Coupled RF-Thermal Analysis of High Power Couplers for Accelerator Cavities

Presented by:

Rajesh Kumar

Scientific Officer
Ion Accelerator Development Division
Bhabha Atomic Research Centre
Mumbai-85

COMSOL CONFERENCE BANGALORE2013

Plan of the talk

- Introduction
- Overview of RF Coupler designs for Low Energy High Intensity Proton Accelerator(LEHIPA) project at BARC
- Coupled RF Thermal Analysis
- Future work

Scheme for Accelerator Development for ADS

Normal Conducting

High current injector 20 MeV, 30 mA

Proton IS 50 keV → RFQ 3 MeV → DTL 20 MeV

Phase 1

Phase II

DTL/ CCDTL

Super-conducting

Phase III

100 MeV

SC Linac

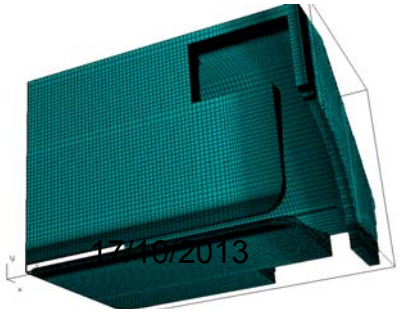
1 GeV

Proton beam from high power accelerator

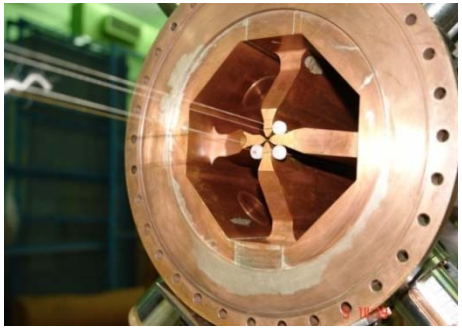
Design completed and fabrication is in progress

ECR Ion Source

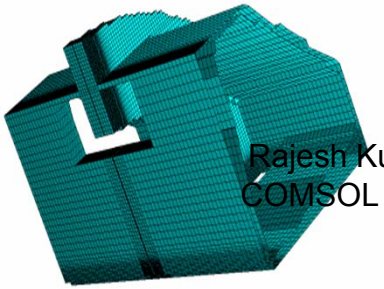
Beginning/End Cell



RFQ

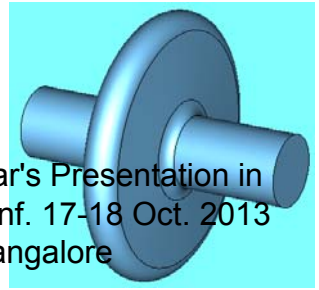


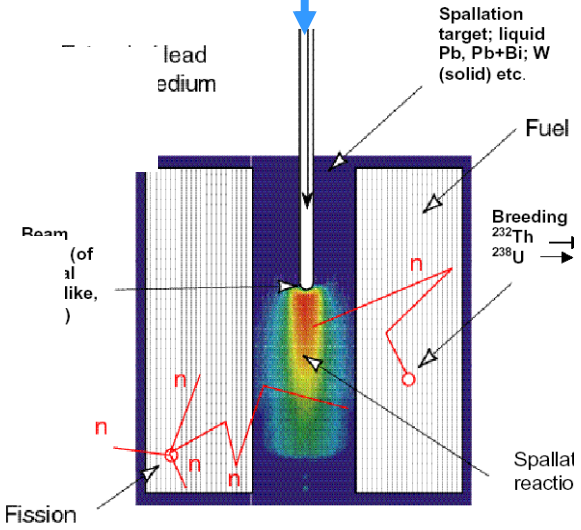
Coupling Cell



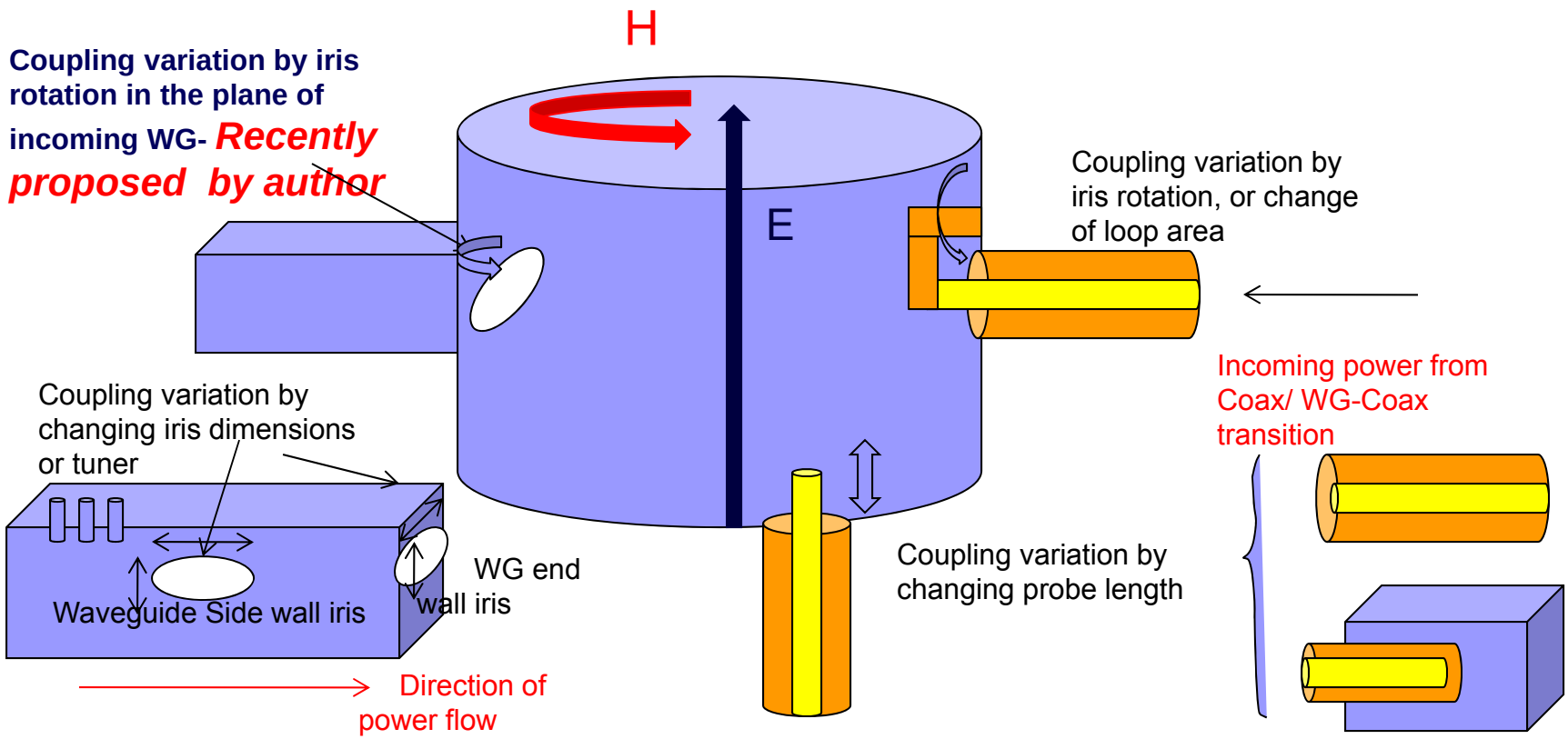
DTL

Elliptical SC Cavity



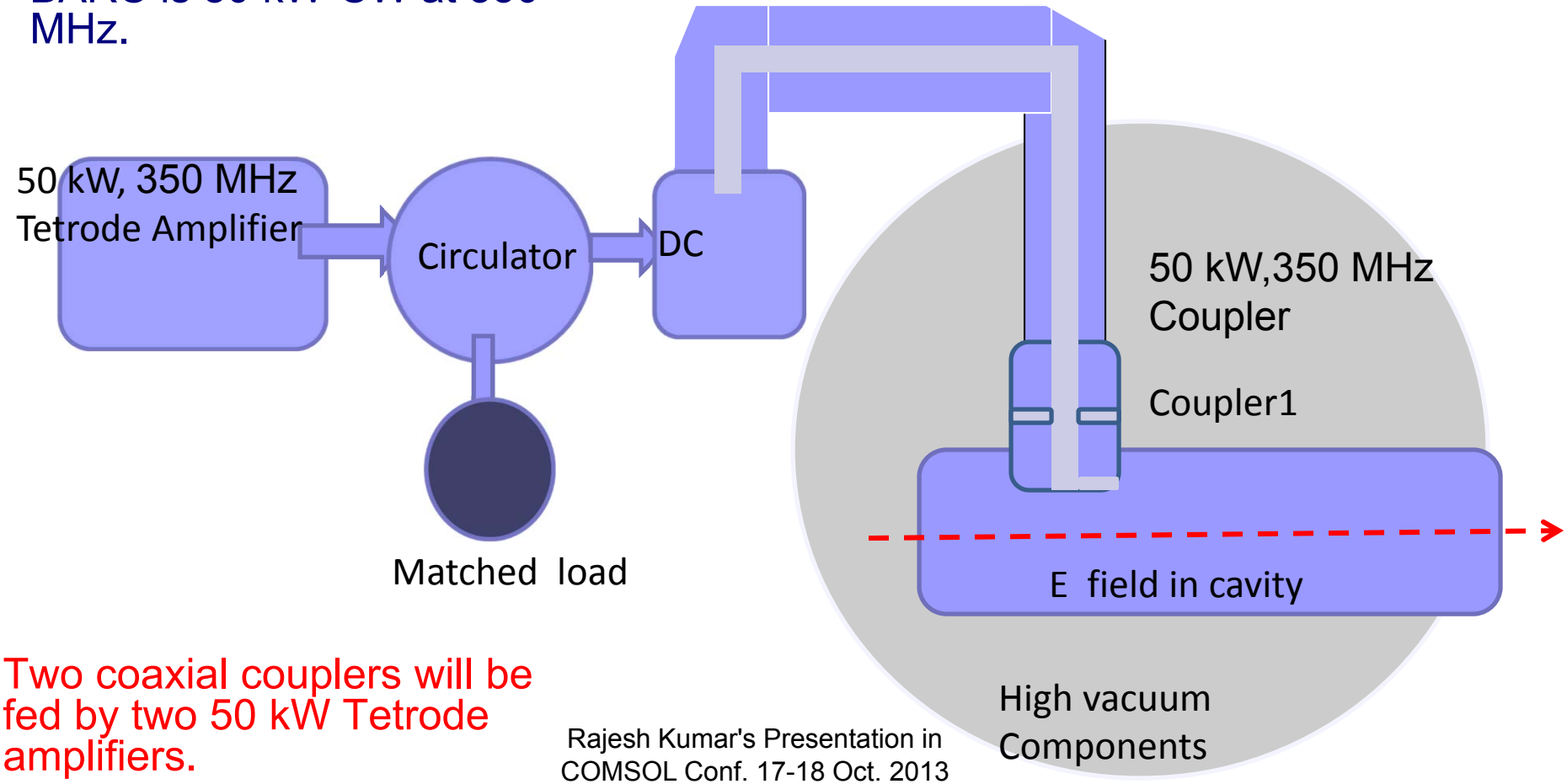


Different techniques for RF Power coupling



Existing Coaxial Coupler scheme for 400 keV RFQ cavity of deuteron accelerator

Total Power Requirement of 400 keV RFQ accelerator at BARC is 80 kW-CW at 350 MHz.



Two coaxial couplers will be fed by two 50 kW Tetrode amplifiers.

Coaxial Coupler design choices

- EIA standard sizes are available Rigid coaxial lines

- Standard sizes for 50 Ohm are 7/8", 1 5/8", 3 1/8" , 4 1/16", 6 1/8" and 9 3/16 "

- For our power requirement of 50 kW, 6 1/8" line can be used as it can handle more than 80 kW CW power at 350 MHz.

- However, because of limited size available port on cavity, coupler size is chosen to be 1 5/8" (38 mm OD, 16 mm ID for 50 Ohm). This can handle approx. 8 kW CW without cooling.

- The high purity alumina window is used as barrier between air side of line to isolate cavity side vacuum. Hence, it needs careful RF-thermal analysis.

COMSOL Simulation model with 'RF Module' for Coaxial Coupler

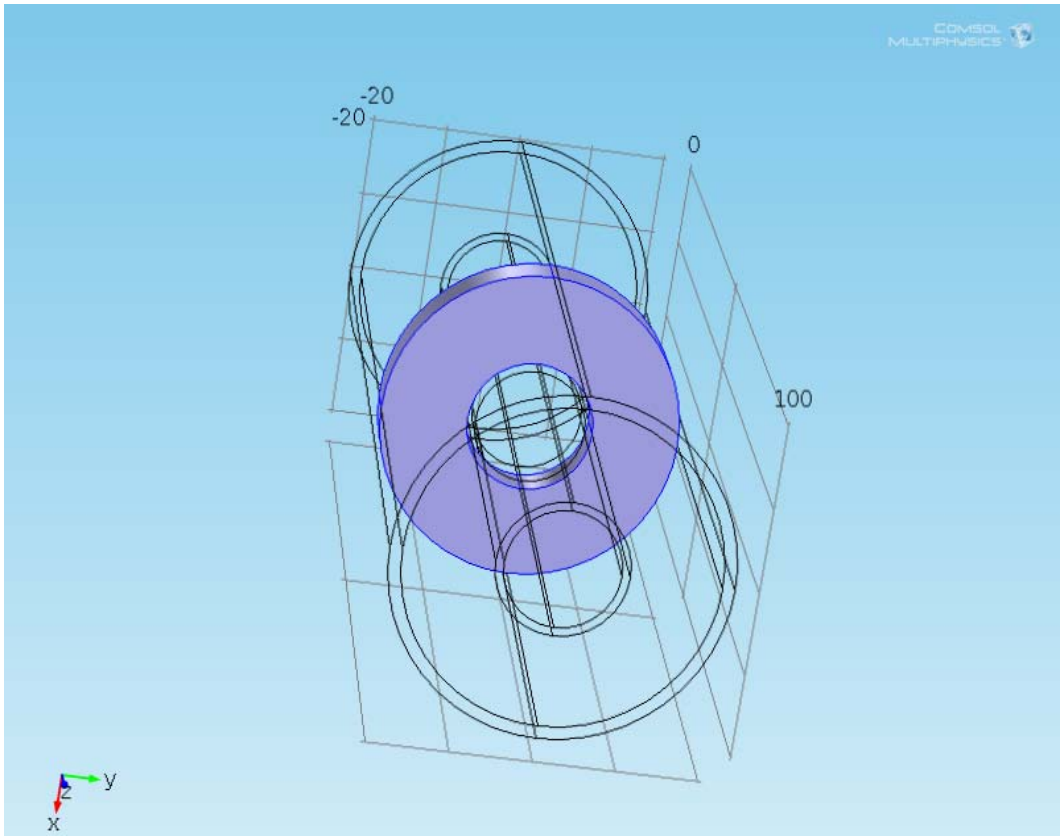
Inner conductor: Copper (16 mm OD)

Outer conductor: Copper (38 mm ID)

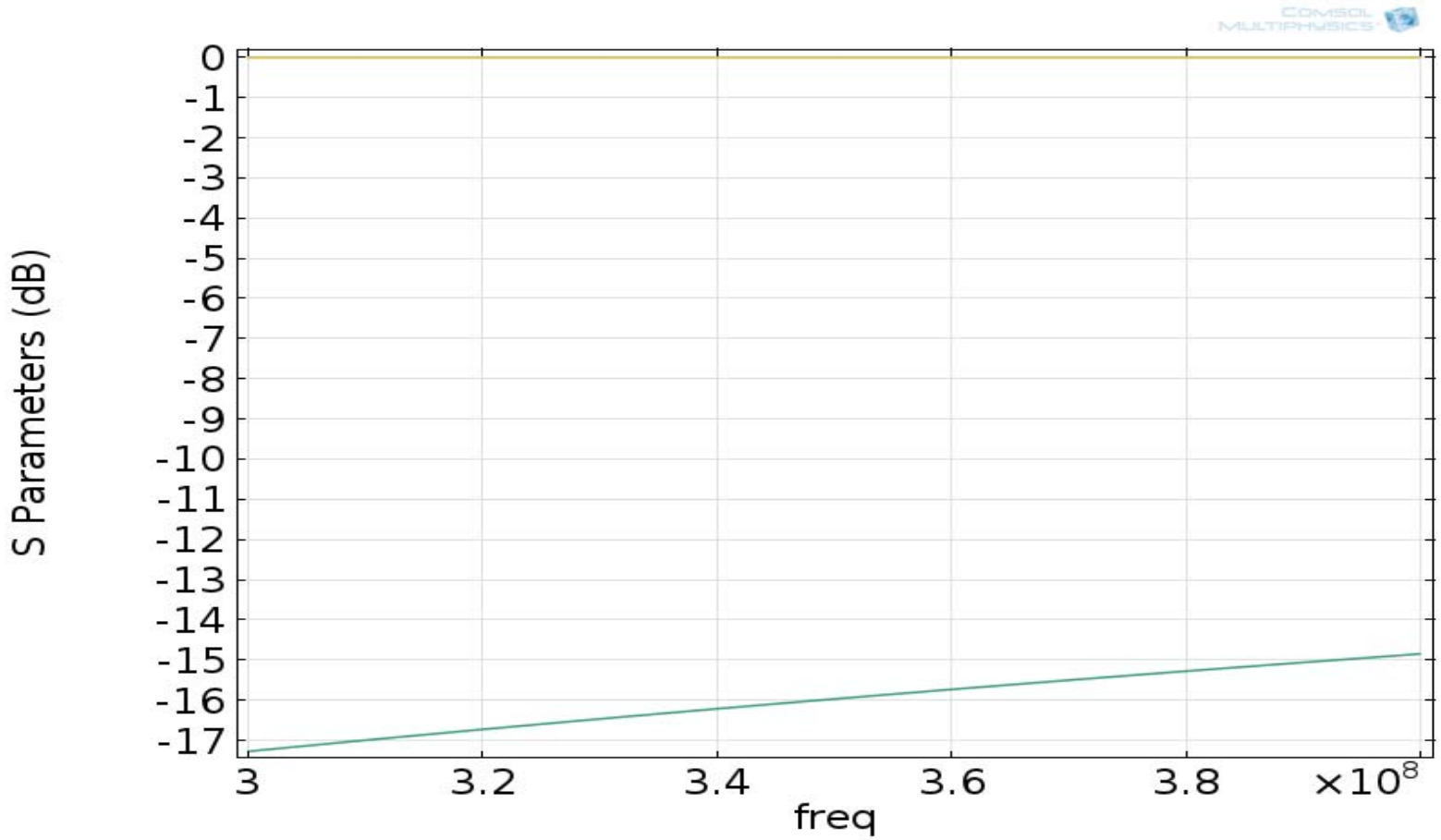
Length : 100 mm

Zo ~ 50 Ohm

RF window: High purity alumina
(εr=9.8, tandelta= 1e-3 to 1 e-4)



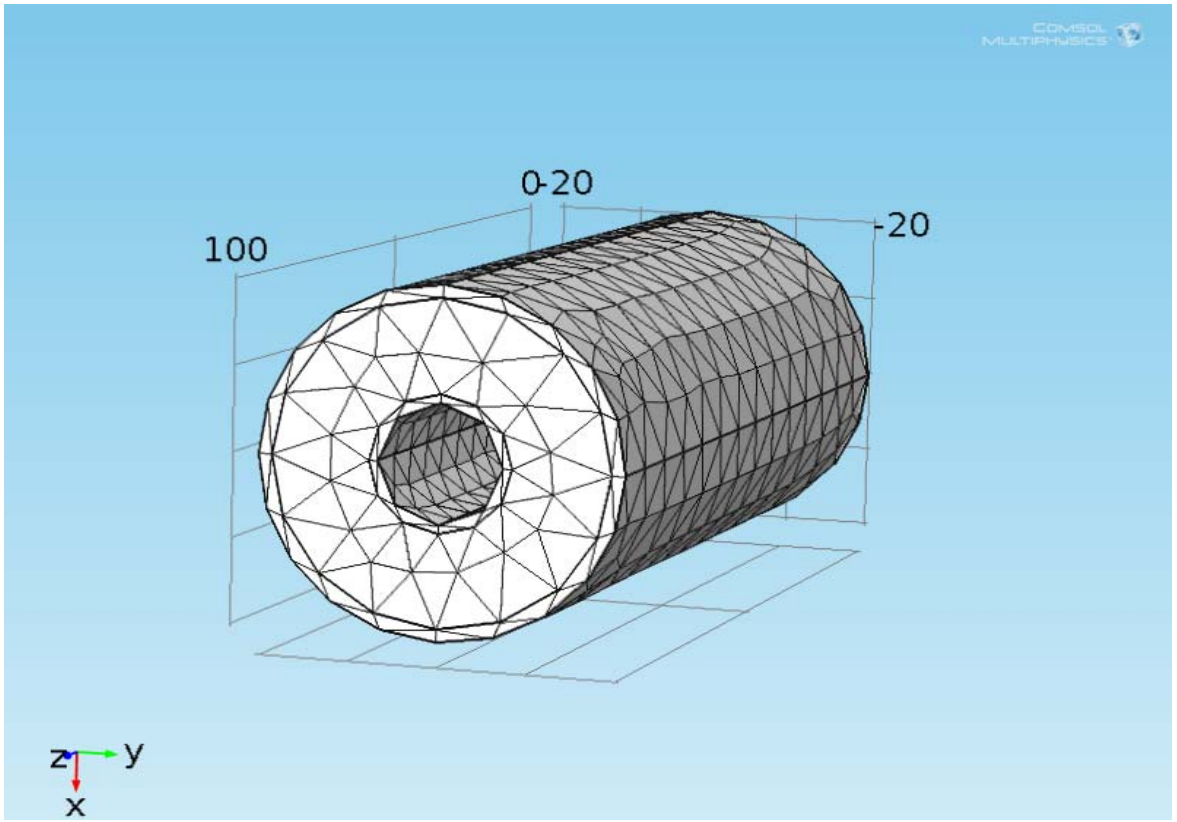
S parameter results from COMSOL simulations



Solver settings

Mesh – User defined
Extra Coarse:

Ambient Temperature:
293 K (20 deg. C)



Temperature distribution with 'Microwave heating' Module

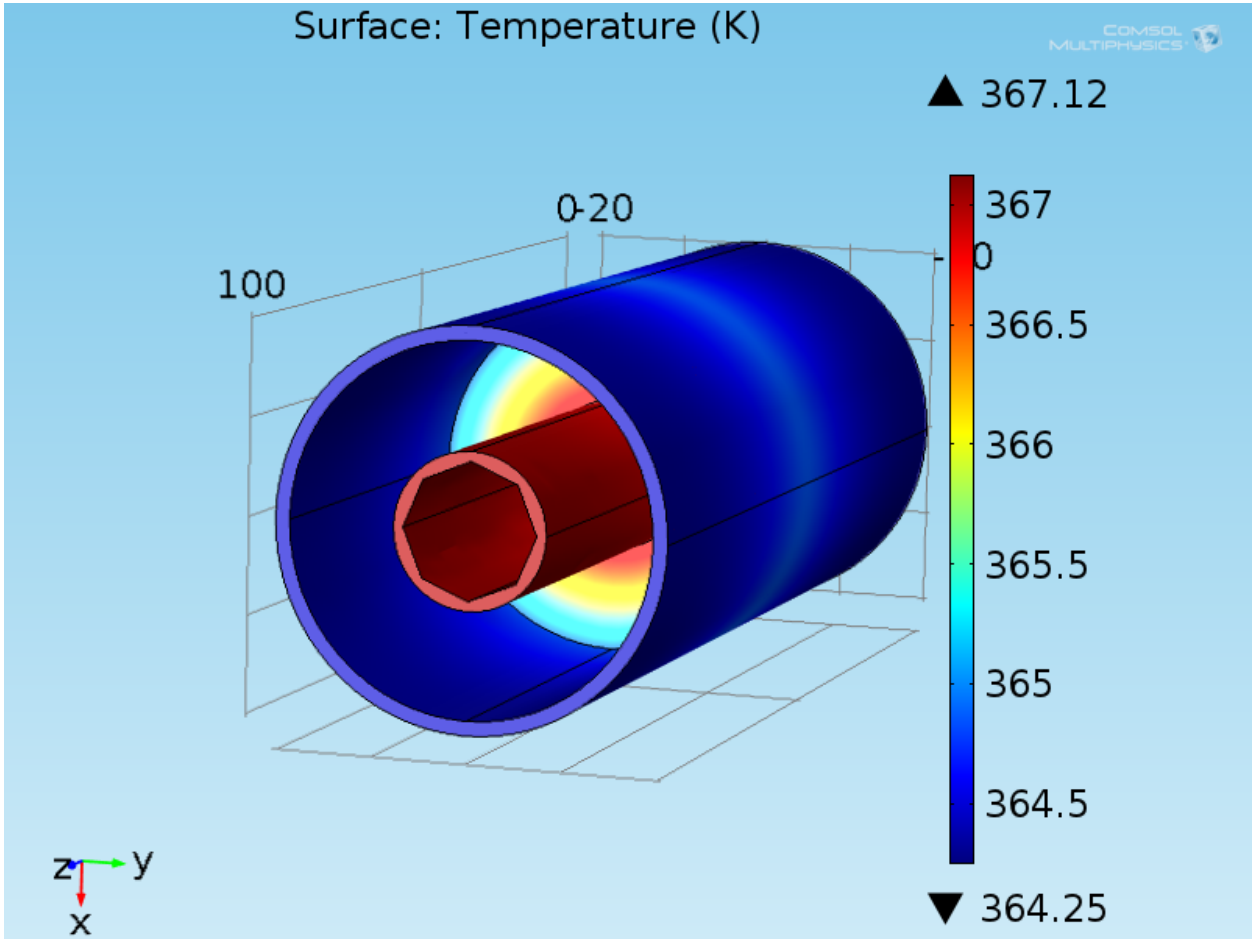
Disc Material:
ALUMINA

Pin: 10 kW

Freq. 350 MHz

Thermal conductivity of Alumina : 27 W m/K

Loss tan. = 1E-3



Meshing optimization

The simulations are performed with extra-course mesh as temperature values do not vary much with meshing

Mesh	Memory (MB)	Min Temp. (K)	Max. Temp. (K)
Extra Coarse	400/440	364.25	367.12
Coarser	427/485	363.95	366.85
Coarse	473/539	363.95	366.85

Temperature distribution with 'Microwave heating' Module contd.

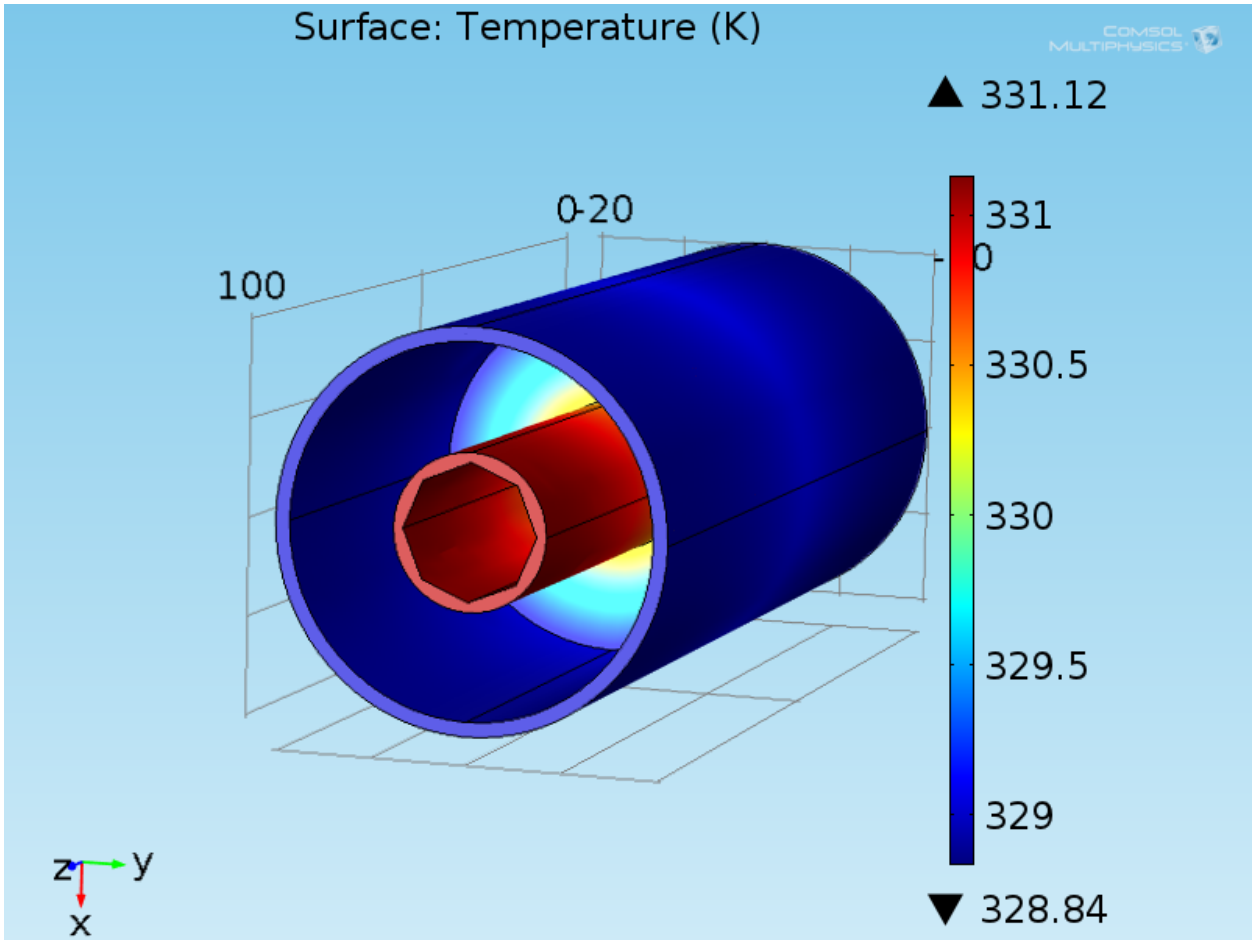
Disc Material:
ALUMINA

Pin: 10 kW

Freq. 350 MHz

Thermal conductivity of Alumina : 27 W m/K

Loss tan. = 1E-4



Temperature distribution with 'Microwave heating' Module contd.

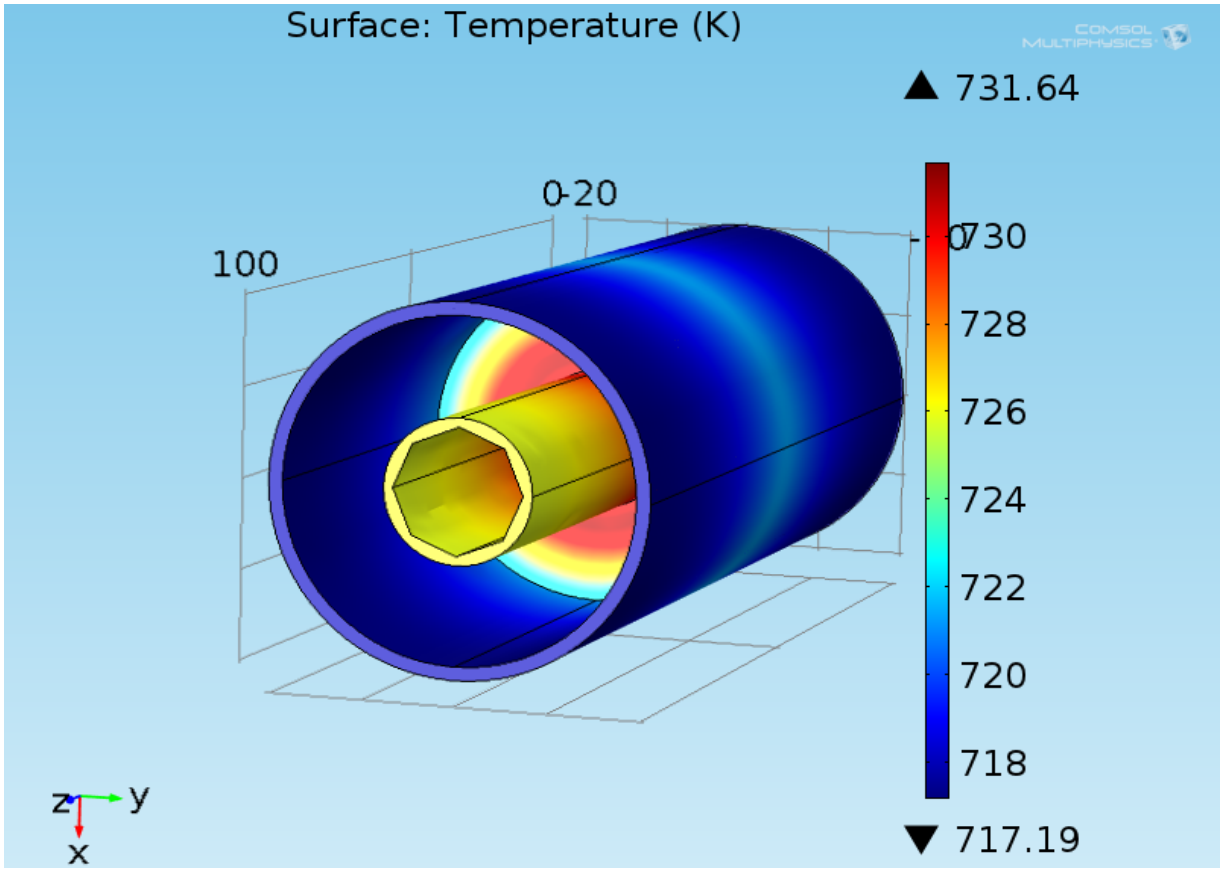
Disc Material:
ALUMINA

Pin: 10 kW

Freq. 350 MHz

Thermal conductivity of Alumina : 27 W m/K

Loss tan. = 1E-2



Temperature distribution with 'Microwave heating' Module contd.

Disc Material:
TEFLON

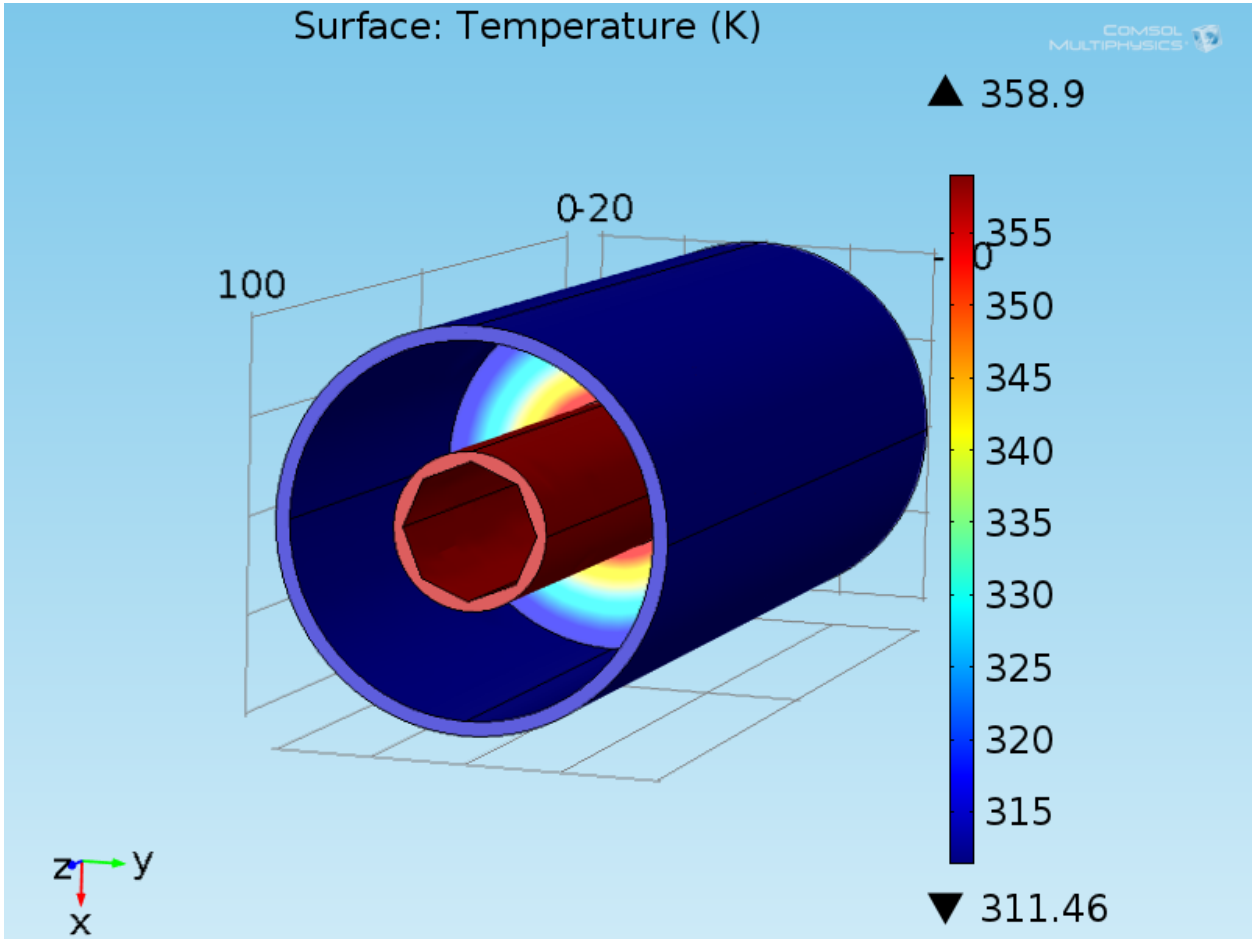
Pin: 10 kW

Freq. 350 MHz

Rel. Permittivity= . 2.2

Thermal conductivity of Teflon : 0.2 W m/K

Loss tan. = 3E-4



Temperature distribution with 'Microwave heating' Module contd.

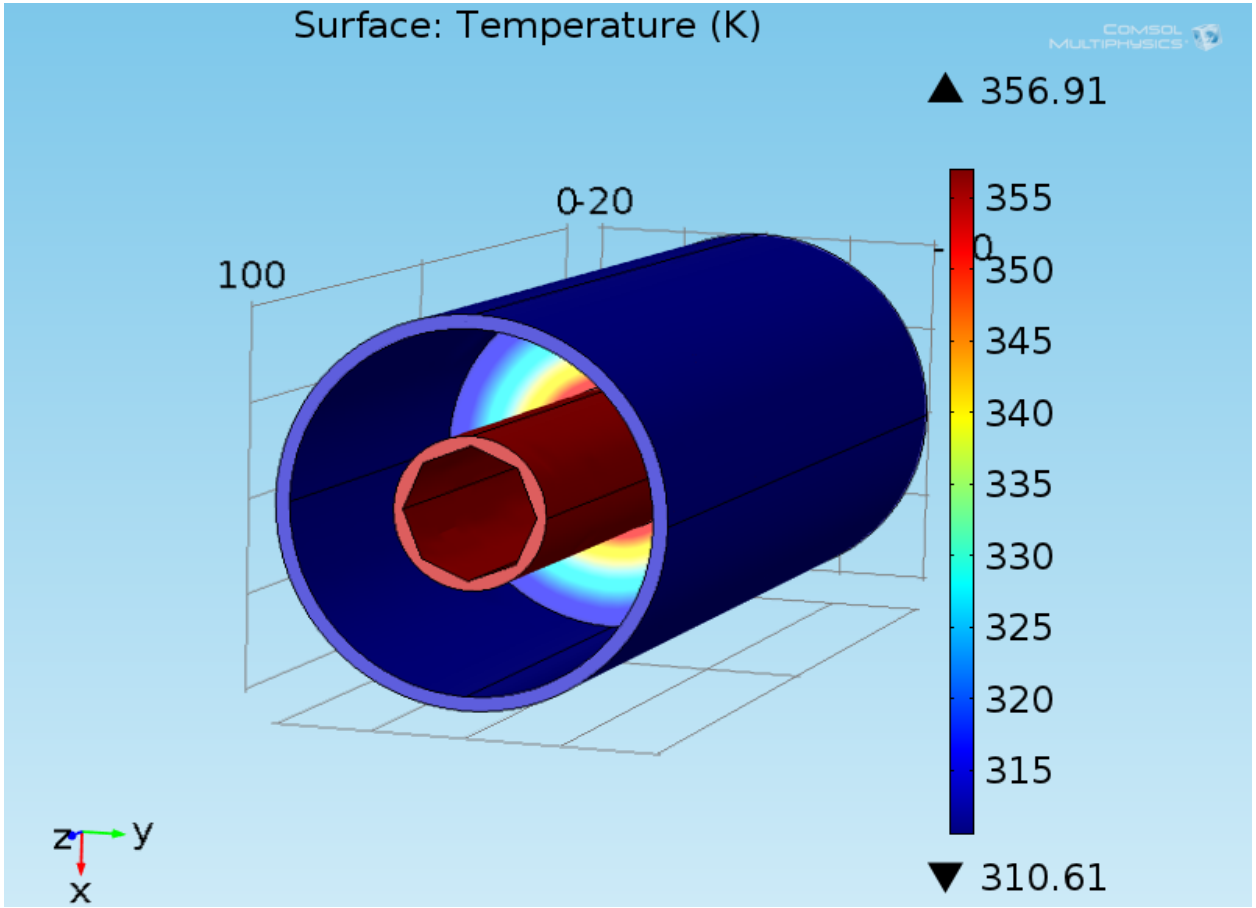
Pin: 10 kW

Freq. 350 MHz

Rel. Permittivity= 1.0001

Thermal conductivity : 0.2 W m/K

Loss tan. = 1E-7



Simulations with longer coupler

Length of the structure increased to 20 cm

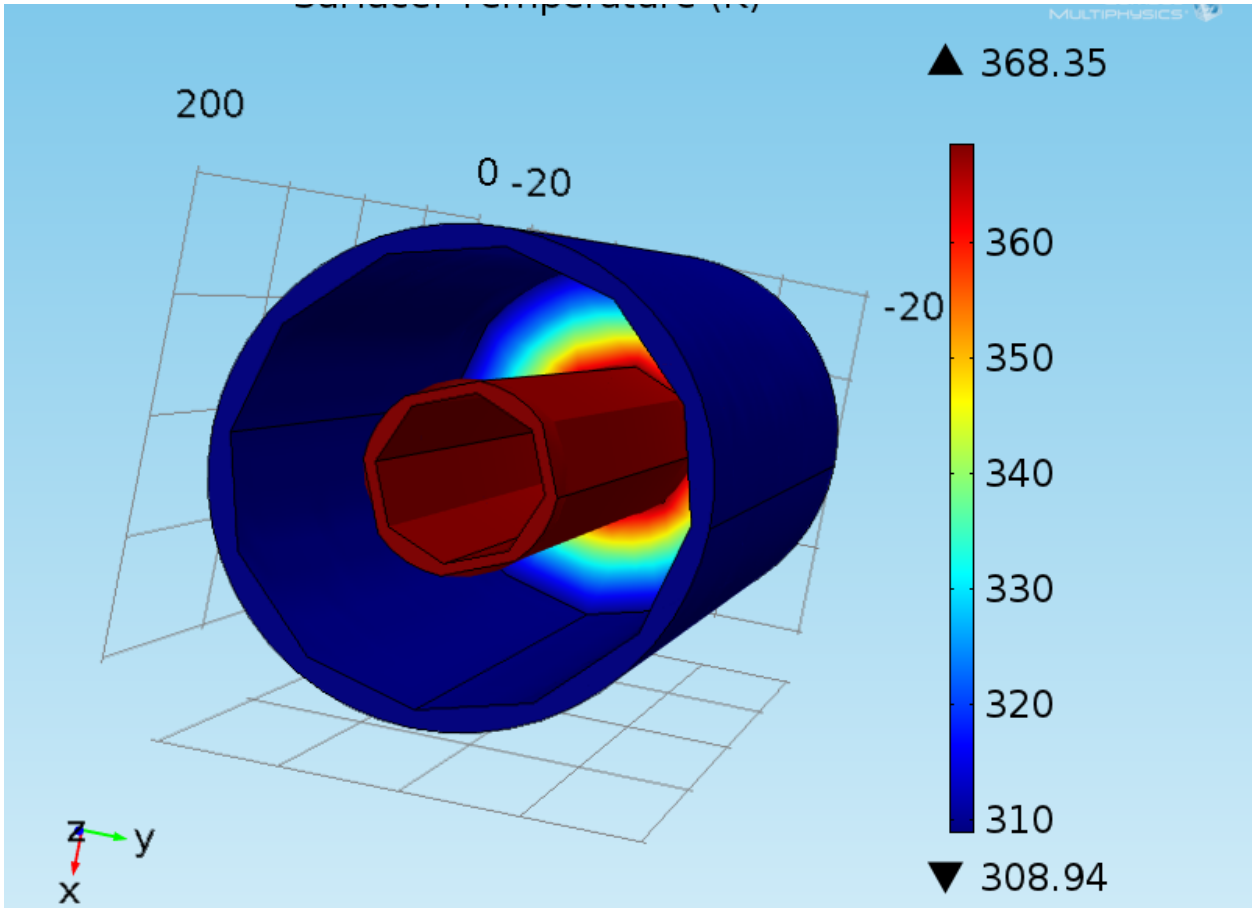
Pin: 10 kW

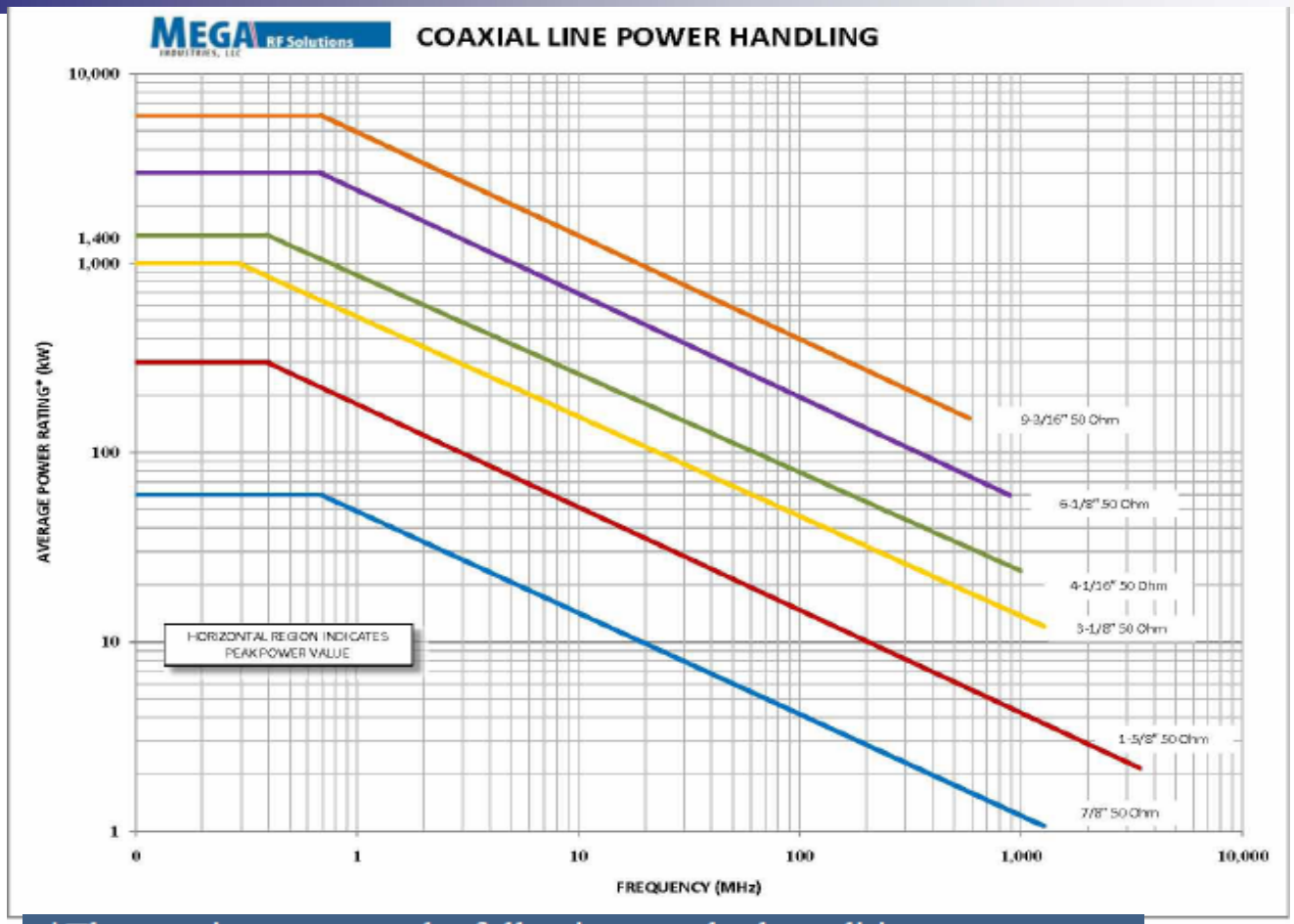
Freq. 350 MHz

Rel. Permittivity= 1.0001

Thermal conductivity : 0.2 W m/K

Loss tan. = 1E-7





*These ratings assume the following standard conditions: 40°C (104°F) Ambient Temperature, 100°C (212°C) Inner Conductor Temperature, VSWR 1.0:1, Dry Air @ Sea Level Atmospheric Pressure

1 5/8” line at 350 MHz will handle around 7.5 kW

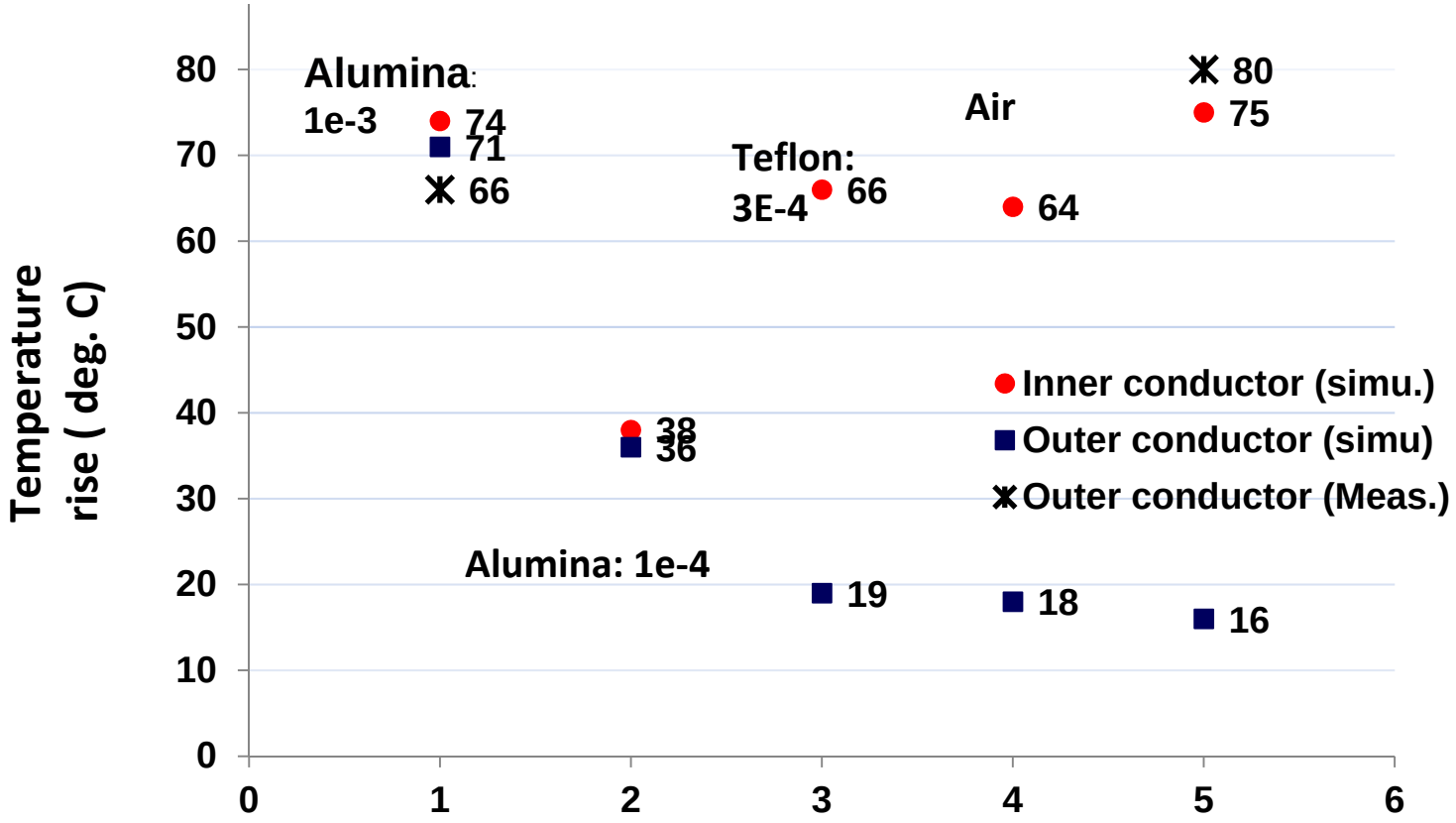
Ref. Mega Industries Ltd. catalogue

Coupler Fabrication and Testing status

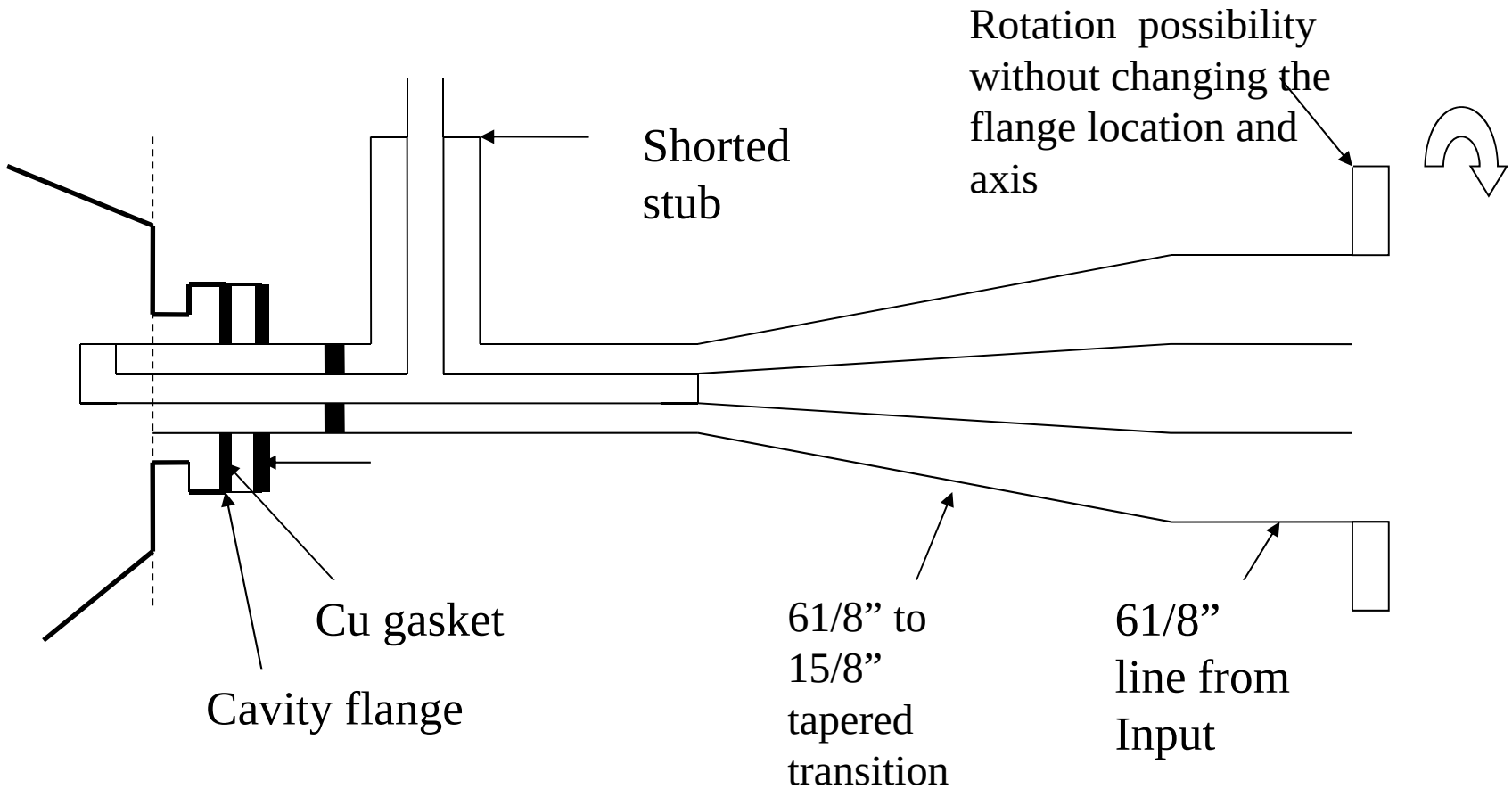
During RF tests at 15 kW, 350 MHz, 1% duty cycle, temperature rise of around 1 deg. C was observed on outer conductor. This is equivalent to 66 deg. C at 10 kW CW.

50 kW Peak power Coaxial coupler used during beam acceleration from RFQ

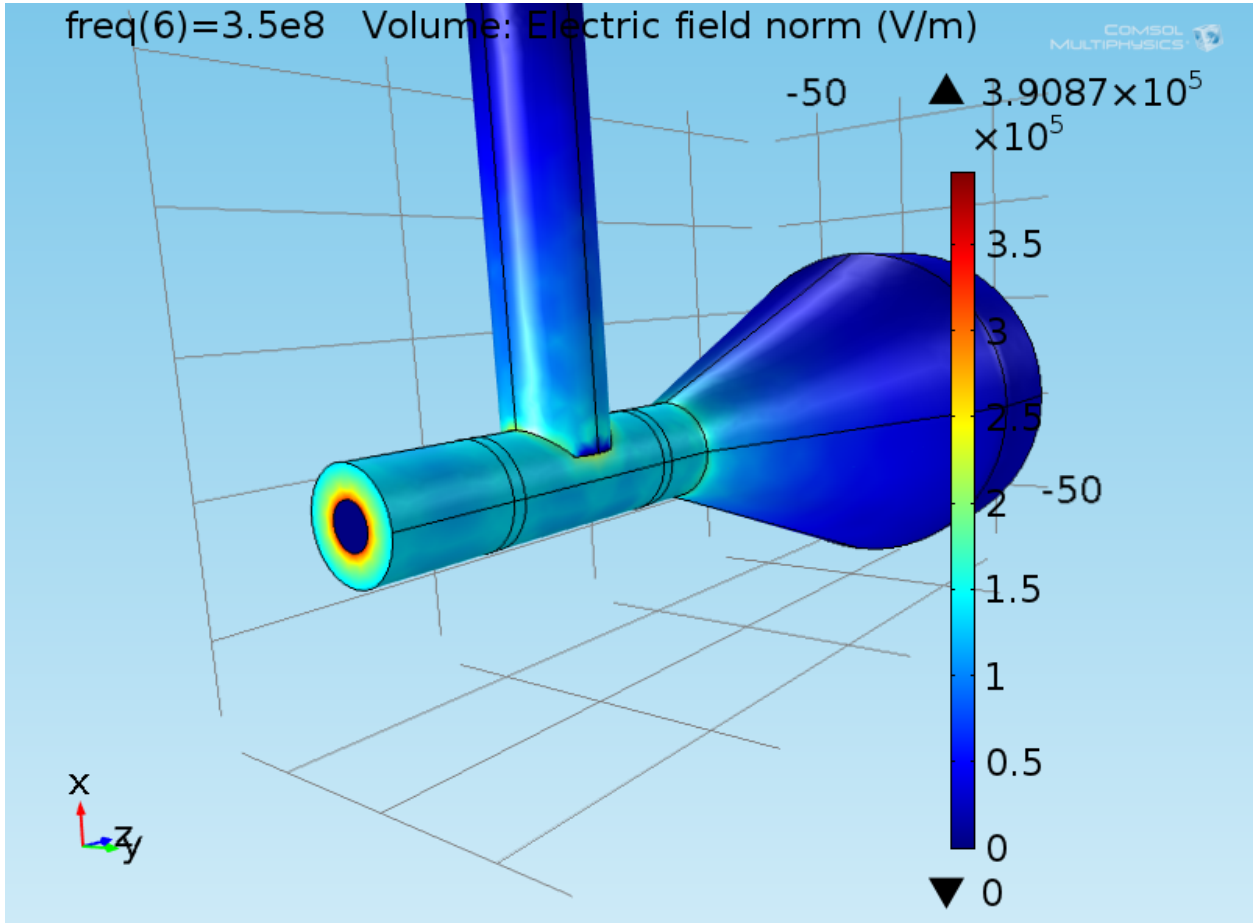
Comparison of simulation results for different window materials



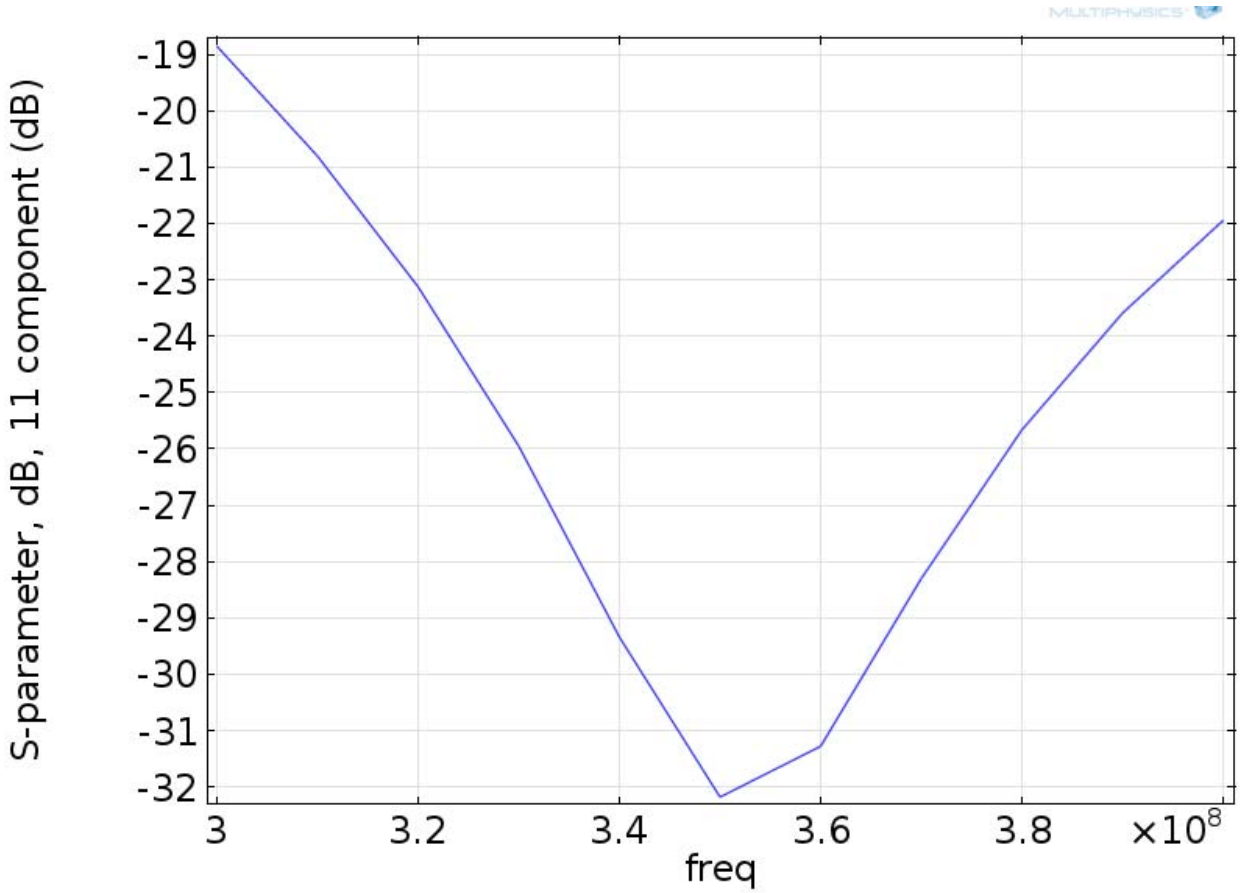
Schematic of 50 kW CW, 350 MHz Coaxial Coupler



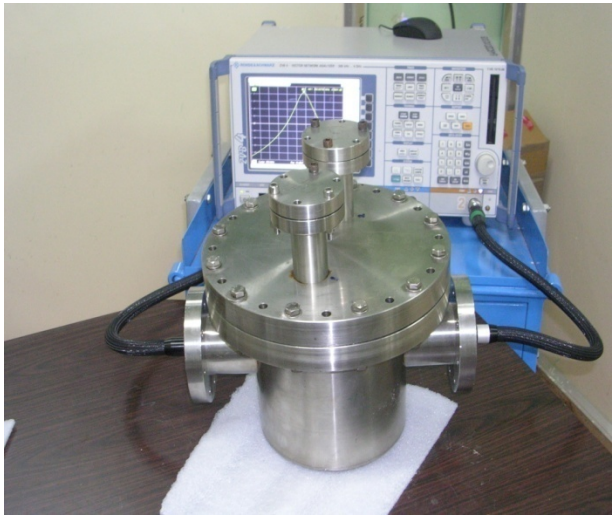
Simulations with COMSOL for E field



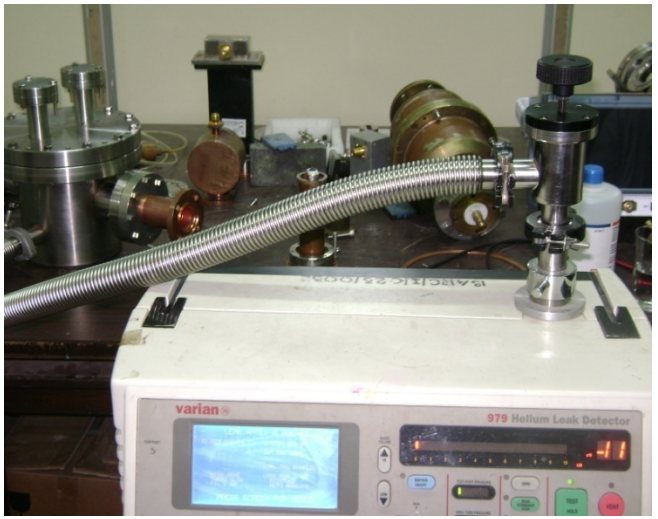
Return loss simulations



Testing with cavity

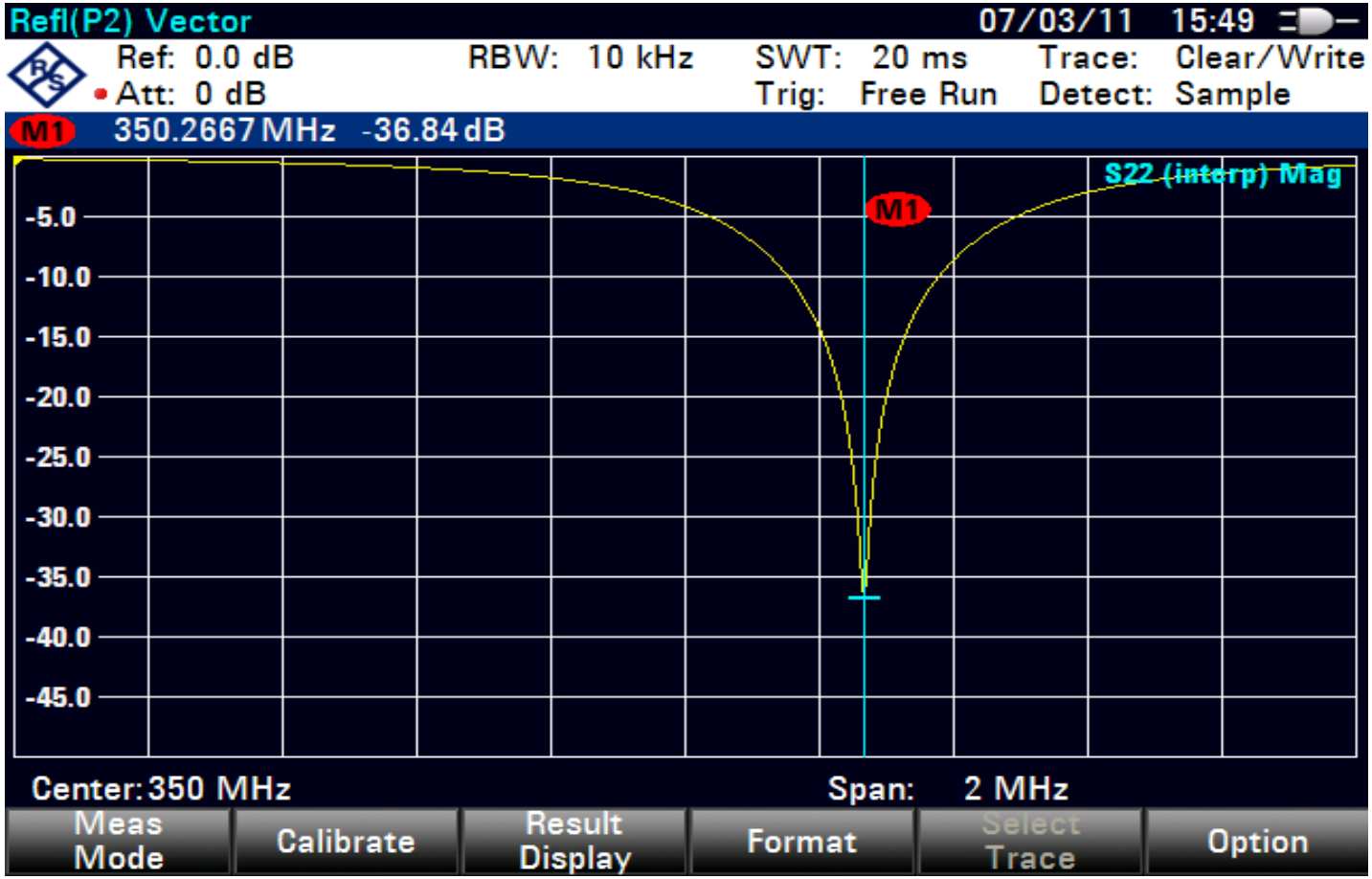


RF Cavity developed for Coaxial Coupler Conditioning

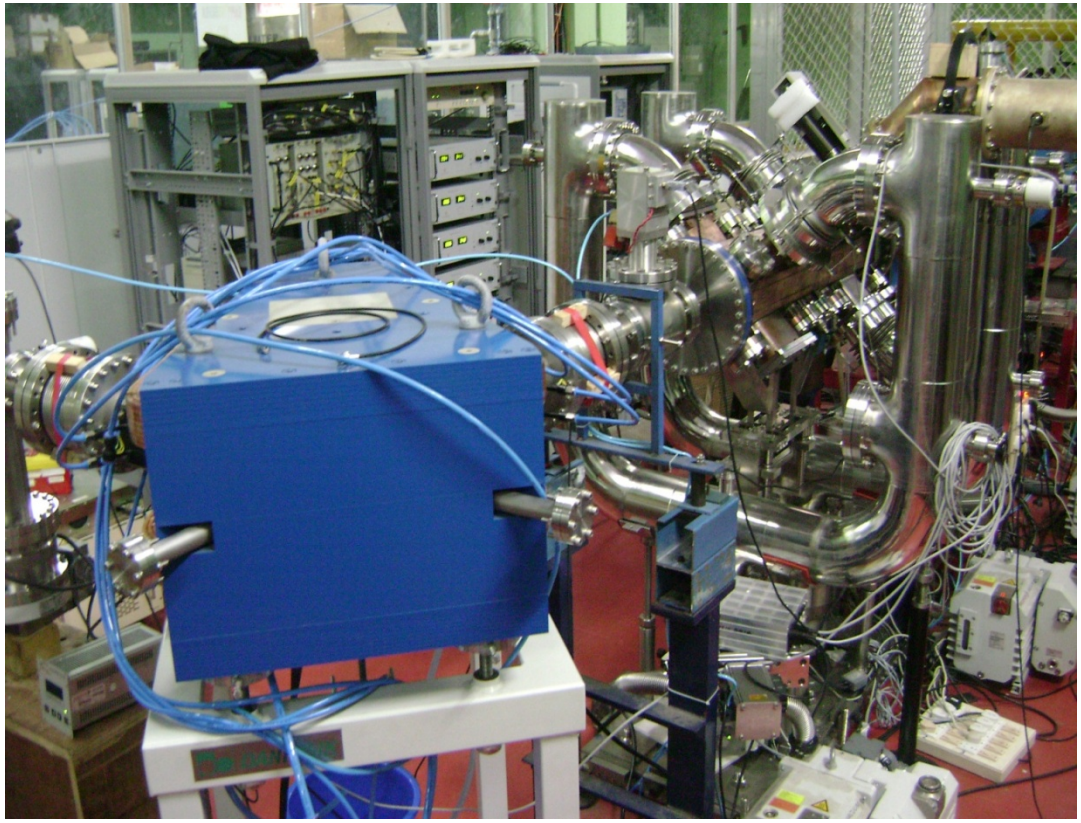


RF Coupler leak tested at LEHIPA, BARC

Return loss measurements under vacuum



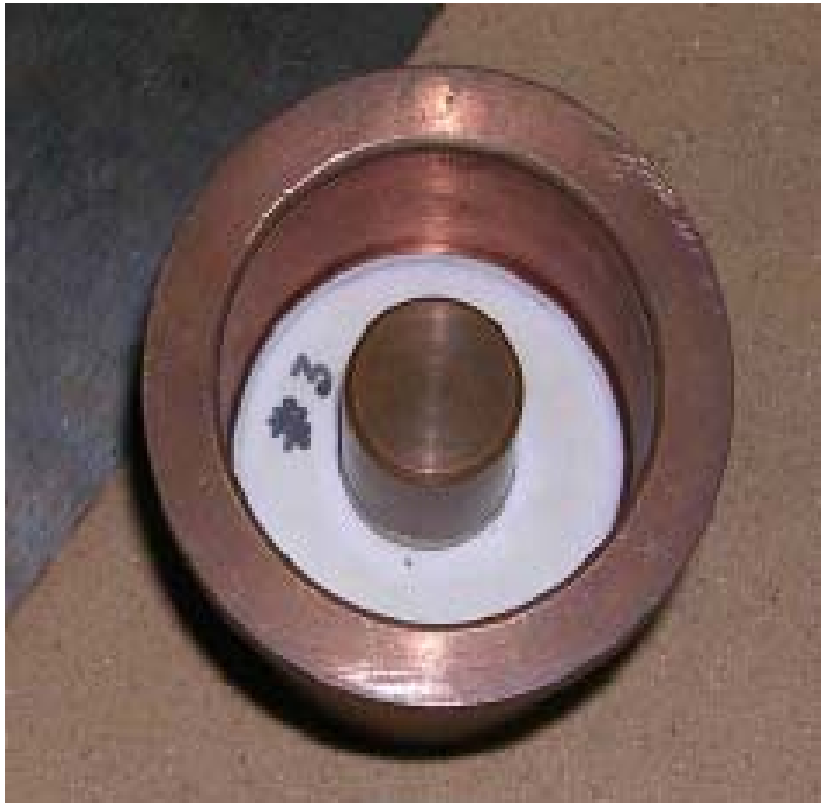
Coaxial Coupler feeding power to RFQ cavity



High power testing (up to 20 kW, 350 MHz RF power with 5 ms, 1 Hz RR) and beam acceleration from RFQ

- Coaxial coupler was also conditioned up to 50 kW, 350 MHz RF power with 5 ms, 1 Hz RR in SW mode on RF test bench
- During beam experiments, less than 0.5 % reflected power was observed from coupler-cavity system
- The RFQ-Coupler system could be conditioned up to 20 kW in about 48 Hrs. No serious multipacting levels were observed

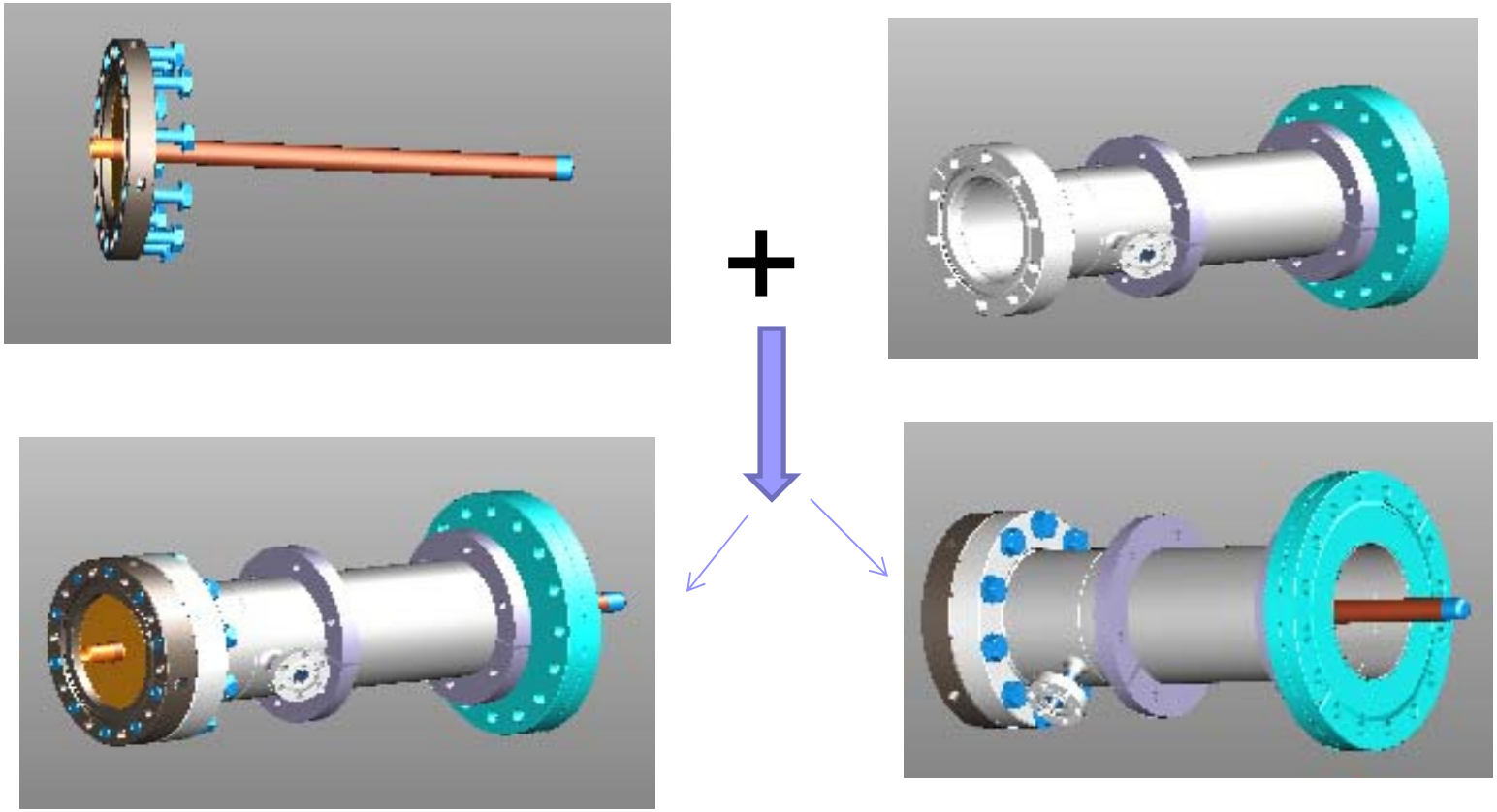
Fabrication issues in coaxial coupler development



50 kW coaxial coupler with coolant channels

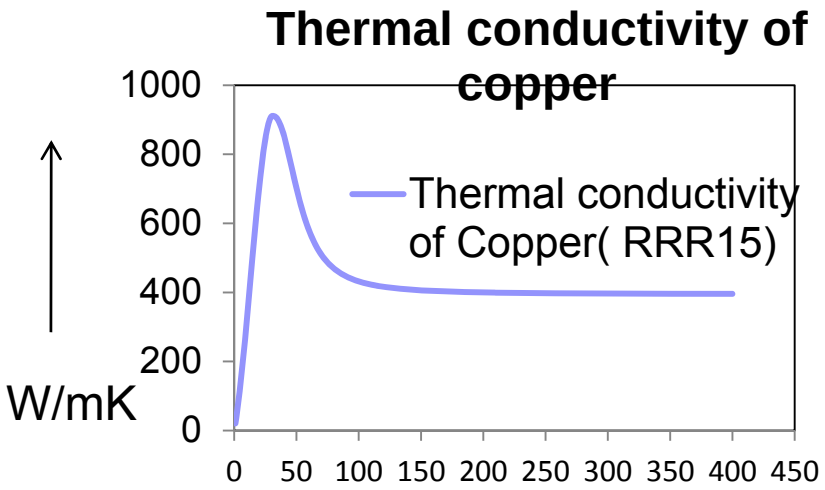
Coaxial couplers (50 kW, 350 MHz) after fabrication

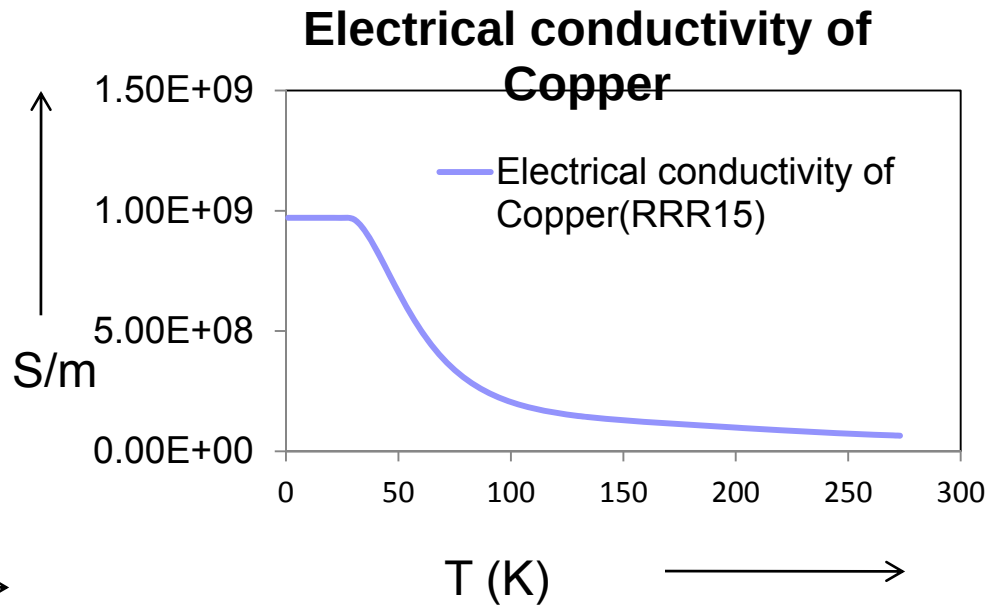
Thermal issues in Superconducting RF Couplers

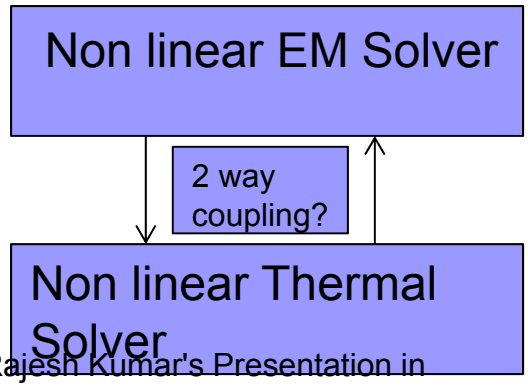


Temperature range spans from 2 K to room temperature

Non linearity in material conductivities







Future work for Coupled RF-Thermal analysis of RF Couplers

- More simulation studies (vacuum on one part and air on other) and temperature measurements at different power levels for 50 kW, 350 MHz peak power coupler

- Detailed RF-Thermal analysis of 50 kW, 350 MHz CW coupler with COMSOL multiphysics/RF Module/Microwave heating Module

- Coupled RF- Thermal analysis of waveguide couplers

- RF-Thermal Analysis of superconducting couplers with non linear conductivities as COMSOL is best suited for these studies

Thanks a lot!