Pacific Northwest
NATIONAL LABORATORY

2-4 GHz Slotted Cavity Prototype Simulations

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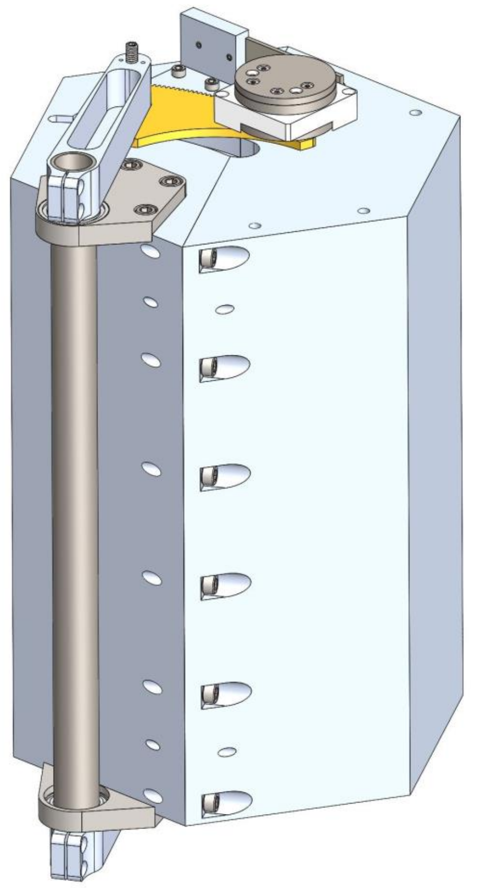
Overview of Slotted Cavity Prototype

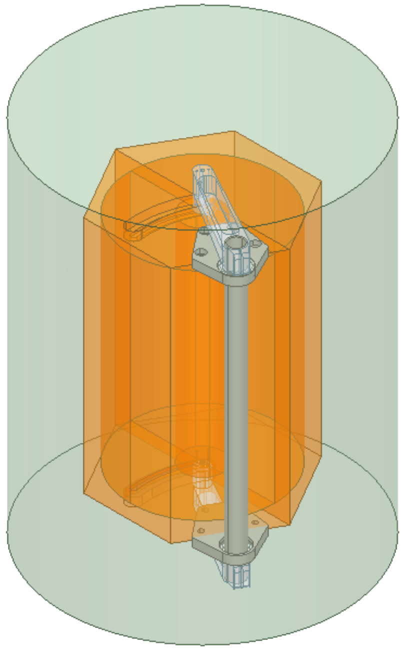
- Short 2-4 GHz prototype cavity assembly being fabricated at UF
- Cylindrical cavity formed from two clamshell halves
  - Diameter = 13 cm
  - Length = 19.558 cm
  - Tuning rod diameter = 3.5 cm
- Tuning concept uses slotted ends similar to 2A design with sapphire pins
- 0.007” gap at ends of tuning rod
- EM simulations needed to evaluate field leakage and comparison with measurements

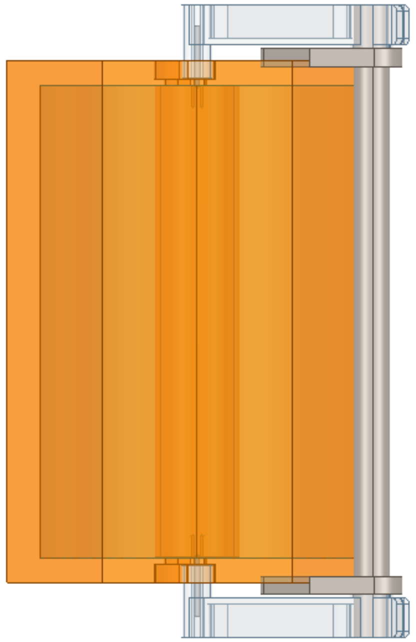


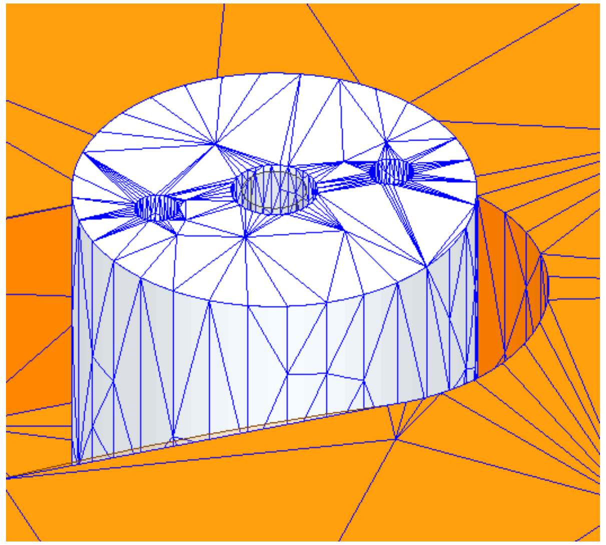
SolidWorks model of 2-4 GHz slotted cavity prototype

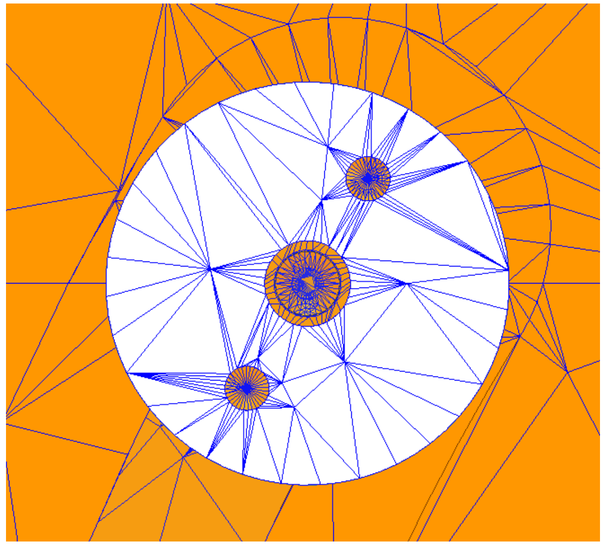
HFSS Simulations of Slotted Cavity Prototype

- Imported from Solidworks model
  - Defeatured to remove unneeded geometry such as fastener holes
  - Tuning rod located in center of cavity
- Cavity inside larger air-filled cylindrical volume with 377 Ohms/sq impedance boundary assigned to outer surfaces
  - Allows prediction of radiation leakage from cavity into larger air volume
- Used eigenmode solver with curvilinear mesh elements and mesh operation to enforce 32 segments around circumference of curved objects
- Parameterized rotation of tuning rod using theta angle









32-segment mesh

V1 Cavity: Tuning Rod At Center

- Investigated conductivity cases for center-positioned tuning rod

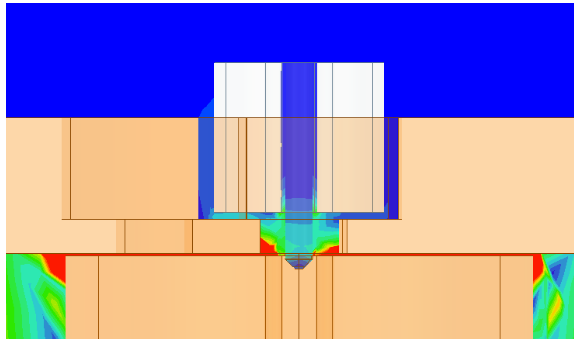
Index	Simulation Model Description	Conductivity (S/m)	Frequency (GHz)	Unloaded Q-factor	Form Factor
1	Sealed simple cavity, copper	5.8E7	3.096	16,475	0.78
2	Slotted clamshell, copper	5.8E7	3.097	15,484	0.78
3	Slotted clamshell, copper, simple external arm	5.8E7	3.097	15,363	0.78
4	Slotted clamshell, ASE copper, simple external arm	2.15E9	3.097	76,176	0.78
5	Slotted clamshell, superconducting cavity and rod, simple external arm	Inf	3.097	328,575	0.78
6	Slotted clamshell, superconducting cavity, simple external arm	Inf	3.097	125,014	0.78
7	Slotted clamshell, superconducting rod, simple external arm	Inf	3.097	113,730	0.78

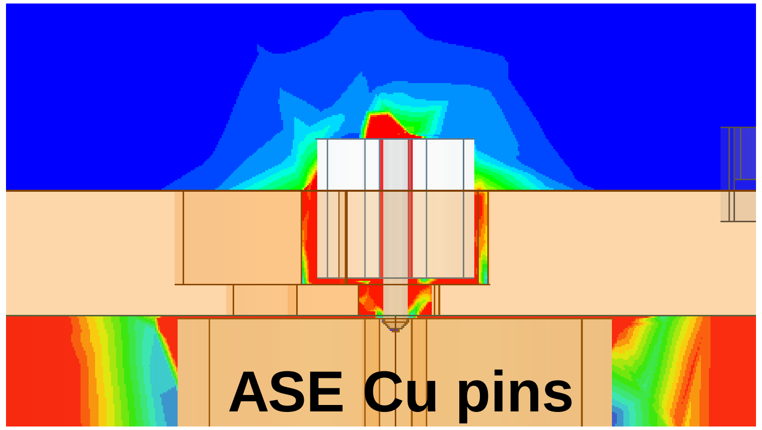
V1 Cavity: Sapphire vs Copper Tuning Rod Pins

- Compared sapphire and ASE copper tuning rod pins
  - Conductive pins reduced Qu by 40% and produced more field leakage outside cavity
- Sapphire pins worked significantly better than conductive pins in previous experiments

Simulation Model Description	Frequency (GHz)	Unloaded Q-factor	Form Factor
Slotted clamshell, ASE copper cavity and tuning rod, simple external arm, 32-segment mesh, ***sapphire pins***	3.097	74,472	0.78
Slotted clamshell, ASE copper cavity and tuning rod, simple external arm, 32-segment mesh, ***ASE copper pins***	3.096	45,512	0.78

Sapphire pins





V1 Cavity Model

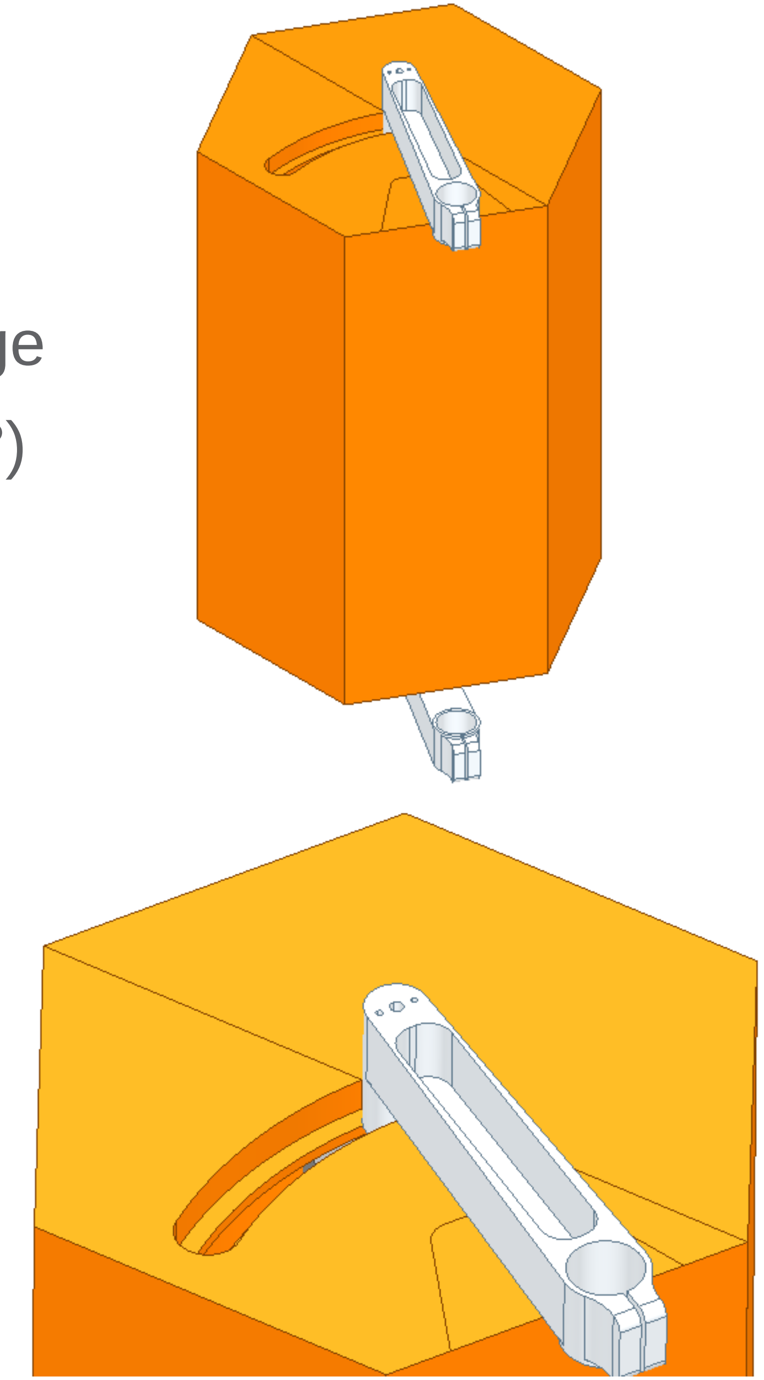
- V1 compares well with ideal sealed cavity for much of tuning range
- Significantly lower Q-factor when tuning rod is at wall (theta = 33°)

Theta angle (deg)	Frequency (GHz)	Unloaded Q-factor
0	3.097	15,579
5	2.889	15,691
10	2.648	18,224
15	2.449	19,299
20	2.288	20,964
25	2.156	21,170
30	2.049	22,260
31	2.030	19,884
32	2.012	17,534
33	1.996	**9,036**

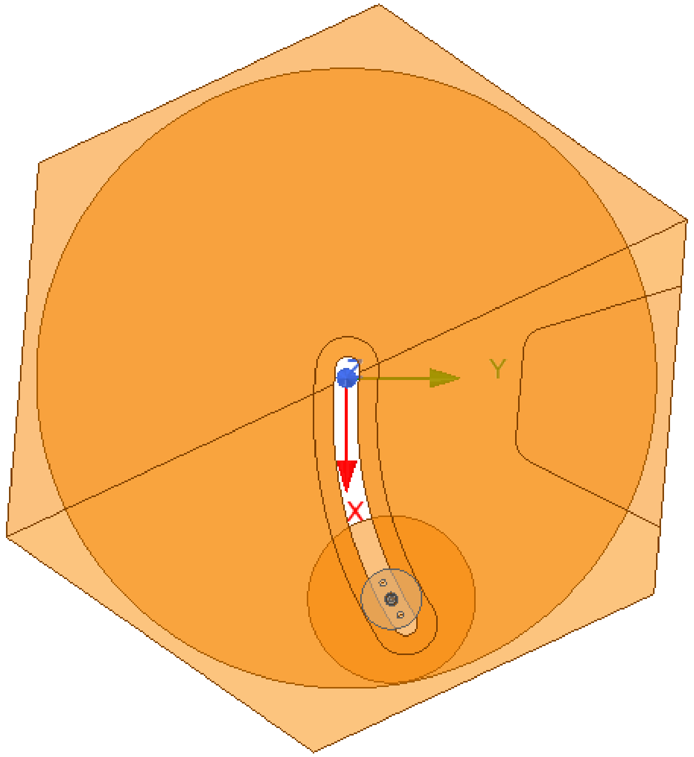
V1 cavity model

Theta angle (deg)	Frequency (GHz)	Unloaded Q-factor
0	3.097	16,500
5	2.889	16,938
10	2.648	18,548
15	2.449	19,962
20	2.288	21,495
25	2.156	22,779
30	2.049	24,185
31	2.030	24,483
32	2.012	24,786
33	1.996	17,576

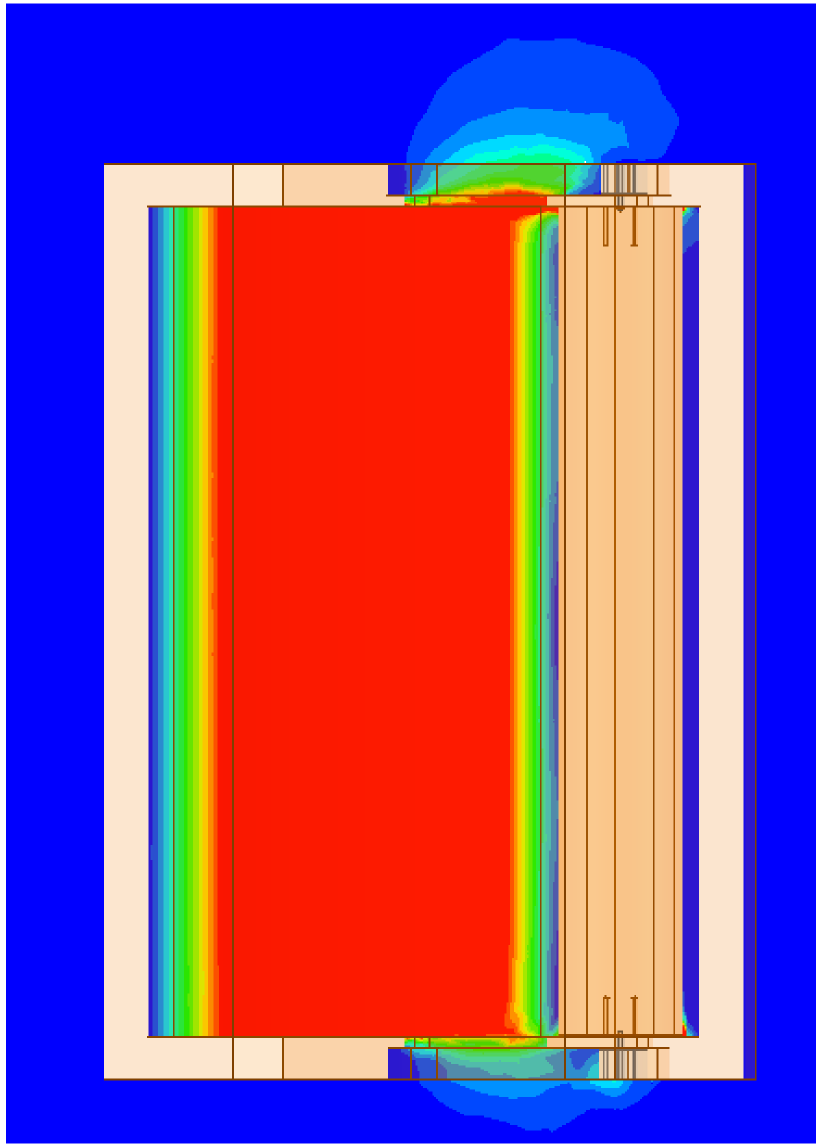
Ideal sealed cavity



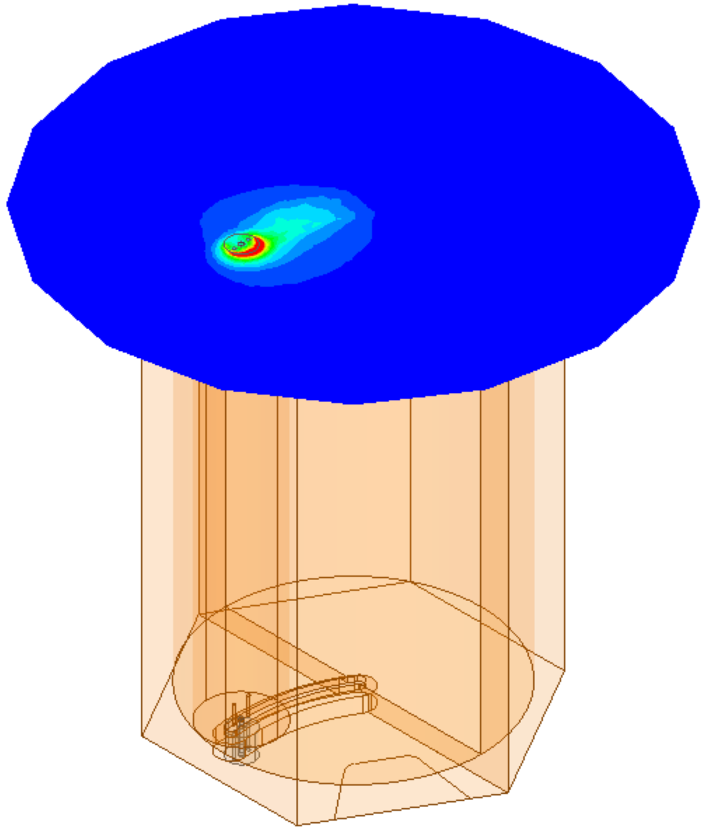
V1 Cavity: Field Leakage with Tuning Rod at Wall



Top view showing location of XZ plane aligned with slot opening



Electric field in XZ plane shown on left



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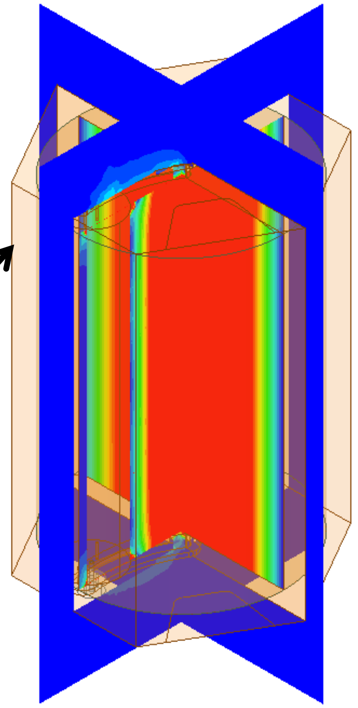
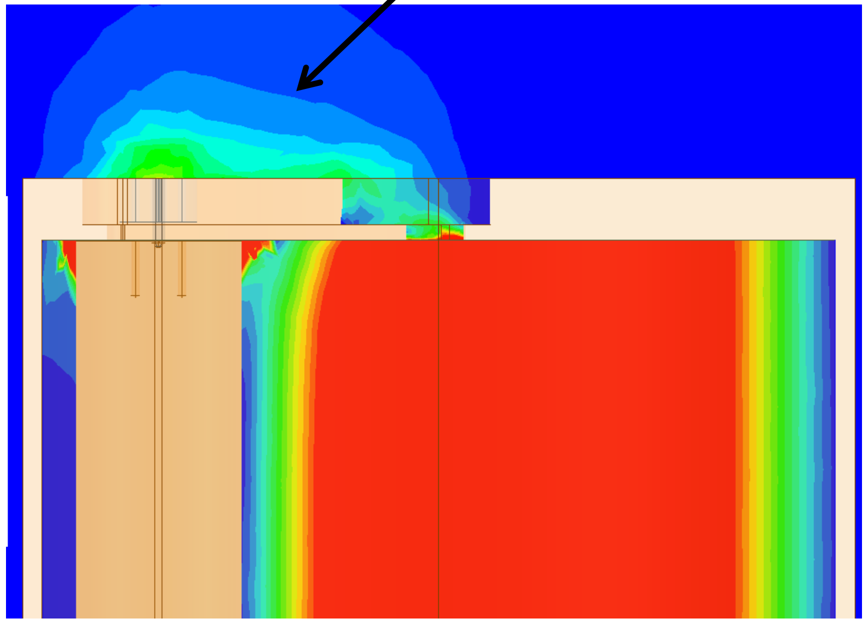
V1 Cavity: Thicker Slot with Tuning Rod at Wall

- Thicker slot wall reduces E-field leakage
- Increases Q-factor, but still lower than desired

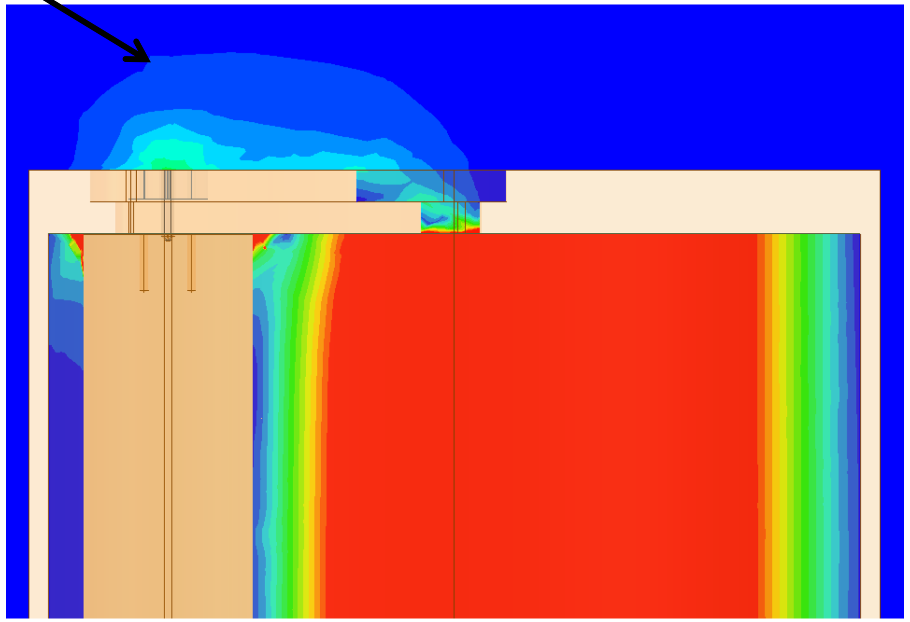
E-field leakage

Vertical cutplane shown below

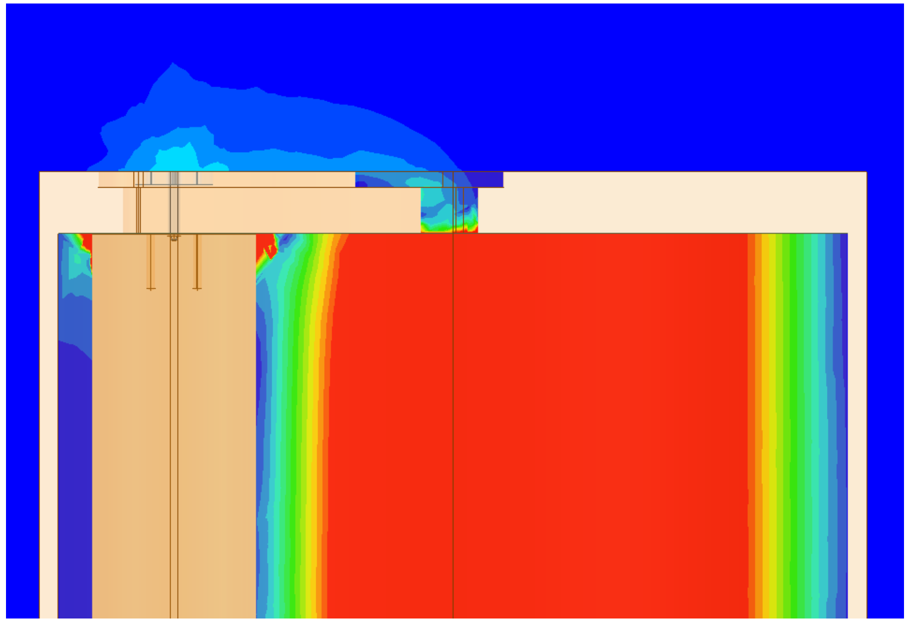




2.54 mm slot thickness (baseline)



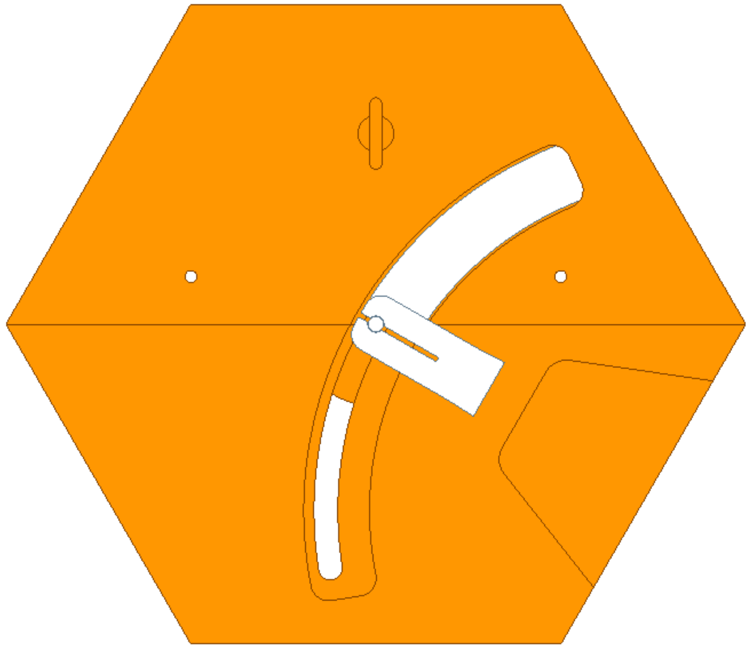
5.08 mm slot thickness

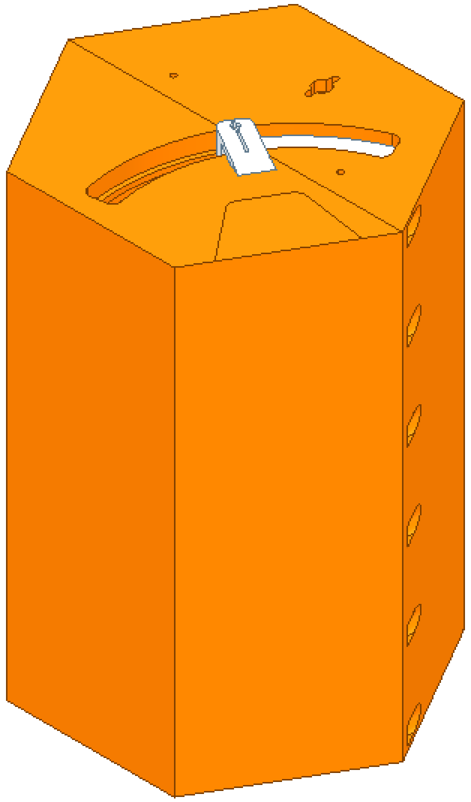


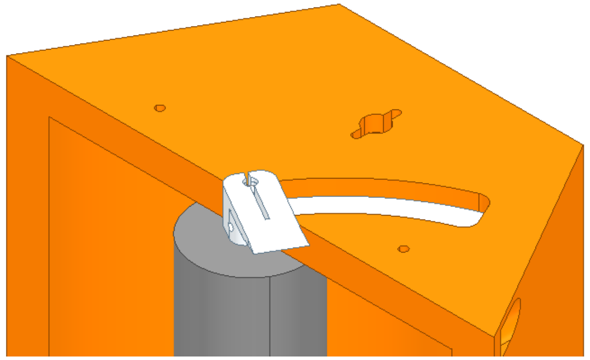
7.62 mm slot thickness

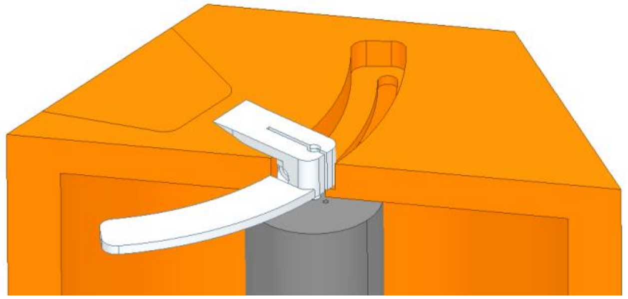
V2 Cavity Design

- Tuning armature changed to flexture clamp for sapphire pins
  - Sapphire pins are larger
  - Center of rotation is different
- Slots in v1 and v2 are notionally the same
  - Tuning arm channel is extended to other clamshell to provide space for slot cover but there is no slot in that half
  - Slot symmetrically located in channel in V1 and offset in V2
- V2 cavity has 3 small antenna ports
- Solidworks model significantly defeatured for EM simulation







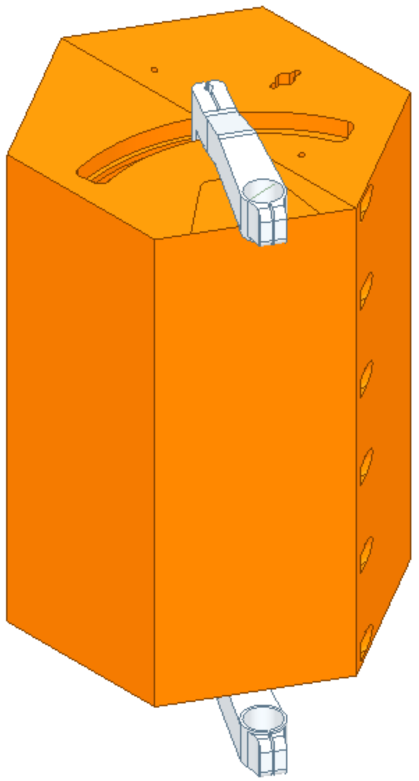


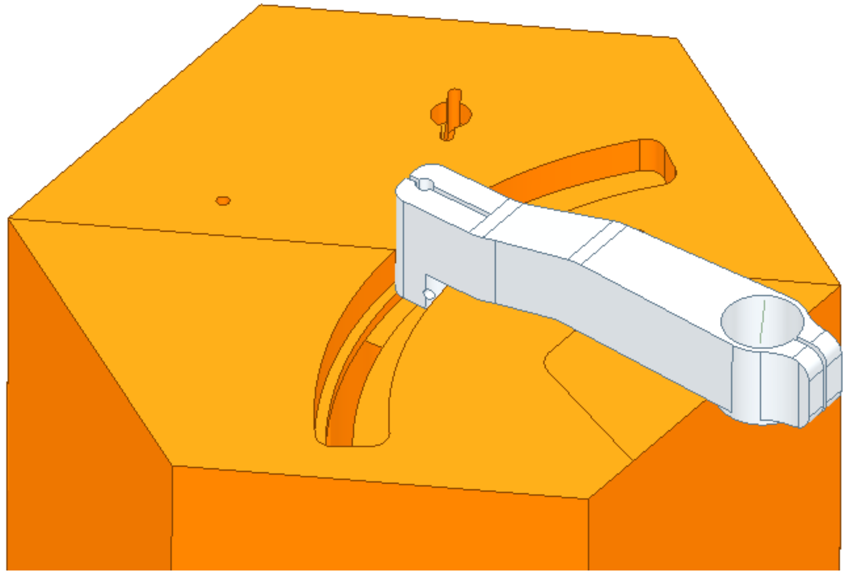
V2 Cavity: No Slot Covers

- Model shows good performance with somewhat lower Q-factor at 30°
- At this angle, a TE mode (Qu ~1,000) is within 3 MHz

Theta angle (deg)	Frequency (GHz)	Unloaded Q-factor
0	3.097	15,440
5	2.901	16,493
10	2.668	18,112
15	2.474	19,333
20	2.315	20,425
25	2.184	21,337
30	2.077	17,018
32	2.039	21,127
34.5	1.997	22,986

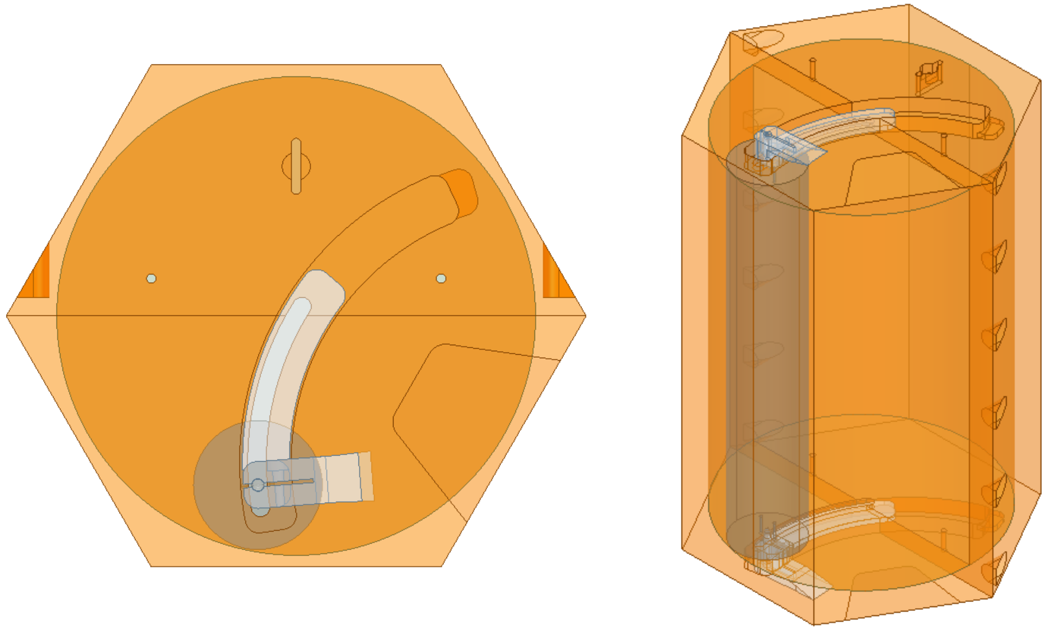
V2 cavity model without slot covers





V2 Cavity: Tuning Rod at Wall

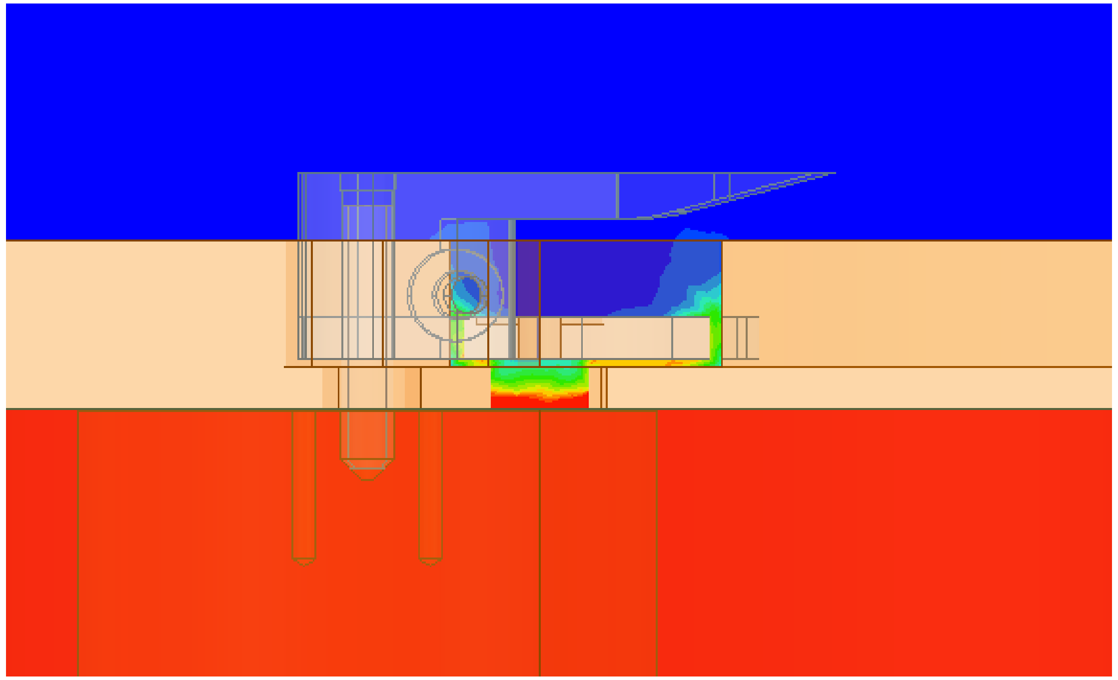
- Tuning rod angle 34.5°
  - ~0.42mm between rod and wall
- Slot covers significantly reduce Q-factor (to approximately half)



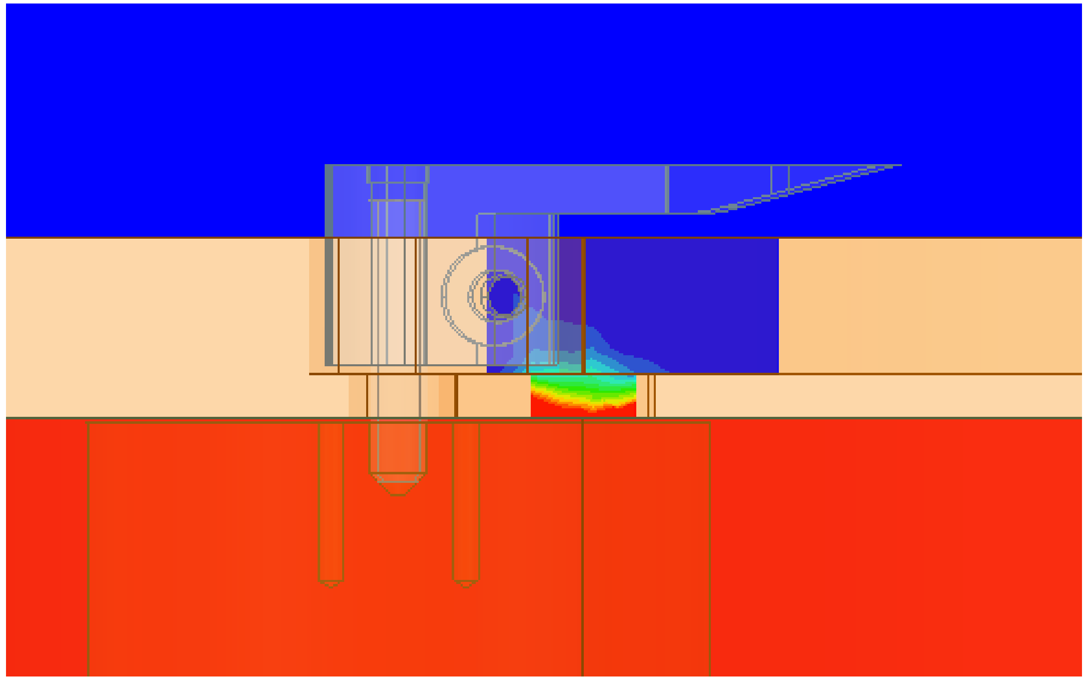
Index	Simulation Model Description	Tuning Rod Location	Frequency (GHz)	Unloaded Q-factor
1	Copper slotted clamshell, copper slot covers	Cavity wall	1.997	11,206
2	Copper slotted clamshell, no slot covers	Cavity wall	1.997	23,183

V2 Cavity: Tuning Rod at Wall

- Cavity with slot covers has higher E-field outside cavity volume
- Electric field plots show capacitive coupling produced by slot covers



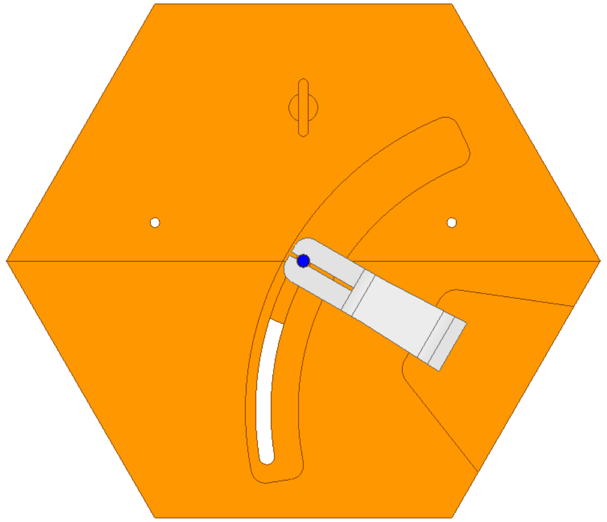
V2 cavity with slot covers

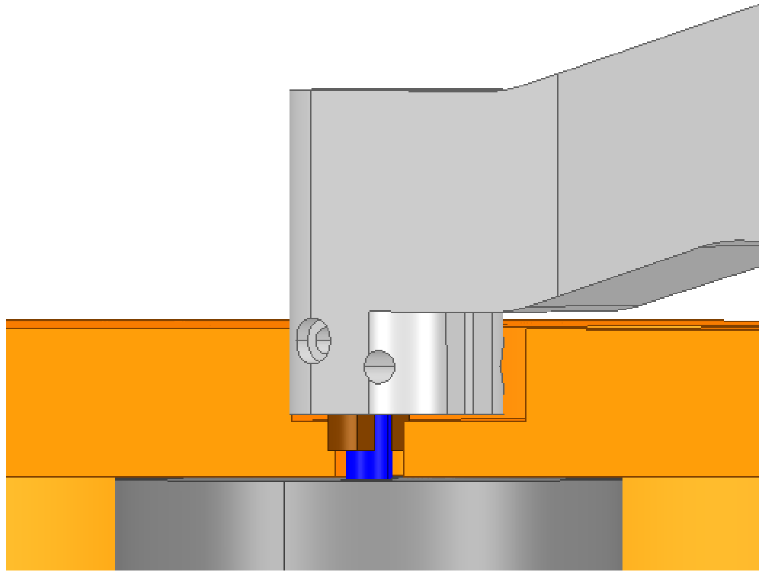


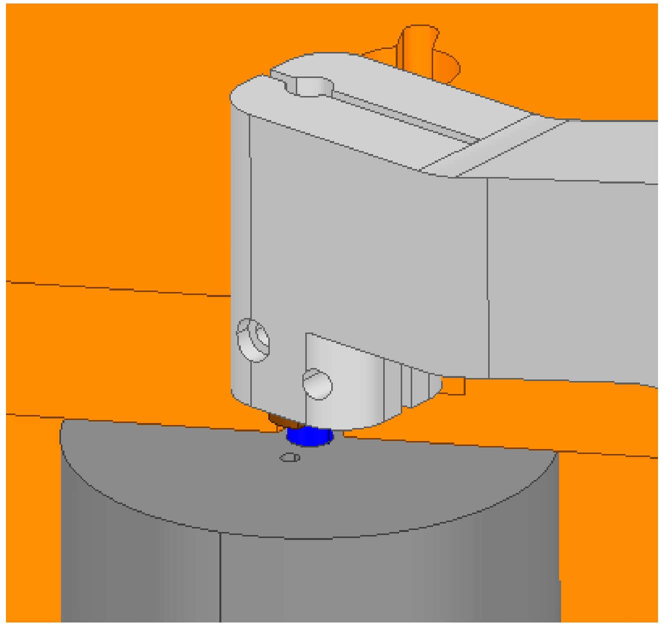
V2 cavity without slot covers

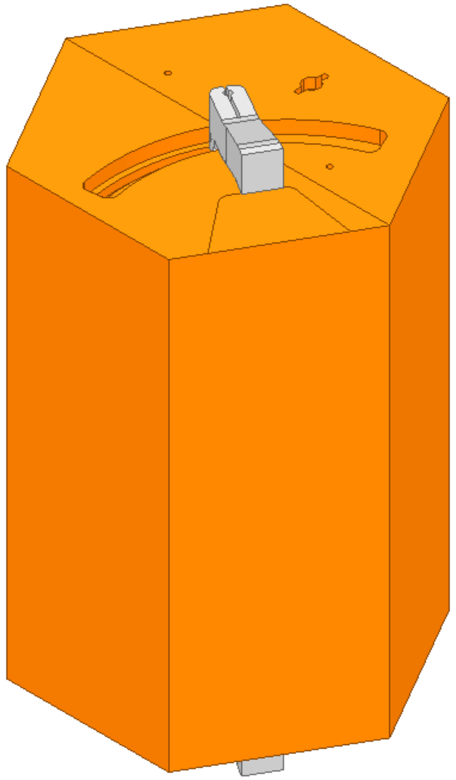
V3 Cavity Design

- Tuning pins held by cylindrical collets (PEEK or Aluminum)
- Slots are slightly deeper (from 2.54 mm to 3.81 mm)
- Clearance slots for tuning arm are correspondingly shallower







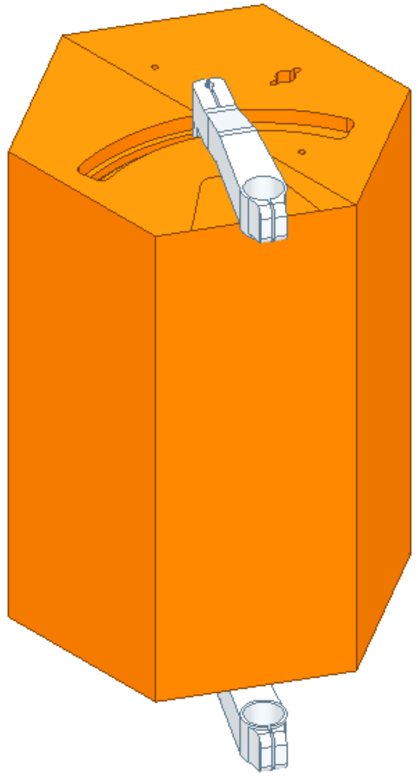


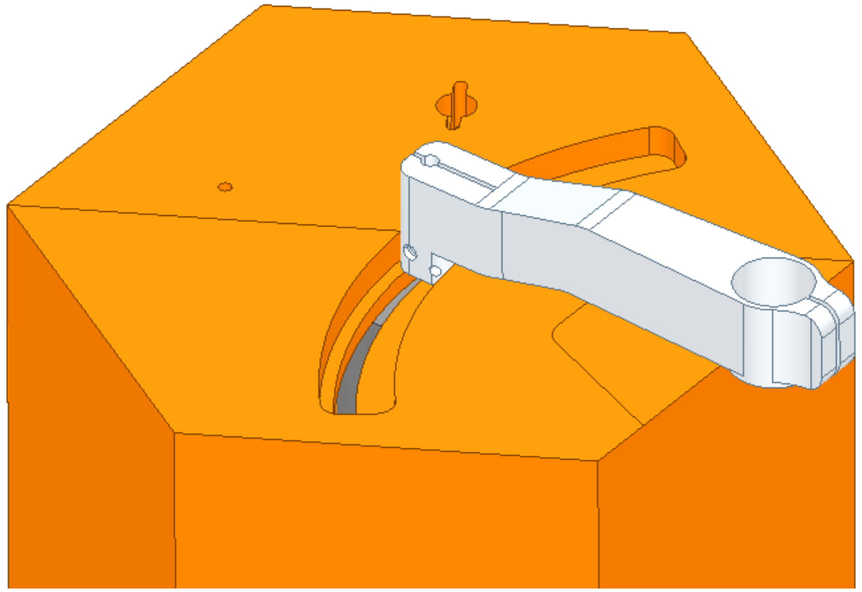
V3 Cavity Model

- Model results similar to V2 design, also somewhat lower Q-factor at 30°
- At this angle, a TE mode (Qu ~3,500) is within 3 MHz

Theta angle (deg)	Frequency (GHz)	Unloaded Q-factor
0	3.097	15,918
5	2.901	16,594
10	2.668	18,079
15	2.474	19,516
20	2.315	20,748
25	2.184	21,841
30	2.077	15,052
32	2.039	20,852
34.5	1.997	23,577

V3 cavity model w/ PEEK collets





Summary

- Simulated 3 iterations of new 2-4 GHz slotted clamshell cavity design
- V1 design
  - Used to compare range of surface conductivities
  - Used to examine field leakage due to conductive tuning rod pins
  - Results compared well with ideal sealed cavity except when rod is at wall (near 2 GHz)
  - Thicker slot walls reduced field leakage and improved Q-factor
- V2 design
  - Results compared well with ideal cavity but with smaller Q-factor near 2.1 GHz
  - Qu ~17k possibly due to TE mode mixing
  - Slot covers produced field leakage and reduced Q-factor when rod is at wall
- V3 design
  - Results very similar to V2 design with same lower Q-factor near 2.1 GHz
  - Dielectric and conductive tuning pin collets gave similar results
- Next steps
  - Validate HFSS simulation results with COMSOL
  - Create mode map to fully examine performance
  - Model 3-4 GHz tuning range with different tuning rod diameter