RF TEST FLANGE MODELLING

Motivation:

An RF test will give us a lot of information on the alignment and quality of the machining by observing the RF modes at low power.

Not only is the RF highly sensitive to errors, but the relation of quadrupole to dipole modes in position and height will tell us something of the "direction" of misalignment. In addition if we get the RF right we should also get the best beam transmission......

Capacitance (energy stored in the electric field)
Any misalignment of the vane tips relative to each other is influencing the capacitance (a function of the separation of the vanes) and as the "reference distance" is only ~ 7.5 mm every 10 micron misalignment will have a large influence.

Inductance (energy stored by the magnetic field),
In case of the inductance, the length of the loop or current path is from tip to tip around 3/4 circle. With a reference distance of about 200mm this parameter is less affected by a similar amount of misalignment.

Case:
Consider the case of a misaligned minor vane – positioned too far in towards the beam axis.

- Moving the vane tips close together will increase the capacitance.
- The shortened current path decreases the inductance.
- The change of capacitance will be more influential than the change in inductance due to their different reference distances.
- So the net effect is an increase in the value *LC* which decreases the frequency.

$$f = \frac{1}{2\pi\sqrt{LC}}$$

Aside:
We tune in the high magnetic field region and not in the high electric field region so that tuning can be made independently of the beam dynamics requirements.

RF test flange:
At the downstream end of RFQ section 1 there are no vane cutbacks and hence there is no path for the magnetic field to loop around at the ends. We therefore need to design an end flange specifically for the RF test that is shaped to substitute for the missing cutbacks.

Juergen, Scott, Pete, 5th Jan 2012

Two finite element models are required:

Model 1: Baseline or reference model

The internal volume of RFQ sections 1 & 4 mated together with the 'real' end flanges attached. Eigenmodes required. Real material properties and Q values not required. Actual frequency is not relevant. Model is fully de-featured.

Model 2: RF End Flange model

The internal volume of RFQ sections 2&3 mated together with the RF test end flanges attached. Model is fully de-featured. The plan is to tune the RF test end flange design by altering the nose and hence altering the capacitance until the frequency of model 2 matches that of model 1.

Who is doing what?

Pete	SAT files for models 1 & 2
Saad	Modelling using Microwave Studio
Morteza	Modelling using COMSOL

Model 1

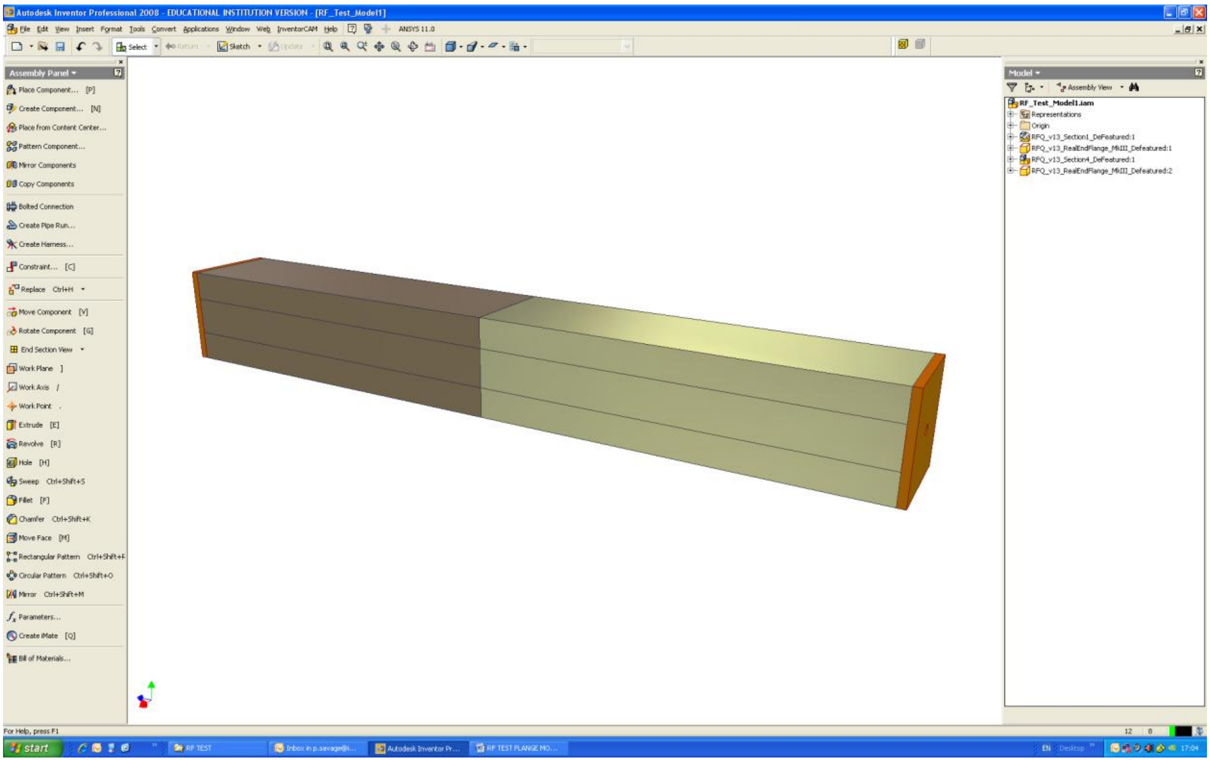

Figure 1: RFQ sections 1 and 4 with real end flanges.

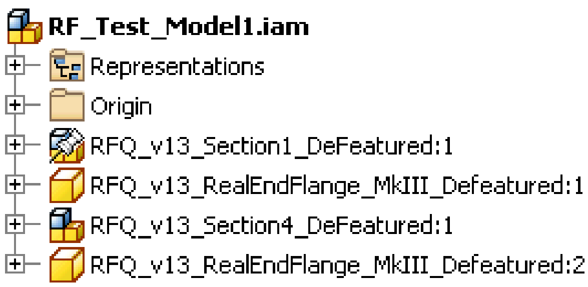

Figure 2: Listing the parts and assemblies used for Model 1

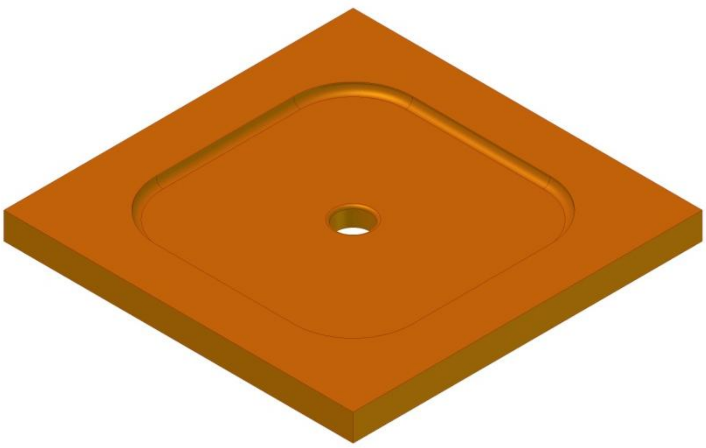

Figure 3: The ‘real’ end flange

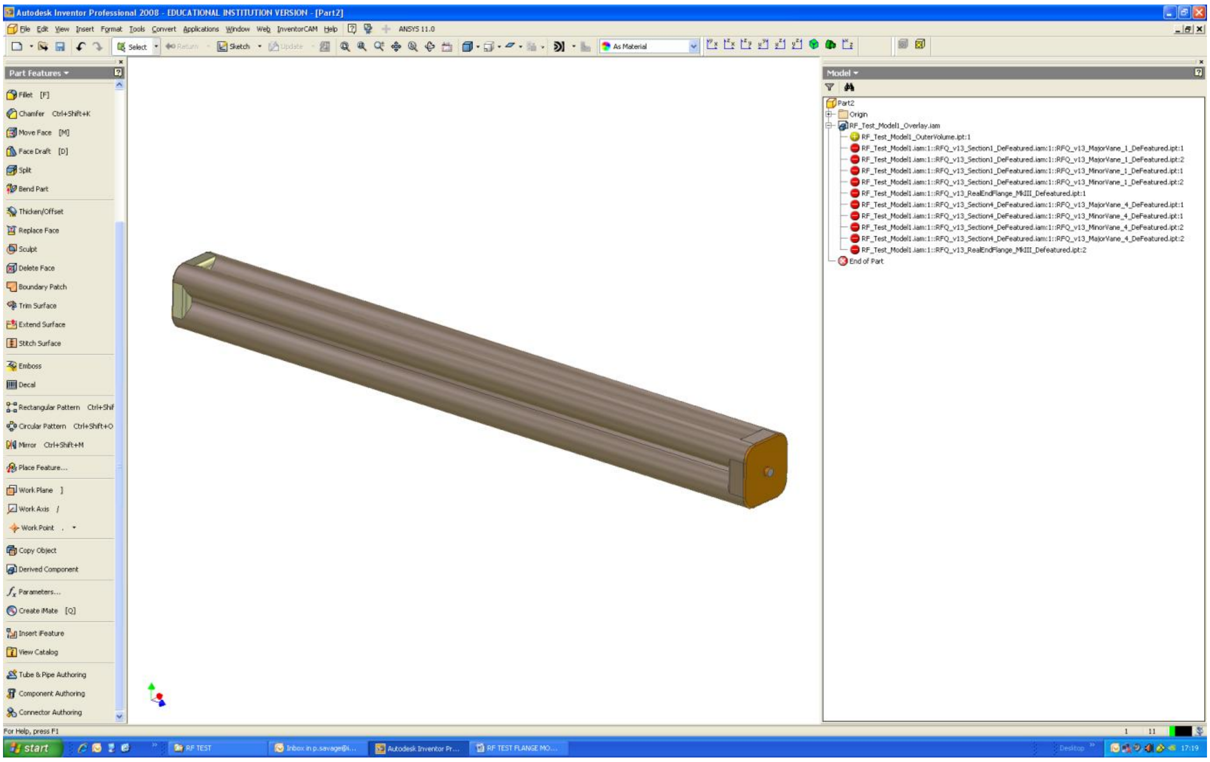

Figure 4: Model 1 Internal Volume, filename = RF_Test_Model1_Reference

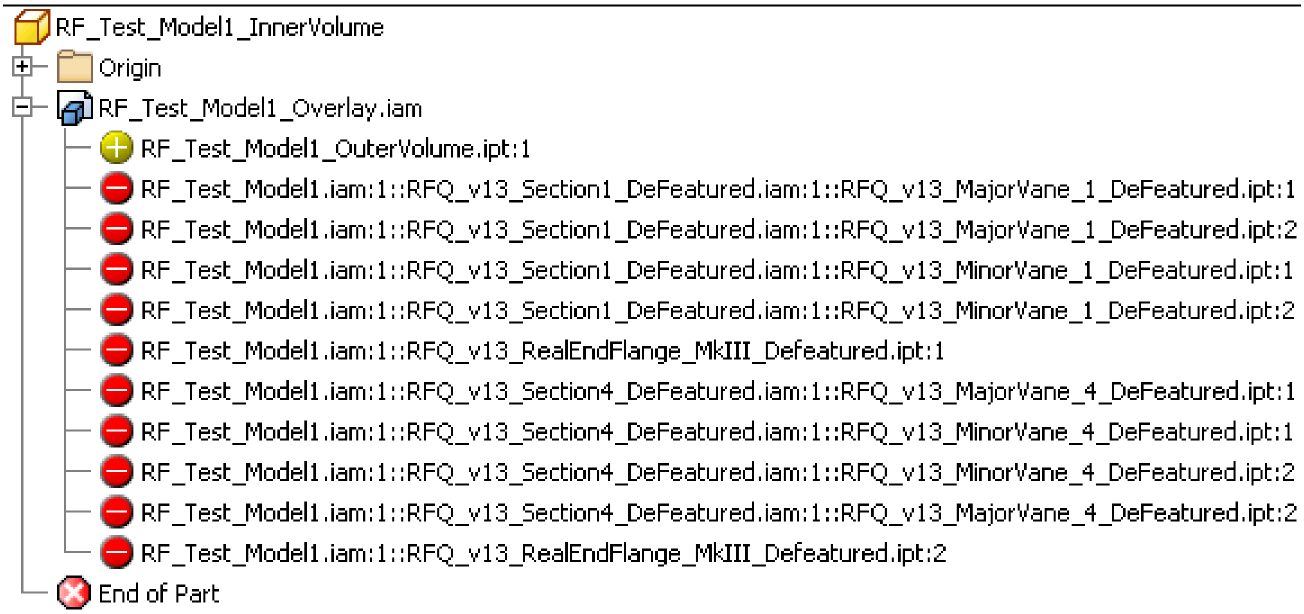

Figure 5: Model 1 Internal Volume model creation history

Model 2

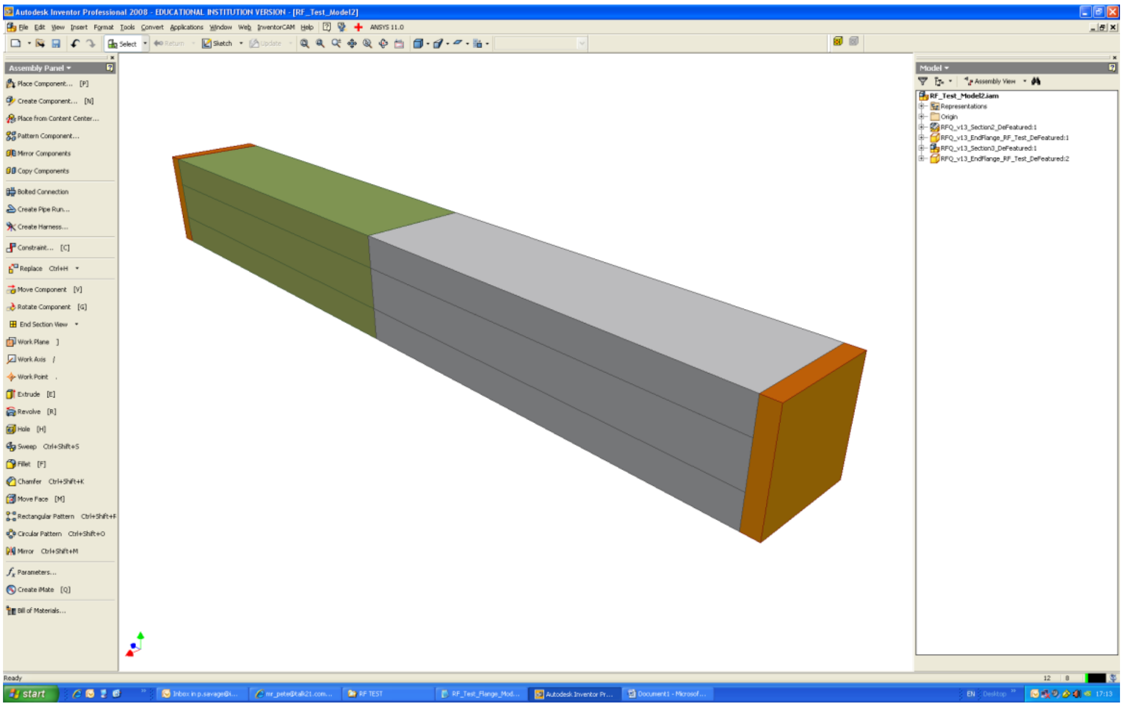

Figure 6: RFQ sections 2 and 3 with RF test end flanges.

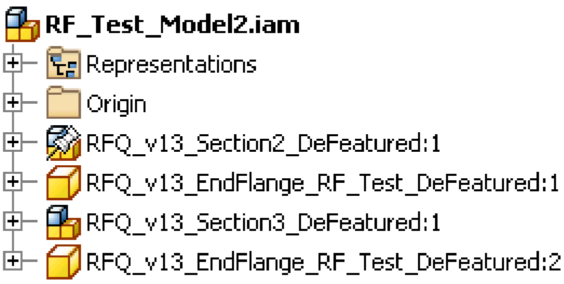

Figure 7: Listing the parts and assemblies used for Model 2

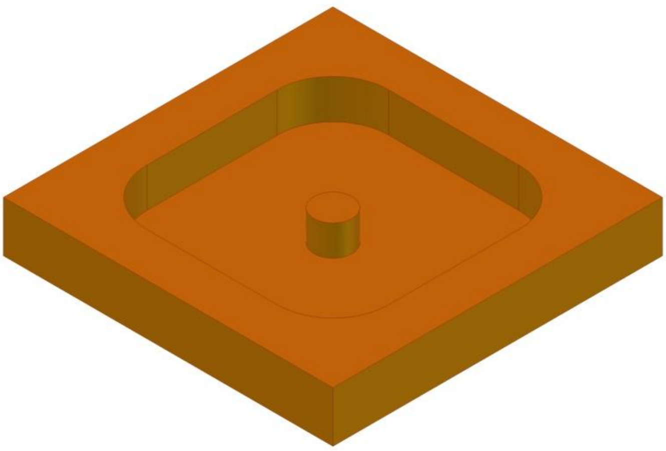

Figure 8: The RF test flange

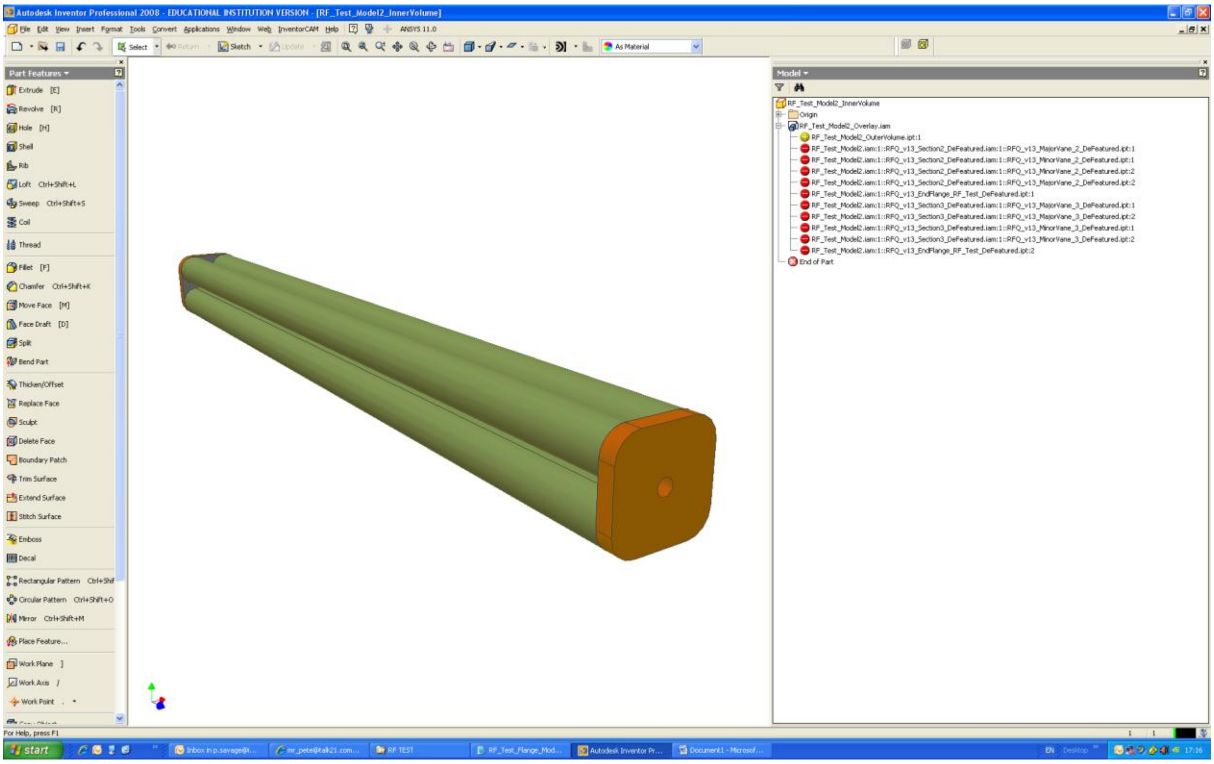

Figure 9: Model 2 Internal Volume, filename = RF_Test_Model2_D30_C7_I24

Figure 10: Model 2 Internal Volume model creation history

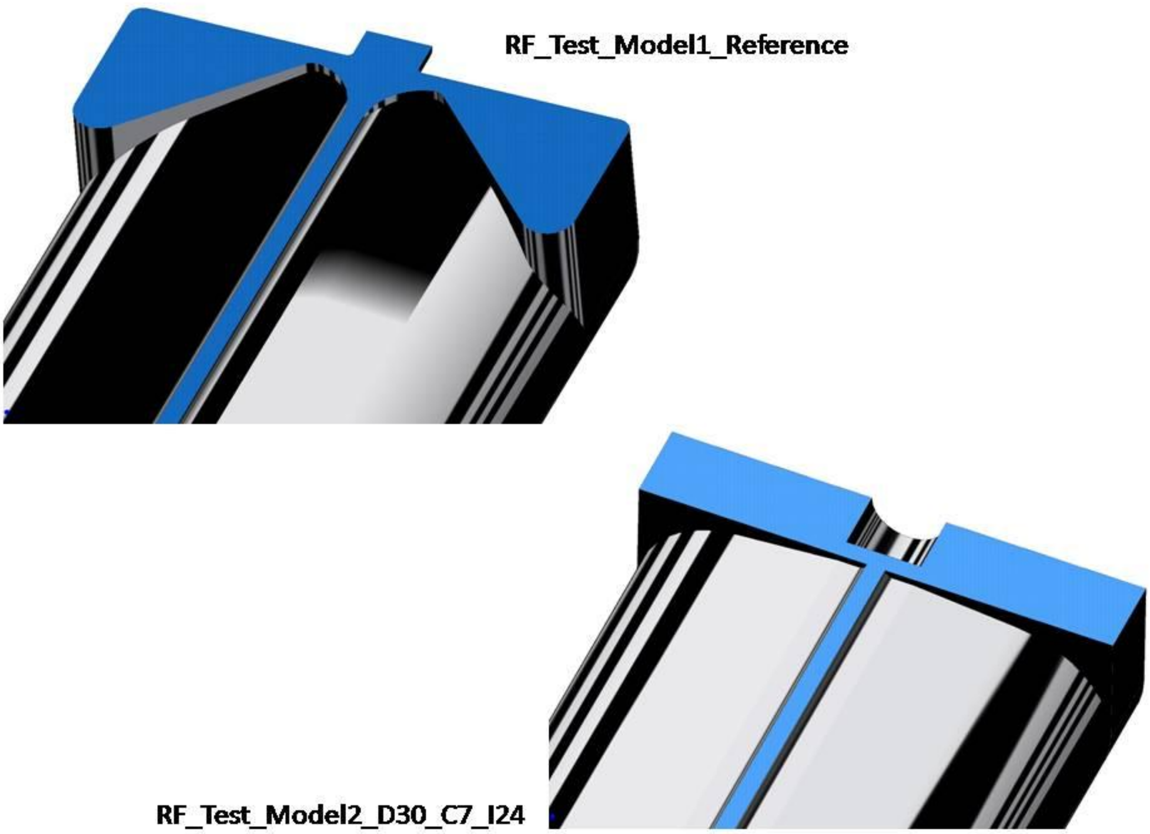

Figure 11: Sliced views to compare field paths for both models

Why won’t these models mesh?

The first versions of both these models would not mesh in COMSOL.

We have encountered this problem in the past and it is usually caused by a small discrepancy in the build of the model. The first step is to find out where the problem might be located. We therefore created several test models to isolate the problem area.

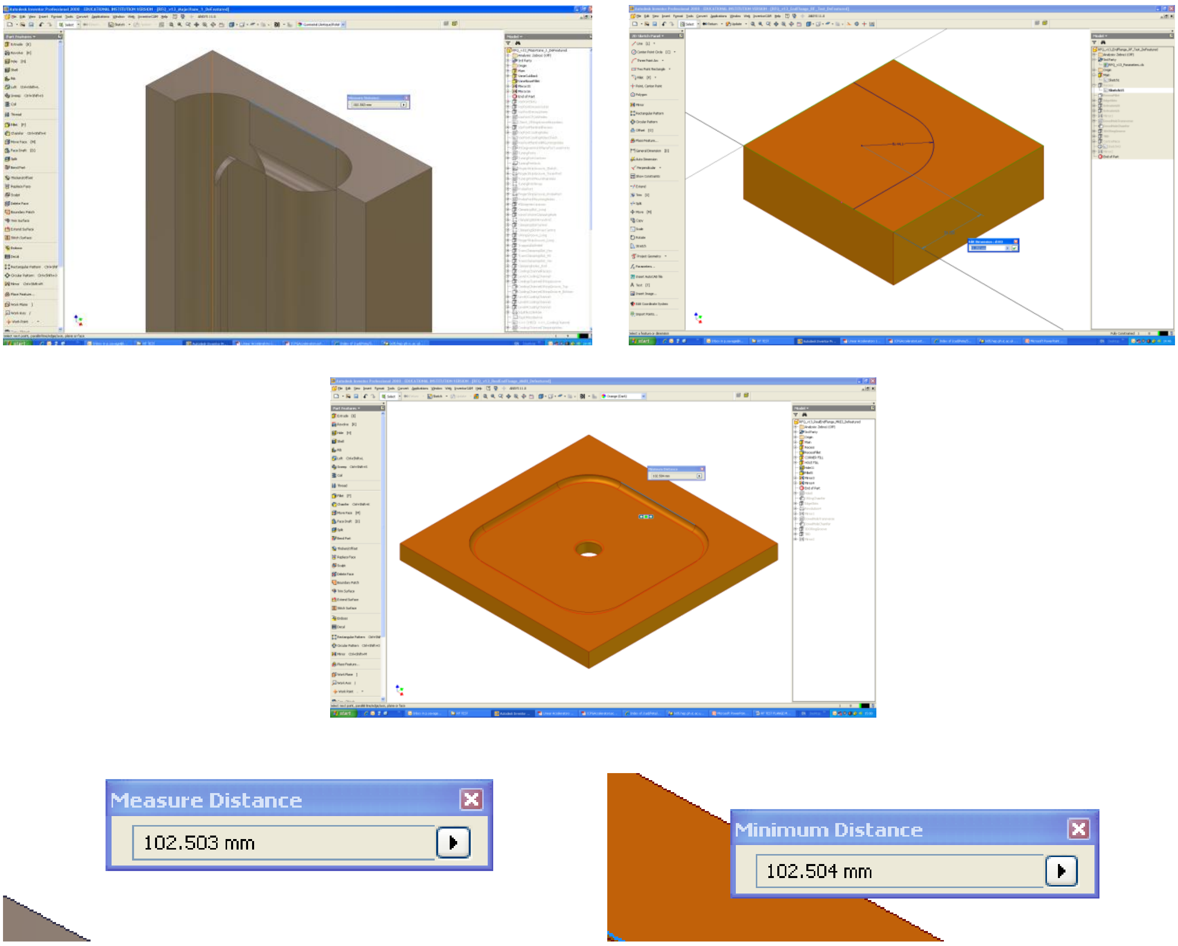

Figure 12: Views showing where discrepancy was found

The straight edge of both end flange types measured 102.504mm whereas the corresponding measurement for the RFQ vanes was 102.503. After the flange dimension was altered to match that of the RFQ vanes COMSOL was able to mesh model 2 with no errors. However, there remained a problem with model 1.

After a lot of searching another discrepancy was found – this time of just 0.0002mm!

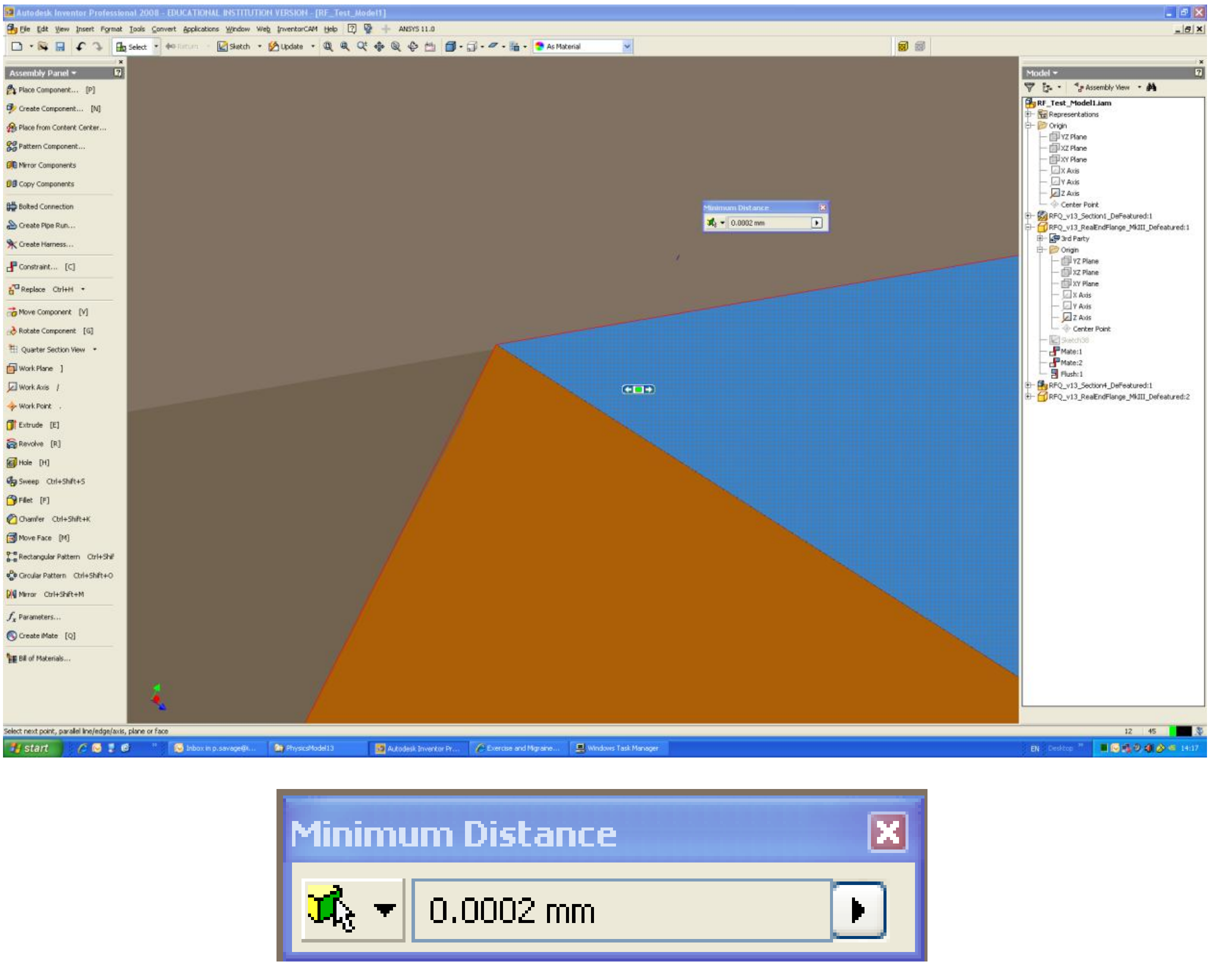

Figure 13: And the source of the second error in Model 1

The source of the error was found but proved impossible to change and so it was decided to remodel the end flange from the beginning, this time as a part derived from the vane to vane assembly. This required manual subtraction of the original (parent) assembly but otherwise was easy to perform.

2nd Feb 2012

First results from Morteza:

There are several mesh qualities available:

1. Extra coarse
2. Coarse
3. Normal
4. Fine
5. Finer
6. Extra fine
7. Extremely fine

When the extremely fine mesh was used on the entire **reference model** the computer still had not meshed at 48 hours. Clearly this is not usable.

When the extra fine mesh was used everywhere except on the edges where extremely fine was used the model was meshed in about 15 minutes. The results were the same when extra fine was used for the whole model. It is therefore safe to assume that the extra fine mesh has small enough elements to produce a believable result.

The eigenfrequency results for the reference model were:

1. 315.6325 – a dipole mode
2. 315.7958 – a dipole mode
3. 323.0724 – the 1st quadrupole mode
4. 327.9328 – a bifurcated mode *
5. 328.1129 – a bifurcated mode *
6. 331.3722 - ?

So the first quadrupole mode is close enough to 323MHz. * these two results are thought to be one result that has split into two due to the details of the modelling.

9th Feb 2012

Model 2 will not mesh at the optimum settings.

Model 1- the reference model meshes using the following settings:

Volume -> Extra fine

Edges -> Extremely fine

Model 2 DOES NOT mesh using the same settings. Suspect a discontinuity somewhere in the model.

It will mesh the volume using extra fine but cannot mesh the edges using extremely fine.

Ideally we want both models to have the same trusted mesh quality.

Interestingly, by over-riding the predefined mesh settings for Model 2 and changing the element growth rate from 1.3 to 1.35 COMSOL is able to mesh the model without problems. This technique could be used as a last resort but is not ideal.

Remedy:

Examining model 2 in Inventor at the maximum zoom level showed a tiny discontinuity. It was decided to remodel the RF end flange from the beginning as a derived component of the de-featured RFQ section 3 model.

This new end flange model was then used in the assembly and then to create a new internal volume SAT file called:

RF_Test_Model2_D30_C7_I24_v2

This model was placed on the web and imported by Morteza into COMSOL. Now it meshes with the desired settings without ERRORS.

10th Feb 2012

Model 2 shows a curved longitudinal electric field instead of flat.

Indicates that the ends flanges are not in tune with the body of the RFQ – see Scott's documents:

RFQ_eigenmode_overview

RFQ_Field_Flattening_Manuscript

The curve shape is lower at the ends than in the middle. Therefore the ends have too low voltage and therefore too high frequency.

To reduce the frequency we must increase the capacitance or the inductance. Increasing the capacitance has less effect on the material volume from a production point of view.

In addition we wish to use the RF test end flanges as the bead-pull end flanges also. They will therefore need a central hole.

Therefore 3 models are proposed:

Model 3: Model 2 with a diameter 7.3mm hole through the centre. This hole size matches the vane tip to vane tip spacing of the RFQ. It is expected to have a low influence because there is empty space directly opposite the hole.

Model 4: Model 3 with a reduced capacitive gap from 7mm to 5mm measured from the end flange 'nose' to the RFQ end face.

Model 5: Model 4 with the end flange nose increased in diameter from 30mm to 40mm.

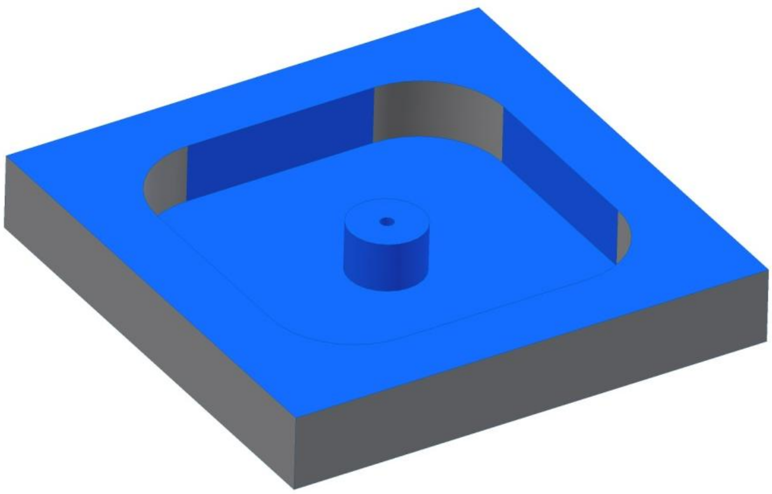

Figure 14: Model 5

To 3D SAT models created are

RF_Test_Model3_D30_C7_I24

RF_Test_Model4_D30_C5_I26

RF_Test_Model5_D40_C5_I26

Where: D = nose diameter

C = capacitive gap

I = inductive length

20th Feb 2012

Model evolution to #8

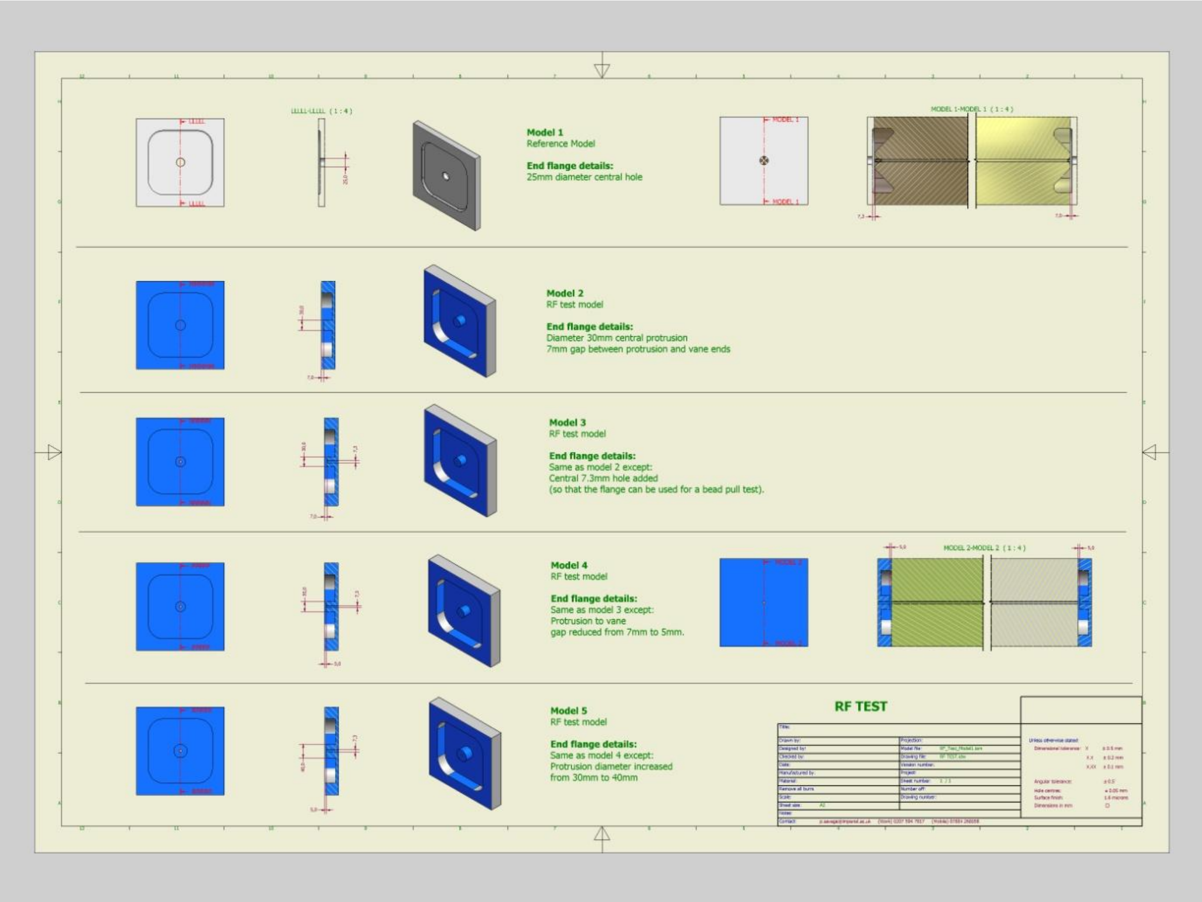

Figure 15: Image showing dimensions for models 1 to 5

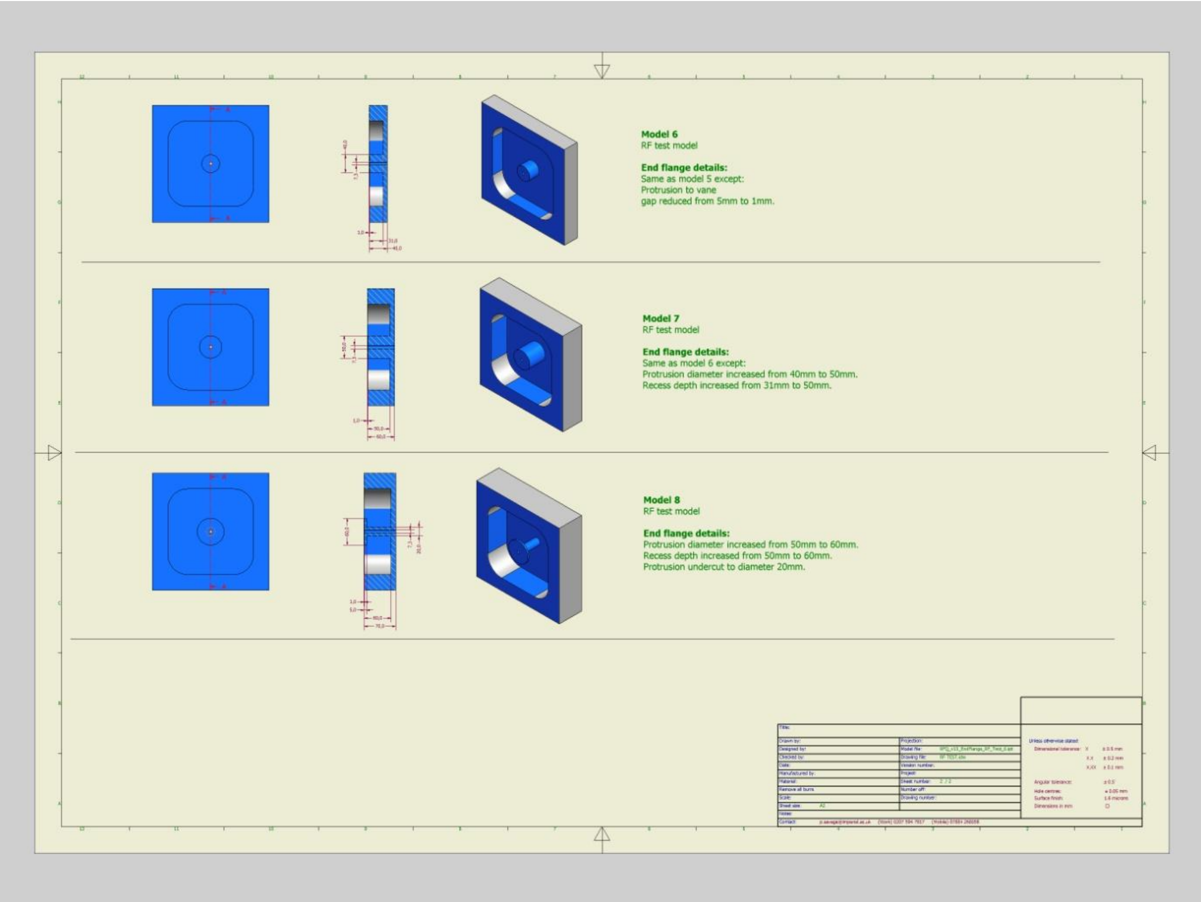

Figure 16: Image showing dimensions for models 1 to 5

Model #	High / Low	Ratio	Frequency
1	**700 / 680**	**1**	**323.08**
2	**740 / 400**	**1.85**	**326.75**
6	**600 / 370**	**1.62**	**326.18**
7	**580 / 420**	**1.38**	**325.29**

As the models evolve we are reducing the curvature of the longitudinal electric field – this can be seen as the ratio of the values approaches 1. In addition the frequency is approaching 324MHz. This shows that the models are moving in the right direction.

One problem is that by increasing the protrusion diameter the inductive current path decreases which acts against what we are trying to achieve – a higher value for LxC. We cannot increase the depth of the pocket too far due to machining practicalities. So to overcome the problem Model 8 uses an undercut along the protrusion while maintaining a large area at the capacitive end.

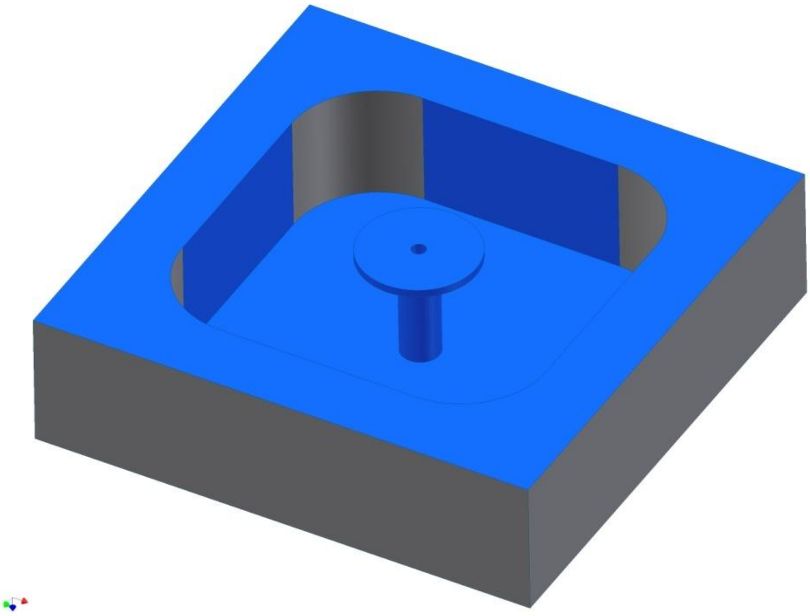

Figure 17: RF Test end flange #8

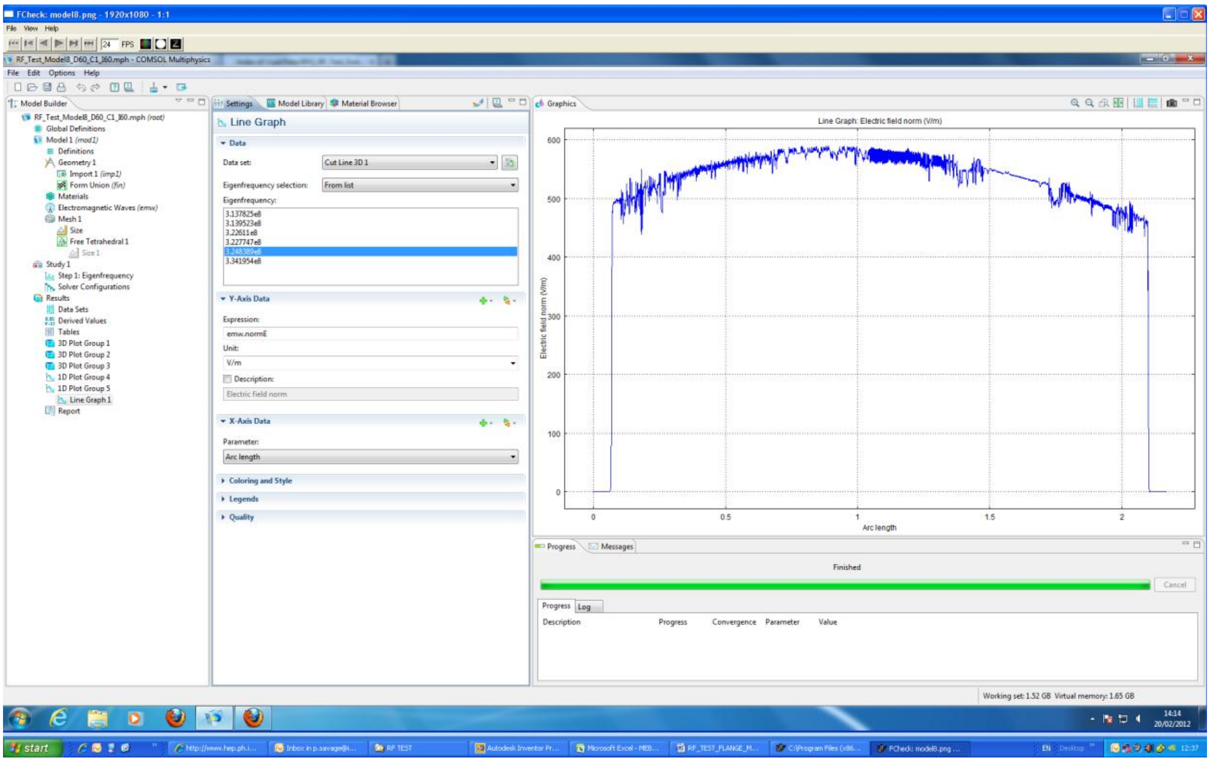

Figure 18: Model 8

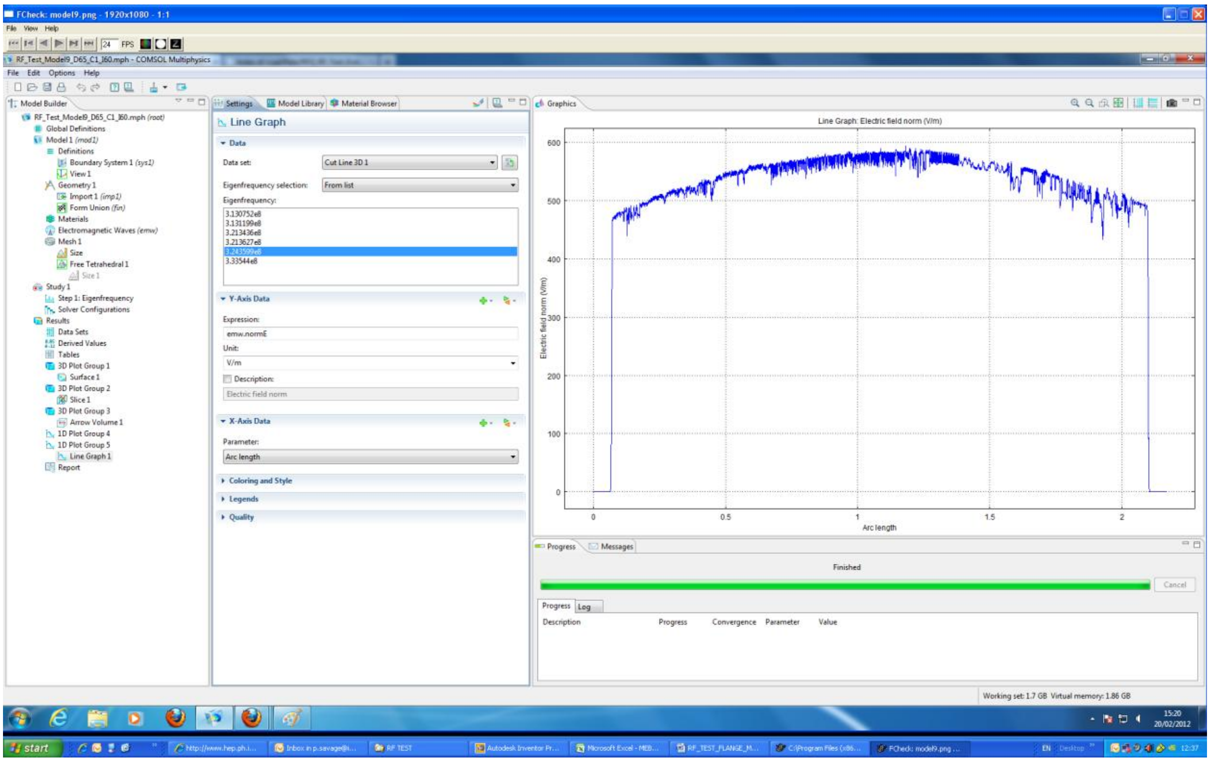

Figure 19: Model 9

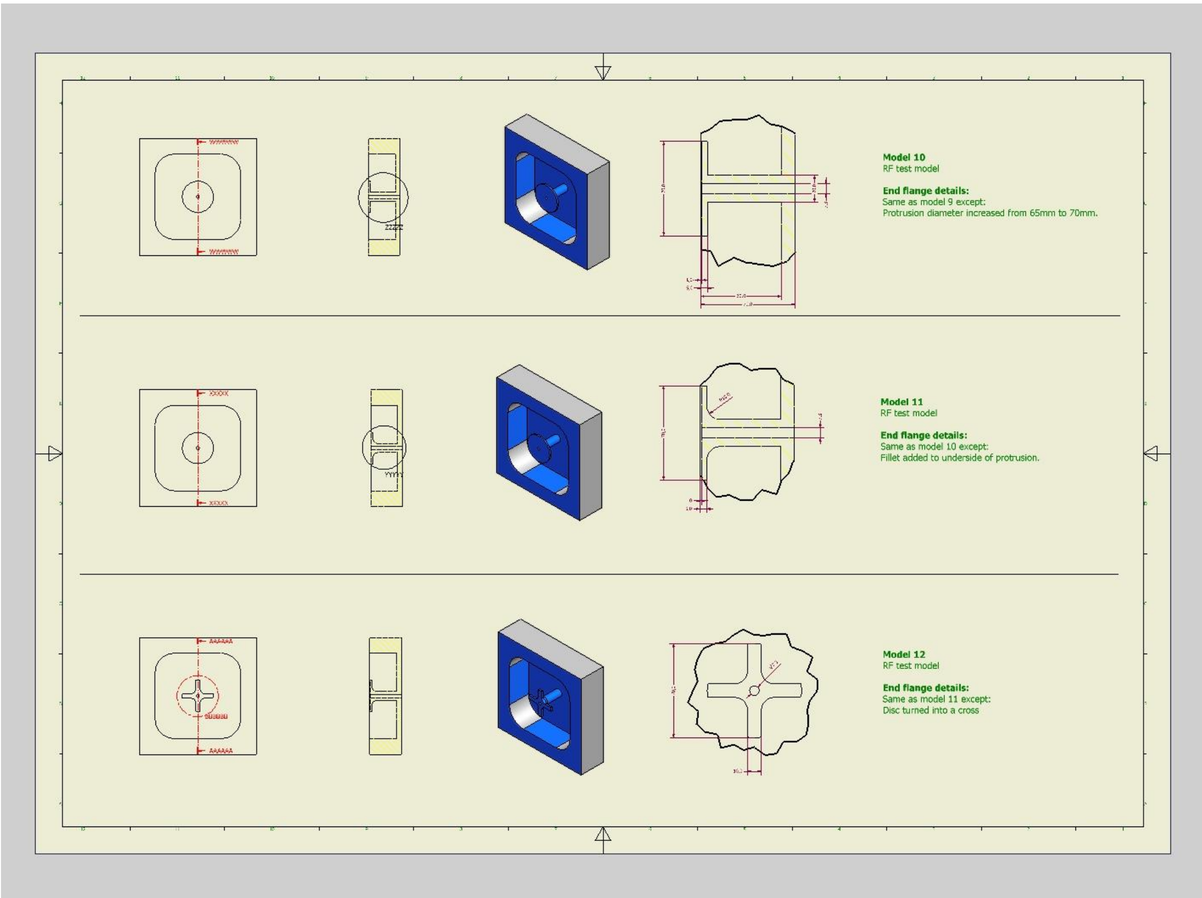

Figure 20: Image showing dimensions for models 10 to 12