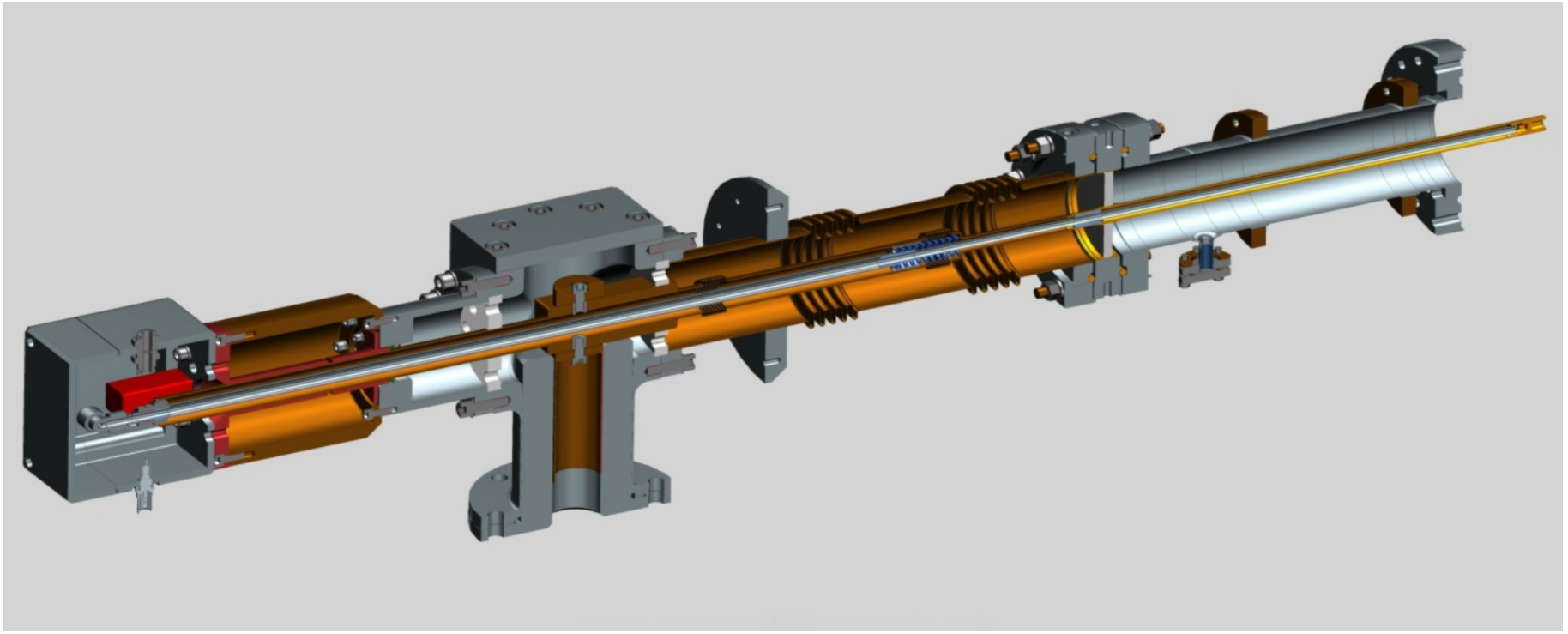
325 MHz Couplers: 3 (1+2)*

650 MHz Couplers: 6 (2+4)**

*One coupler based on SSR1 coupler design and 2 couplers based on SSR2 design

** Two couplers based on 650 MHz prototype B design and 4 couplers based on final 650 MHz coupler design

325 MHz Coupler 3D Model



SSR Coupler (325 MHz) Manufacturing status

- Two couplers are machined based on SSR1 designs. These couplers are for validating the manufacturing process and inhouse testing.
- Material requirements on these couplers are relaxed eg. SS316LN is replaced with SS304 L. Also Nickel bellows (in earlier designs) are replaced with SS bellows.
- Copper plating of a sample bellow is carried out. It has passed physical examination and peel of test. However, thickness measurement of copper plating, RRR measurement and cryogenic tests are yet to be completed.
- Other tests like 1000 cycle fatigue test on a sample bellow and baking test at 400 deg C are also to be conducted.
- Brazing and other joining operations are on hold as 650 MHz prototype cold part brazing trials are prioritized.
- SSR2 deliverable ready drawings available on TC and being downloaded.

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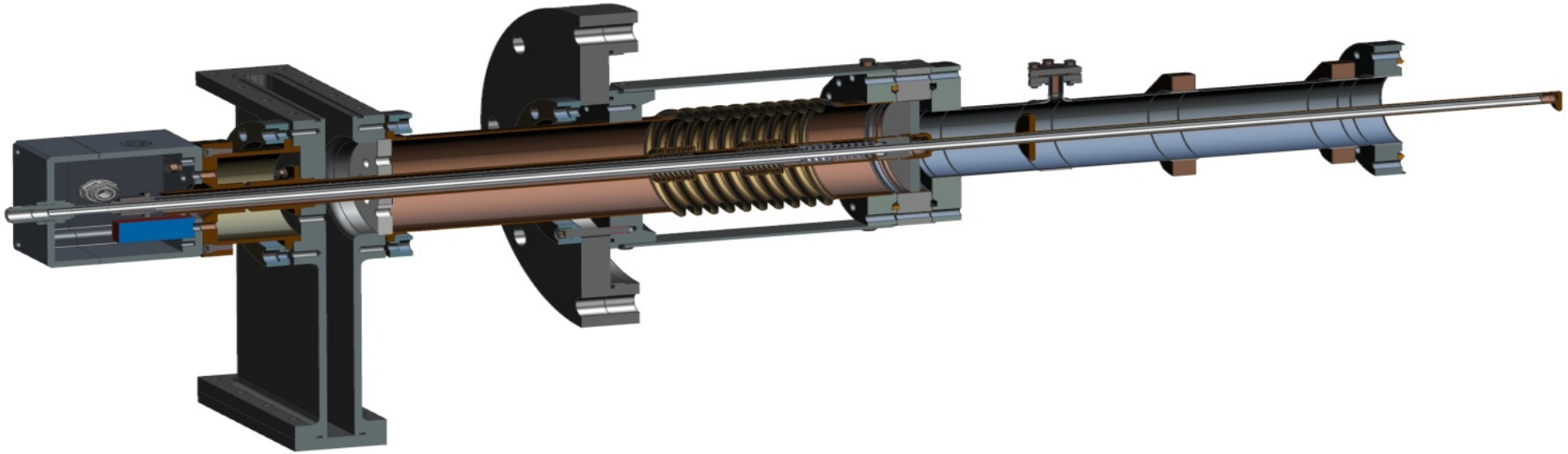
650 MHz Coupler Model



650 MHz Coupler manufacturing status

- Download of the Prototype B drawings and latest 650 MHz Coupler drawings is completed.
- Two nos. of 650 MHz coupler prototypes are under fabrication based on the Prototype-B drawings. Brazing trials of cold part are in progress. Machining of all warm parts (SS and copper) is completed. Aluminium parts are being machined. Bellows will be of SS material and being procured.
- SS bellows will be used for 650 MHz couplers presently being manufactured based on prototype B design.
- Two couplers (based on Prototype B) will be tested at RRCAT on the Warm coupler/HTS and delivered to FNAL.

Manufacturing challenges

- Cold part alumina disc to copper collar brazing trials were carried out. However, leak is observed at braze location.
- Second brazing trial is in progress.
- Some alumina discs were tested at FNAL and loss tangent was found to be:

  3" ceramic loss tangent: 5.3e-4
  4" ceramic loss tangent: 1.74e-4
  Fermi lab ceramics loss tangent for most of the ceramics is < 1.5e-5
  Our specifications as per TRS is for loss tangent <1e-4
  It is agreed that discs with loss tangent of better than 2e-4 can be used for R&D stage deliverables to FNAL.
- Difficulty in locating local AlMgSi seal suppliers, trying international suppliers
- Copper plating on SS bellows yet to be validated.

Other facilities related to Coupler manufacturing

- Titanium Nitride coating facility for alumina discs is set-up. Coating trials on few samples were completed. Thickness measurements and surface characterization are to be carried out.

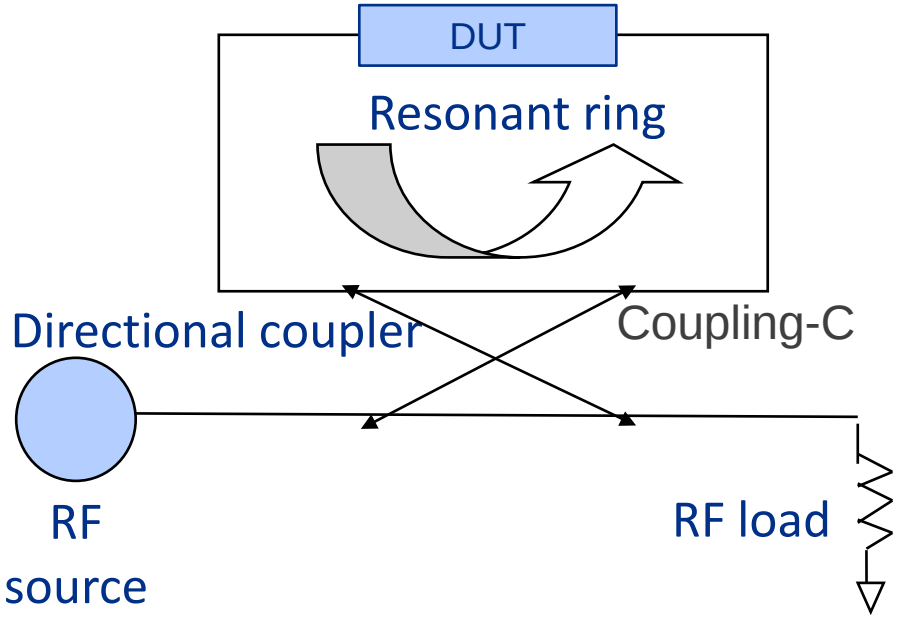
- Alumina disc loss tangent measurement set-up based on FNAL design is under fabrication. It is likely to be delivered by end of Dec 2020.

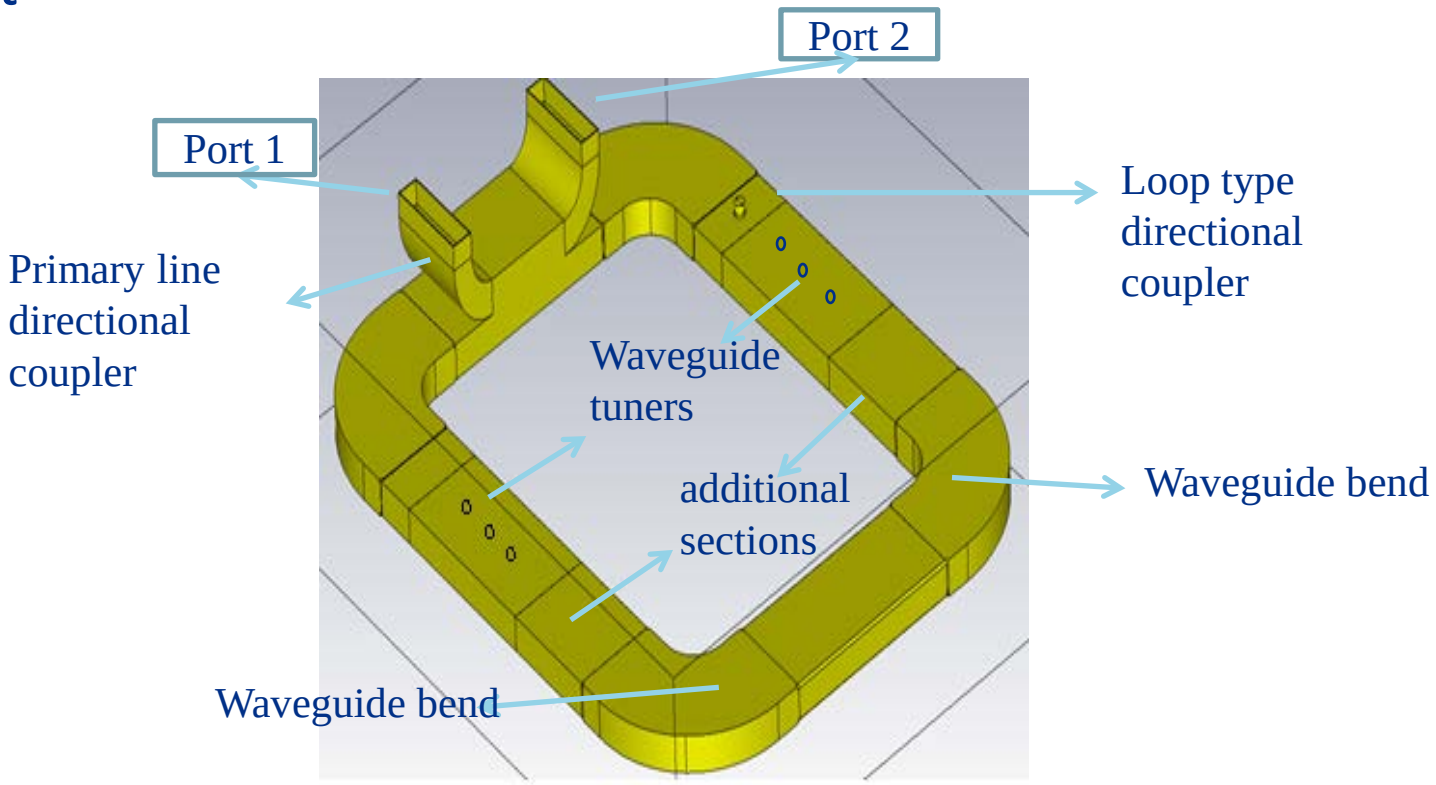
- 650 MHz Coupler test bench will be setup based on the drawings downloaded from TC (except few drawings).

High Power coupler (325 MHz) test bench based on traveling wave resonant ring

Reflection coeff.- Γ

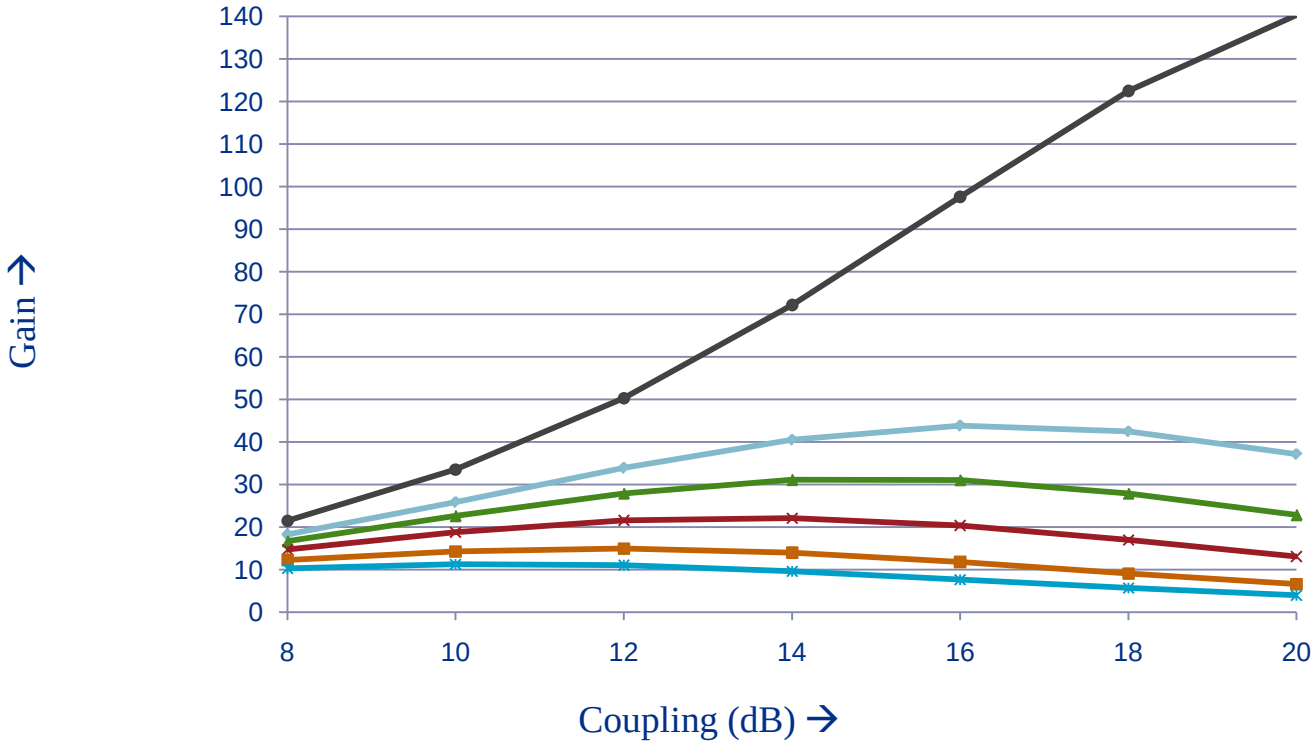
α- attenuation constant





$$Gain(C,\Gamma,\alpha) = P_{ring}/P_1$$

Optimization of Gain with coupling for given attenuation in the ring



attenuation 0.05 dB = 1.2%(360 W@30 kW)

attenuation 0.1 dB

attenuation 0.14 dB = 3.2%(960 W@30 kW)

attenuation 0.2 dB

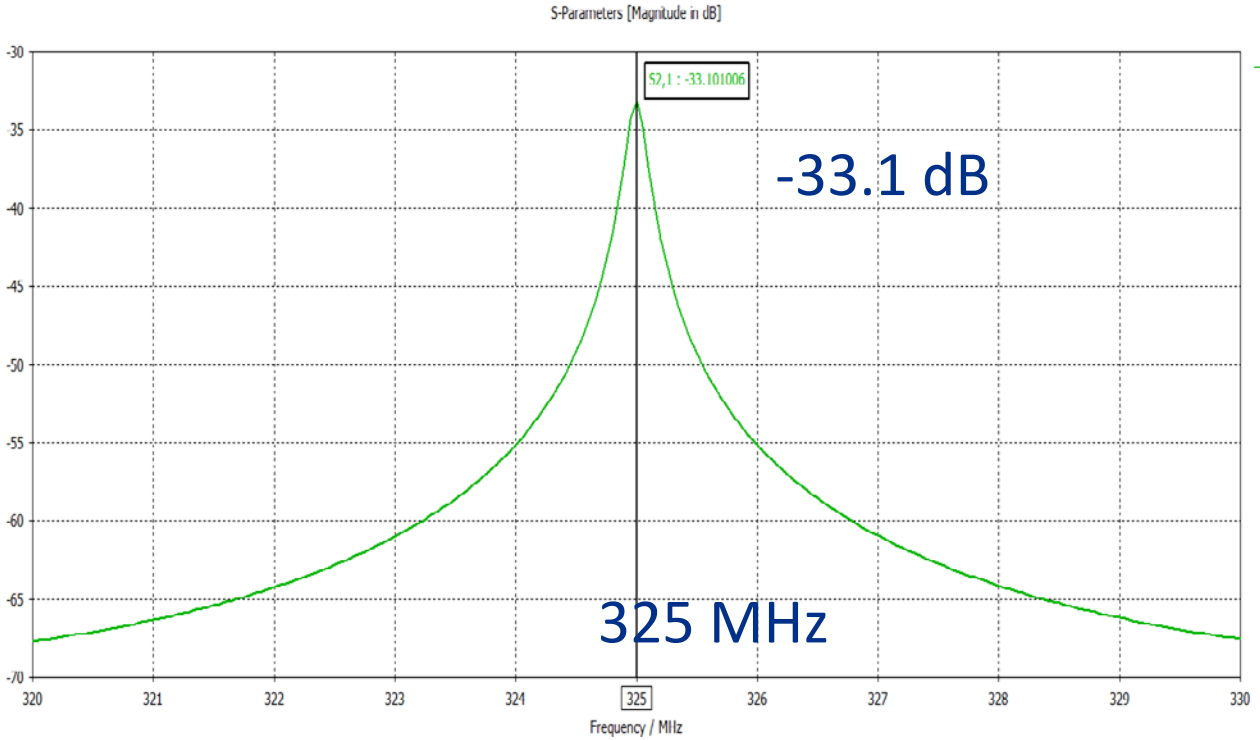
attenuation 0.3 dB

attenuation 0.4 dB = 8.8%(2640 W@30 kW)

$$G = C^2 / (1 - T\sqrt{1 - C^2})^2$$

Based on this, primary line directional coupler is designed for coupling of 13 dB.

Transmission studies



- The value of S21 obtained in the simulation at frequency of 325 MHz is **-33.1 dB**. The gain of the ring can be given as:

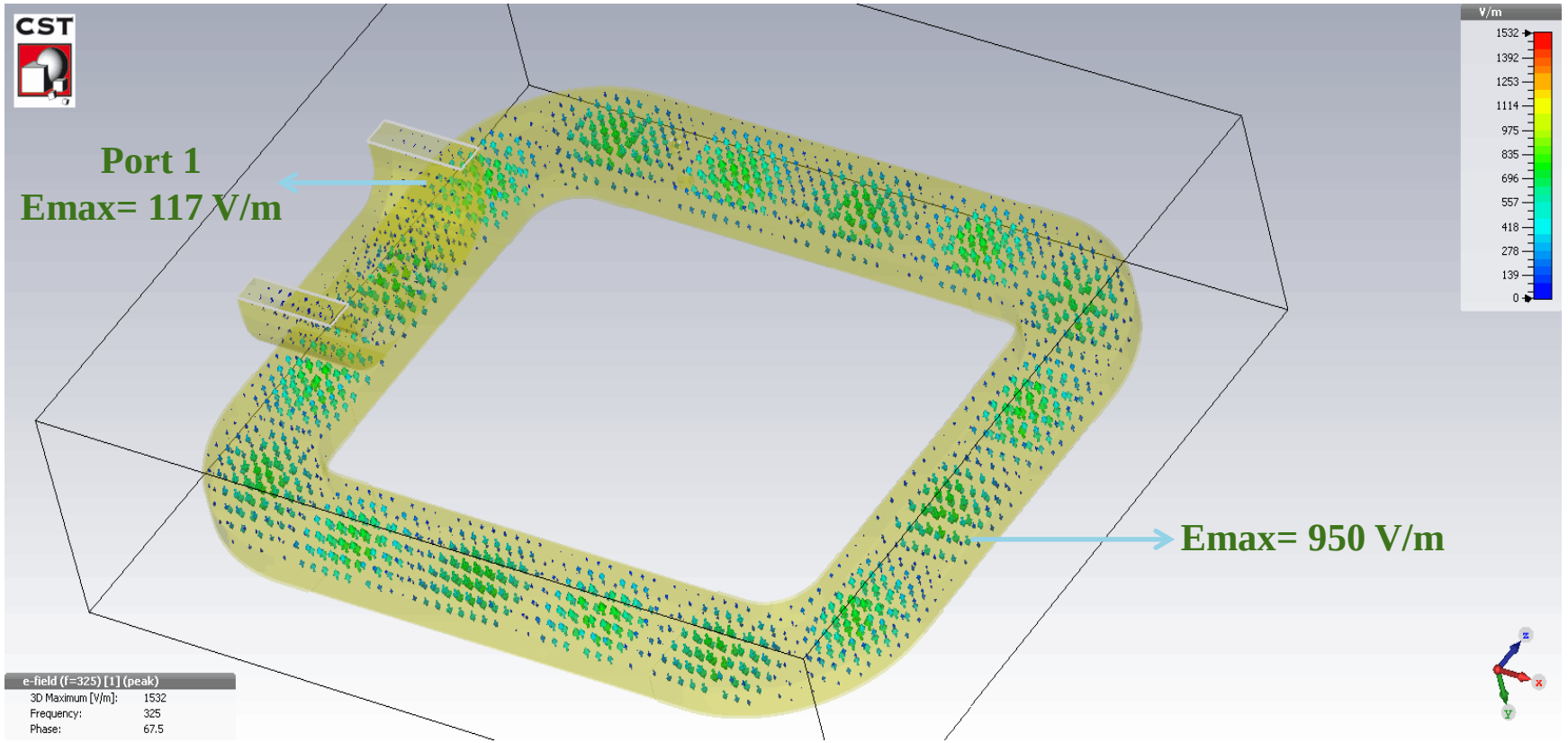
  Gain (G)= 51.4-33.1= 18.3 dB

  Where, 51.4 dB is the coupling factor of secondary line directional coupler

- Thus simulation shows that with all the waveguide components mentioned earlier the ring can provide a gain of about **18.3 dB** i.e. **65 times** which corresponds to attenuation of **0.05 dB**.

Transmission through the ring is measured through a secondary line directional coupler.

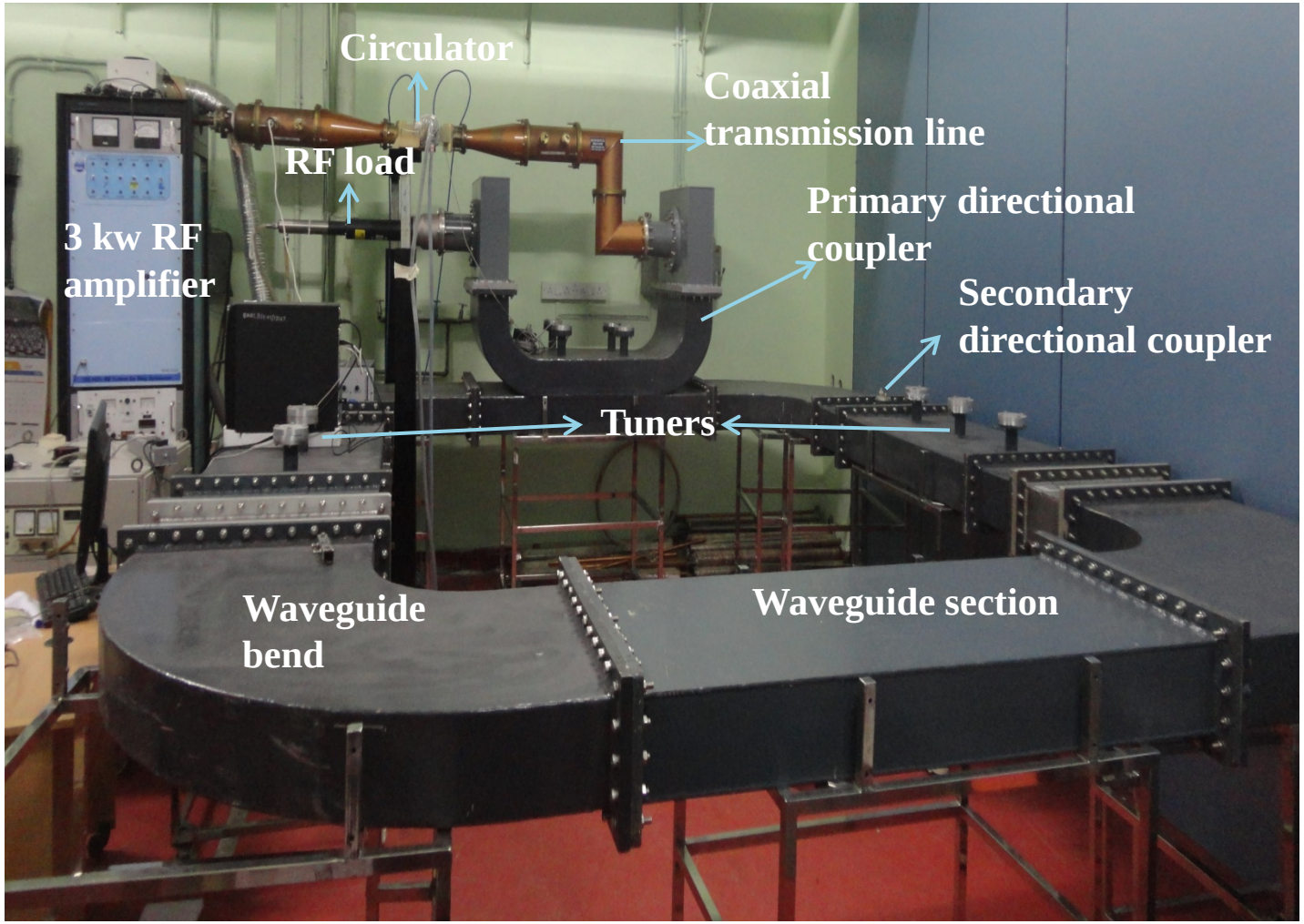
Electric field animation to observe traveling waves in the ring



- Maximum Electric field in the ring: 950 V/m
- Field at input port is 117 V/m for input power of 0.5 watt
- Power in the ring= $0.5 \times (950/117)^2 = 32.5$W
- **Power gain= 65 times (18.1 dB)**

High Power testing of traveling wave resonant ring

- Low power characterization is done using VNA.
- High power testing is done by connecting an amplifier at the input.



High power testing of travelling wave ring resonator

Sr. no	Parameter	Obtained value
1	Input power	1.103 kW
2	Output power	30.45 kW
3	Frequency of operation	324.884 MHz
4	Gain	14.4 dB
5	Bandwidth	270 kHz

- The ring is raised to apparent power of about 30 kW and tested for more than 100 Hrs.
- In the next phase, the ring will be tested with different reflected powers with variable phase.
- It is planned to connect two couplers through an intermediate cavity/bridge for high power conditioning. Because of increase in attenuation, we expect a gain of at-least 10 dB.

Colleagues working on RF Power Couplers

RF design,Test setups, procurement etc.

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Mechanical design aspects and Manufacturing

CDM, BARC

Thanks a lot