C-band two-cell high-gradient RF cavity for high power HOM absorber testing

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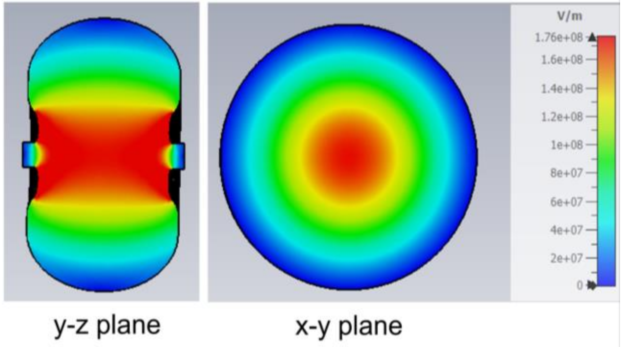
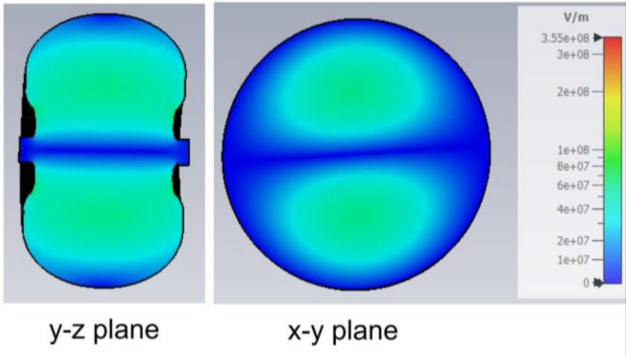
Higher-order modes damping

- Accelerator cell profile provided by SLAC and UCLA.
- Goal: reduction of quality factor and transverse kick-factor of monopole and dipole modes from 5 to 40 GHz.

TM_{010} fundamental mode at 5.712 GHz

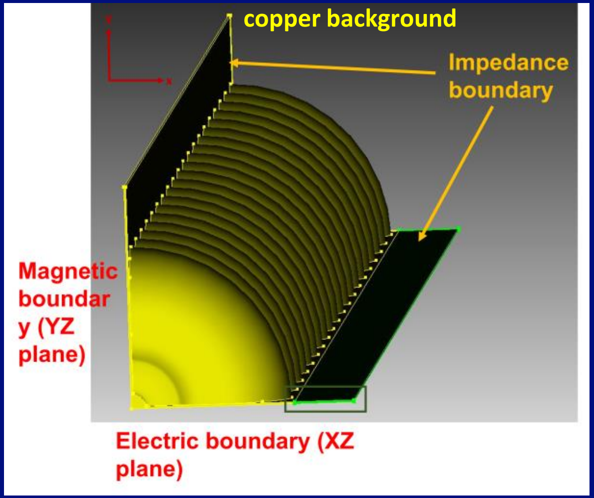


TM_{110} first dipole mode at 9.245 GHz

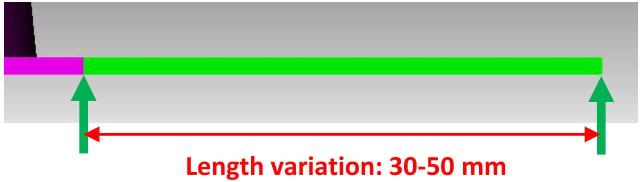


Higher-order modes damping

- Approach: HOM damping waveguides.
- Damping load: NiCr or SiC coating layer.
- 20-cell studies in CST and Omega3P.

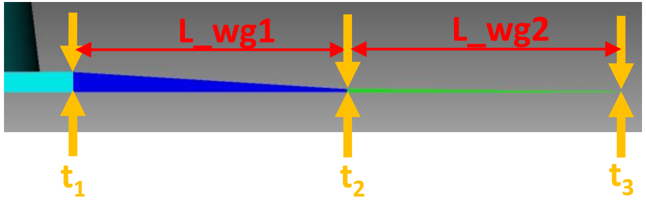


Design 1 – straight waveguide slot



Design 2 – one-section taper waveguide slot

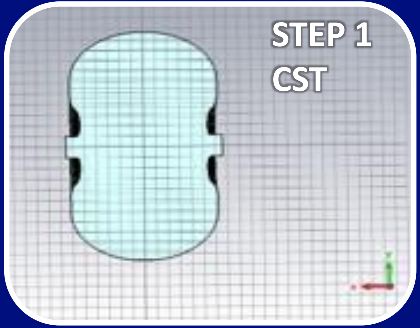
Design 3 – two-section taper waveguide slot

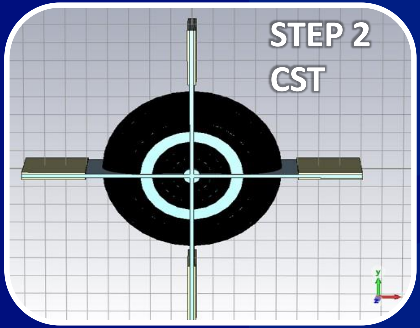


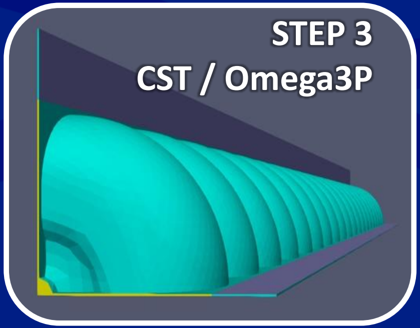
Higher-order modes damping study workflow

Single cell with periodic boundary

20-cell structure







Find all monopole and dipole modes over 5 - 40 GHz.

Compute ohmic Q-factor, shunt impedance, kick-factor.

Add waveguide slots with lossy material coating layers.

Compute ohmic Q-factor, shunt impedance, kick-factor, for modes identified in STEP 1.

Compute Q-factor × kick-factor.

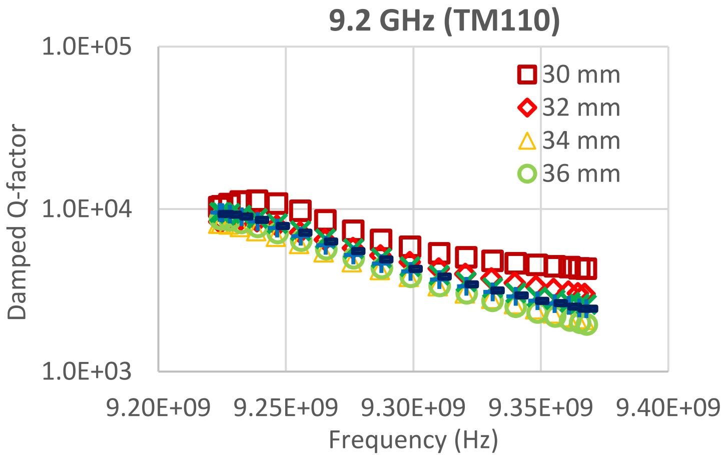
Setup waveguide slot with impedance boundary.

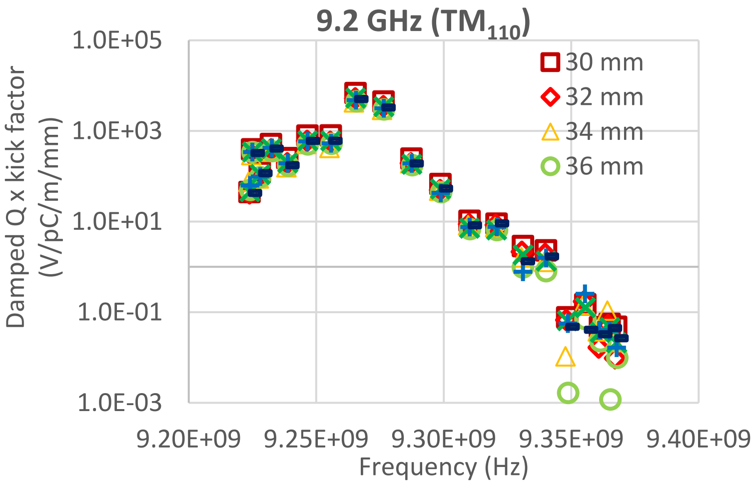
Compute ohmic Q-factor with damping, for modes identified in STEP 1.

Compute Q-factor × kick-factor.

Example: TM_{110} mode damping

- Undamped TM_{110} mode (9.2 GHz).
  - Q factor: 18150
  - Q × transverse kick factor: 5.72×10^4 V/pC/m/mm
- Damped TM_{110} mode in the individual cells of a 20-cell cavity.
  - With Design 1: straight waveguide slot.
  - SiC coating (1.0×10^2 S/m).





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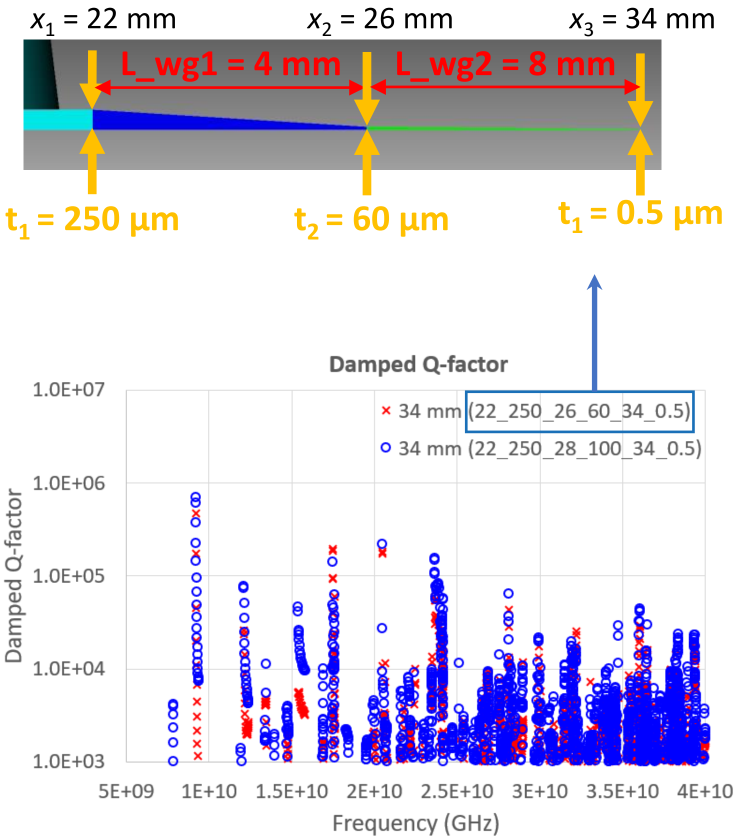
Current best-performing design

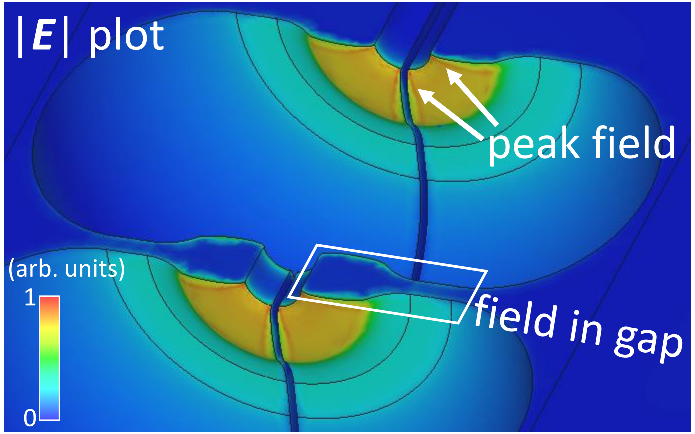
- Design 3 – two-section taper waveguide slot
  - NiCr coating (1.0×10^{6} S/m).
- Optimization setup.

Parameter	Value
Length of first w/g slot (L_wg1)	2 to 8 mm
Length of second w/g slot (L_wg2)	4 to 10 mm
Thickness of initial w/g (t_1)	0.25 mm (constant)
Thickness of 1st tapered (t_2)	20, 40, 60, 80 and 100 µm
Thickness of 2nd tapered (t_3)	0.5 µm



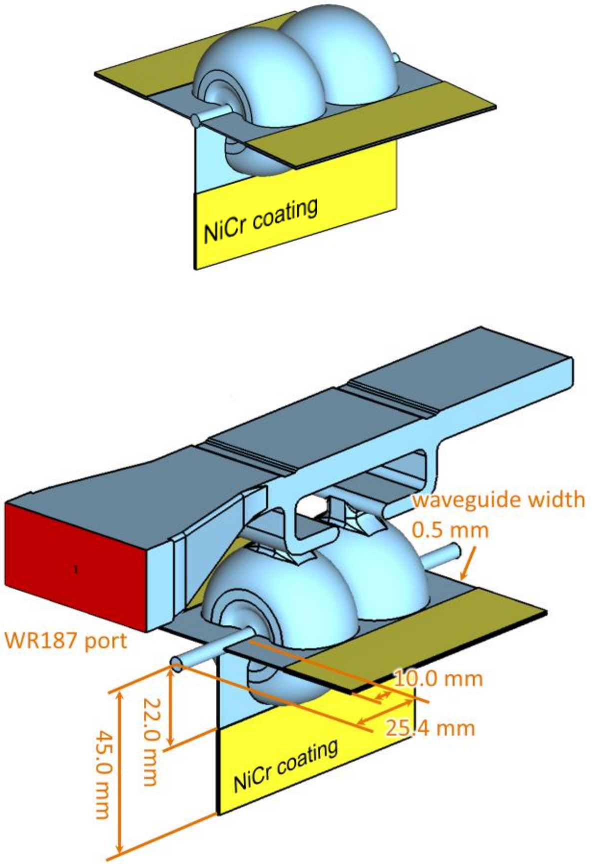
HOM absorber high power test

- NiCr (1.0×10^6 S/m) coating layers.
- RF design verification at high accelerating gradient (~100 MV/m)
  - Breakdown test
  - Multipactor detection
- Absorber performance vs. breakdowns.
  - Damage examination



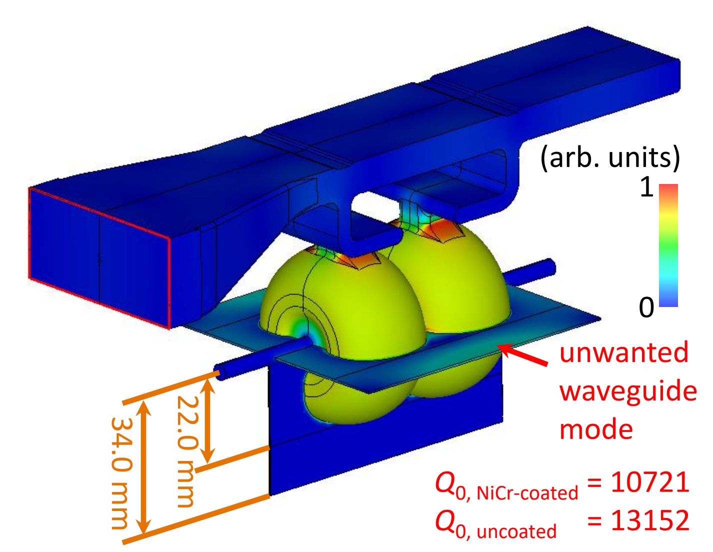
Two-cell cavity design

- π-mode operation, critical coupling.
- HOM damping: straight waveguide slot.
- HOM damping optimization.
  - Waveguide longitudinal extension length
  - Waveguide transverse sizes
    - Eigenmode optimization result: 34 mm & 50 mm
    - Finalized dimension: 45 mm

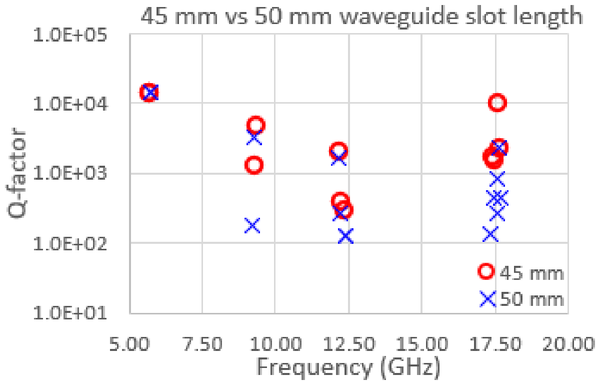


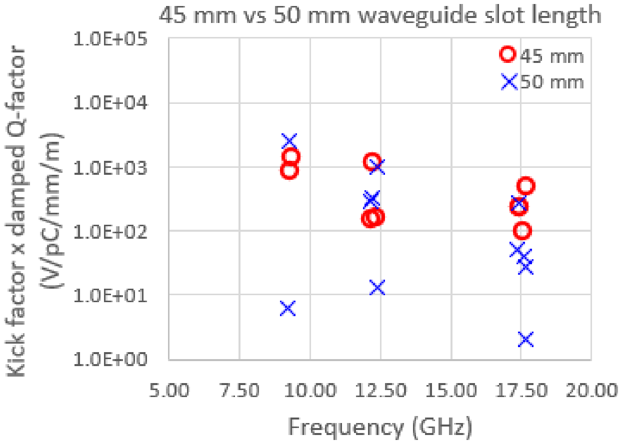
HOM damping waveguide transverse dimension

- Providing maximal damping of HOM.
- Rejecting additional parasitic modes introduced by the HOM damping waveguides.



Two-cell HOM simulation results

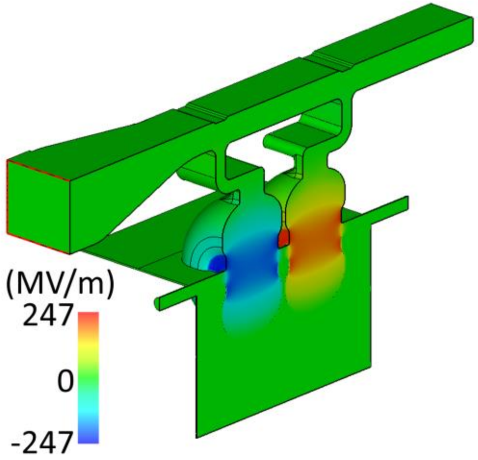


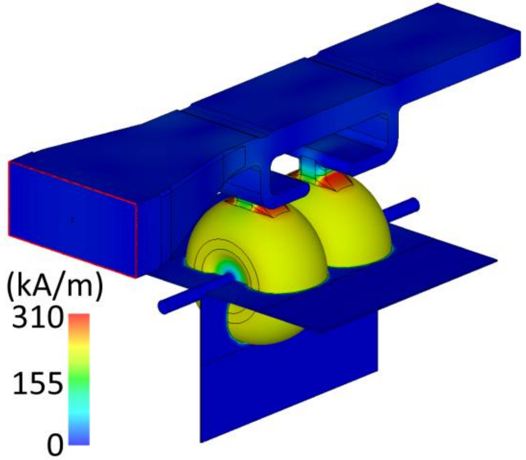


Two-cell cavity RF analysis

- 100-MV/m accelerating gradient.

Design parameters	
Operating frequency f_0	5.712 GHz
unit cell shunt impedance r_{sh}	118 MΩ/m
unloaded quality factor Q_0	13500
unloaded quality factor, no absorber $Q_{0,\ \mathrm{uncoated}}$	13525
Cavity coupling factor β	1.00
RF power for 100-MV/m gradient	4.4 MW
NiCr loss for 100-MV/m gradient	2.5 kW
NiCr average loss for 100-MV/m gradient, 1-µs pluse length, 100 Hz repetition rate	0.25 W
NiCr electrical conductivity	1.0×10^{6} S/m



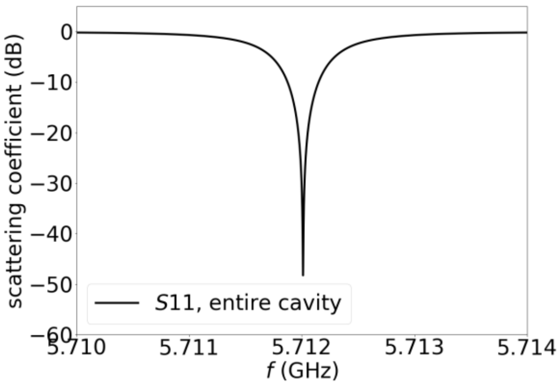


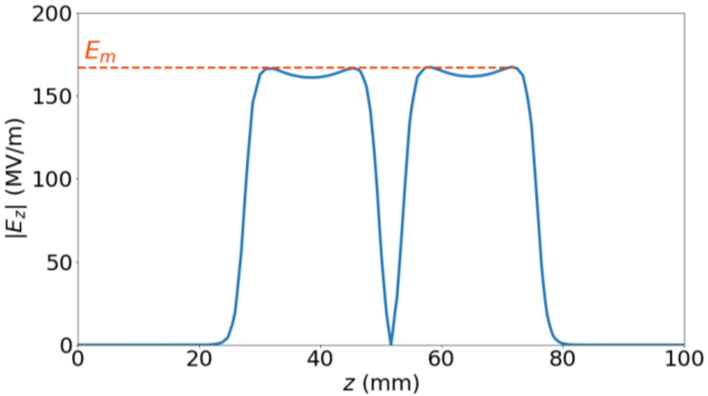
Two-cell cavity RF analysis

- Local peak E-field normalized to E_m.
- Local peak H-field normalized to (E_m/Z_0).
  - $Z_0 = 377\ \Omega$.

Electric field local peak values	
Cavity overall	1.48
Coupling slot	0.28
Waveguide	0.086

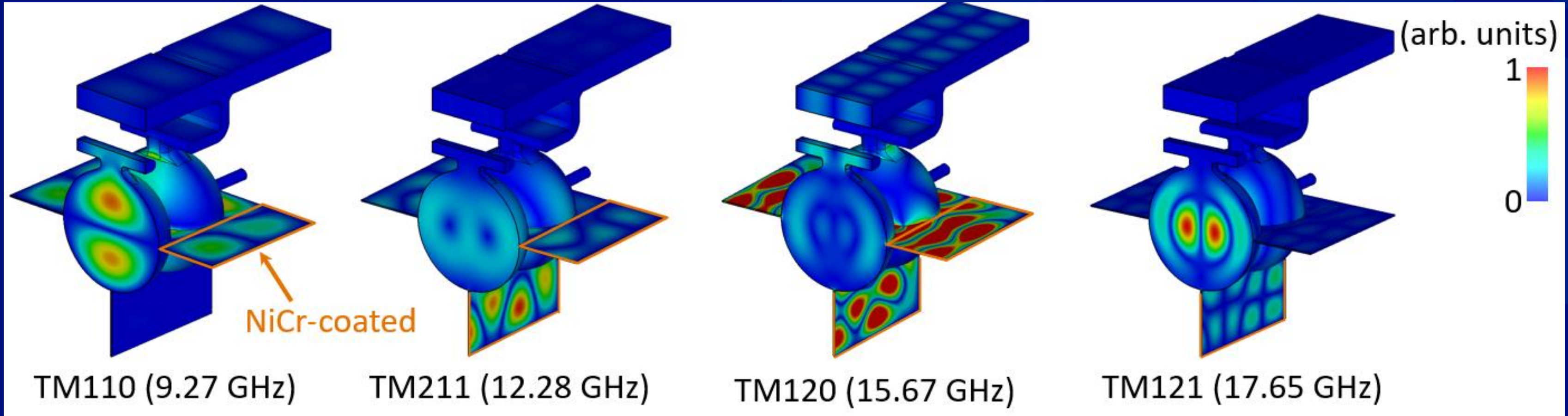
Magnetic field local peak values	
Coupling slot	0.70
Waveguide	0.075





Two-cell cavity HOM damping

- NiCr (1.0×10^6 S/m) coating layers
- HOM E-field magnitude distributions –



Fabrication and challenges

- OFHC copper cavity fabricated in quadrants, coated with NiCr layers, and then brazed together.
- Tuner design for quadrants.
- Machining error sensitivity.
  - 0.001-inch increase of the elliptical cell profile minor radius results in 5-MHz reduction in the cell resonant frequency.

Acknowledgments

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