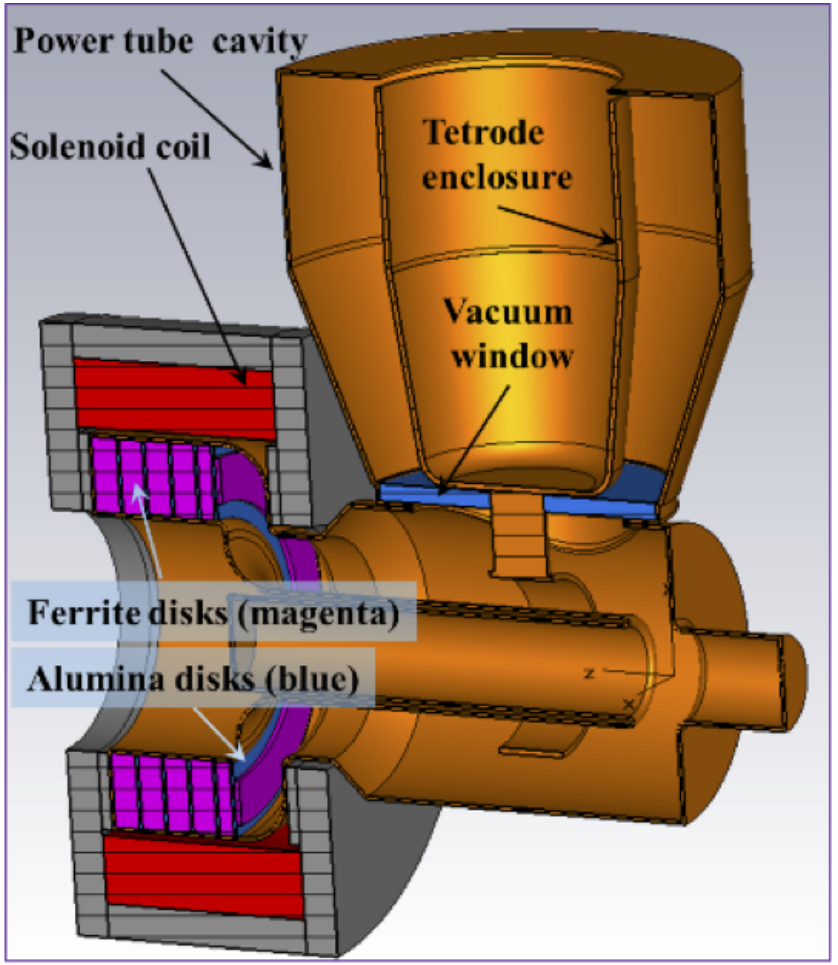
2nd Harmonic Cavity Update

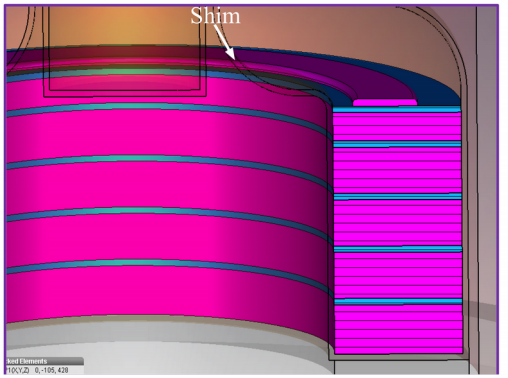
C.Y. Tan
13 April 2016

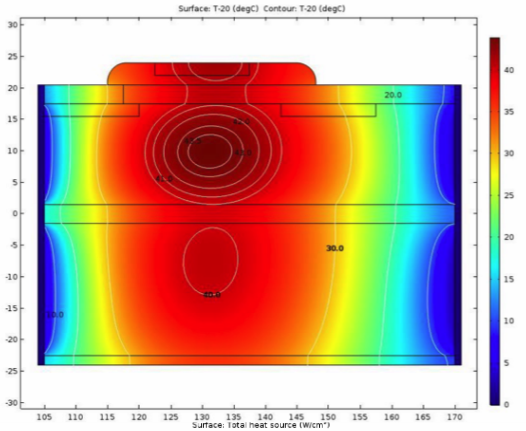
Summary of Activities so far

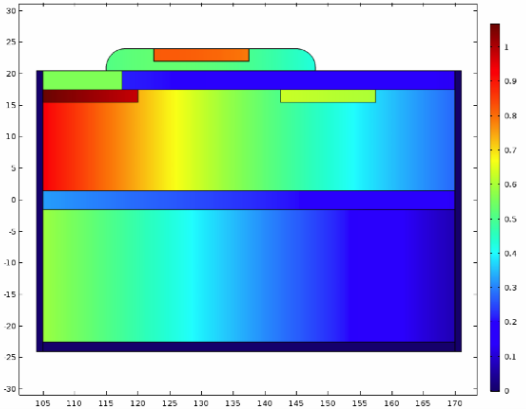
- Continued iteration of the cavity design.
  - Added shim to tuner to improve H-field in garnet.
  - Addition of power coupler in HOM calculations.
  - Addition of RF windows.
- PA test at 76 MHz nearly completed.
  - Test at 71 MHz complete.
    - Frequency is 5 MHz off. Good way to test our model of the tube!
    - Cavity will be modified to get to 76 MHz.
  - Tomco SS driver should arrive soon (06 May 2016)
- First 2 sets of Garnet rings have been procured.
  - Arrive in a few months (22 July 2016).
  - Preparation to perform tests on witness pieces.
    - Graduate student, John Kuharik will be measuring these pieces.
- Started 3D mechanical design.
- Started work on solenoid design.

Latest cavity design (12 Apr 2016)









Addition of power coupler for HOM calculations.

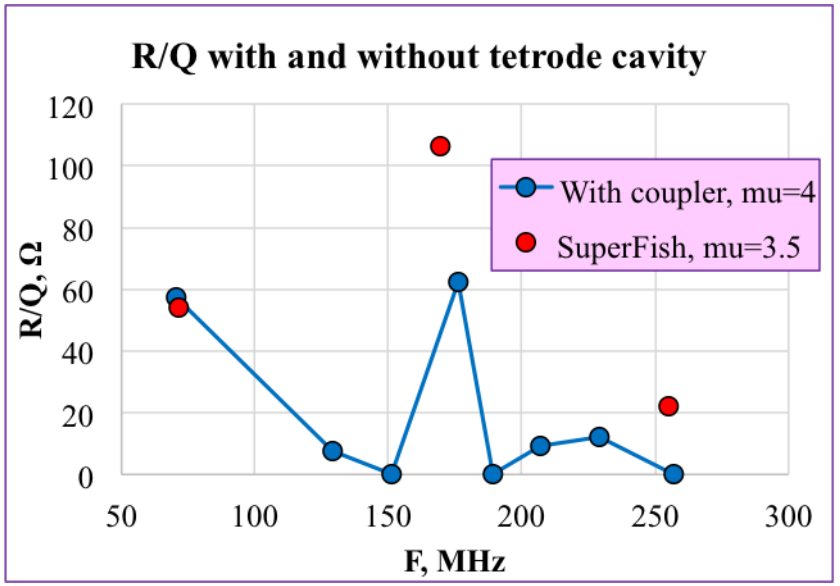
Addition of shim in garnet stack makes field more uniform.

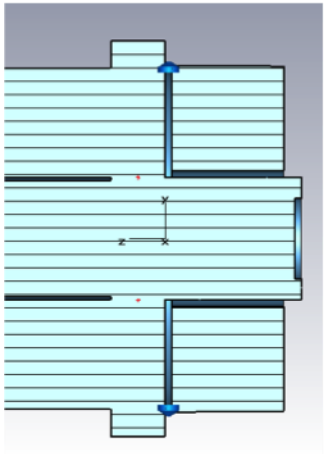
This lowers temperature rise and power density in the tuner stack.

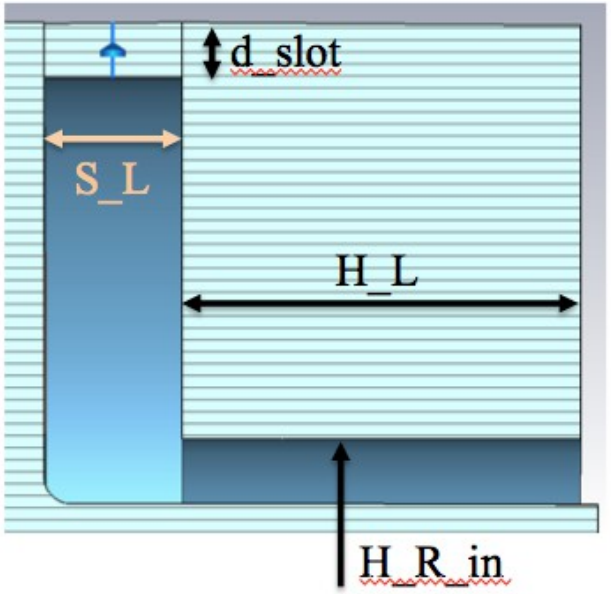
Temperature difference with and without shim is ~10 degC.

Loss power density lowered from 55 W/cm^3 to 21 W/cm^3

HOM damper







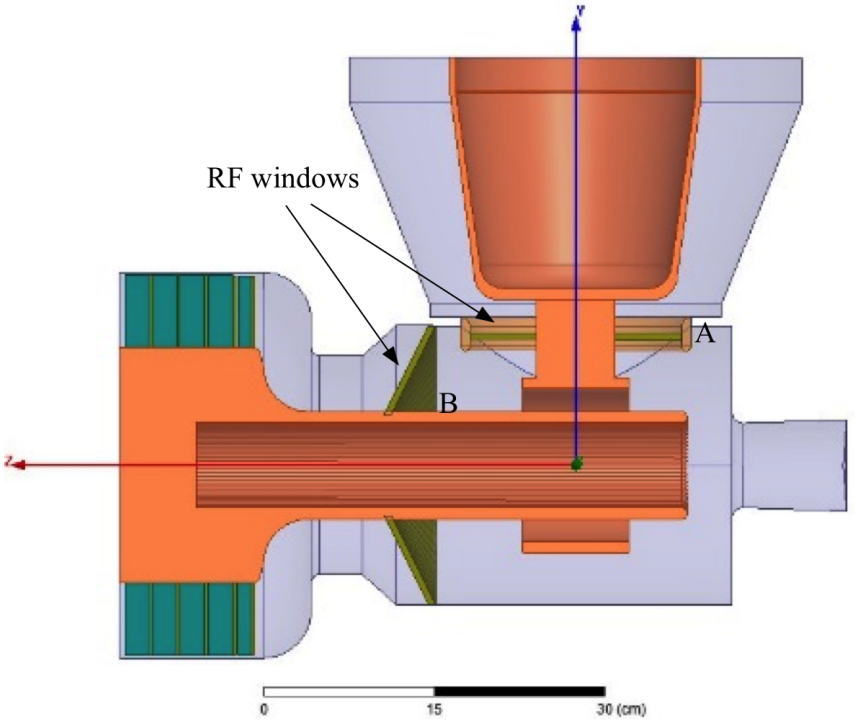
Addition of the HOM cavity (without the power coupler)

Operating mode reduced by 12%.
Next higher mode reduced by 97%.

With Power coupler, next HOM mode should be reduced by even more.

HOM cavity will be tested in mock cavity set up.

RF windows



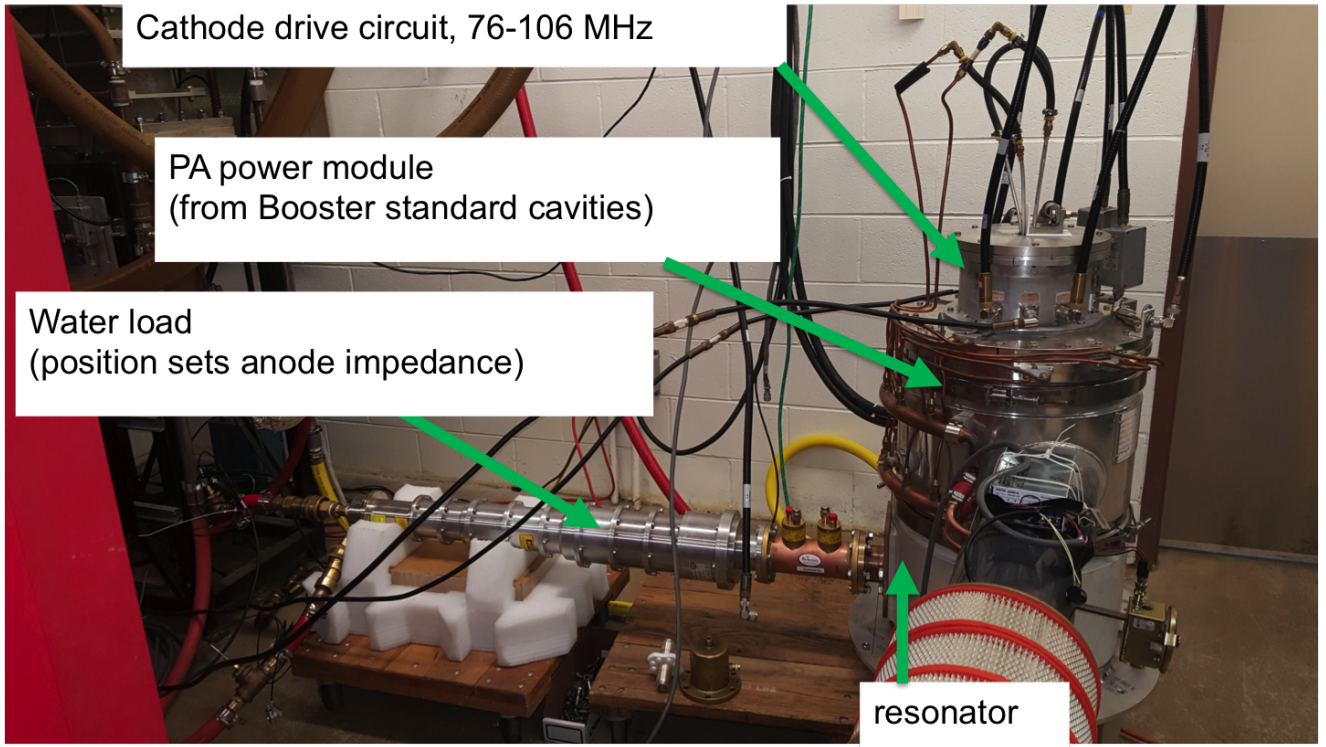
RF windows have to be used to separate the vacuum portion of the cavity from the PA and the tuner portion.

Window A is located inside the cavity because of limited space in the transition area from the tapered coax line of the coupler to the cavity.

The location of window B has been chosen to avoid possible magnetic field enhanced multipacting/sparking in the tuner area.

Both windows will be furnace brazed to form an alumina, copper sleeve sub-assembly that will be welded to the cavity during final assembly.

PA test



PA test conducted at MI60 test area.

Goal is to see whether the Y567 tube can produce > 100 kW at 76 MHz.

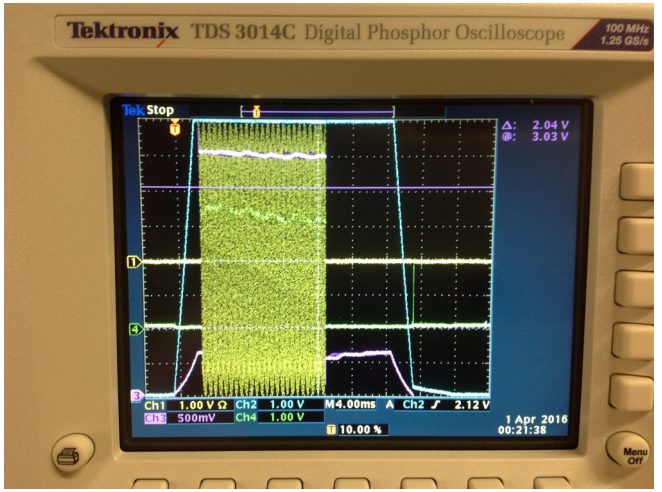
Unfortunately, from our measurements we found that the resonant frequency is ~71.5 MHz.

This is due to the modeling of the tube capacitance which we have taken to be 60 pF.

We will make a shorting ring to shift the frequency to 76 MHz.

PA test setup

- RF load is water cooled
  - Measure input and output temperatures of anode and water load.
  - Calculate power from water flow rate and temperature differential.
- Secondary power measurement
  - Use calibrated directional coupler.
- Tests are all pulsed
  - 14.3 ms on and 160 ms period (6.25 Hz)
    - Duty factor 8.9%
    - At max Va=24 kV, Pout=115 kW with efficiency of 60%.
  - 50% duty factor.
    - Found some problems with AR solid state driver amplifier.
    - Got up to 18 kV, but ran out of drive.
    - At Va=18kV, Pout ~ 100 kW efficiency 67%
    - Impedance (RF) seen by the tube is 1.3 kOhms. This is what we are aiming for in the 2nd harmonic design.

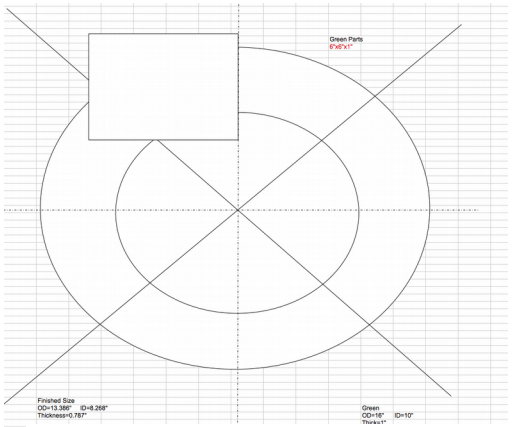


PA test todo

- Figure out what is wrong with the AR amplifier.
  - This is **not** we plan to use. AR amp is only good to 3.5 kW, ordered Tomco amplifier good to 8kW.
- Add insert to increase frequency from 72 MHz to 76 MHz.
  - Good check on improving our model.
- Continue work to get 106 MHz cavity resonator working.
  - Ability to tune frequency with spacers.

Garnets

- 2 rings (each with 8 sectors of garnet) have been ordered on 16 Mar 2016.
  - Expected delivery by 22 Jul 2016.
- Challenge is to glue these garnet pieces onto an alumina substrate.
  - Alumina 99.5% pure alumina.
- National Magnetics visited by I. Terekhine (TD) and K. Duel (AD)
  - Found NM will be able to deliver garnets.
  - Very enthusiastic to make, machine garnets for us.



Dimensions

DESCRIPTION: GARNET ALUMINA DISK ASSEMBLY
CATEGORY:
PROJECT:

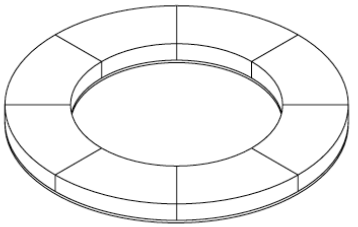
REV	REVISION CONTROL DOCUMENT	DATES	SIGNATURES
-	F10054252---RCD		DRAWN
			APPROVED

.787 [20.0]

.118 [3.0]

Ø 13.386 [340.0]

Ø 8.268 [210.0]



NOTES:
1. ITEM 1 TO BE ADHERED TO ITEM 2 WITH EPOXY. PROCEDURE TO BE APPROVED BY FNAL.

ITEM NO	PART NAME	PART DESCRIPTION	QTY
2	F10045159--	ALUMINA DISK	1
1	F10045158--	GARNET SECTOR	8

UNLESS OTHERWISE SPECIFIED

±.X	±.XX	±.XXX	±X/X	±X°
.1	.02	.005	1/16	1°

BREAK ALL SHARP EDGES .015 MAX.
DO NOT SCALE DRAWING
DIMENSIONS BASED ON ASME Y14.5-2009
MAX. ALL MACH SURFACES 125
DRAWING UNITS: INCHES

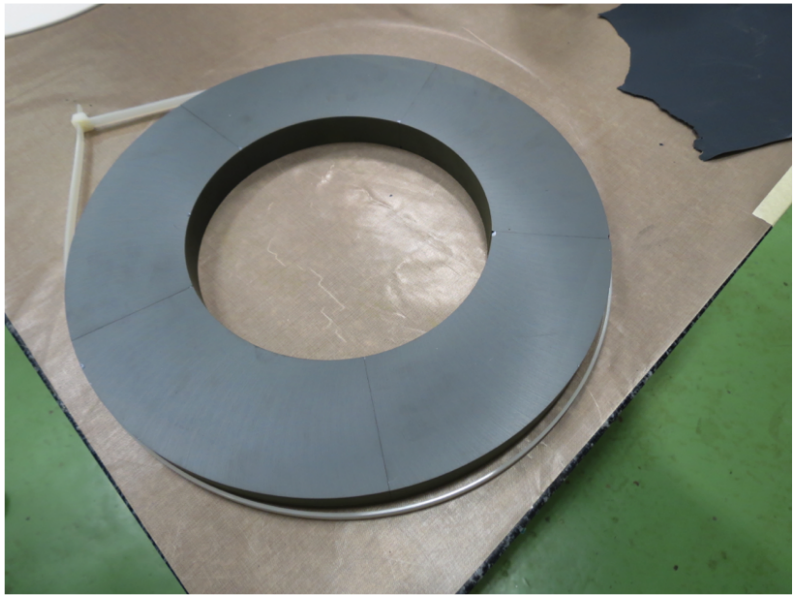
DRAWN	K.DUEL	DATE
CHECKED		DATE
APPROVED		DATE
USED ON		
MATERIAL	SEE PARTS LIST	
GROUP:		CAGE CODE: 0U5R6

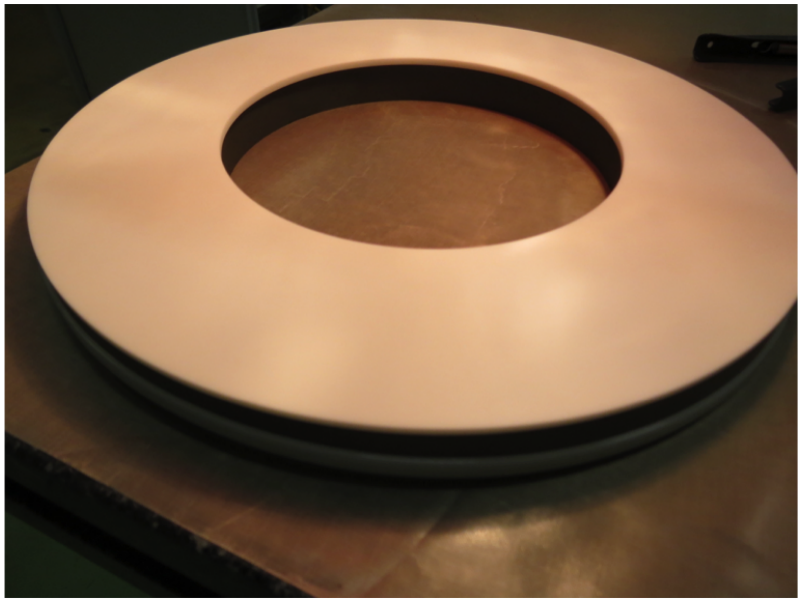
FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

NAME
GARNET ALUMINA DISK ASSEMBLY

SCALE	SIZE	DRAWING NUMBER	SHEET	REV
1:2	B	F10054252	1 OF 1	-

Example of how the final product should look like



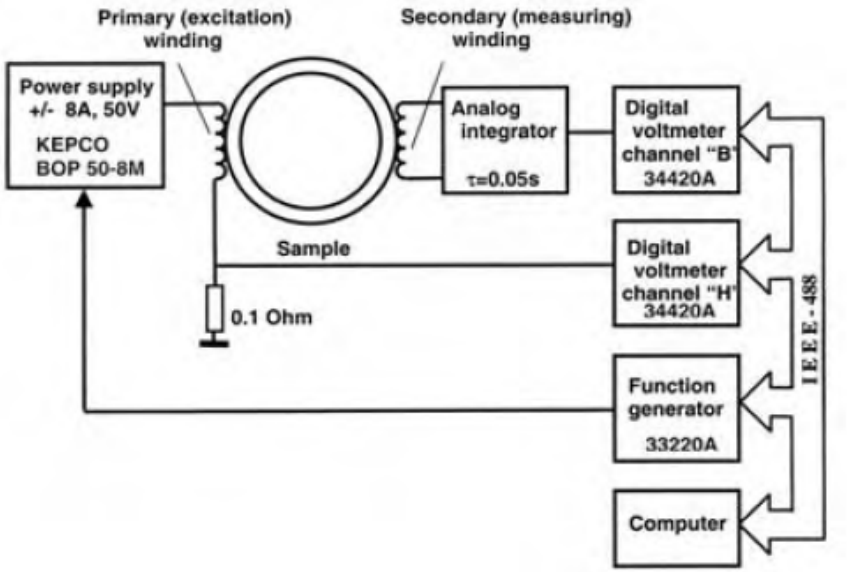


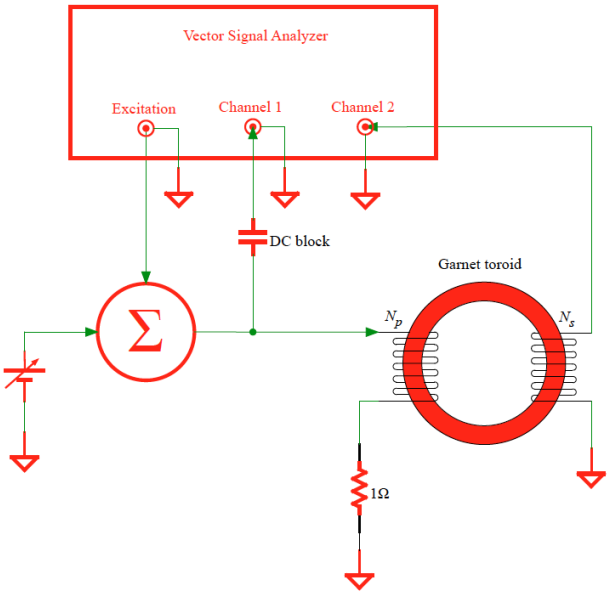
CERN garnet.

Courtesy of S. Clement, polymer lab, CERN.

Also F. Caspers, and C. Vollinger (Beams department).

Test of garnet witness pieces





We are setting up a test stand for measuring the B-H curves (and thus μ) of the garnet witness pieces.
We have a graduate student (John Kuharik) who will do this.

There are two methods to do this:
(a) time domain ← This is the usual way.
(b) I came up with a frequency domain method just for kicks and giggles.

We will compare both methods to see whether the results agree.

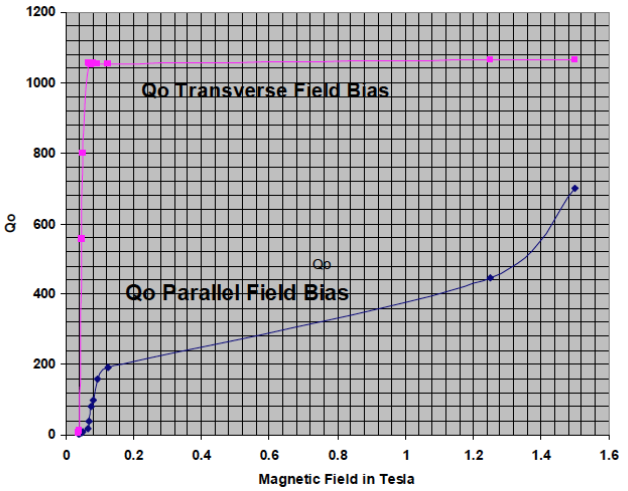
Test of garnet ring

- We are lucky that Al Moretti had built such a test stand many years ago and we can use his (formerly Muons Inc experiment) equipment!
- 

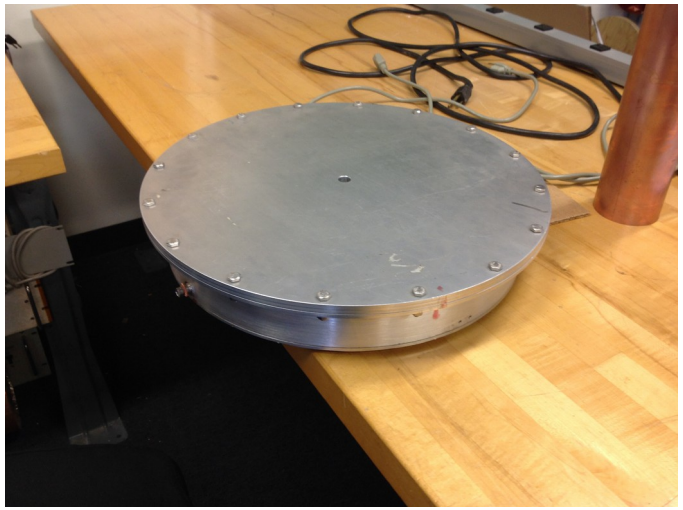
What we have now

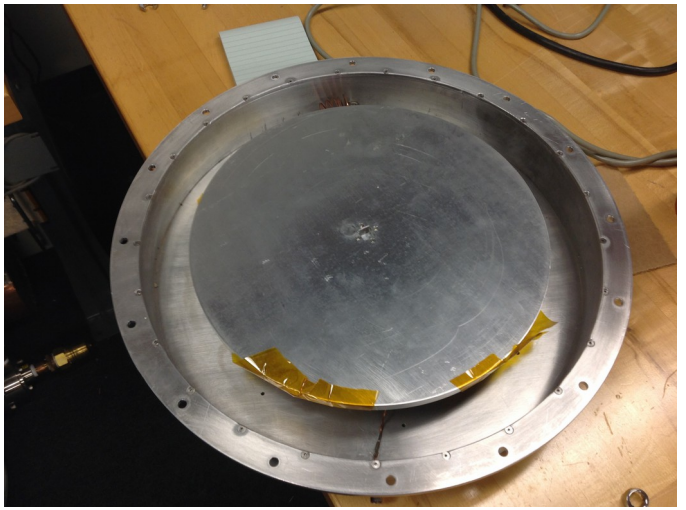
Test area is at MS7.
Magnet is still there (1.6 T field), which is plenty for what we need.
PS is still here.

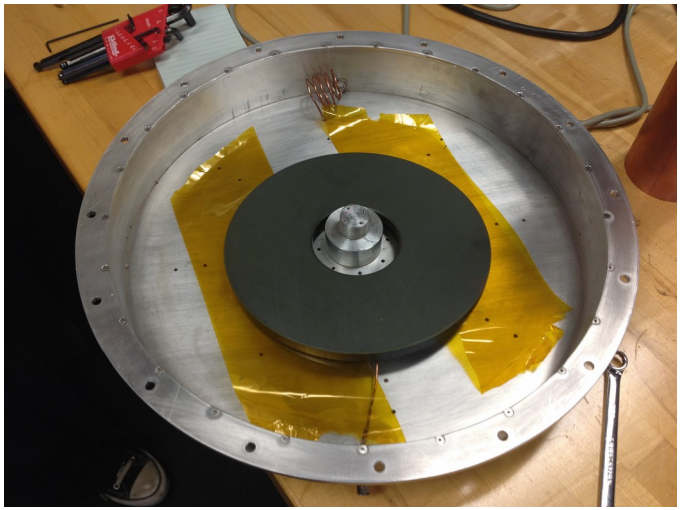
We will need to make new pole pieces to make the field uniform.

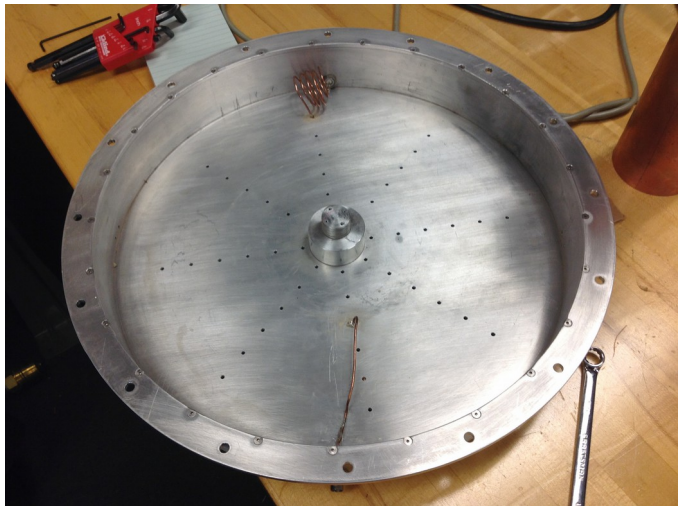


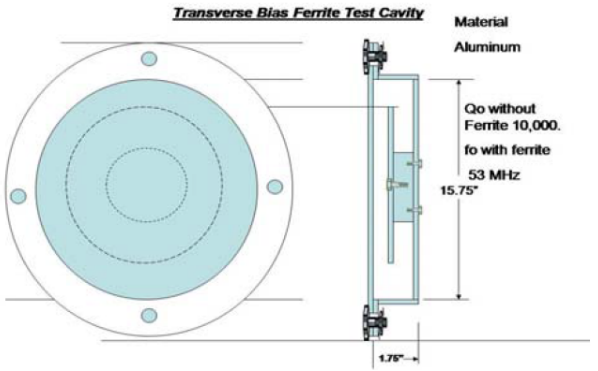
Cavity



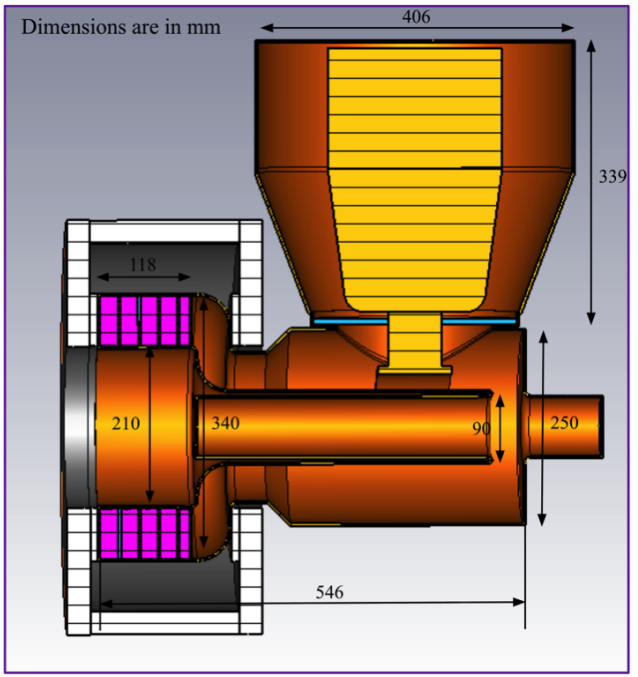




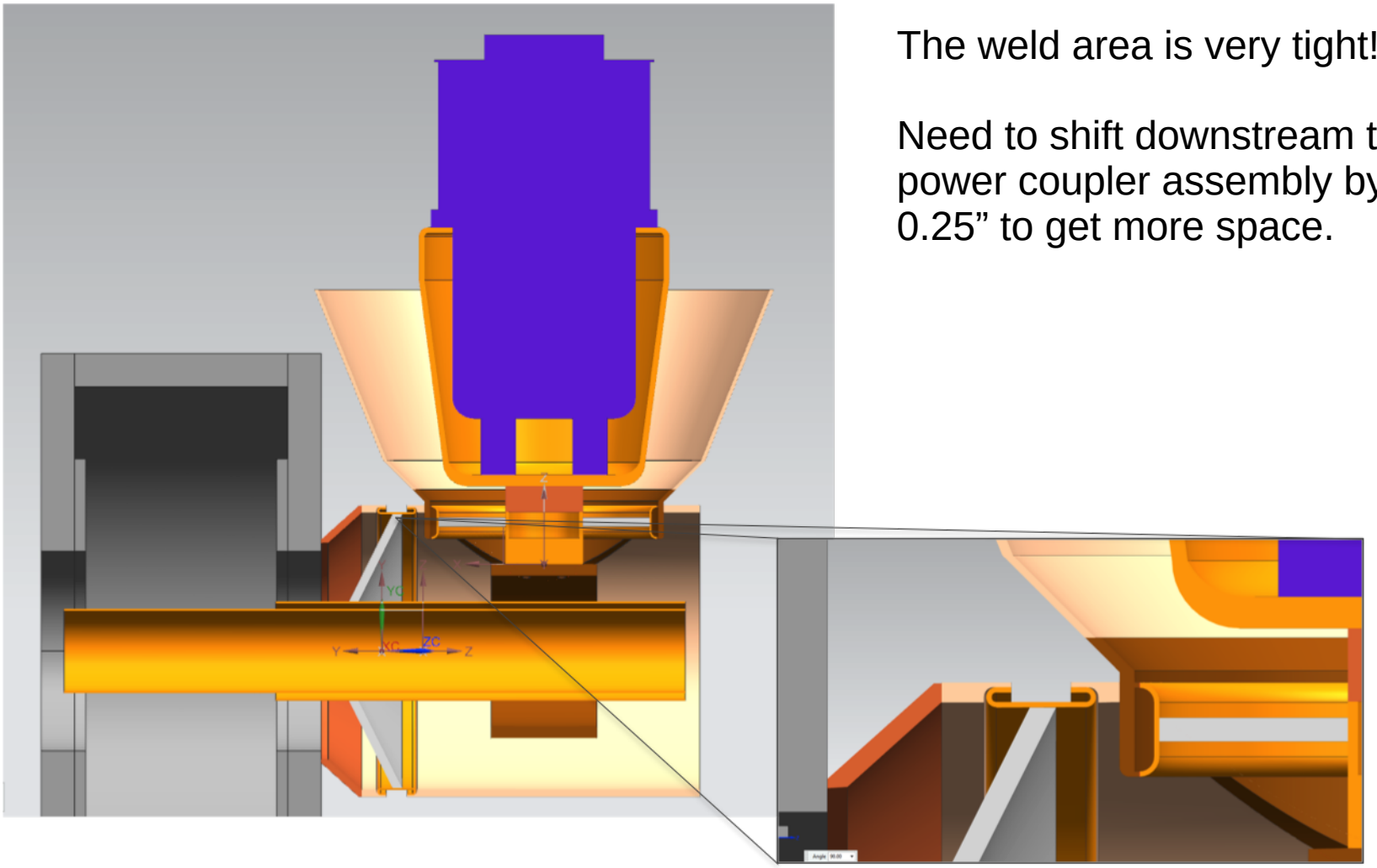




Garnet diameter: 340 mm = 13.4 inches < 15.75 inches, so we can fit in one garnet ring.



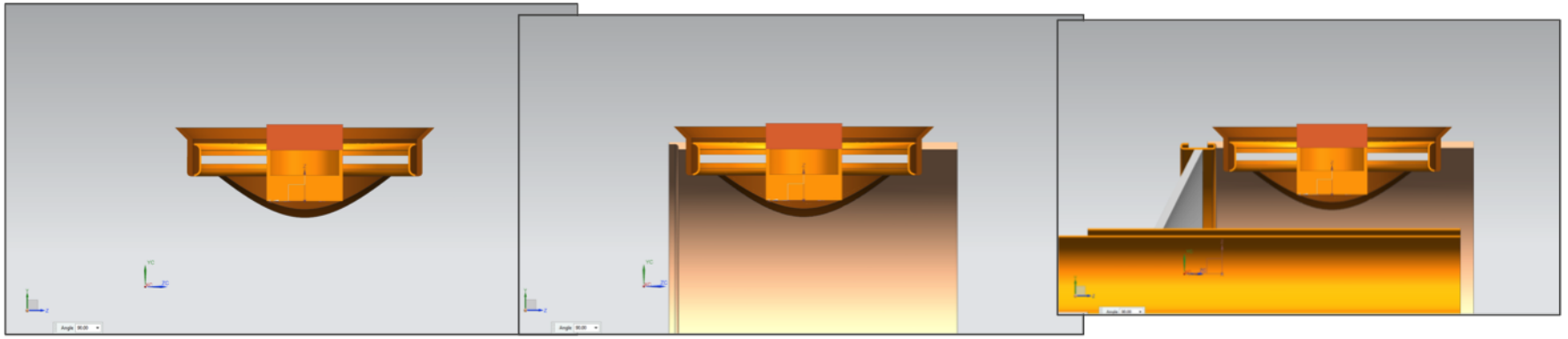
Mechanical Assembly (Preliminary)

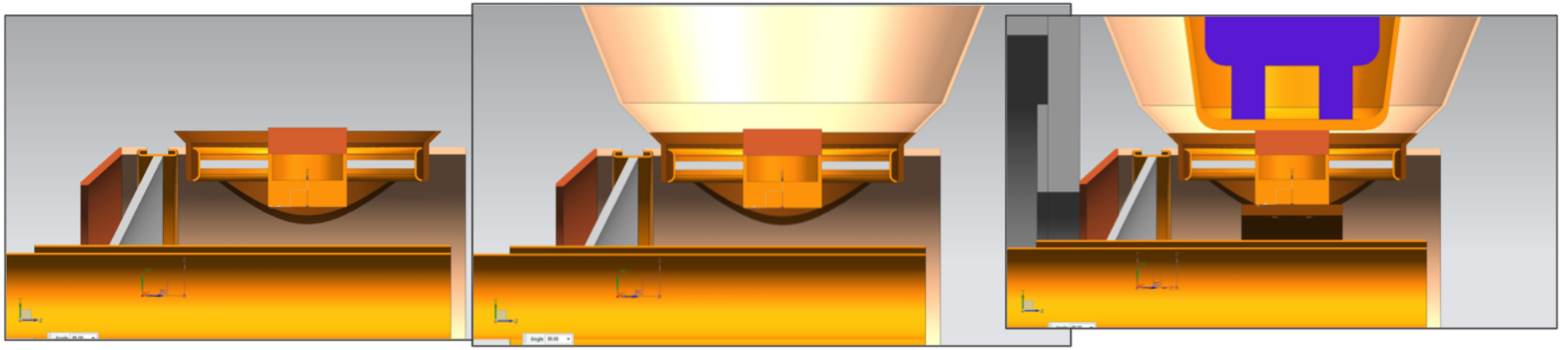


The weld area is very tight!

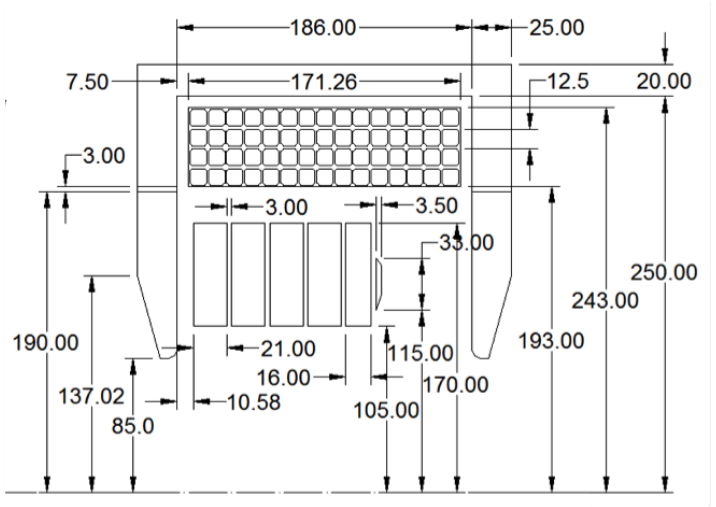
Need to shift downstream the power coupler assembly by 0.25” to get more space.

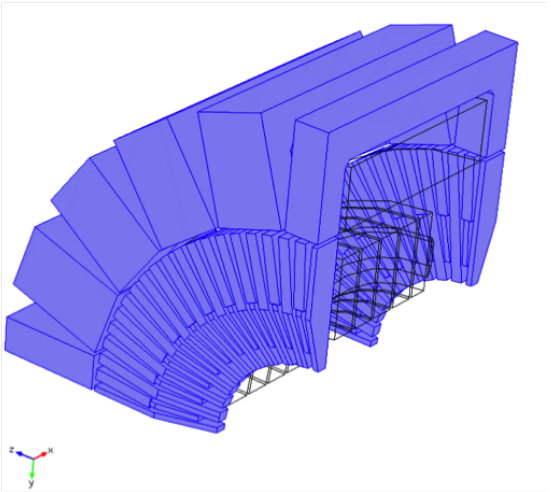
Mechanical Assembly (cont’d)

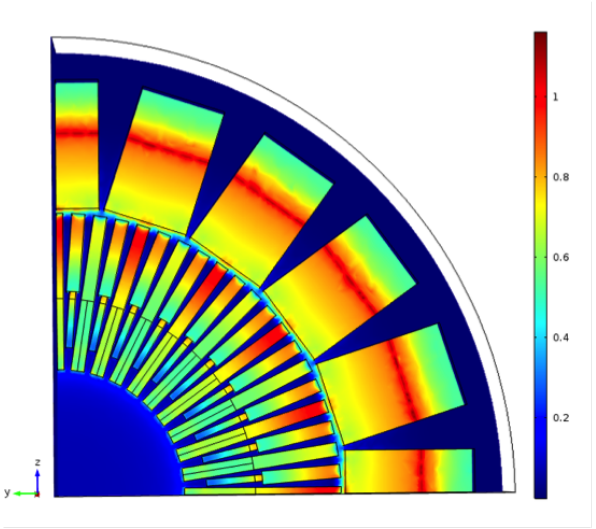


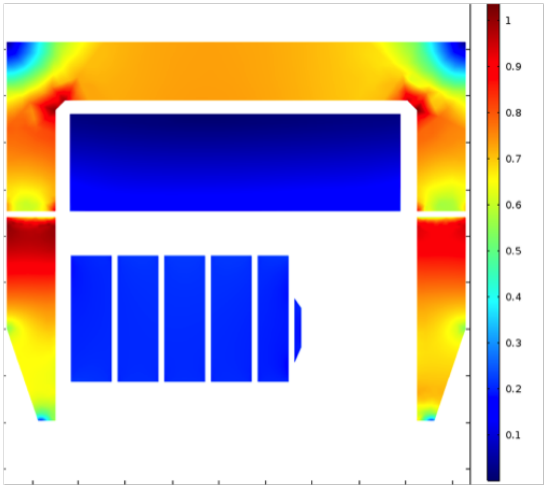


Solenoid assembly (Preliminary)









Preliminary evaluation of the magnet pole and yoke design concluded that laminated silicon steel must be used as a magnetic material.

The thickness of the laminations must be adequate for the working frequency. Gauge 24 (0.025” or 0.635 mm thick) M15 or M19 or even thinner laminations are even better.

Conclusion

- Cavity iteratively being improved.
  - Addition of HOM cavity, power coupler and windows.
  - Changes to make it buildable.
- Work on PA testing continues
- Garnet ordered
  - Test stands being prepared.
- Assembly sequence started
  - Important to have an idea of how things should be built!
- Solenoid design started.
- Heating calculations are complete (so far).
- More work ahead like real windows, solenoids
  - Windows design has started. Vendor contacted.
  - Solenoid design has started.