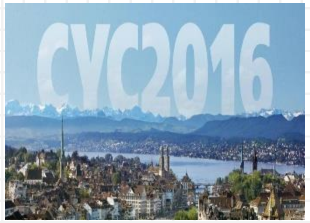
In the Name of GOD

Amirkabir University of Technology (AUT),Tehran,Iran



21^{st} International Conference on Cyclotrons and their Applications

Design and Simulation of Cavity for 18MeV Cyclotron

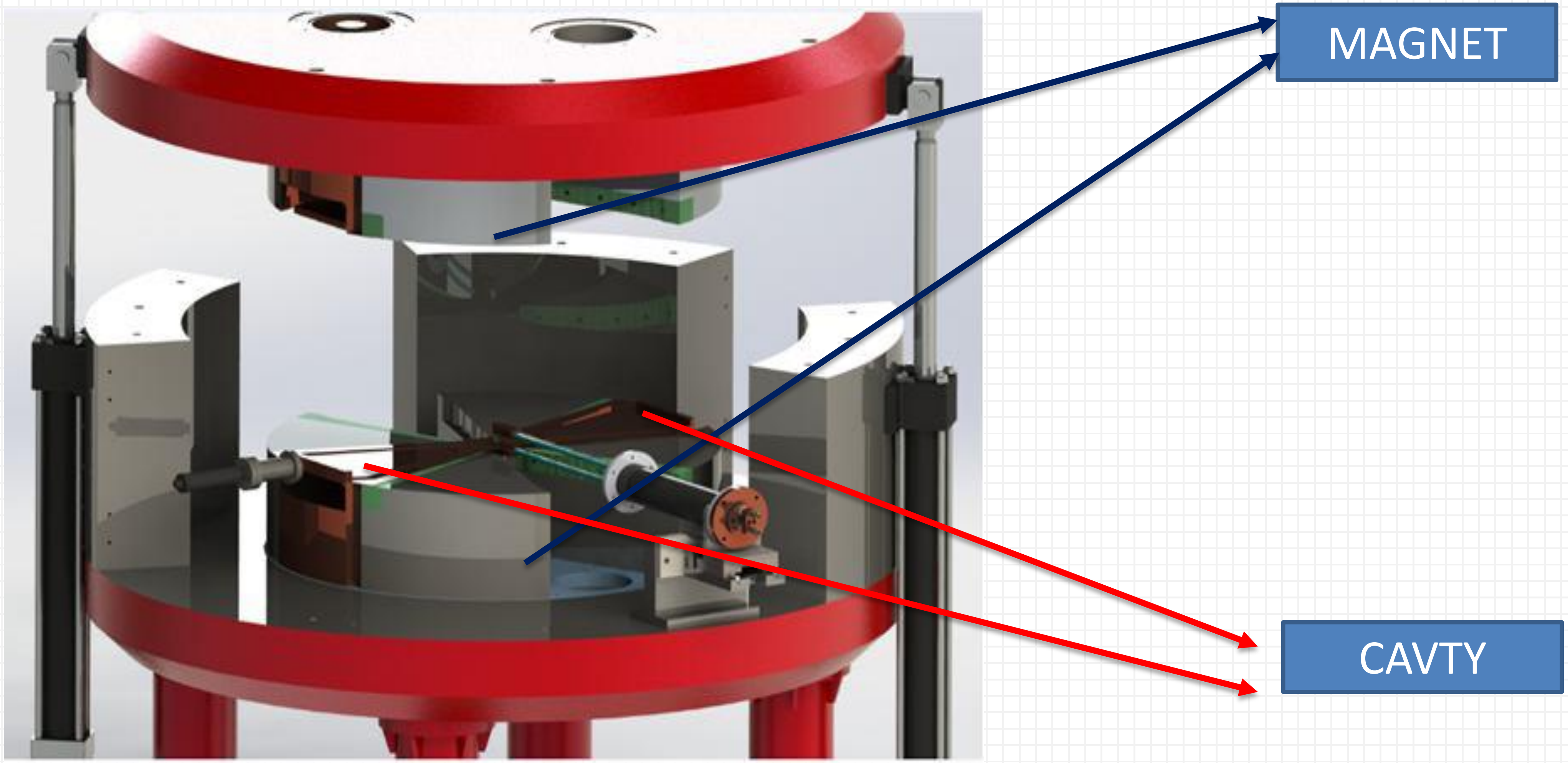
Presenter:
Seyyed Mohsen Mousavinia

September 2016

Content

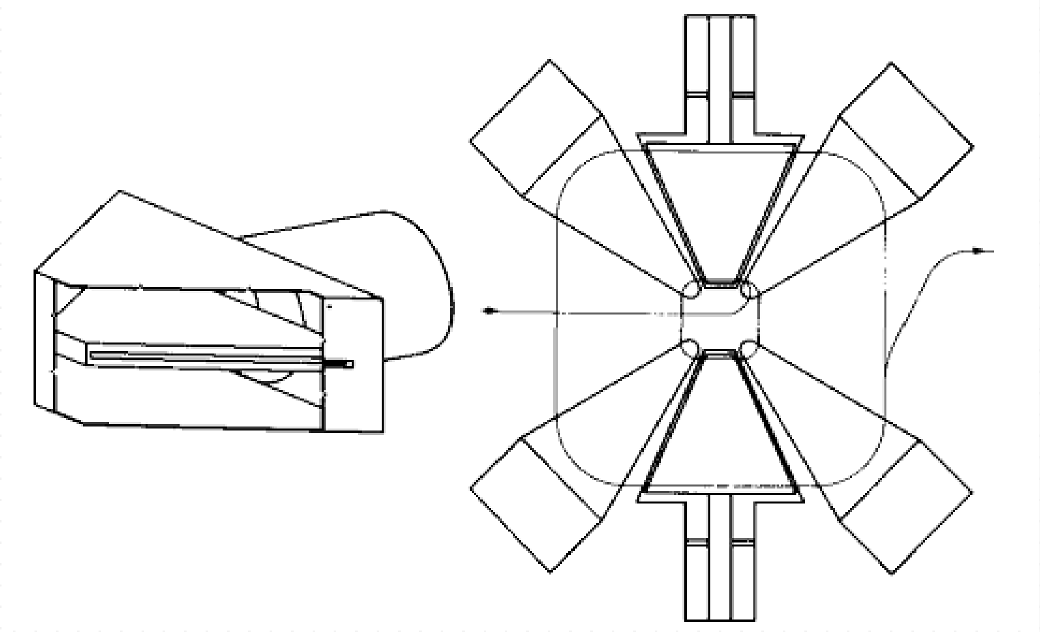
Principle of Cavity

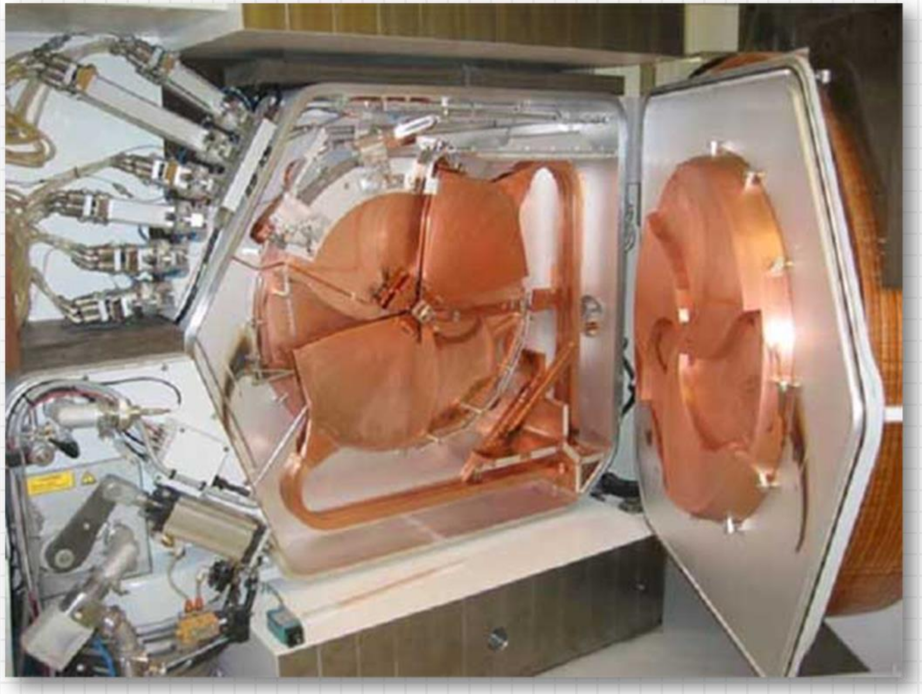
Working principle of Cyclotron



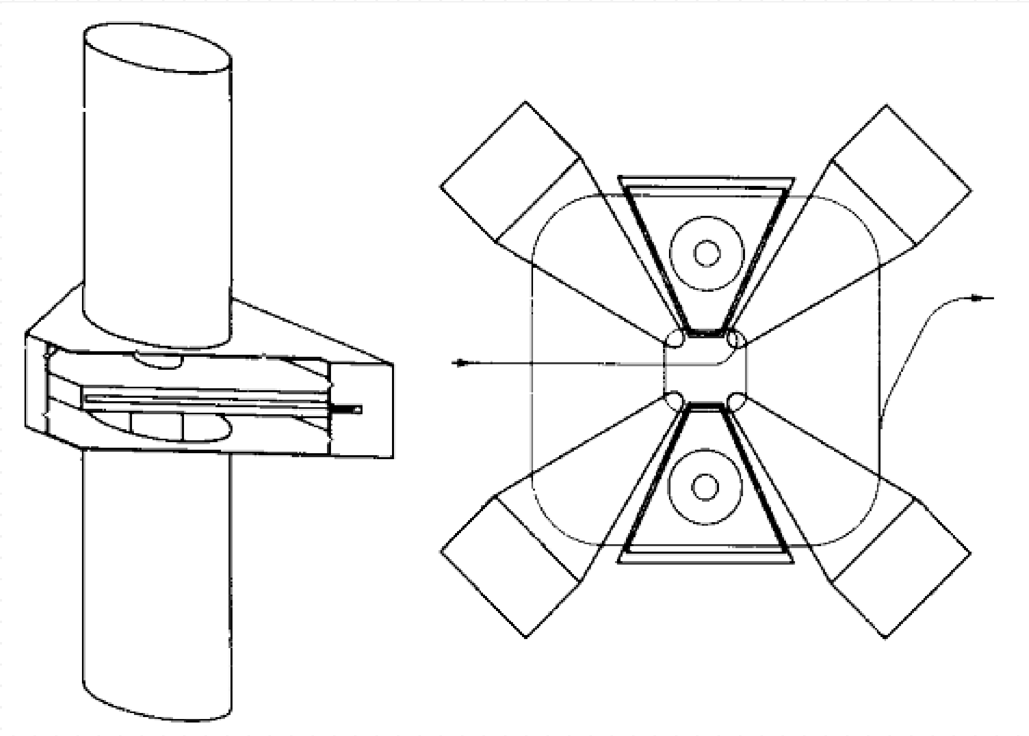
Types of Cavity

Delta Resonator with horizontal stem

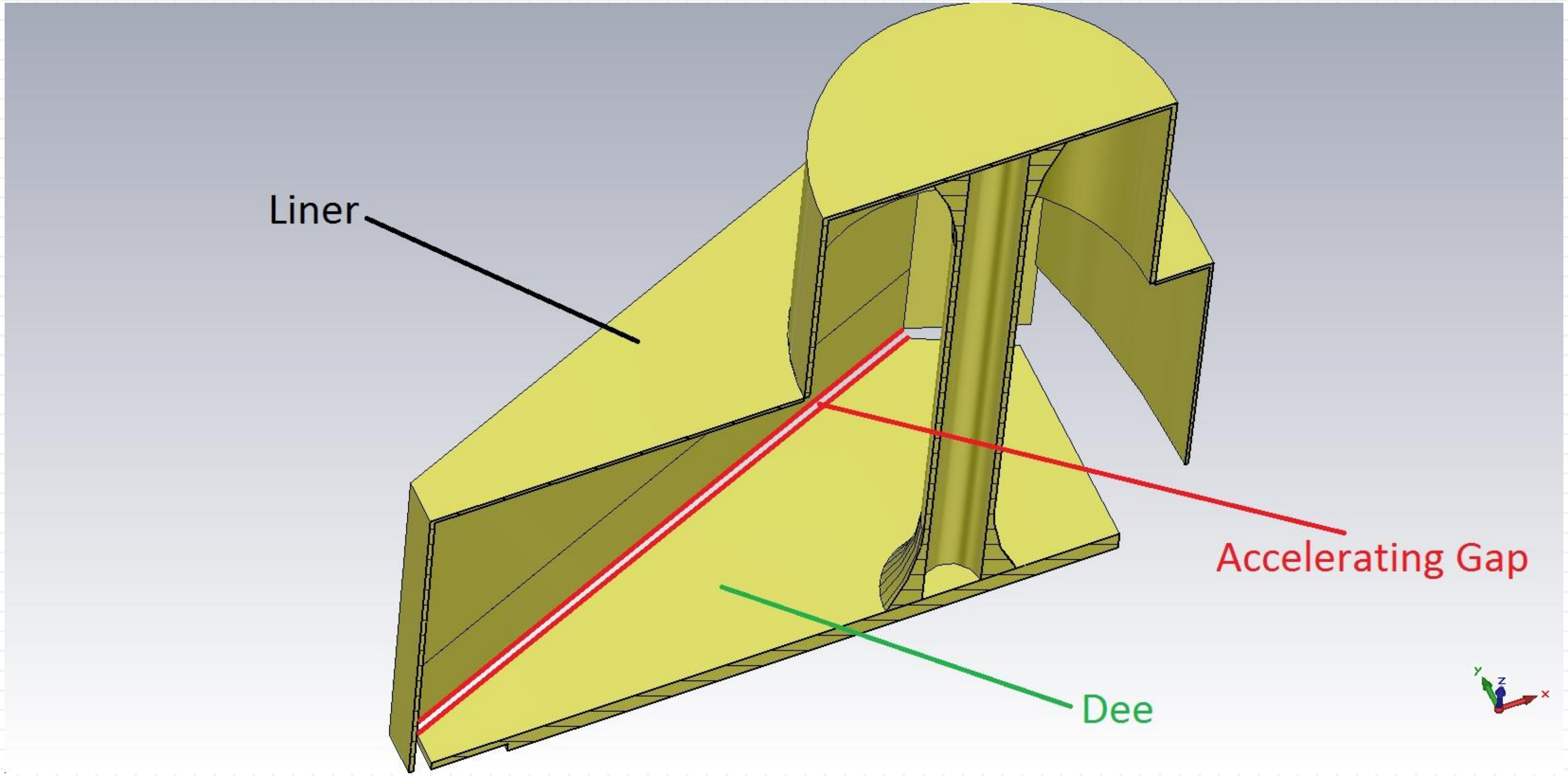




Delta Resonator with vertical stem

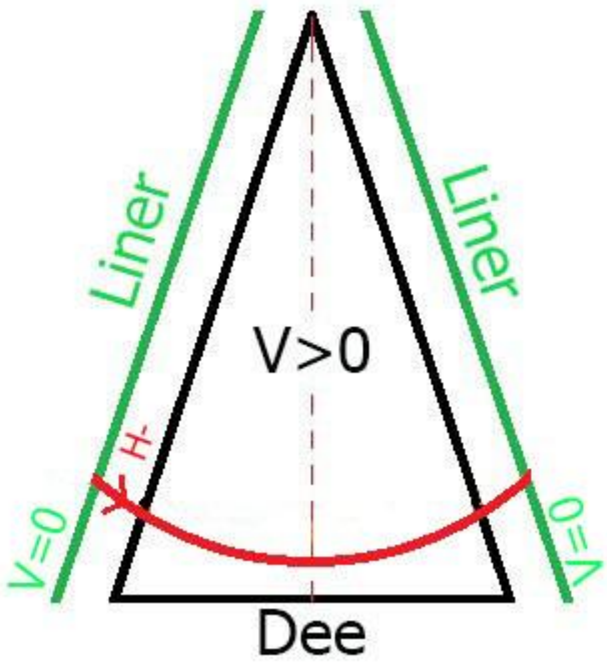


1. Electric Field Created Due to Potential Difference Between Electrodes
2. The Distance Between Electrodes Called Accelerating Gap
3. High Voltage Electrodes Called Dees
4. Ground Potential Electrodes Called Dummy Dee or Liner



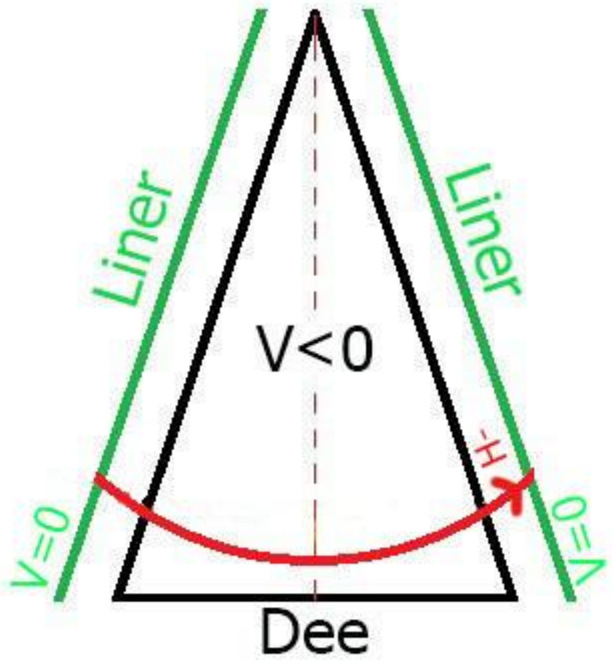
Acceleration Steps

First Acceleration
Dee Entrance

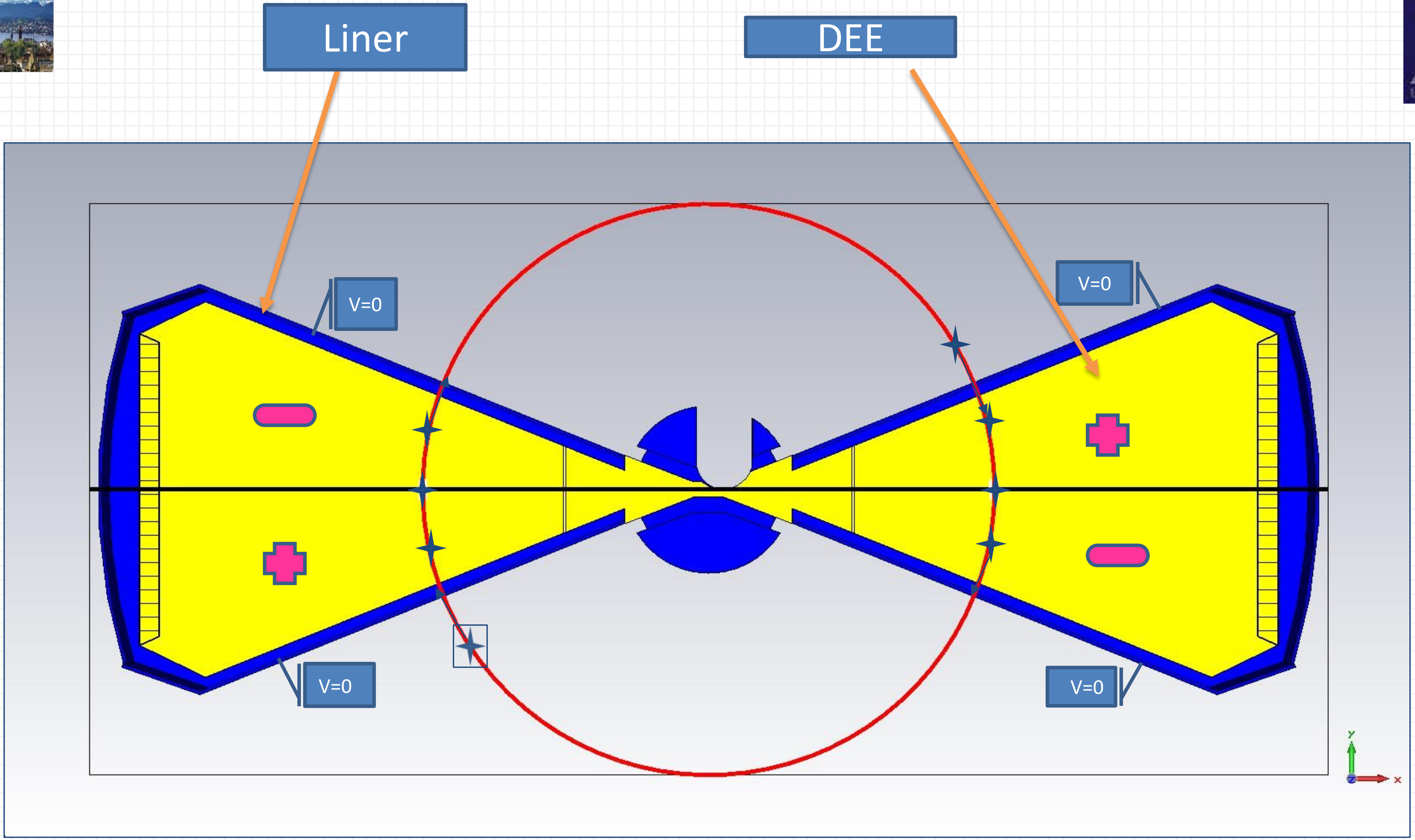


Particle Pulled in Dee Entrance
When
V>0

Second Acceleration
Dee Exit



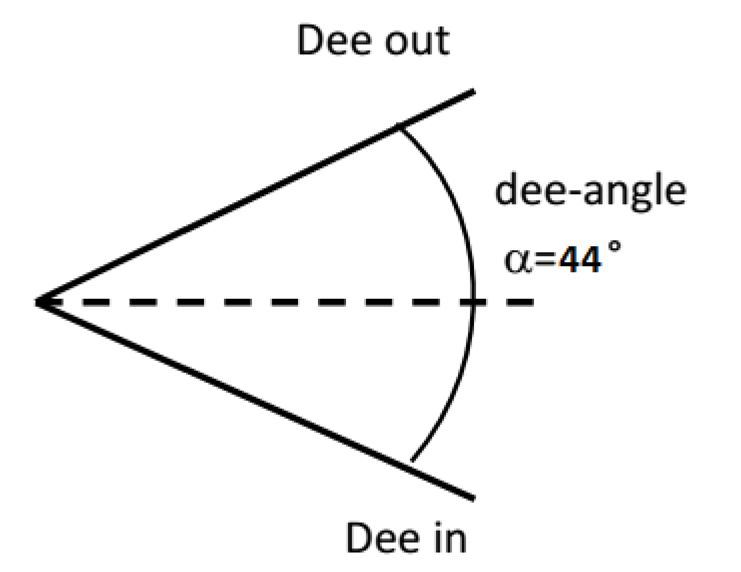
Particle Pushed in Dee Exit
When
V<0

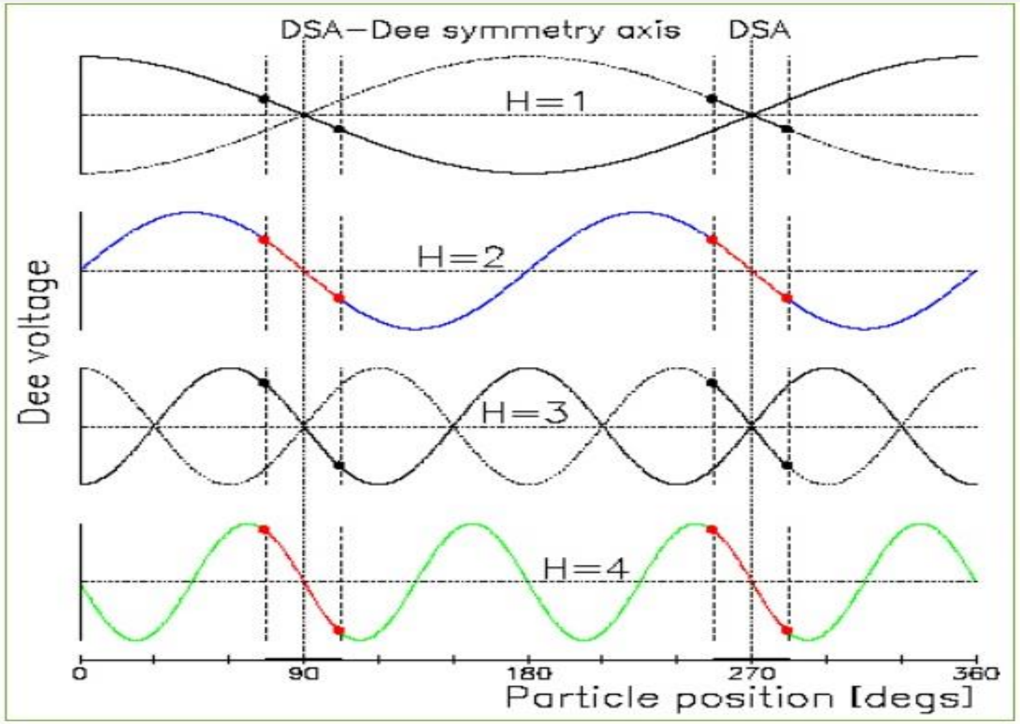


Liner
DEE
V=0
V=0
V=0
V=0

Energy Gain per Turn

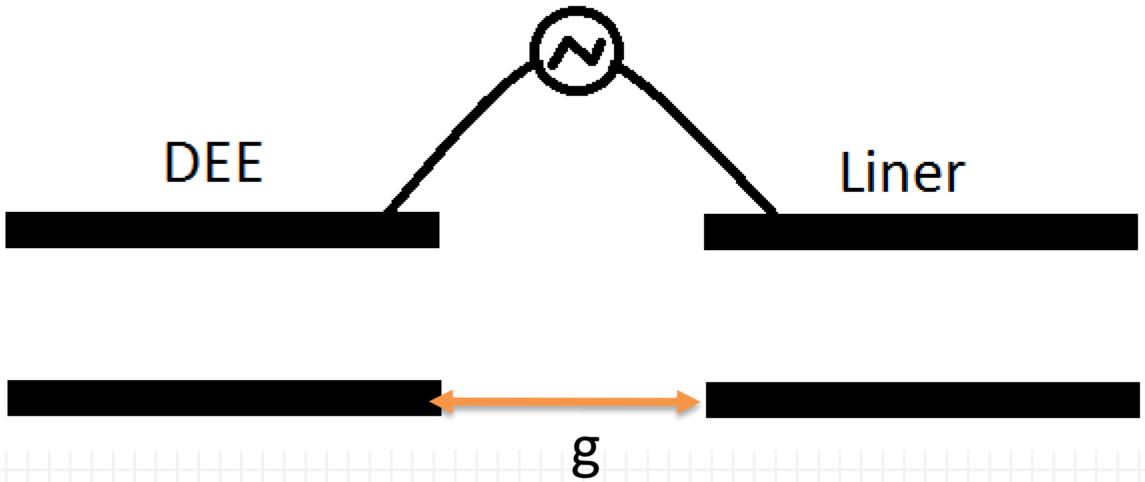
$$\Delta E_k = qV_{dee}\tau N \sin(\frac{h\alpha}{2}) \cos \Phi_{RF}$$





h	1	2	3	4	5	6	7
$\sin(h\frac{\theta}{2})$	0.375	0.695	0.914	0.999	0.939	0.743	**0.438**

THE ACCELERATION GAP AND THE TRANSIT-TIME FACTOR



$$V_{eff} = V_0 \cos(\omega t) \times \frac{\sin(\frac{gh}{2R})}{(\frac{gh}{2R})}$$

Transit Time Factor

Kilpatrick criterion

$$f = 1.643(E_k)^2 e^{(-8.5/E_k)}$$

$$E_s = bE_k = 1.5 \times 9.7\frac{MV}{m} = 14.55\frac{MV}{m}$$

$$E = \frac{V}{d}$$

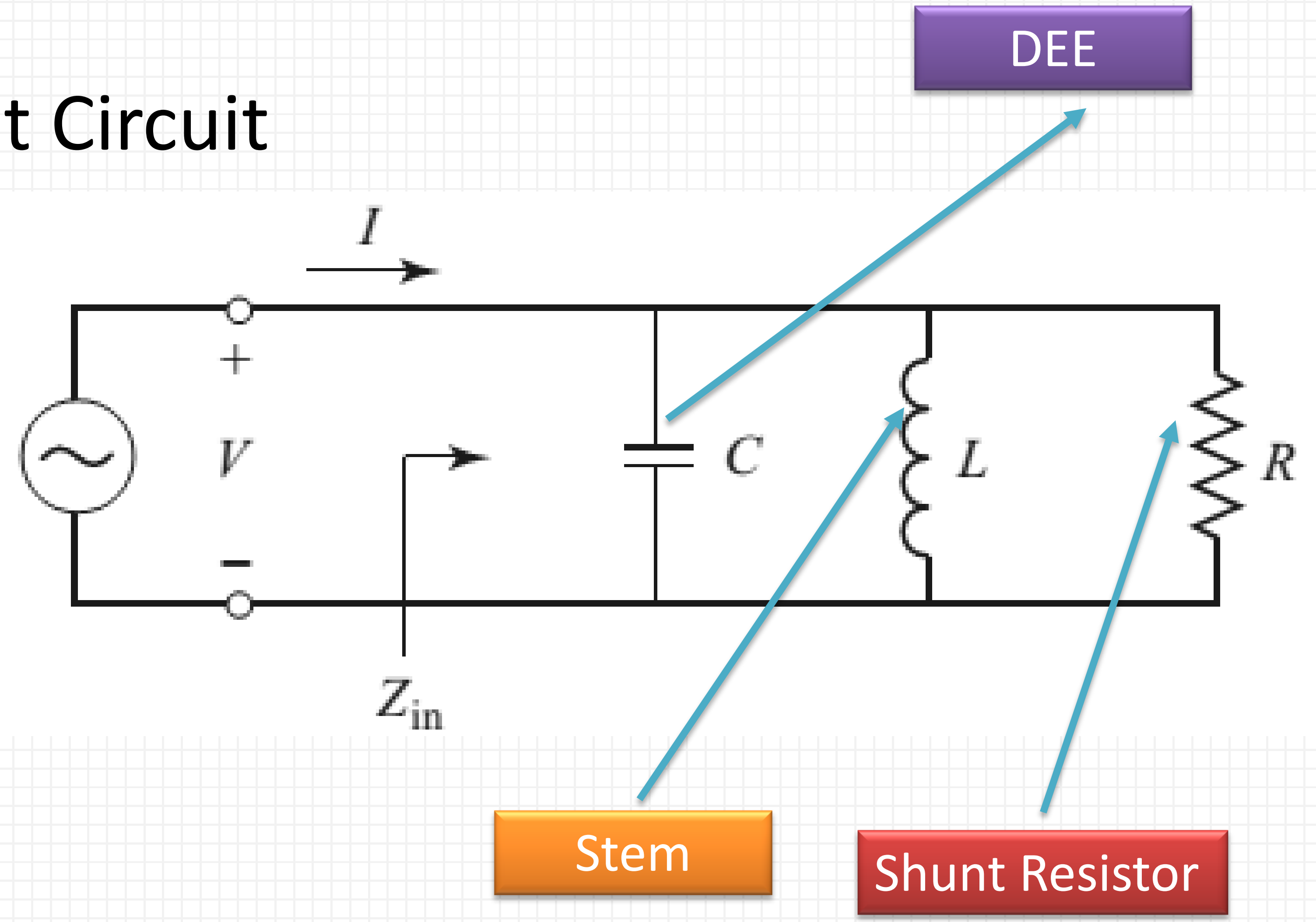
$14.55\text{M} = \frac{76k}{d}$ dmin=5.22 mm

Resonator Design

Equivalent Circuit of Resonator

Parallel Resonant Circuit

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



Calculate the particle rotation frequency

Proton Energy: E_0=938.272 Mev

Cyclotron energy: T=18 Mev

45.783 tesla meter Br =

If B=1.7 T → r =63 cm

According to this equation, ω.r is determined:

If r =63 cm → $f_{particle}$=16.075MHz

$$f_{rf} = hf_{particle} = 4\times 16.075 = 64.3\ MHz$$

Characteristics of Parallel Resonant Circuit are:

Input Impedance is :
$$Z_{in} = \left(\frac{1}{R} + \frac{1}{j\omega L} + j\omega C\right)^{-1},$$

Complex Power Delivered to the Resonator is:
$$P_{in} = \frac{1}{2}|V|^2\left(\frac{1}{R} + \frac{j}{\omega L} - j\omega C\right).$$

power dissipated by the resistor, *R*, is
$$P_{loss} = \frac{1}{2}\frac{|V|^2}{R}$$

Average Electric Energy Stored in the capacitor, *C*, is
$$W_e = \frac{1}{4}|V|^2 C$$

Average Magnetic Energy Stored in the Inductor, *L*, is
$$W_m = \frac{1}{4}|I_L|^2 L = \frac{1}{4}|V|^2\frac{1}{\omega^2 L}.$$

Resonance Occurs
when
$W_m = W_e$

Quality Factor

$$Q = \omega \frac{\text{average energy stored}}{\text{energy loss/second}}$$

Q of the parallel resonant circuit can be expressed as

$$Q_0 = \omega_0 \frac{2W_m}{P_{\text{loss}}} = \frac{R}{\omega_0 L} = \omega_0 RC,$$

This result shows that the *Q* of the parallel resonant circuit increases as *R* increases.

Coupling and Matching

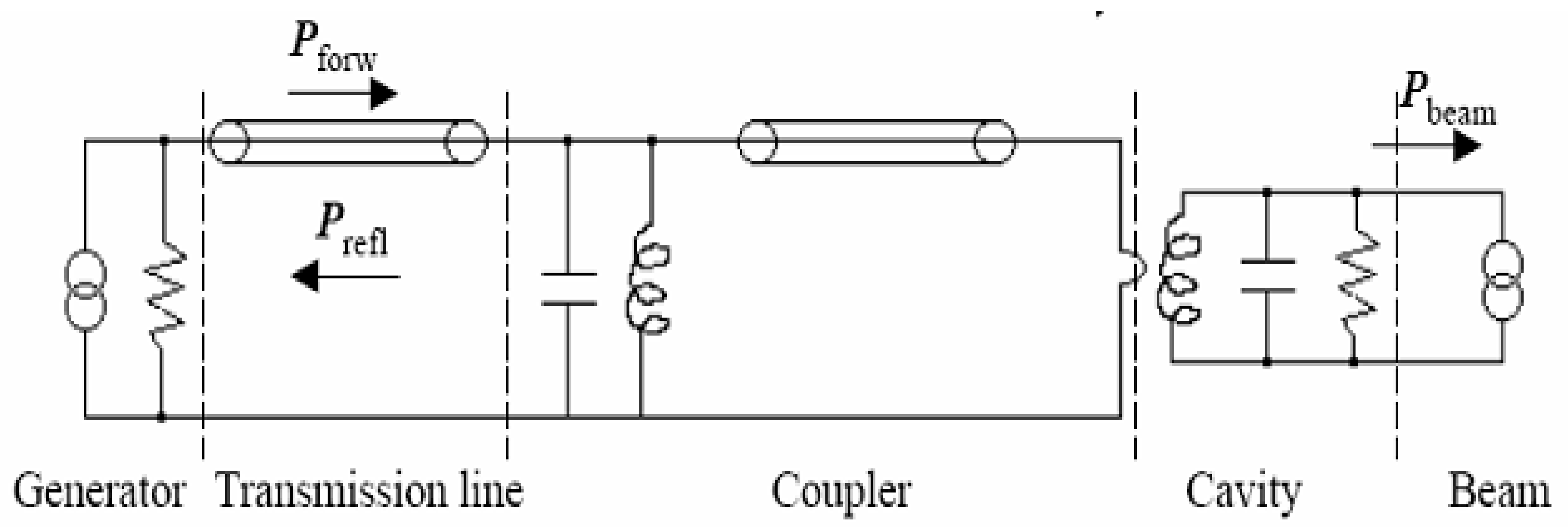
Tasks:

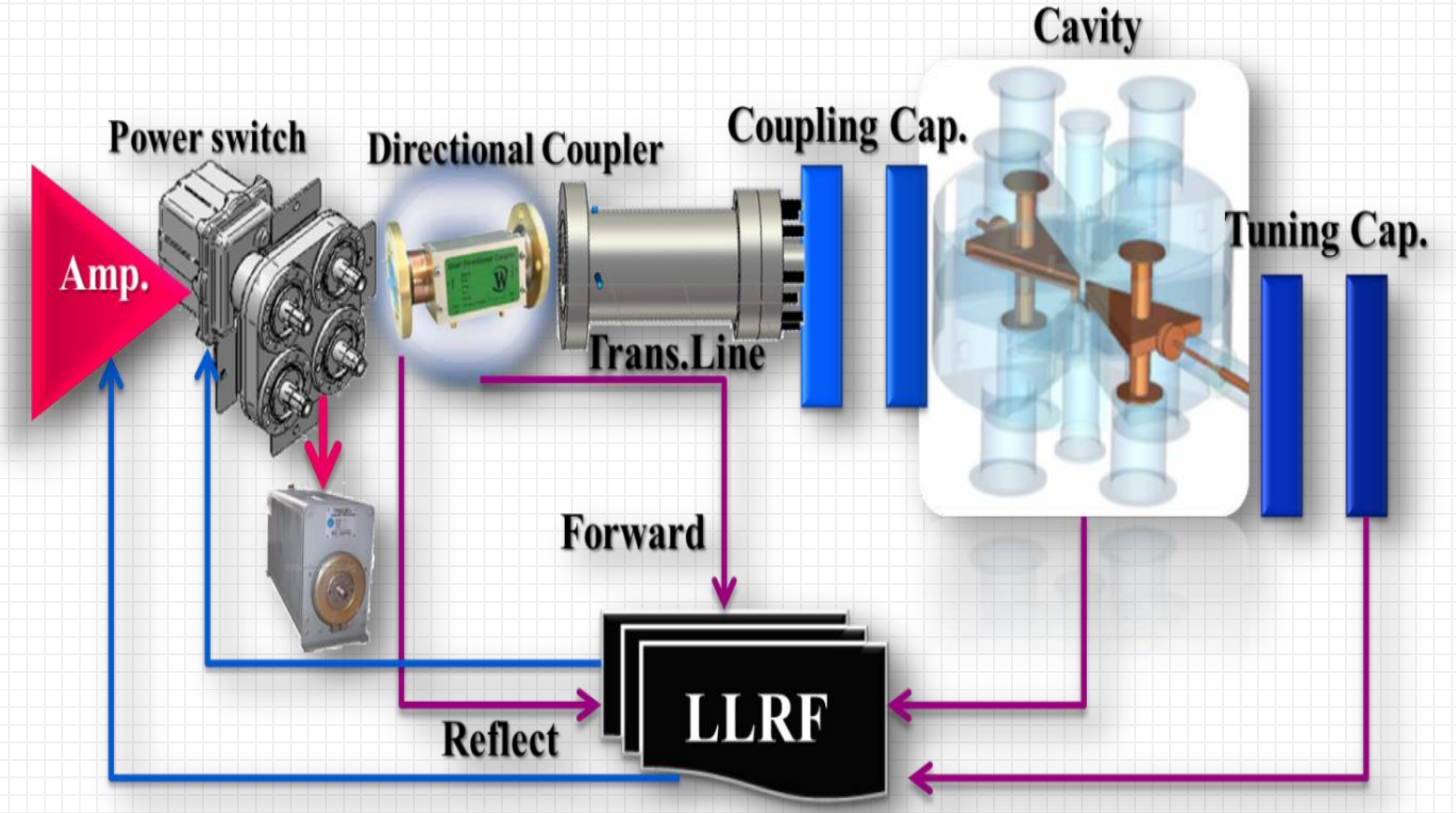
Maximum power transfer and impedance matching of line to cavity

Types of cavity:

Capacitive(Electric)

Inductive(Magnetic)




Cavity
Power switch
Directional Coupler
Coupling Cap.
Tuning Cap.
Amp.
Trans.Line
Forward
LLRF
Reflect

Possible problems during operation of the cyclotron

Mismatch Leads to:

a. the transmitter may not be able to supply enough power to maintain the desired accelerating voltage if the cavity's resonant frequency drifts too far from the driving frequency;

b. the power supply could be damaged by dissipation of excessive power reflected back from the load;

c. breakdown and sparking could occur

d. the phase and amplitude response of the transmitter may be severely affected by the change in the load

The factors that can cause changes in the cavity's geometry and loading are

1. Thermal expansion and contraction of the cavity structure, which will greatly affect the cavity's resonant frequency;

2. Electrical discharge phenomena such as sparking which will lower the cavity's quality factor and which may also slightly detune the cavity

3. Multipacting

And changes cavity geometry leads to changes in:

Resonant Frequency, Quality Factor and Input Impedance

Calculate the required power

Beam power

$$P_b = V_f \times I_b = 18\ MV\ \times 150\ \mu A = 2.7\ KW$$

Resonator dissipated power

$$P_r = \frac{{V_{dee}}^2}{2R_s} = \frac{44\ KV^2}{2\times 151\ K\Omega}\text{=6.411 KW}$$

Total power

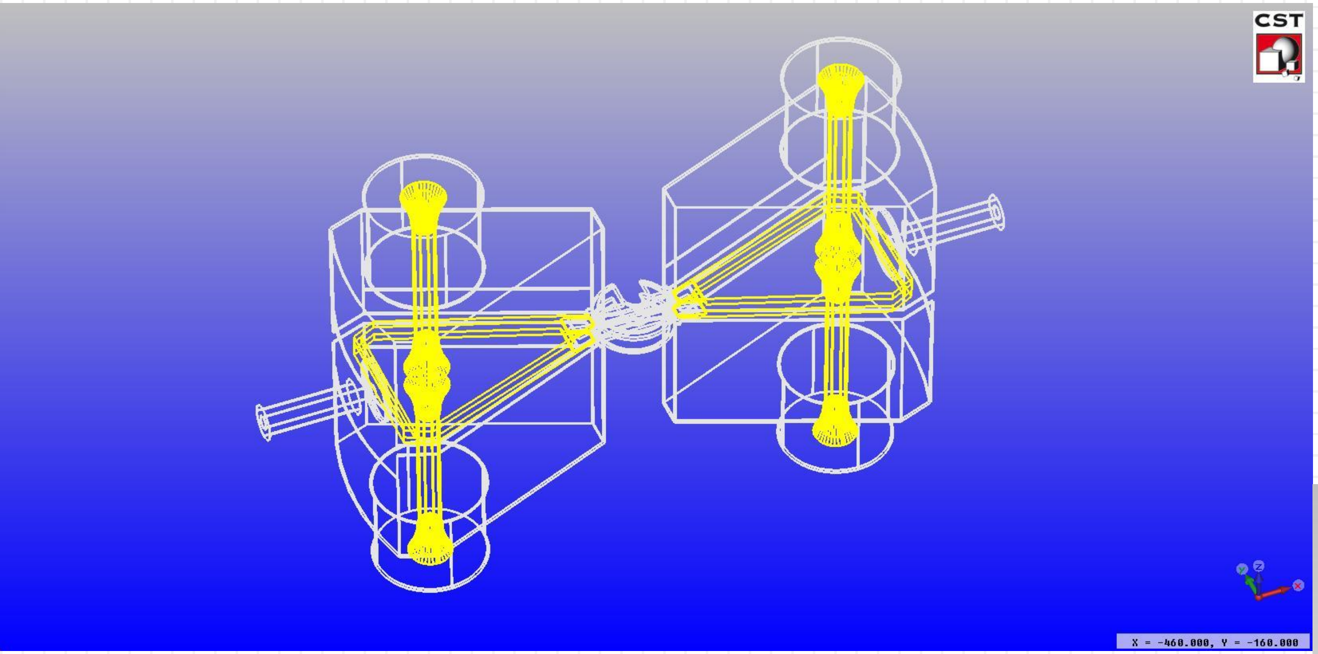
$$P_t = 2.7\ KW + 6.41\ \text{KW} = 9.11\ KW$$

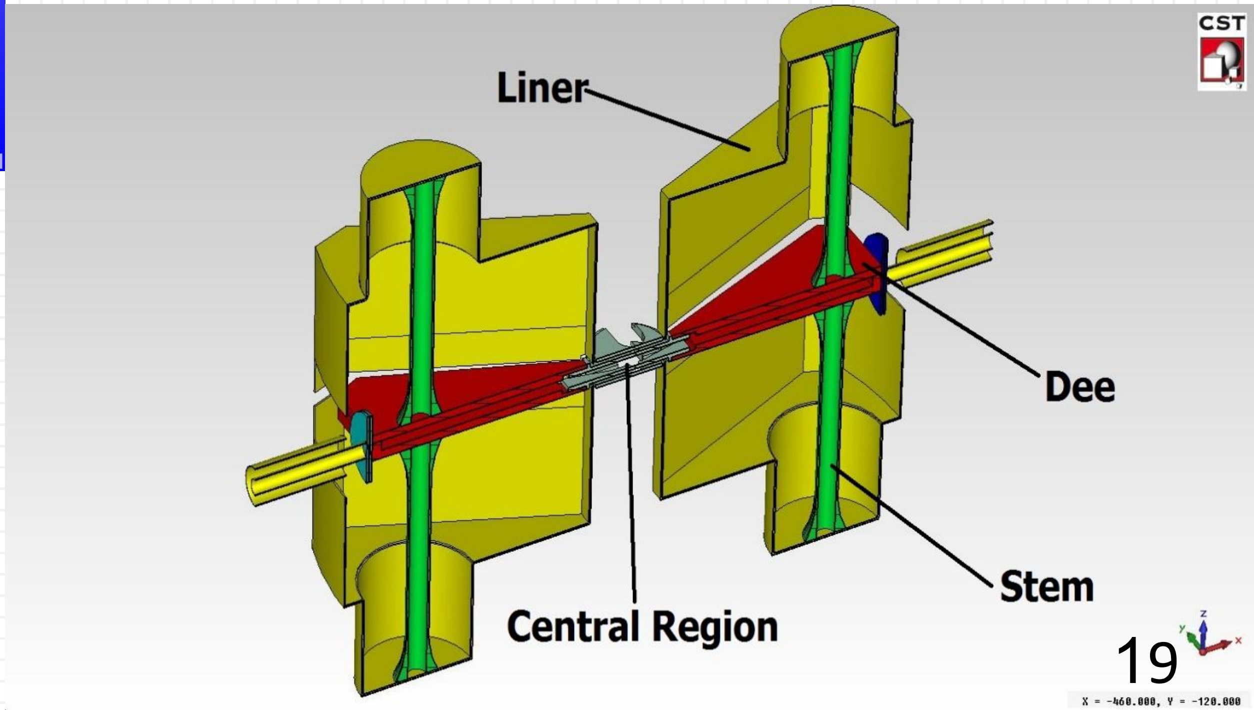
Adding 20% safety margin

$$9.11\ KW * 1.2 = 10.93\ KW$$

Simulation Results

Geometry designed in CST MWS





Design Items

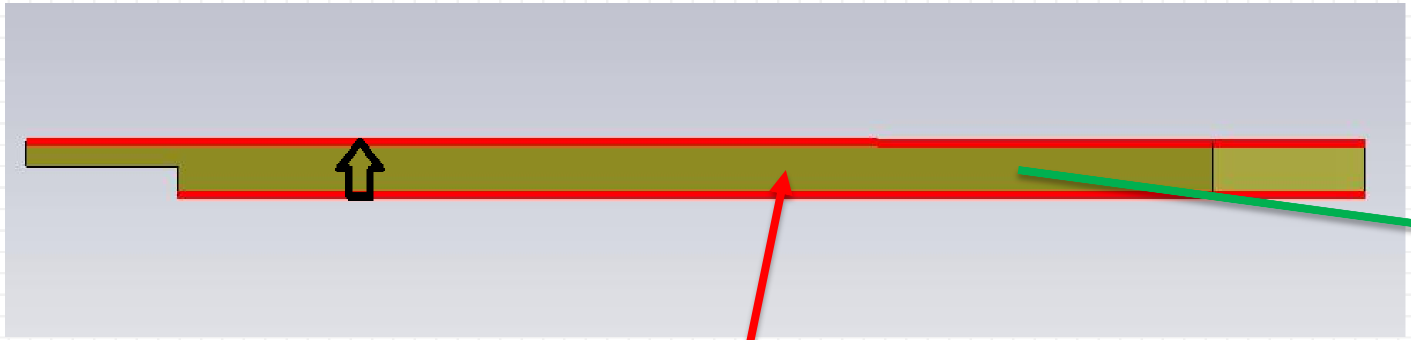
Items that should be considered in the design of dee

1. Angle and width of the Dee
2. Gap between the Dee and Liner
3. Dee thickness

Items that should be considered in the design of stem

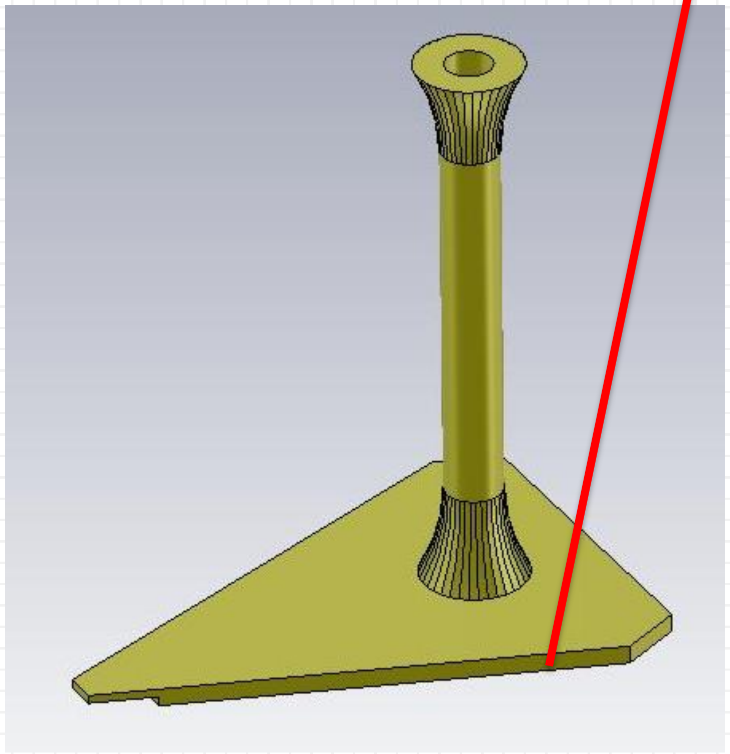
1. Radius
2. Length

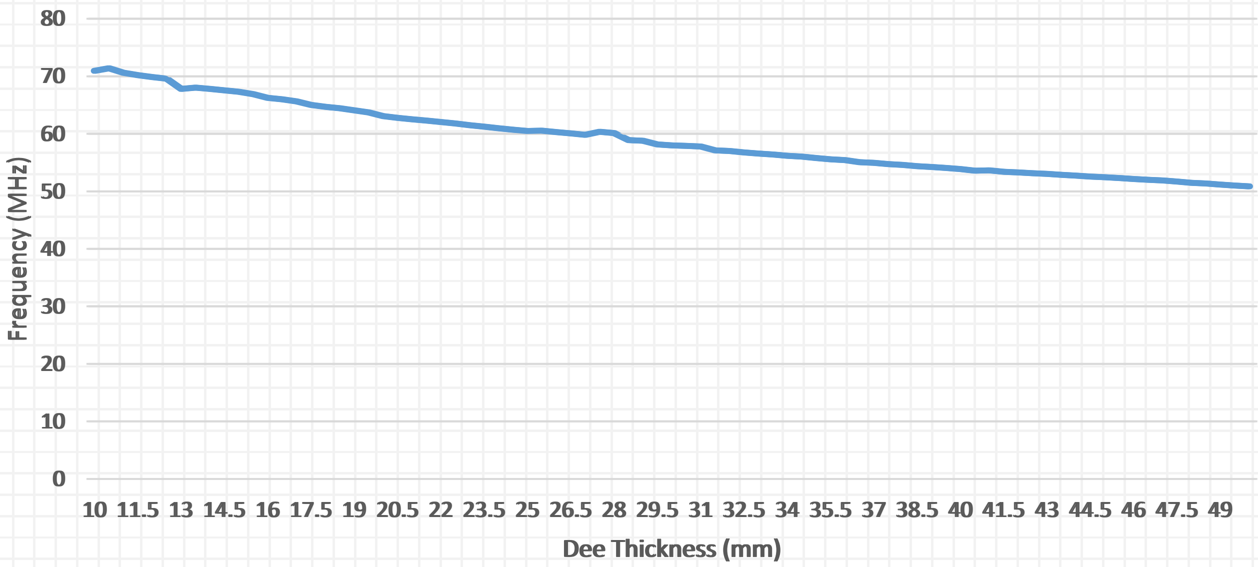
The effects of changing the thickness of the dee



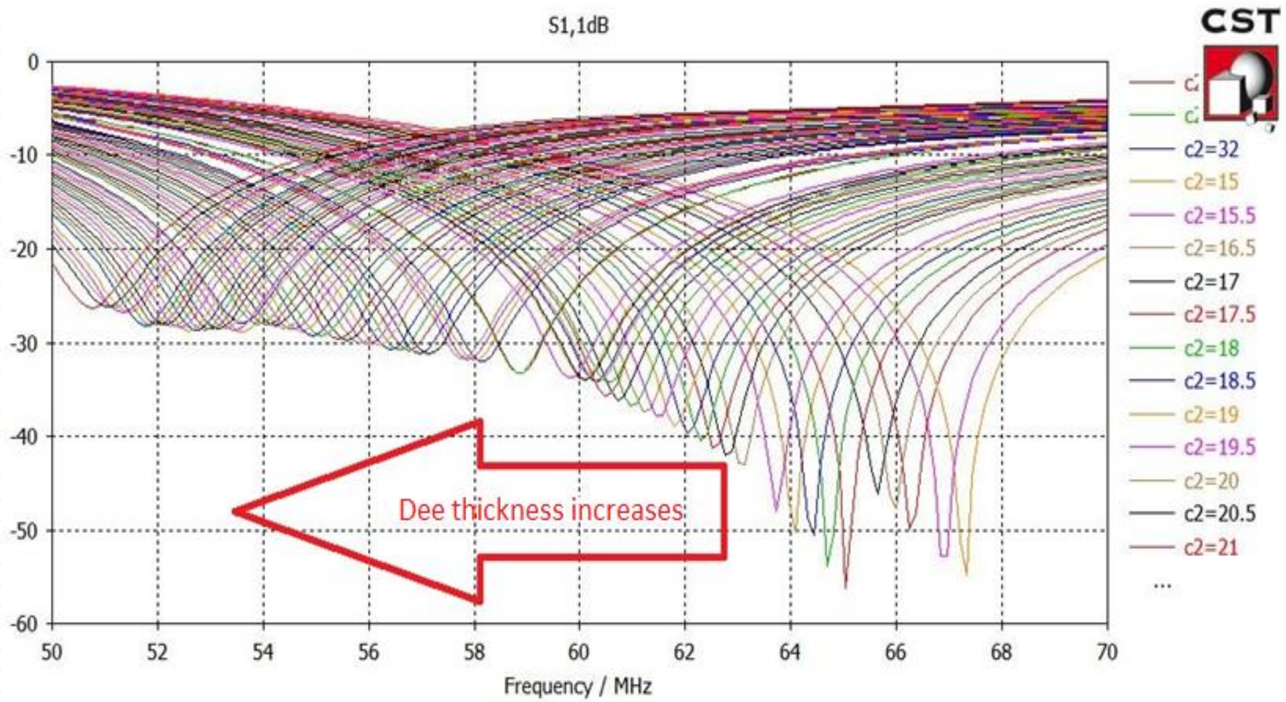
$C \approx \frac{A}{d}$ and $f = \frac{1}{2\pi\sqrt{LC}}$

$A \uparrow \;\rightarrow\; C \uparrow \;\rightarrow\; f \downarrow$

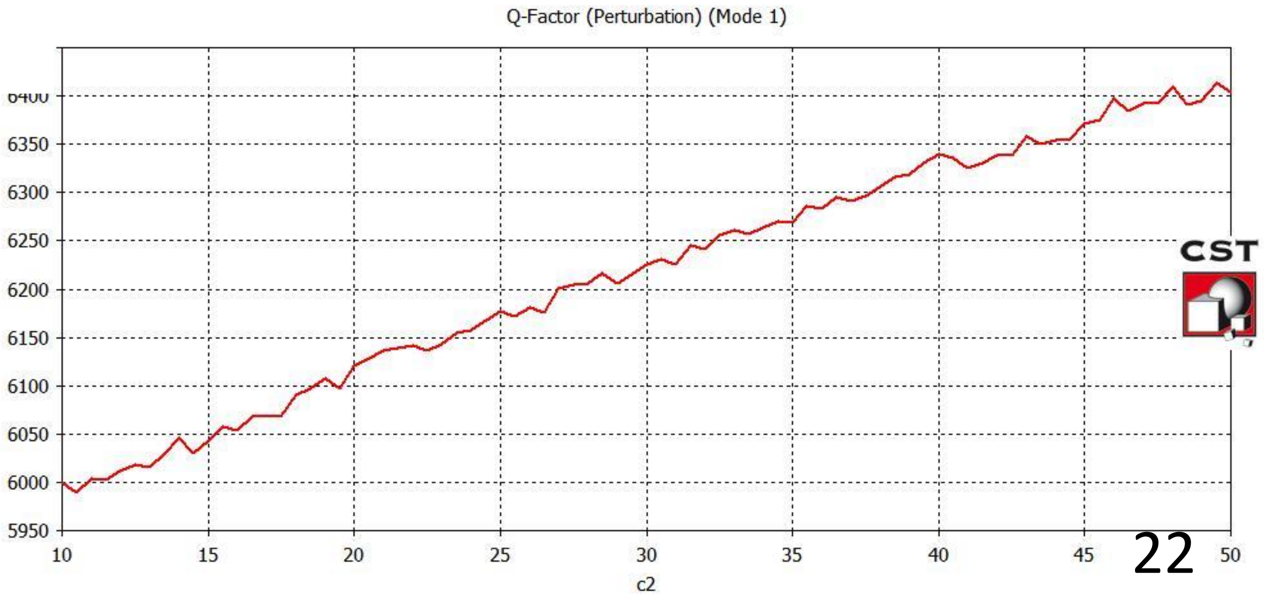




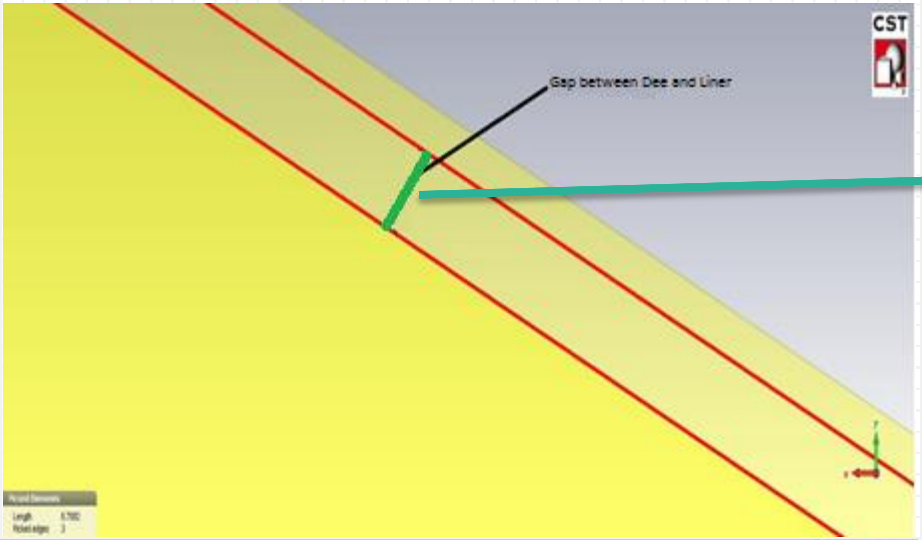
The effect of Dee thickness variation on return loss

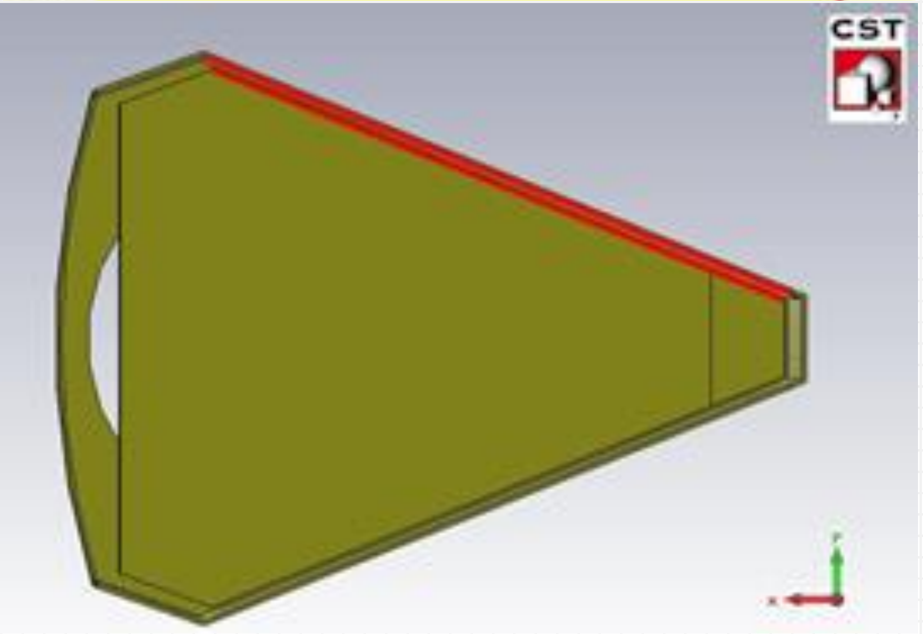


The effect of changing thickness of the Dee on quality factor



The gap between dee and liner

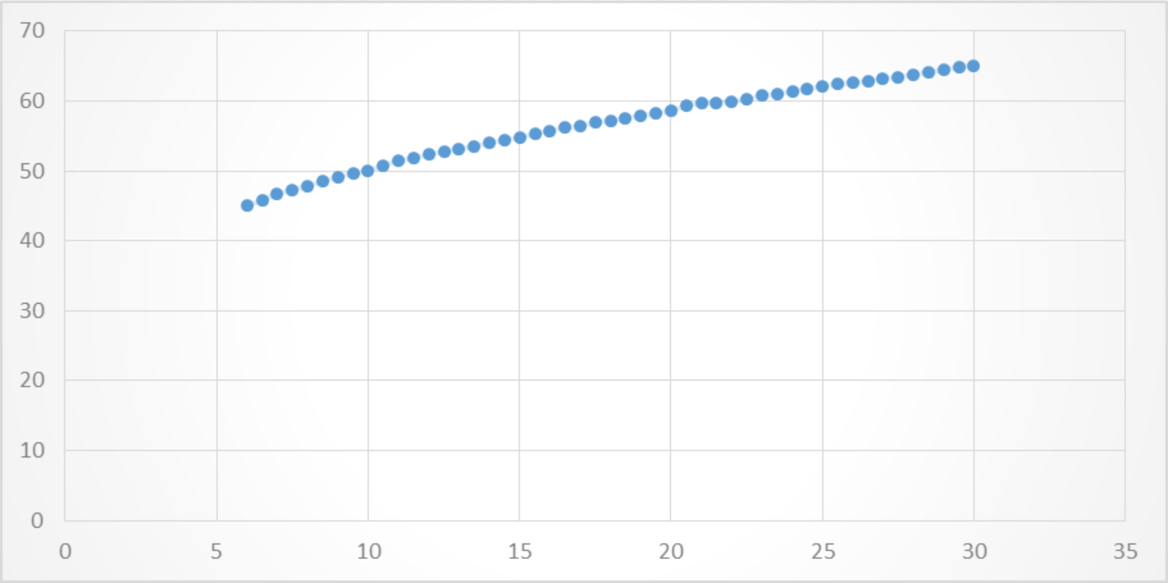




$$C \approx \frac{A}{d} \quad \text{and} \quad f = \frac{1}{2\pi\sqrt{LC}}$$

$$d \uparrow \;\rightarrow\; C \downarrow \;\rightarrow\; f \uparrow$$

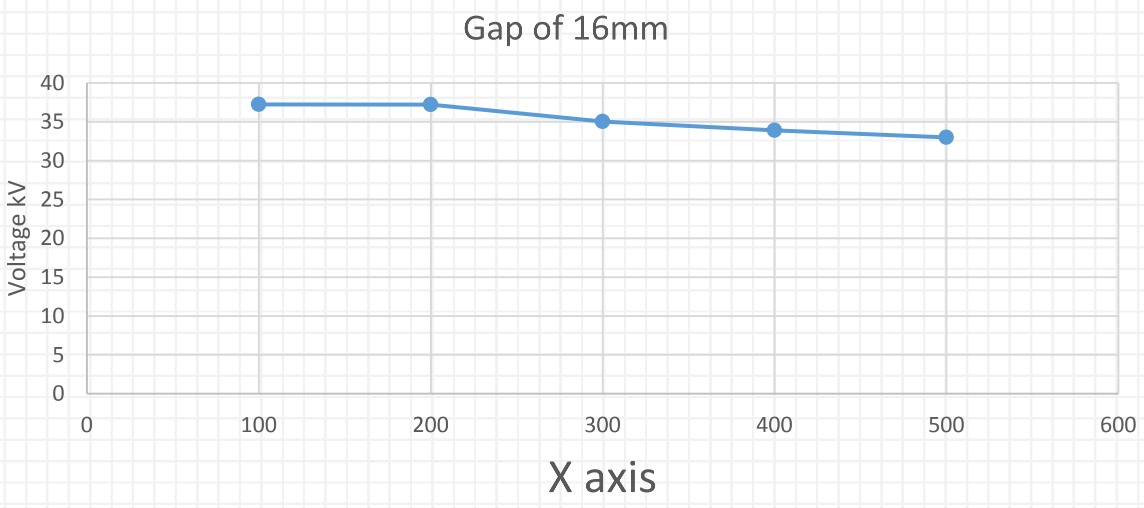
frequency

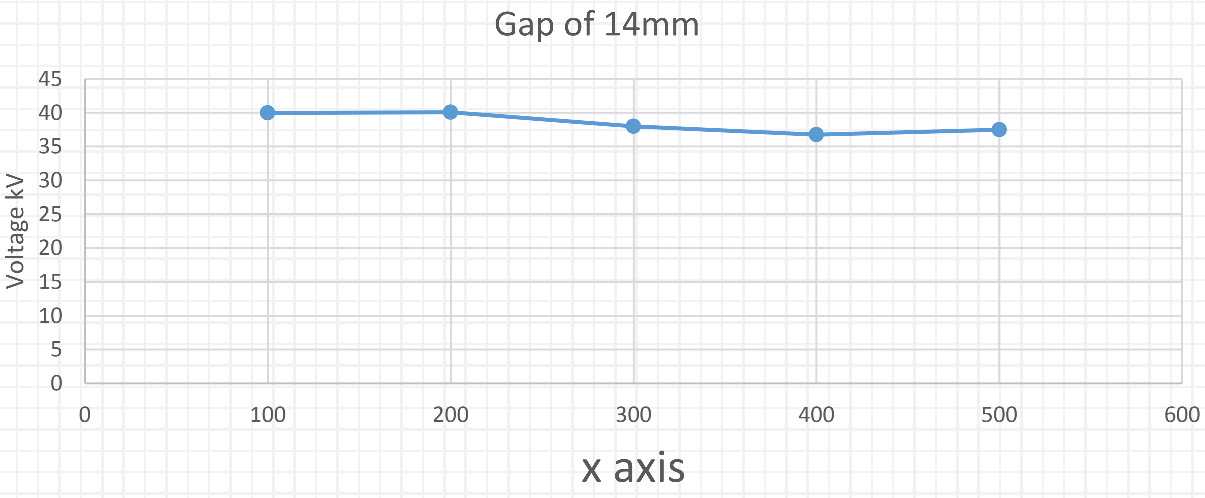


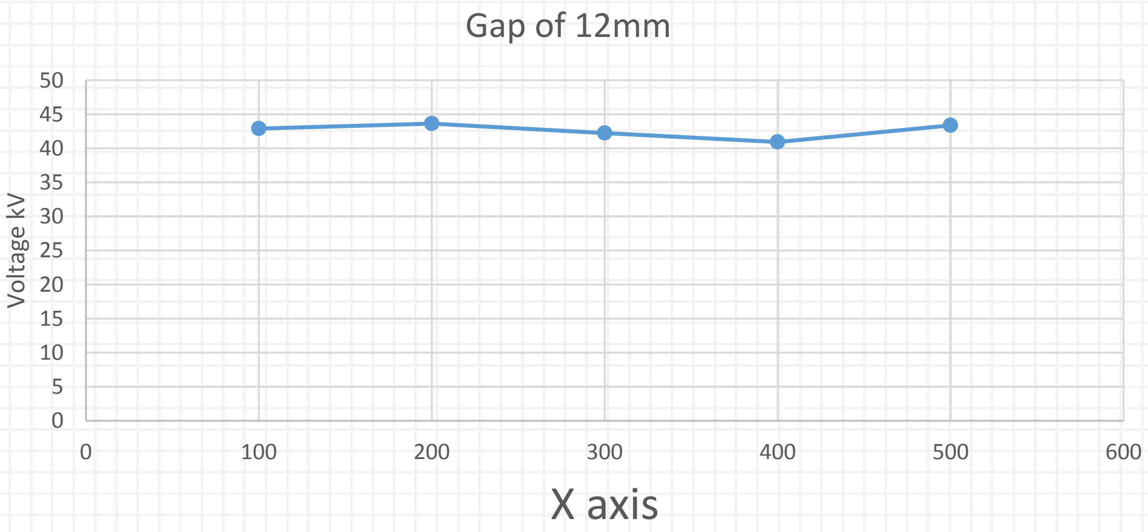
Gap distance

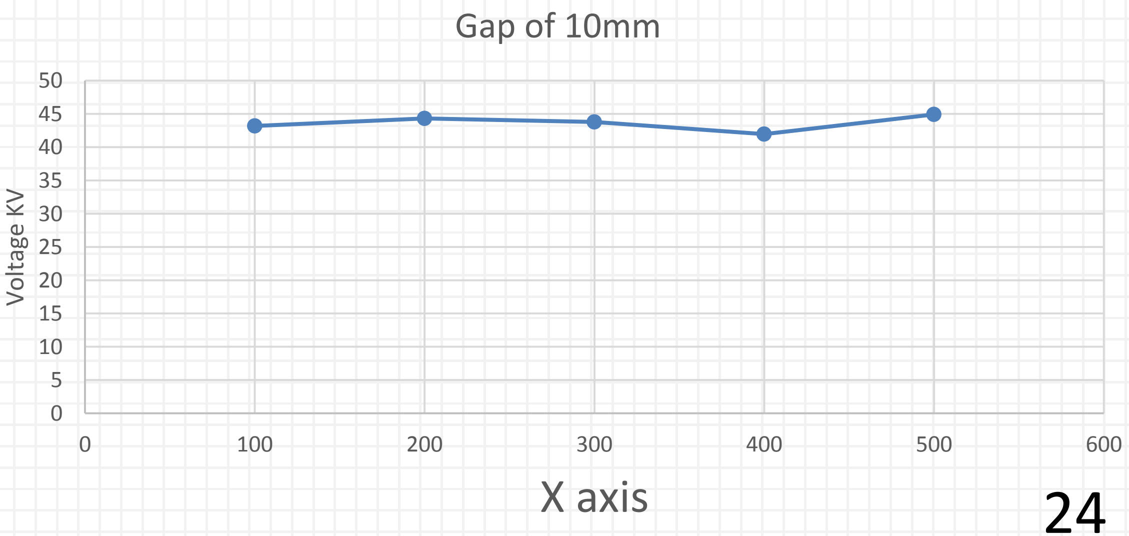
The effect of changing the gap On the frequency

Voltage distribution in size of different gaps

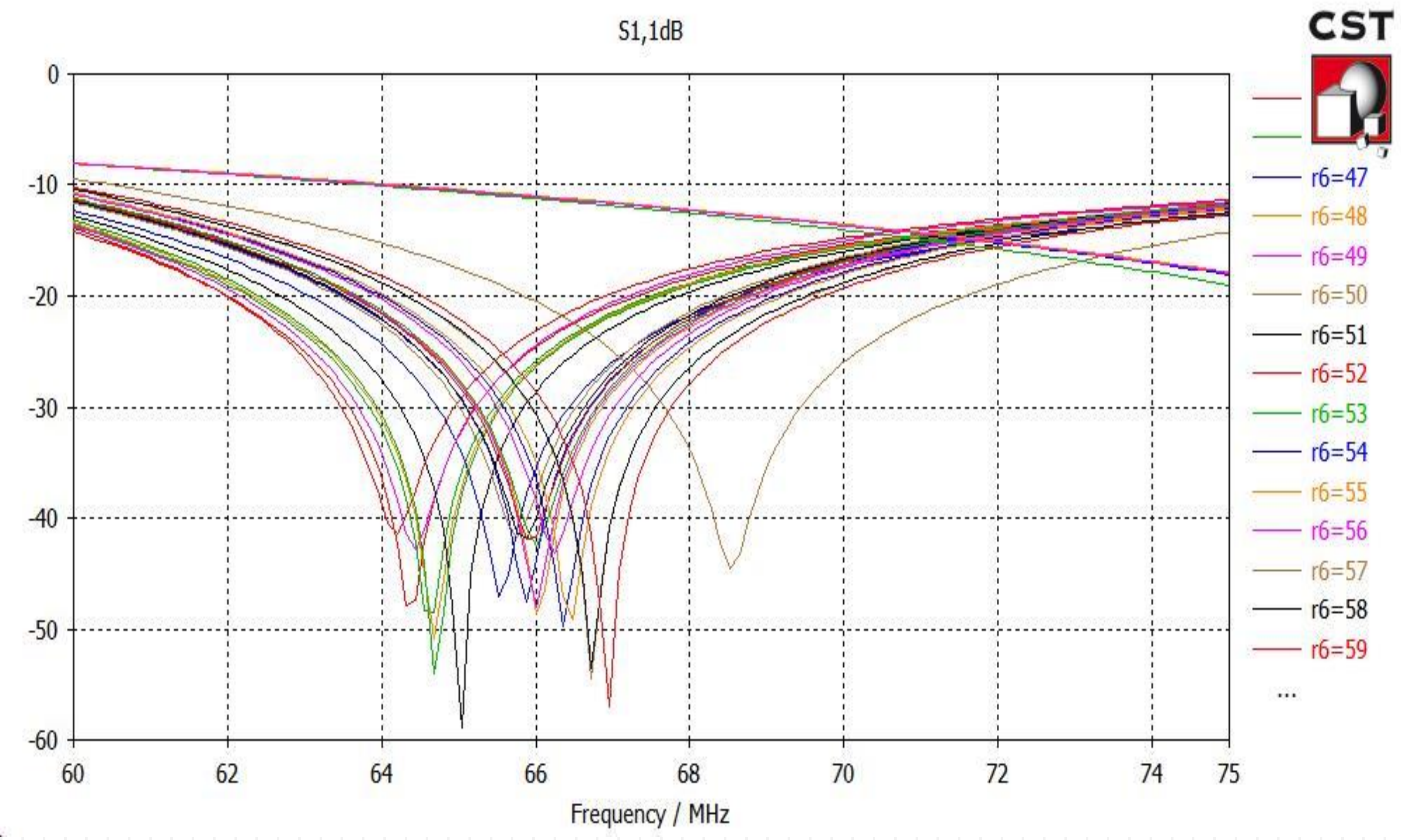


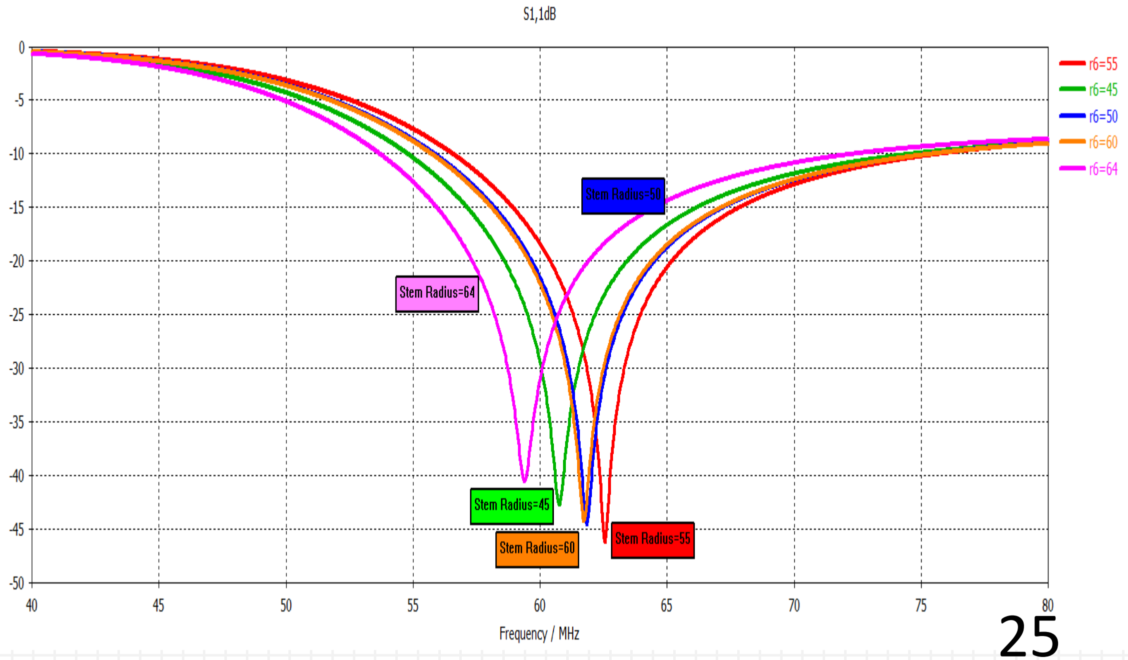




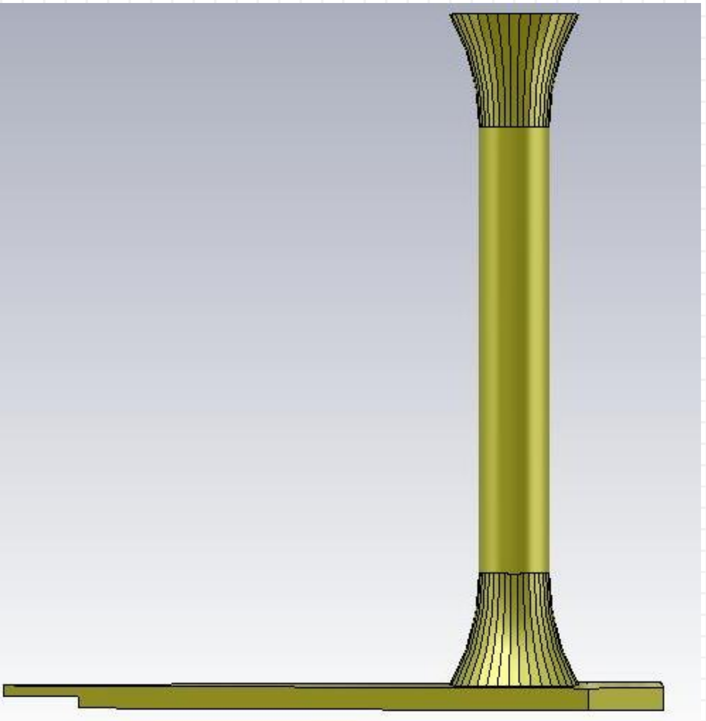


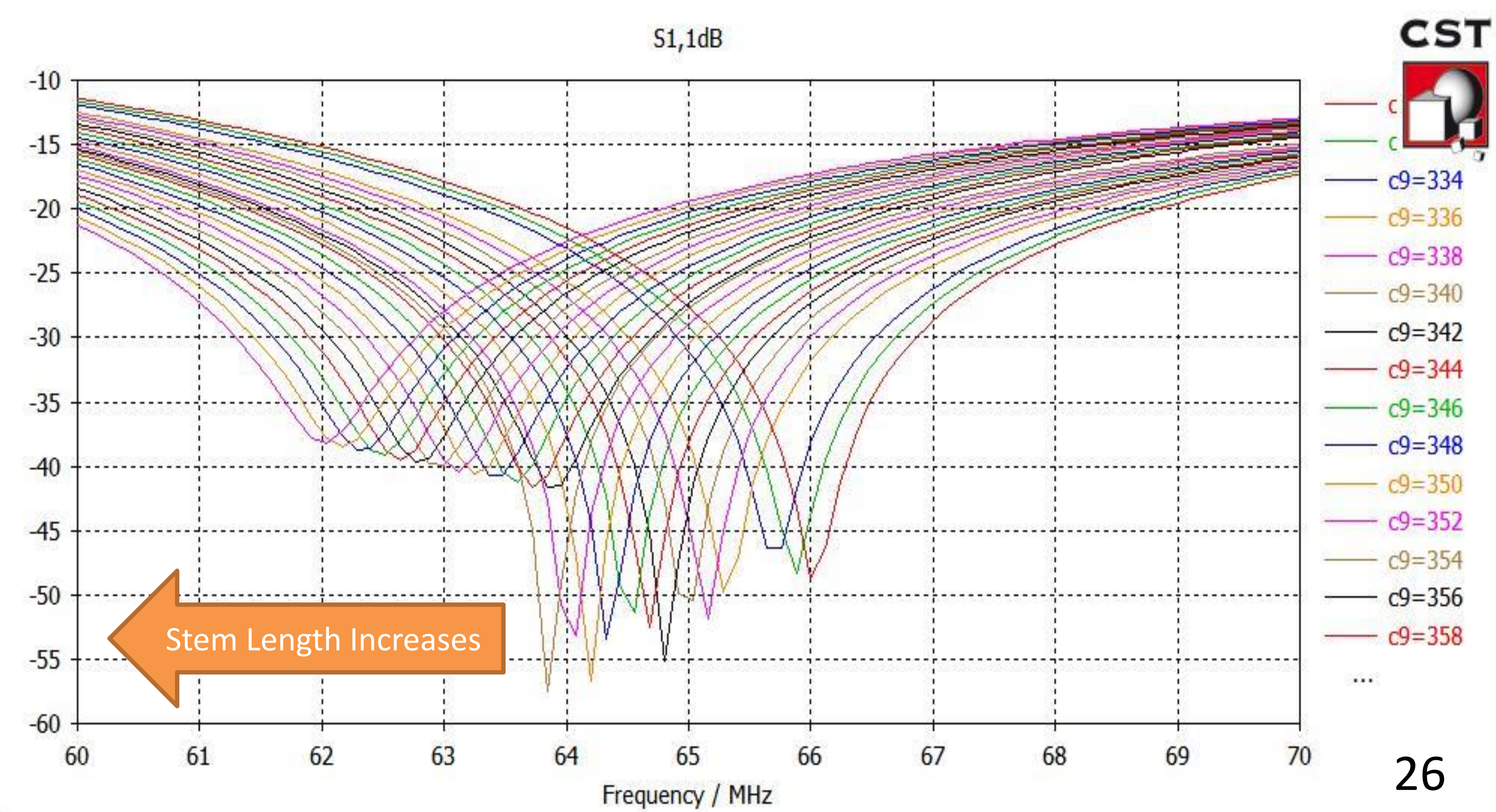
The effect of changing the stem radius



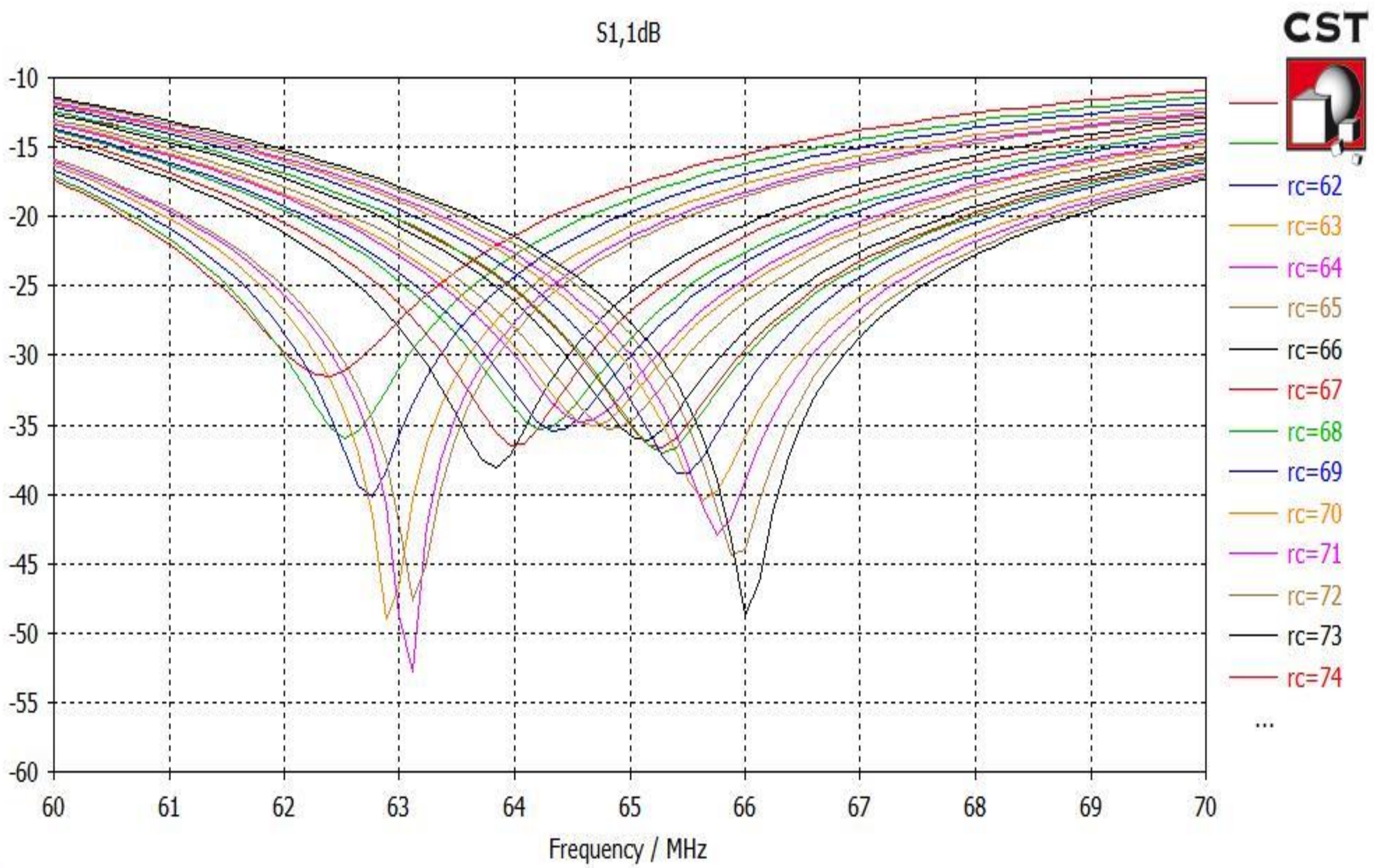


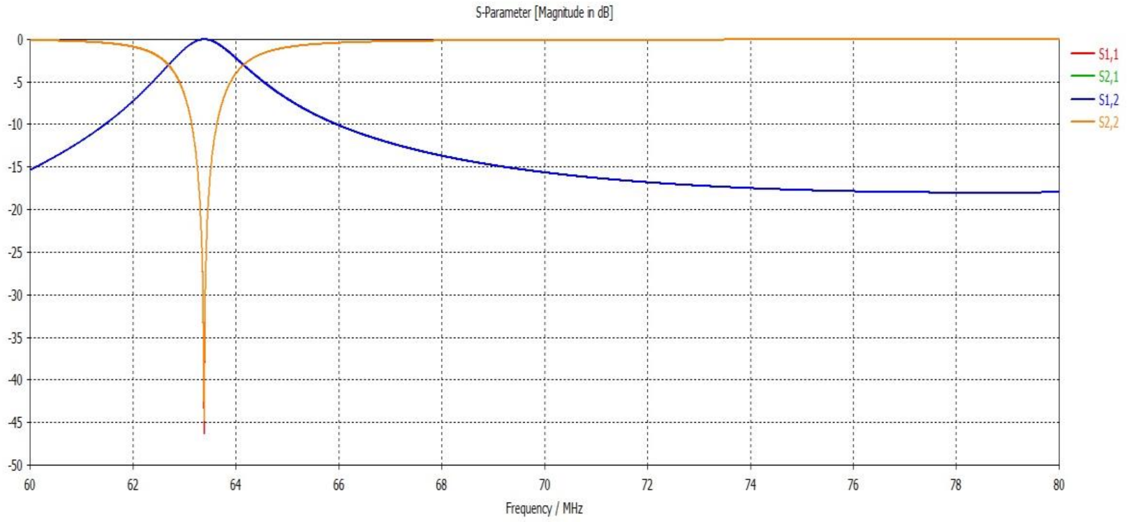
The effect of changing the stem length on the frequency and return loss



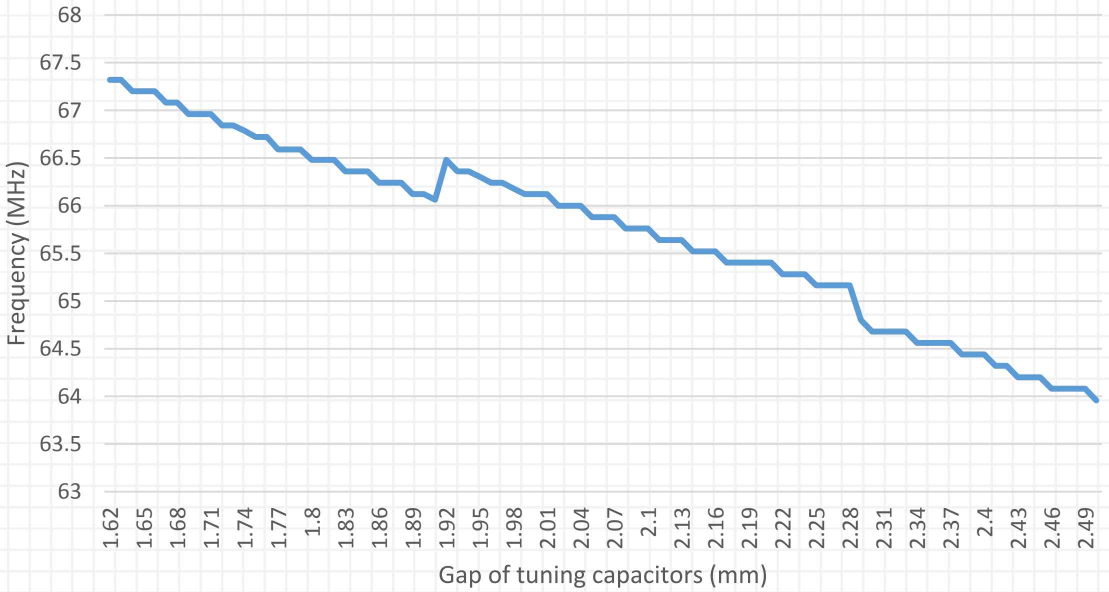


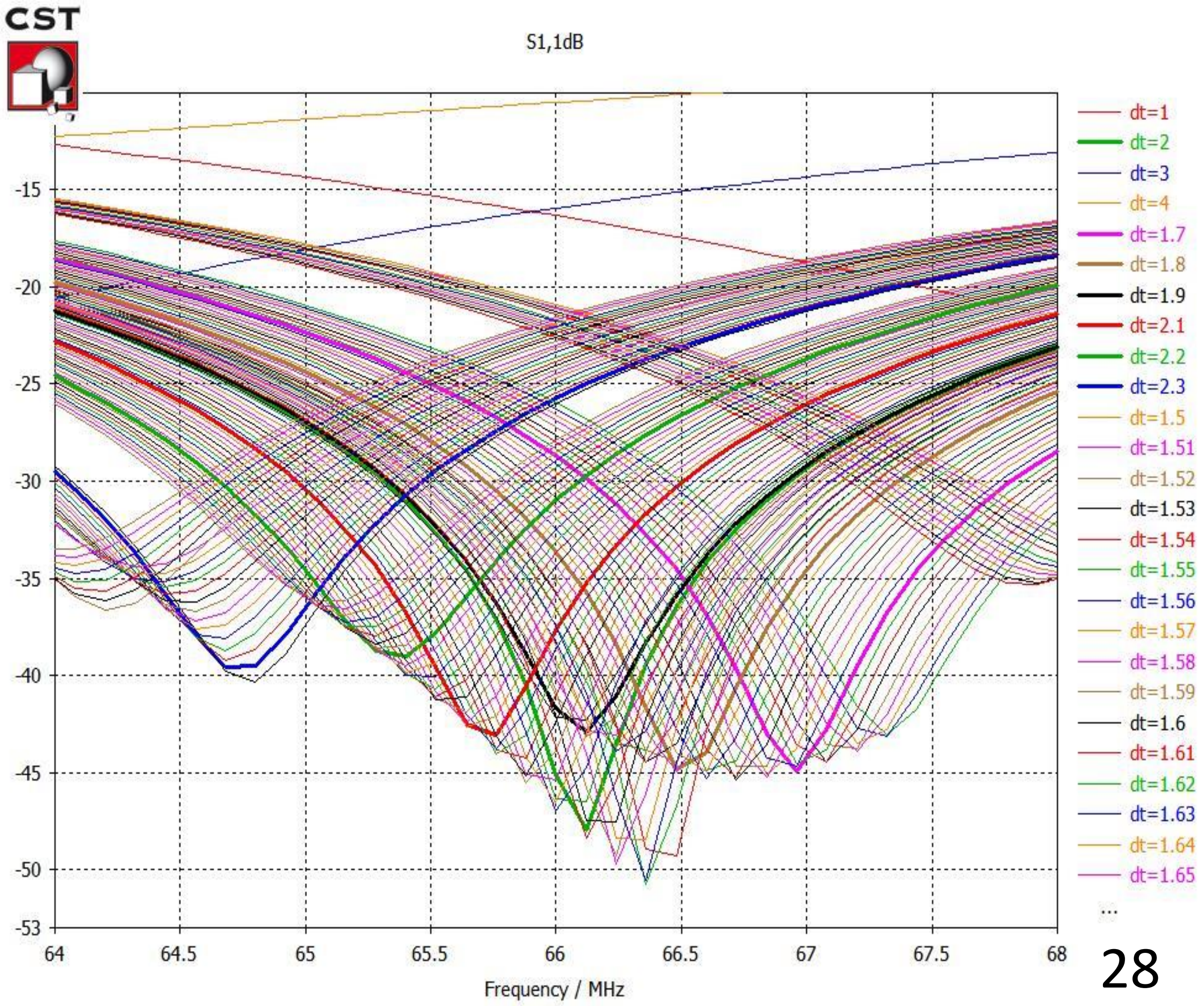
Coupling Result



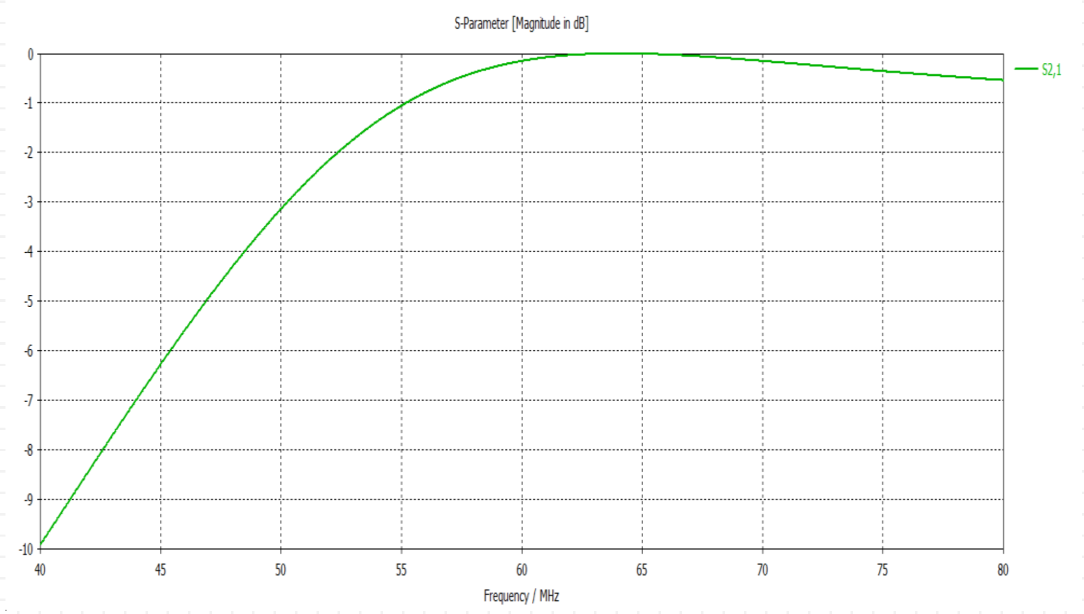


Tuning Result

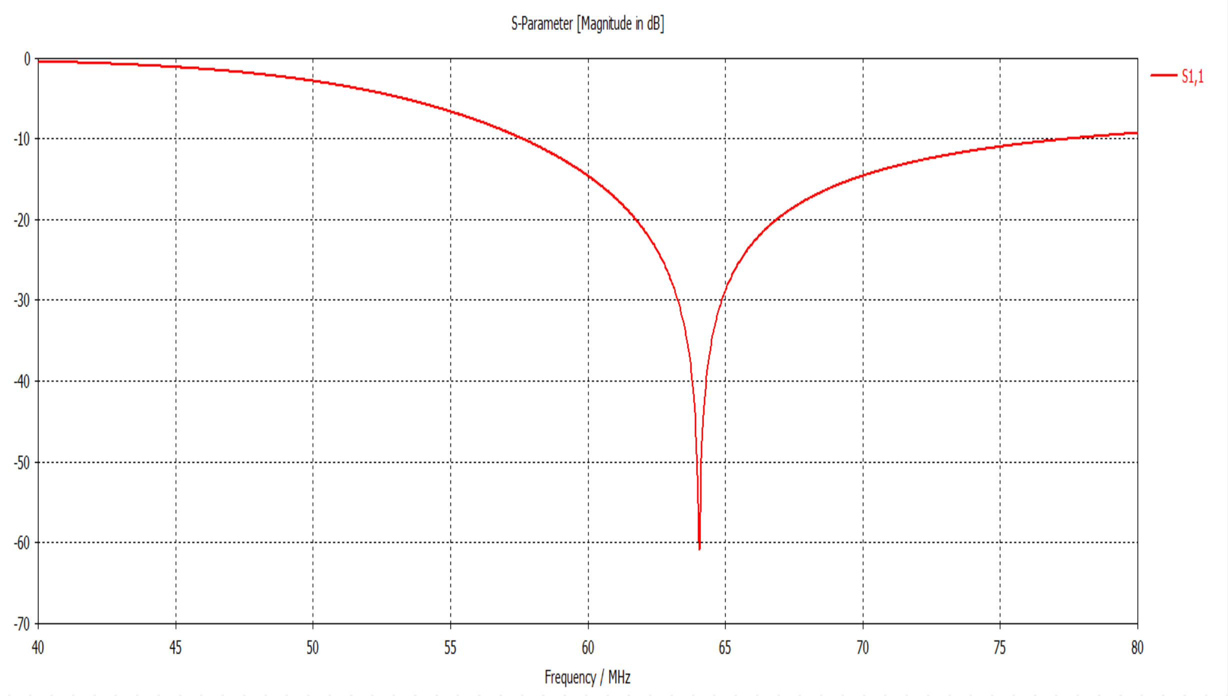




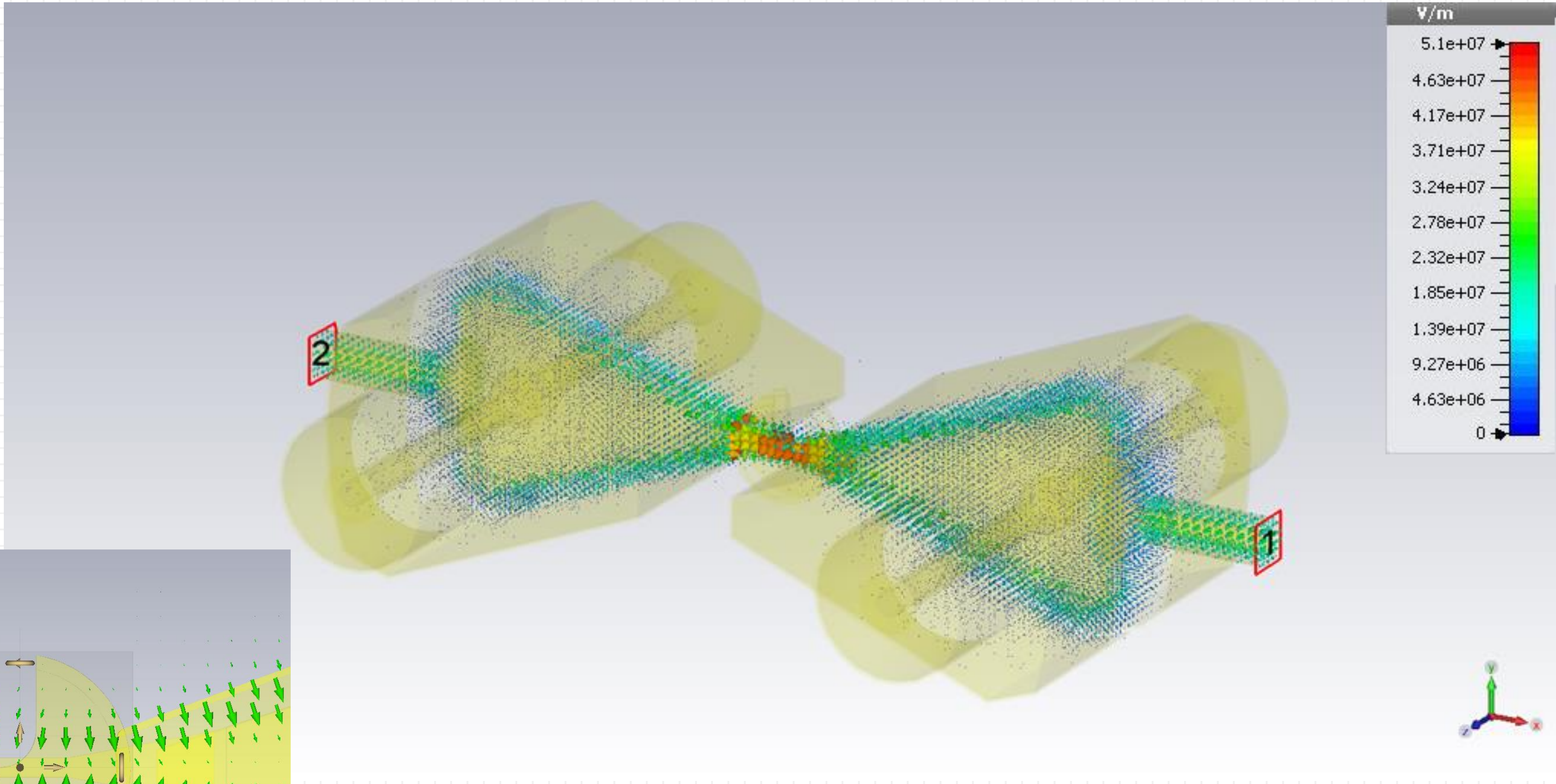
Final S_{21} Parameter

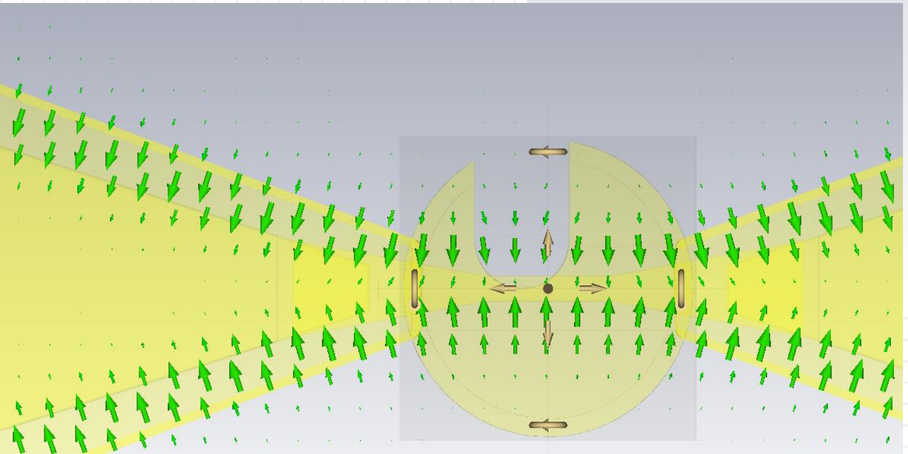


Final S_{11} Parameter

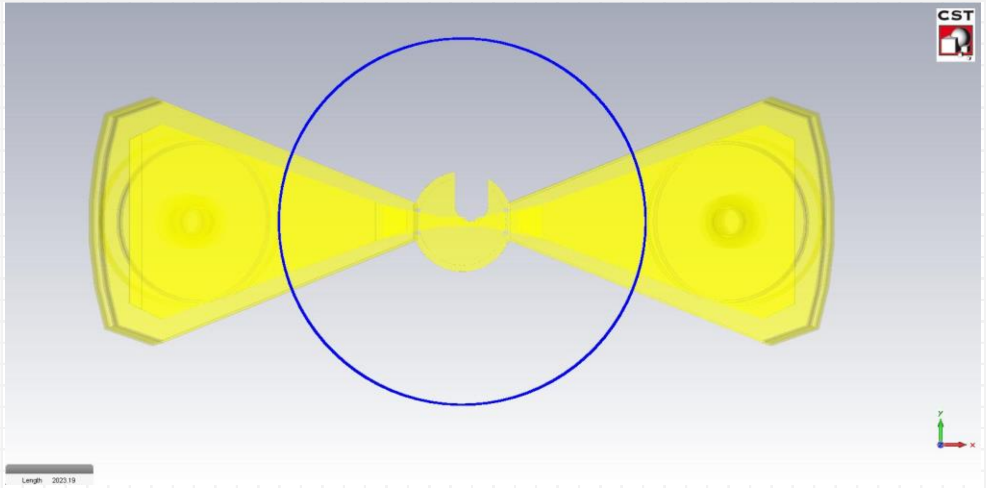


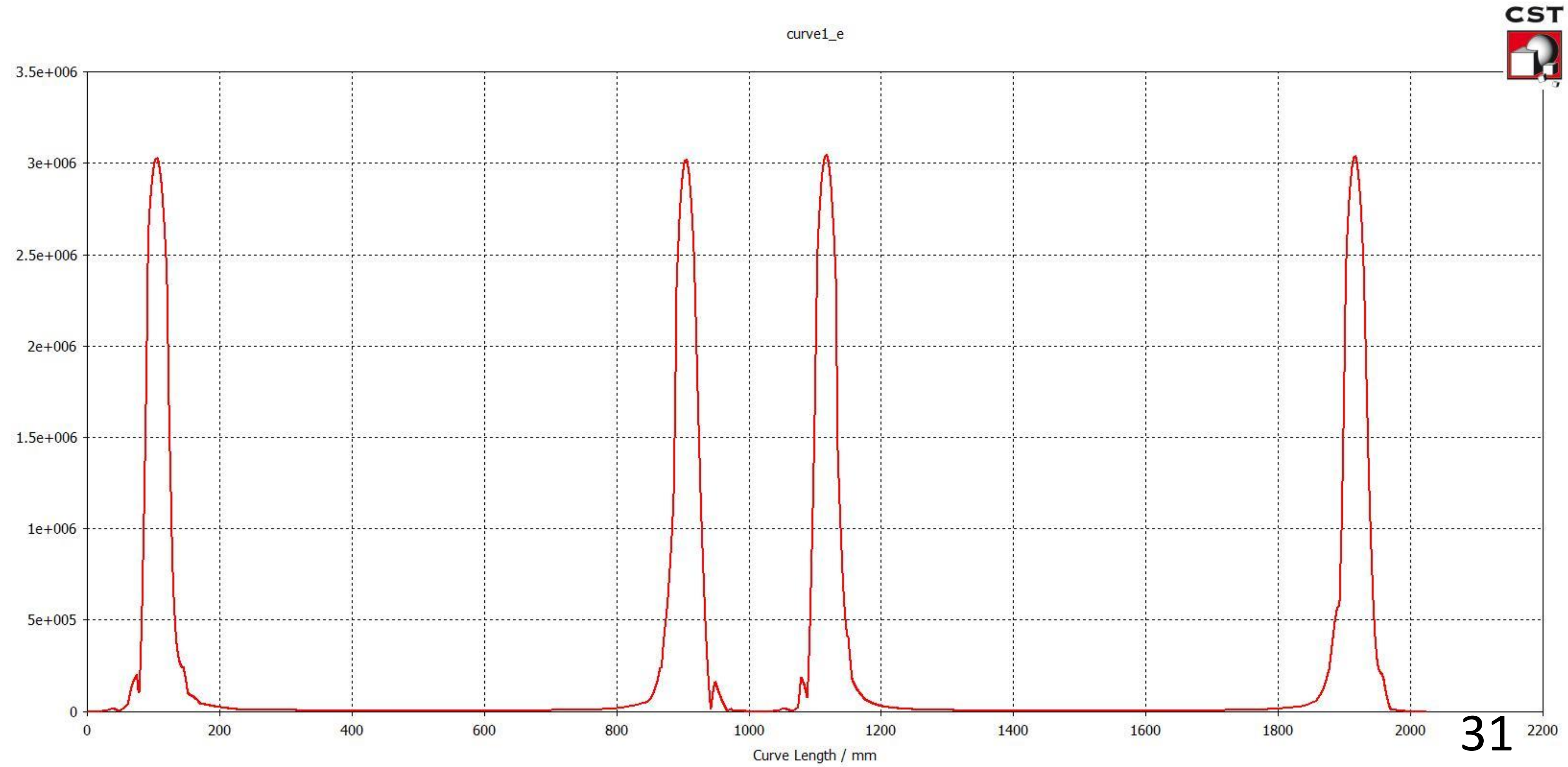
Electric field view



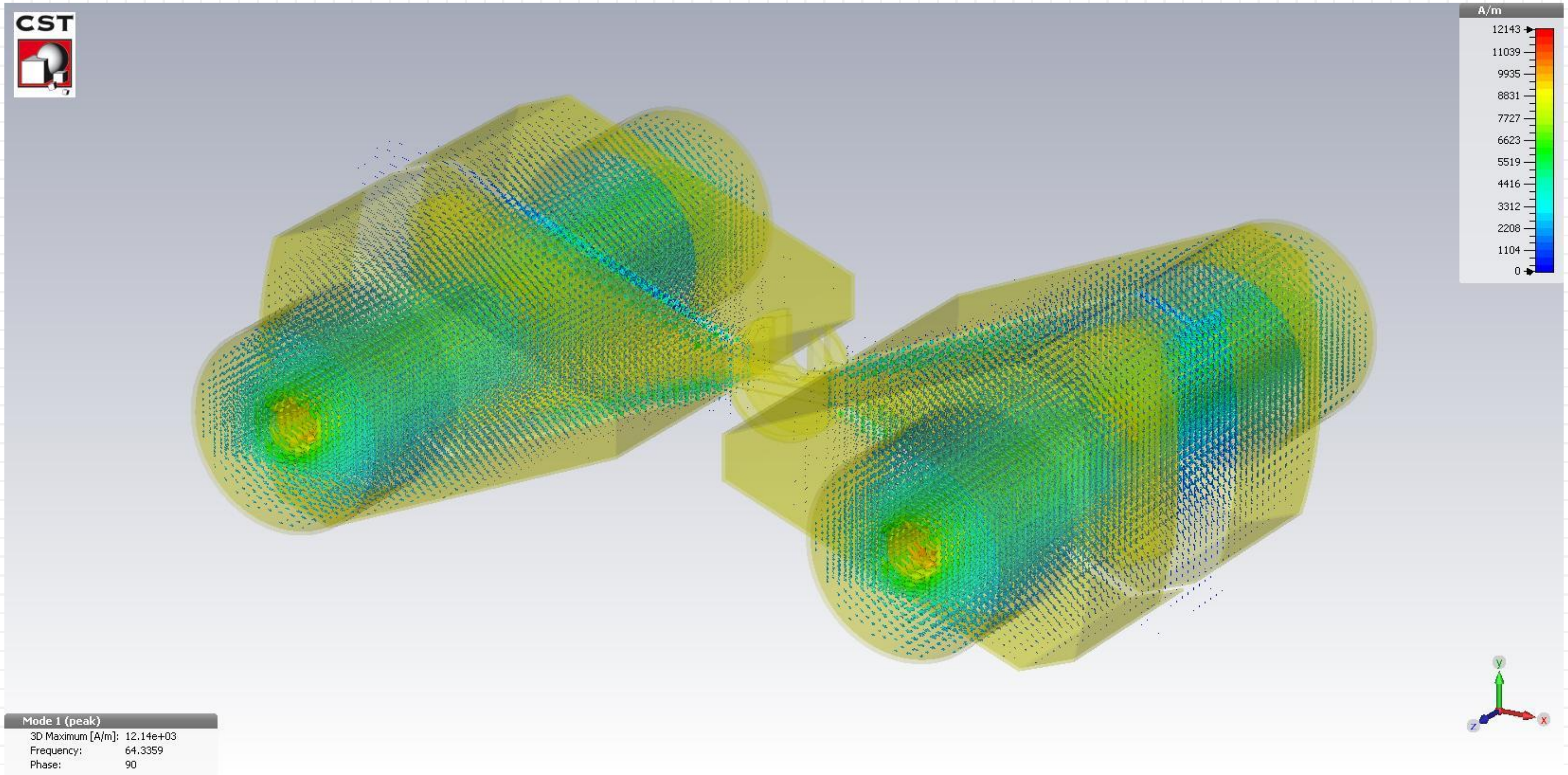


Electric field strength in an arbitrary radius

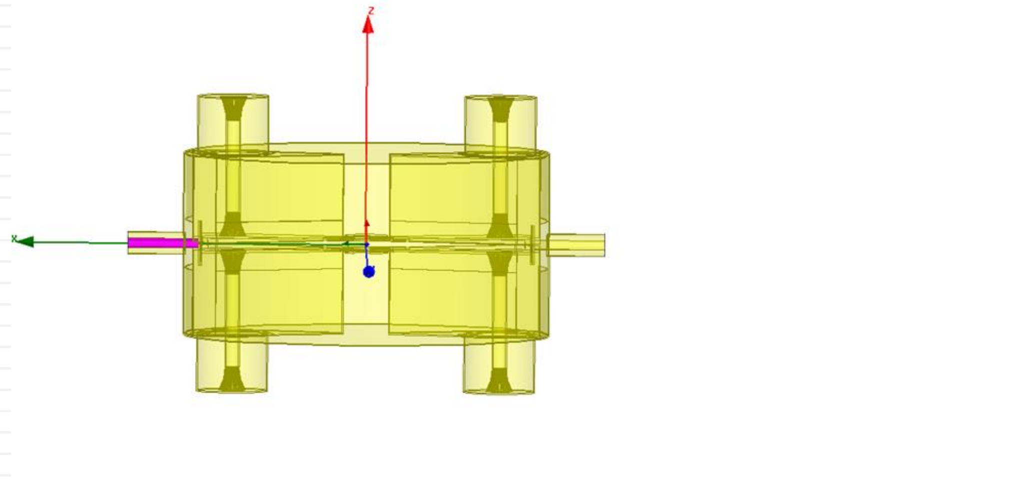


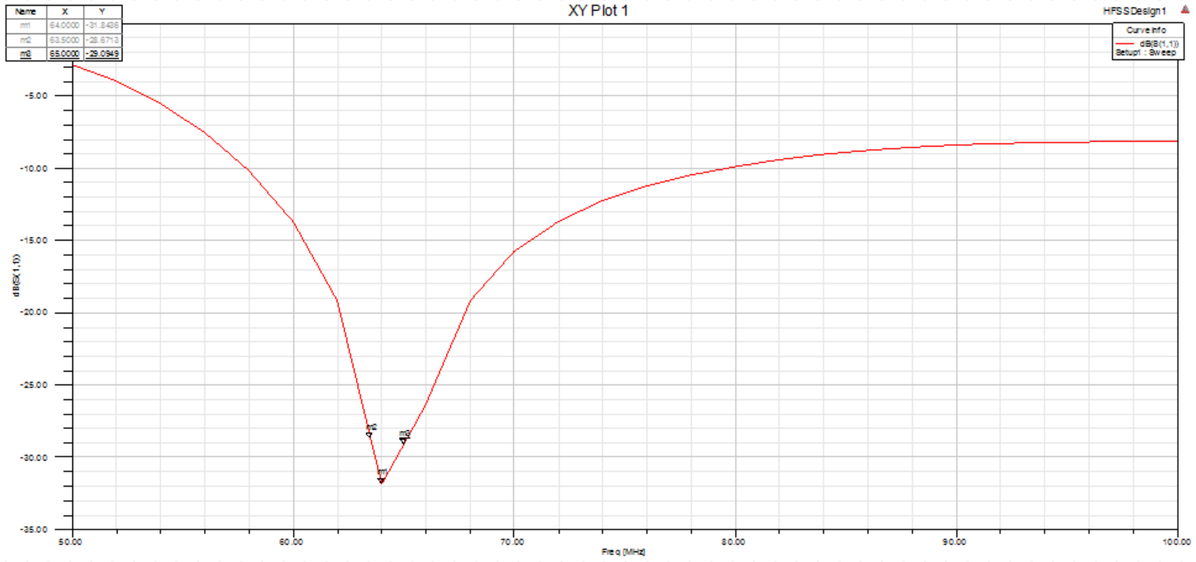


Magnetic field view

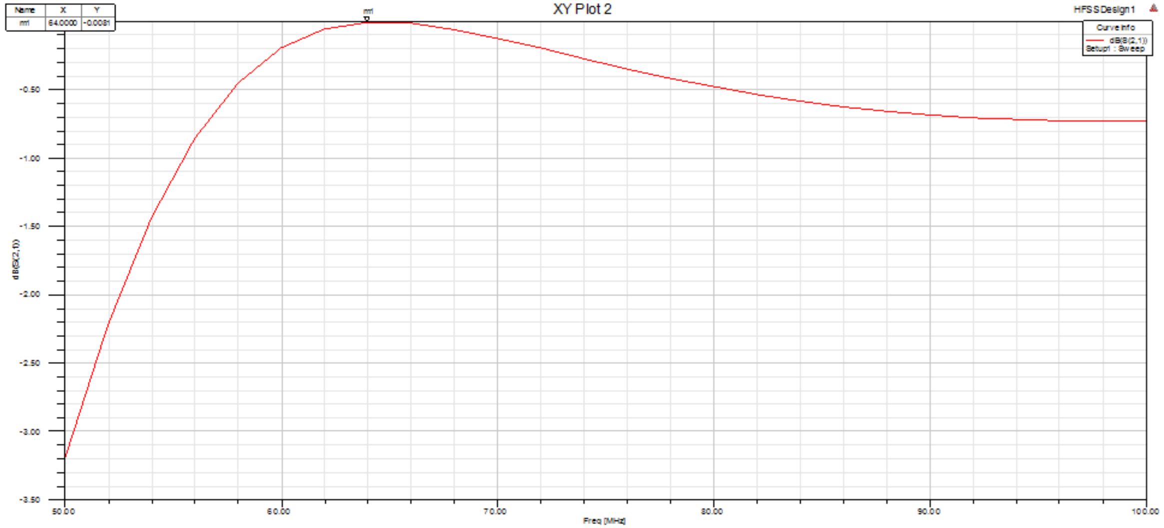


Verify the results with the HFSS software





S_{11} with hfss



S_{21} with hfss

Final specifications of cavity simulated

Parameter	Value
Number of Dees	2
Dee Angle	44
Harmonic Number	4
Resonant Frequency	64.3 MHz
Dee Voltage	45 kV
RF Power	11 kW
Coupling	Capacitive, fixed
Tuning	Capacitive, variable
Quality Factor	6220

THANK YOU FOR YOUR ATTENTION

ANY QUESTIONS?