Design of RF Power for Couplers for Accelerator Cavities using COMSOL Multiphysics

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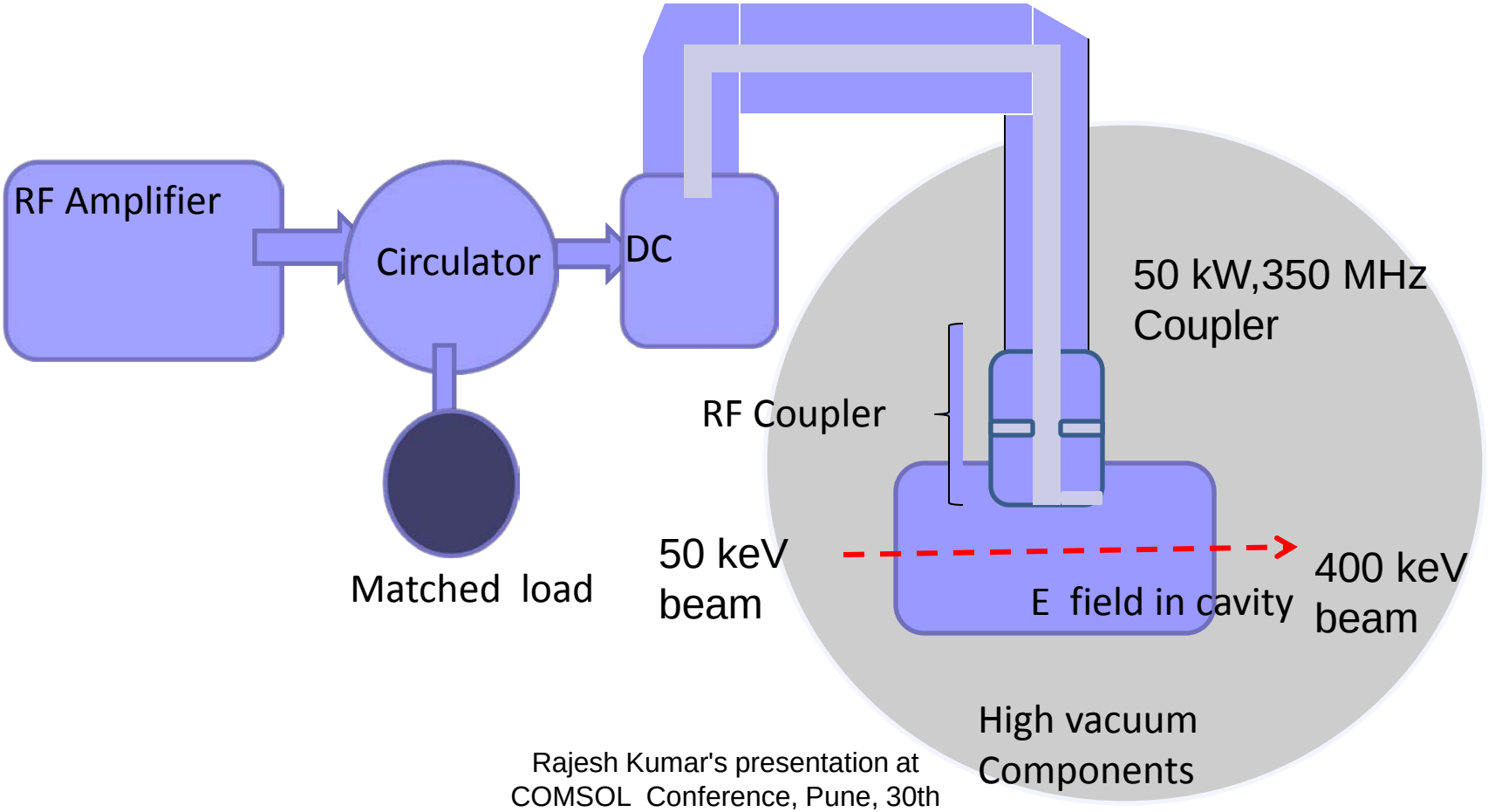
Plan of Talk

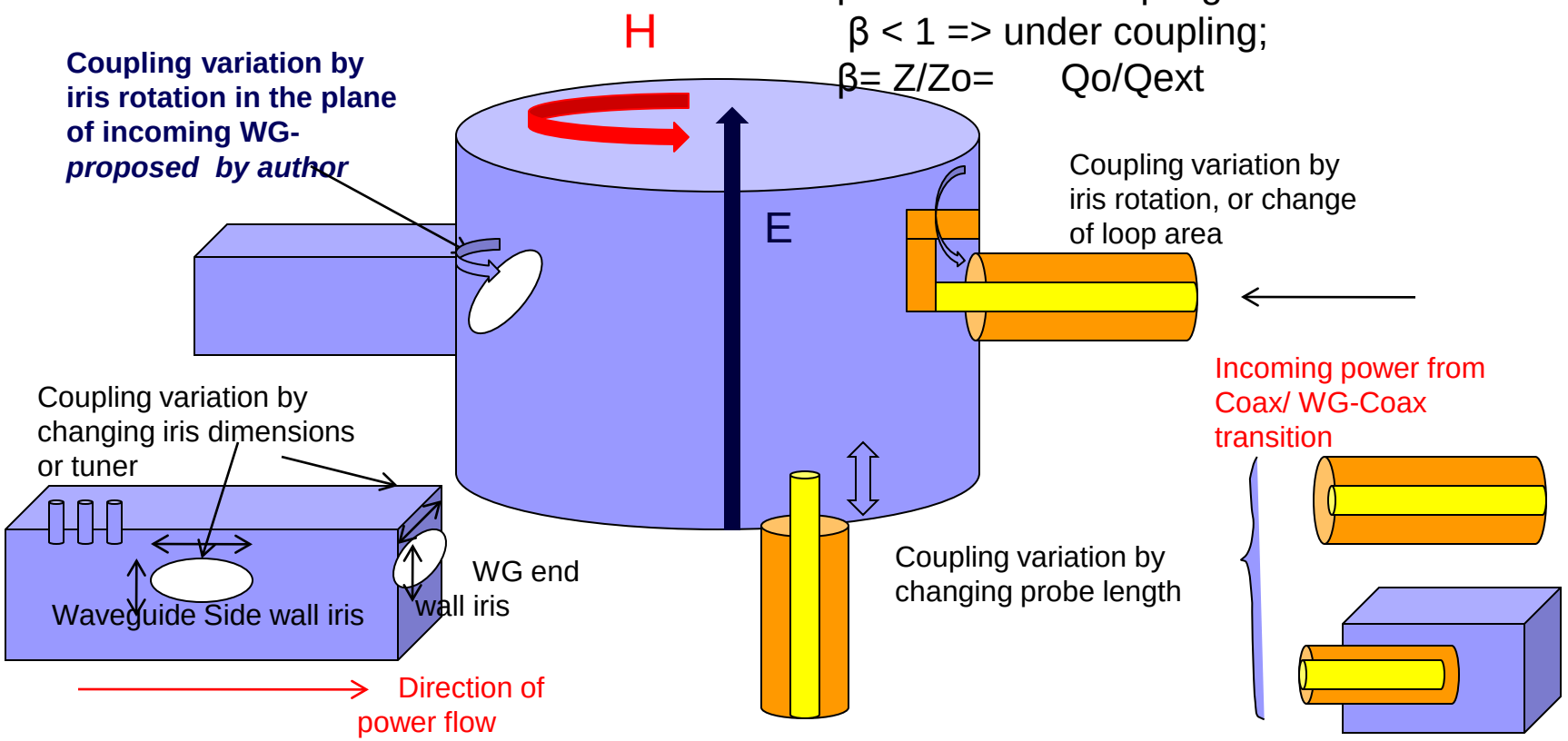
- **Brief Introduction to RF Couplers**
- **Design of waveguide iris type couplers**
- **Design of Coaxial loop type couplers**
- **Preliminary Thermal analysis of couplers for Superconducting cavities**

Typical RF system for accelerators



Different type of coupling tuning schemes

Coupling Coefficient (β)= 1 => Critical coupling => No reflections
β> 1 => Over-coupling
β < 1 => under coupling;
β= Z/Zo= Qo/Qext



Ridge waveguide iris coupler

Design goals :

Return loss: Better than -20 dB at 352.2 MHz

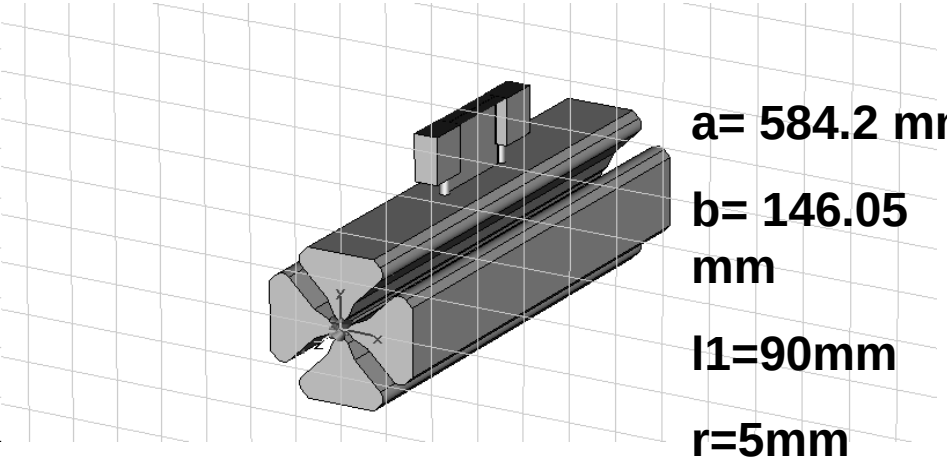
Cavity frequency shift: < 0.03 %

Power level: 250 kW CW

RF design steps for Ridge waveguide coupler

- Finalize the port size on RF cavity and calculate iris dimensions to obtain desired coupling by simulations. RF cavity model is required at this stage.
- In the coupler designed for LEHIPA, Incoming waveguide WR2300 (584.2 mm by 146.05 mm) is to be reduced to 190 mm by 35 mm. The required transition is realized in ridge waveguide form and optimized to obtain required specs using EM solver.
- Maximum Electric and magnetic fields are estimated using the solver for the required power of 250 kW at 352.2 MHz.
- Parametric studies are carried out to know the sensitivity of Return loss and design frequency to the changes in dimensions

RF Simulations for Coupling Coefficient



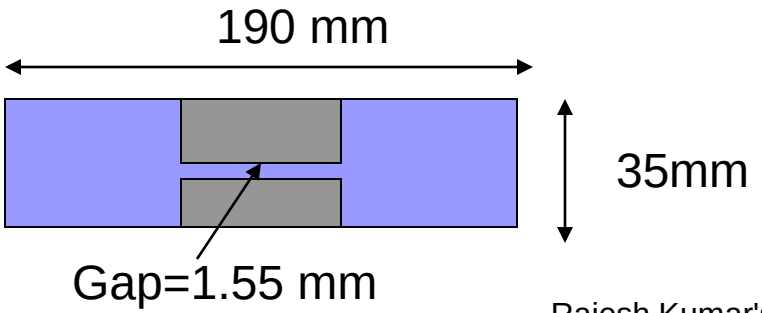
a= 584.2 mm

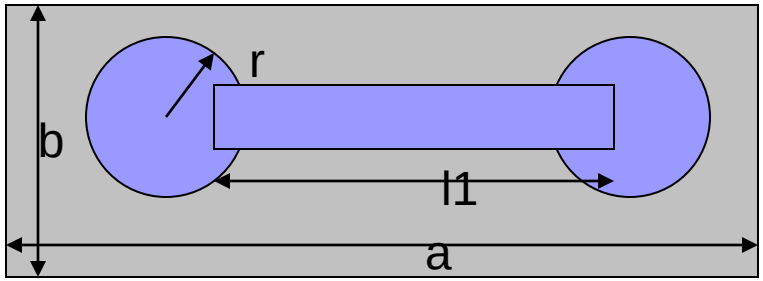
b= 146.05 mm

l1=90mm

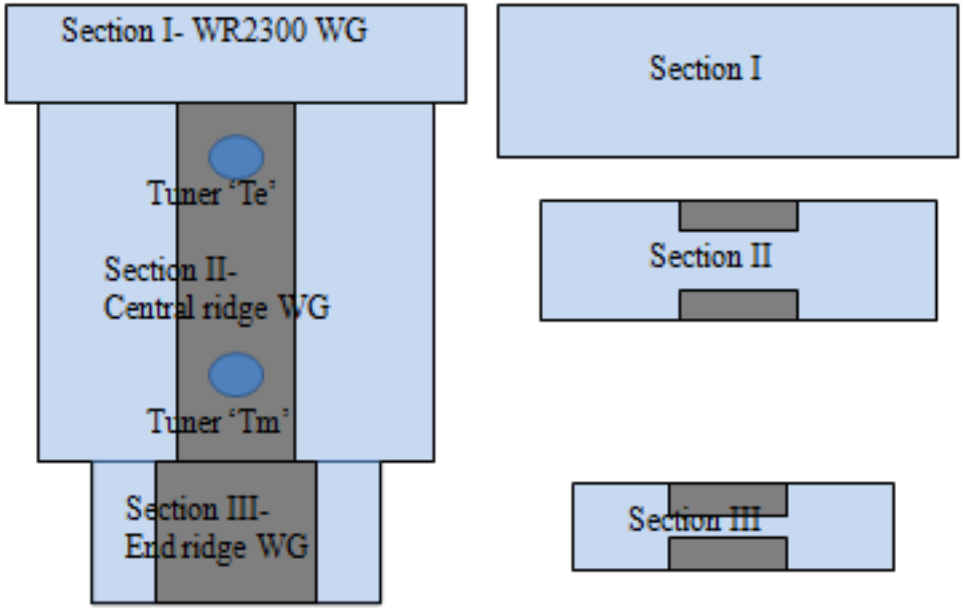
r=5mm

- Half Height WR2300 waveguide is reduced to small cross-section on the RFQ cavity
- Ridge loading is used to maintain the same cut-off and impedance match
- Cavity Frequency shift caused by the coupler is < 0.03 %



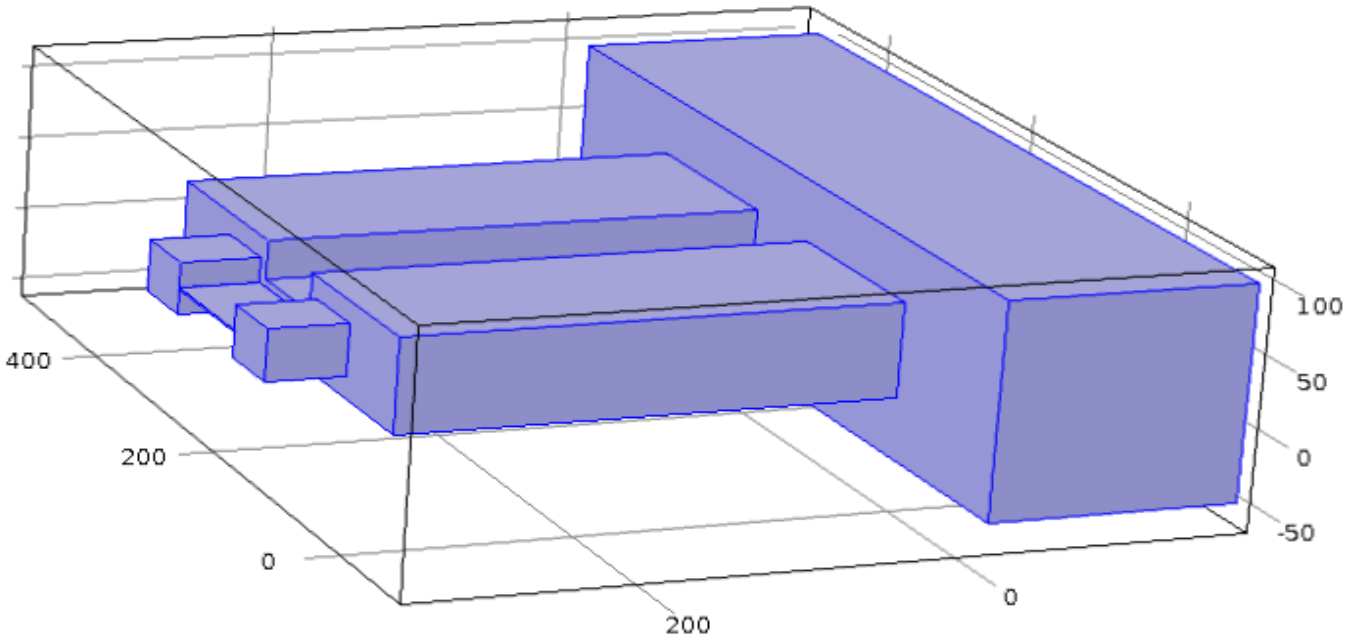


Straight ridge transition based coupler for 352.2 MHz



(a) Top view of the coupler **(b) cross-section view of coupler**

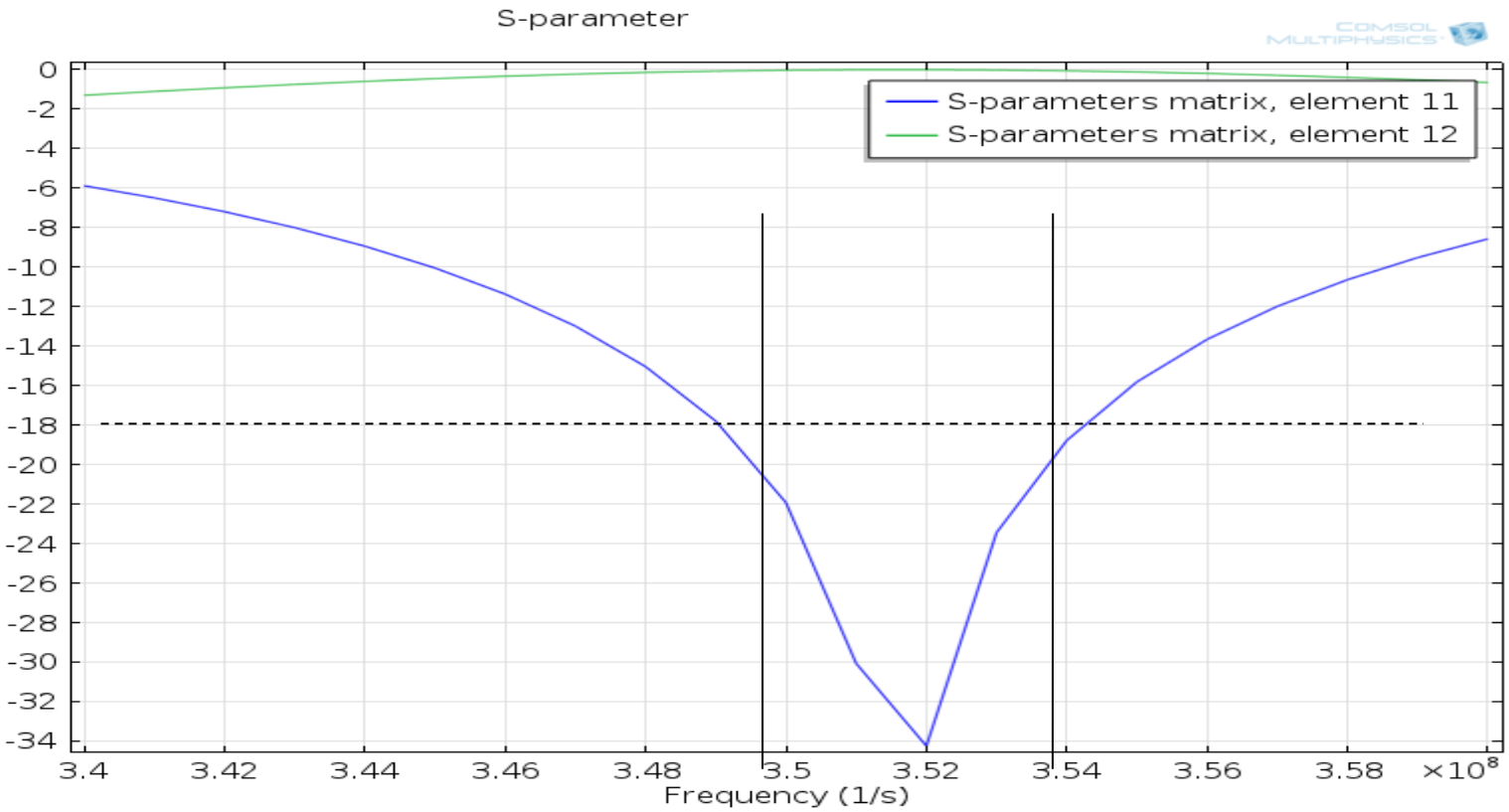
COMSOL simulation model of straight ridge waveguide coupler



Optimized dimensions for straight ridge transition based coupler

Parameter	Description	Value (mm)
w	WR2300 width	584.2
h	WR2300 height	146.05
wl	Input Port length	160
c-ow	Central section- overall width	334
cw	Central ridge width	69.4
cl	Central ridge length	315
cg	Central ridge gap	11.5
ch	Central ridge height	64
ew	End ridge width	89
e-ow	End section- overall width	189
eg	End ridge gap	1.55
eh	End ridge height	35
el	Output Port length	20

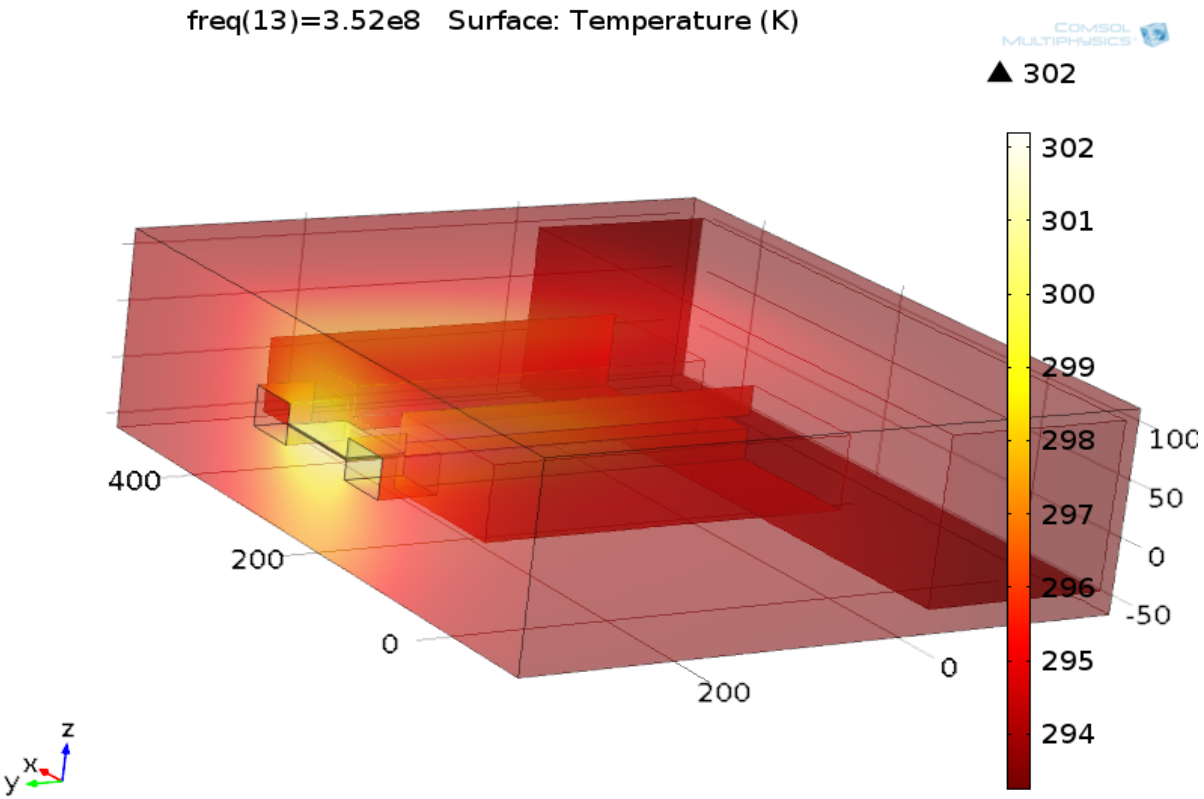
RF Simulations for Return loss of coupler transition



Iterative simulations are performed in COMSOL to reach at optimized dimensions.

BW ~ 4 MHz

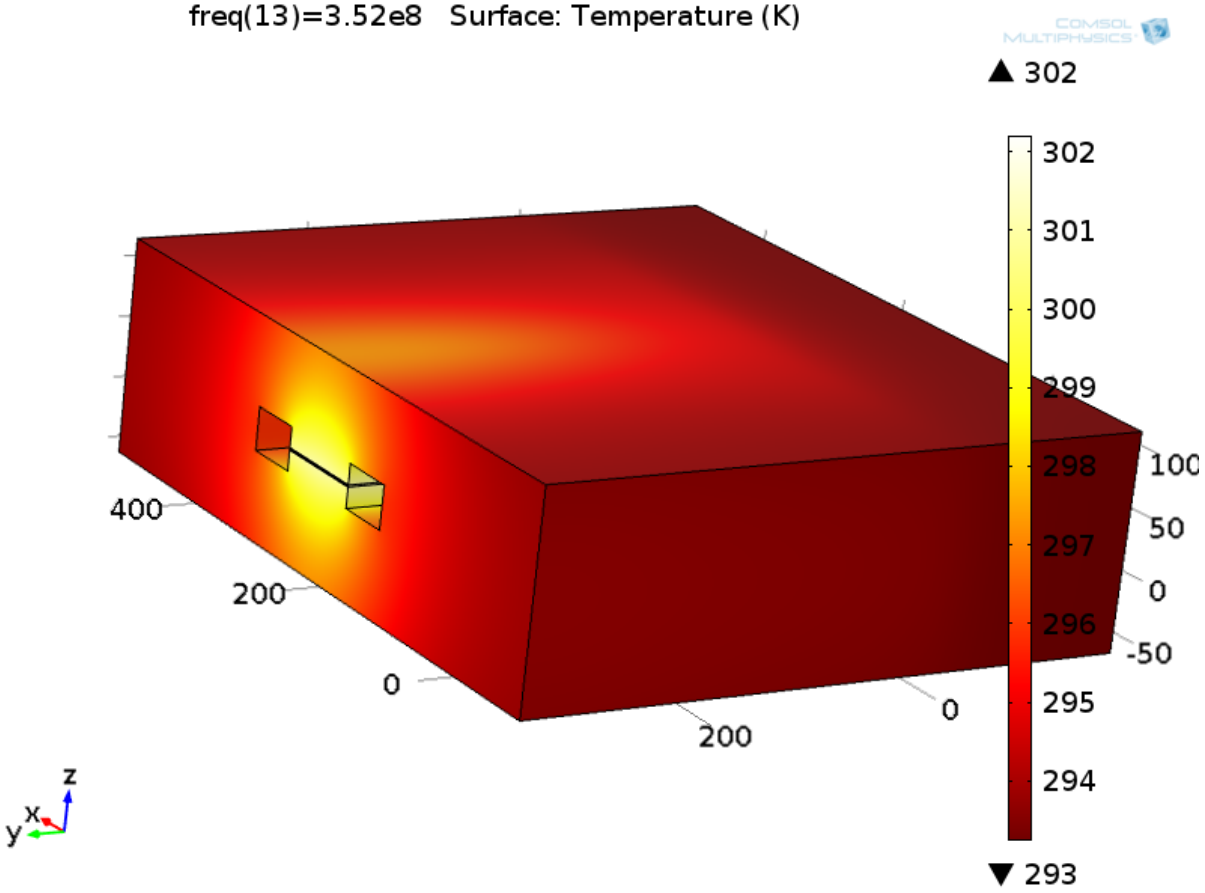
Preliminary Coupled RF-Thermal simulations



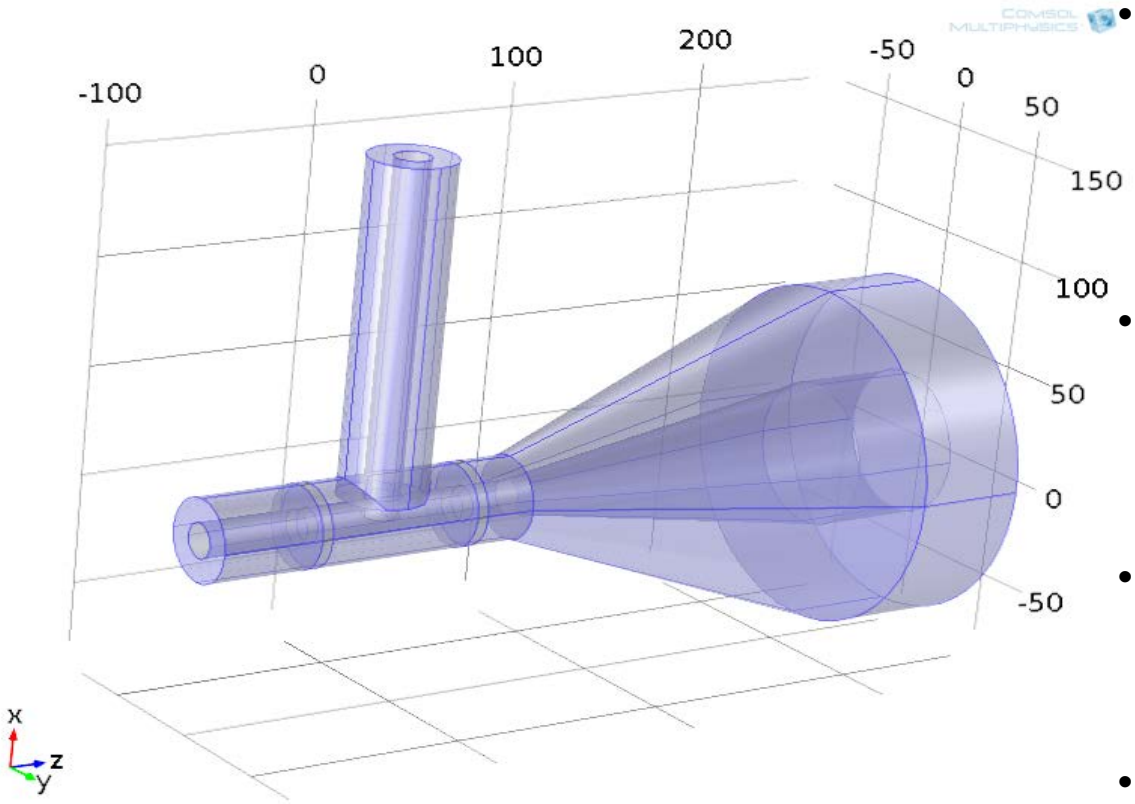
Max. surface temp. should be < 50 deg. C to avoid thermo-structural effects on performance

- Electromagnetic waves-frequency domain (emw) and heat transfer in solids (ht) modules are used
- Boundary electromagnetic heat source is used for RF loss on copper surface
- Convective heat transfer coefficient = 1000 W/M2k, Ambient temp. = 293 K
- P_{in} at Port 1 is taken as 250 kW at 352.2 MHz

Coupled RF-Thermal simulations contd.

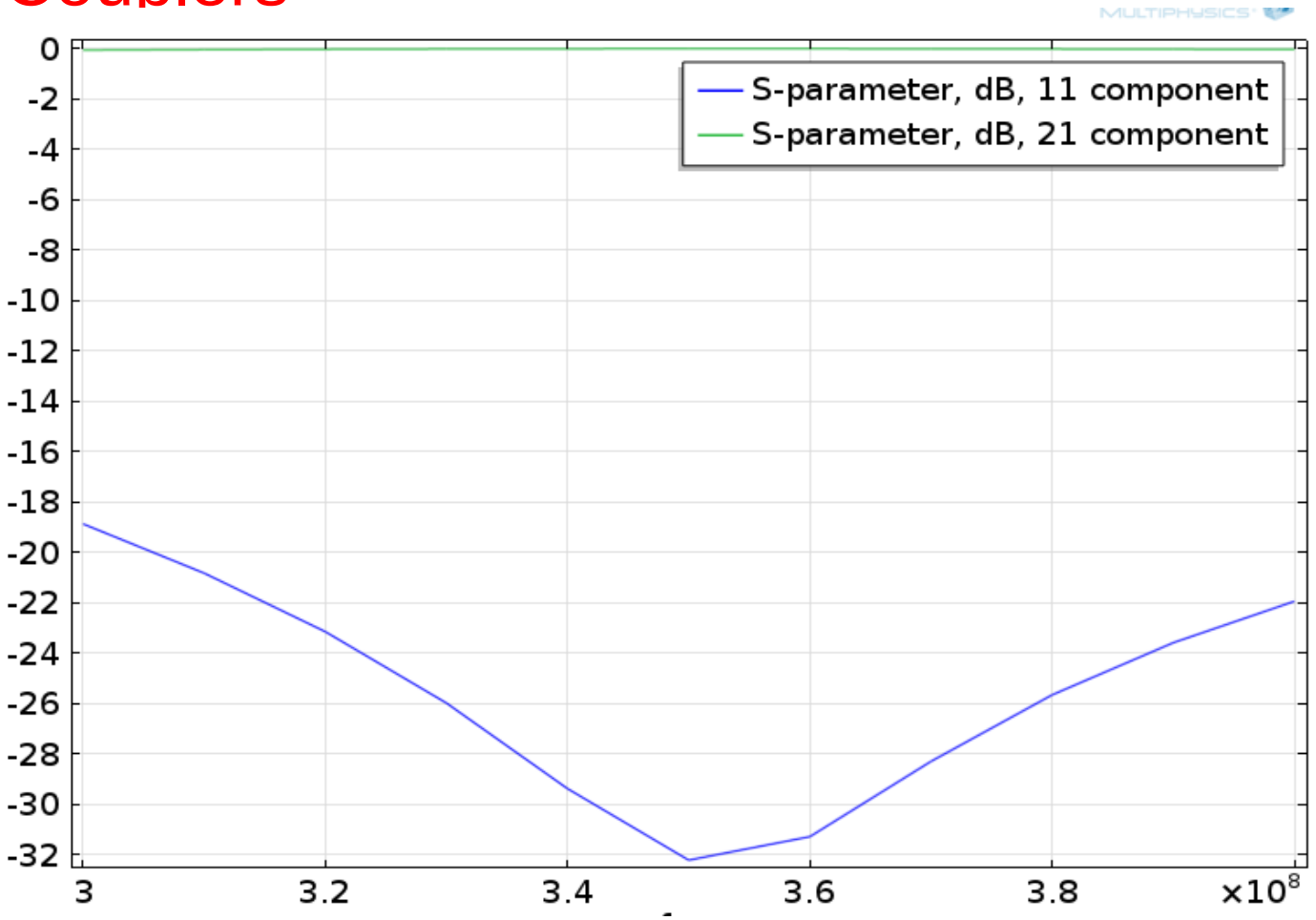


Design of Coaxial Couplers

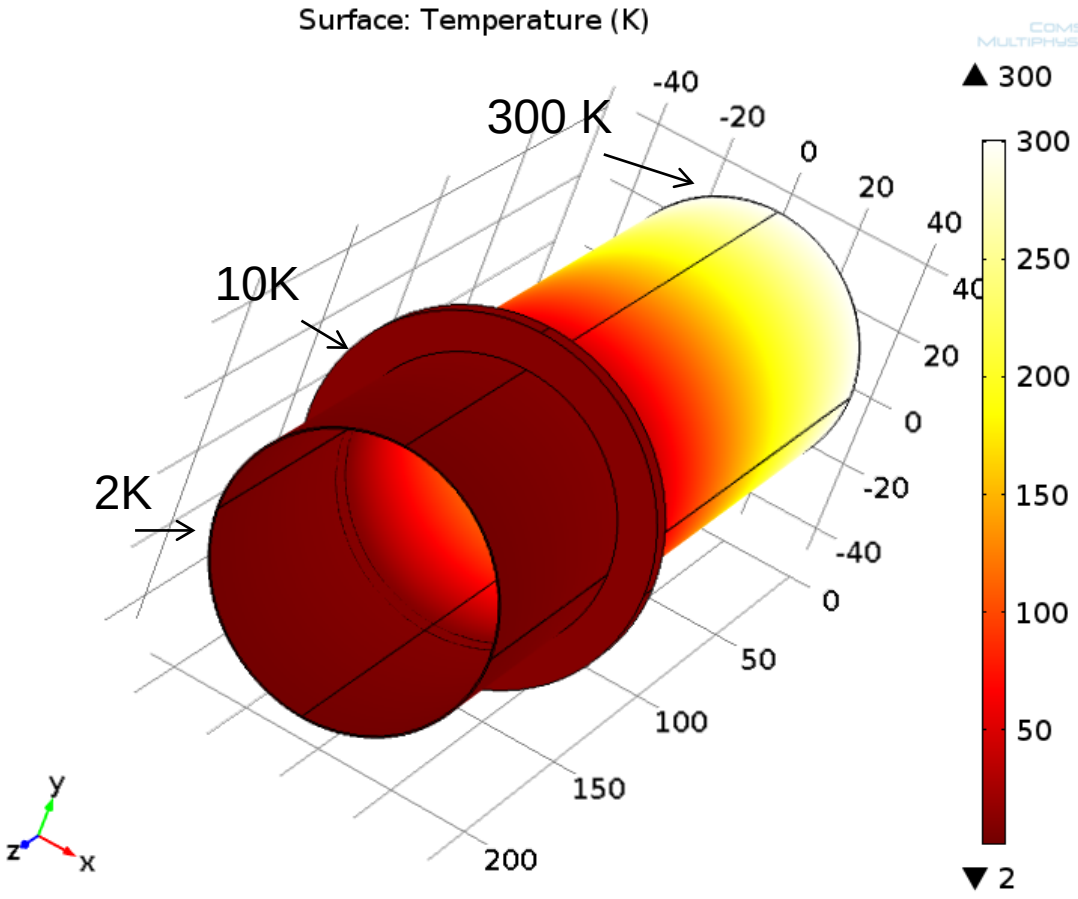


- Electromagnetic waves-frequency domain (emw) module is used.
- 6 1/8” rigid coaxial line made up of Copper is tapered to 1 5/8” using a 160 mm long tapered transition.
- Capacitive discontinuity of alumina discs is cancelled by quarter wave shorted stub.
- Shorted stub is used to circulate cooling water to inner conductor
- Return loss is optimized for 350 MHz.

Return loss optimization of Coaxial Couplers



Preliminary Thermal analysis of coaxial couplers for superconducting cavities



- Heat transfer in solids (ht) module is used in these simulations
- Outer conductor of coupler with 72.2 mm inner diameter and 220 mm length is simulated for different thicknesses
- Thermal strap at 10K is used to optimize static thermal load on to 2 K helium cryogenic system

Static heat load optimization

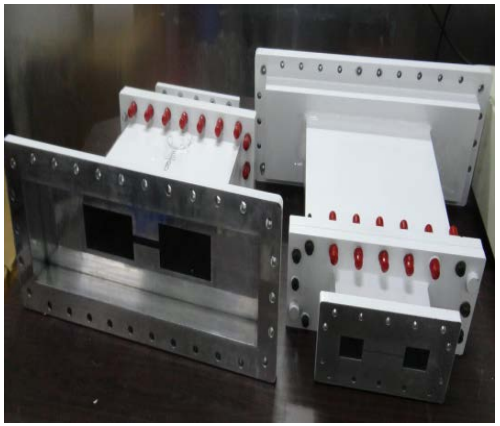
ID (mm)	OD (mm)	Thickness (mm)	Heat load to 2 K system	Total heat load (W)	d (Thermal strap position in mm)	Length (mm)	Material
72.2	73.5	0.65	0.31	4.9	50	220	SS- (COMSOL material library SS-ASI4340)
72.2	73.8	0.80	0.38	6.03	50	220	
72.2	74.1	0.95	0.46	7.17	50	220	
72.2	74.4	1.10	0.53	8.32	50	220	
72.2	74.7	1.25	0.60	9.47	50	50	
72.2	75.0	1.40	0.67	10.62	50	220	

Thickness of outer conductor , thermal strap position is optimized to have min. heat load onto 2K cryogenic system

Typical RF couplers designed and developed

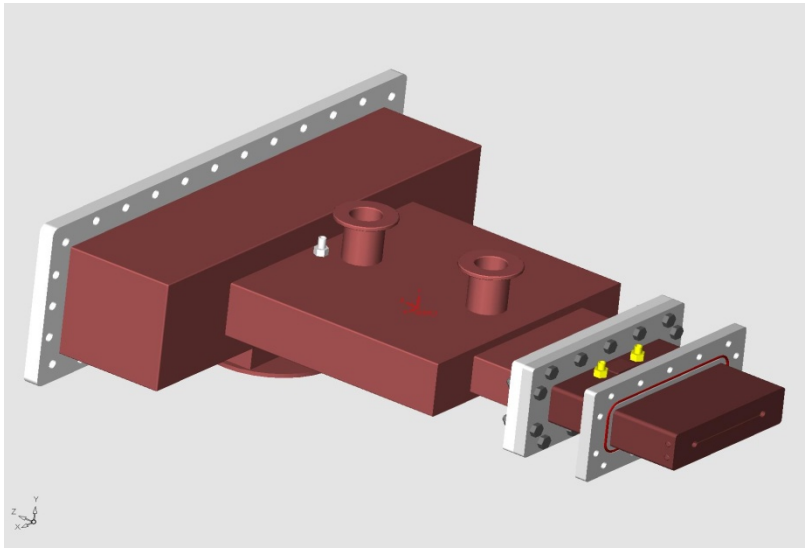
50 kW , 350 MHz peak peak power Coaxial loop coupler of 40 mm dia. and 150 mm length

50 kW CW , 350 MHz Coaxial loop coupler of 155 mm dia. and 400 mm length



250 kW , 352.2 MHz Waveguide coupler of width 584.2 mm, height 146.05 mm and length of 600 mm

High power ridge waveguide coupler with tuners (250 kW, 352.2 MHz) for LEHIPA



3 D Model of Waveguide Coupler with tuner, diagnostic and vacuum ports

The coupler is being used on RFQ cavities of LEHIPA and have been conditioned up to 280 kW, 2.5 ms ,1Hz

Fabricated ridge waveguide Coupler and tuners. The coupler has been successfully tuned to the RFQ cavity for -27 dB Return loss

Conclusions

- COMSOL Multiphysics is used to design waveguide iris couplers using RF module. Preliminary RF-thermal analysis is carried out.

- RF design of coaxial couplers is carried out.

- Preliminary studies for static heat load optimization on to 2 K cryogenic system is done for Coaxial RF coupler's outer conductor.

- Coupled RF-Thermal-structural simulations will be carried out to design RF couplers for superconducting cavities

Thanks a lot.