A K band TW accelerating structure for the Compact light XLS project

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on behalf of the SPARC - LAB collaboration

Summary

Analytical estimations of the group velocity

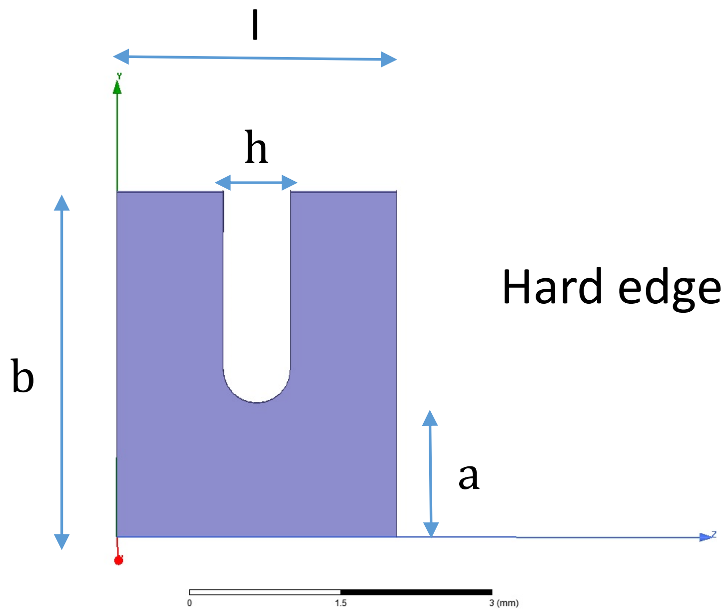
HFSS numerical estimations

Cavity dimensions calculations

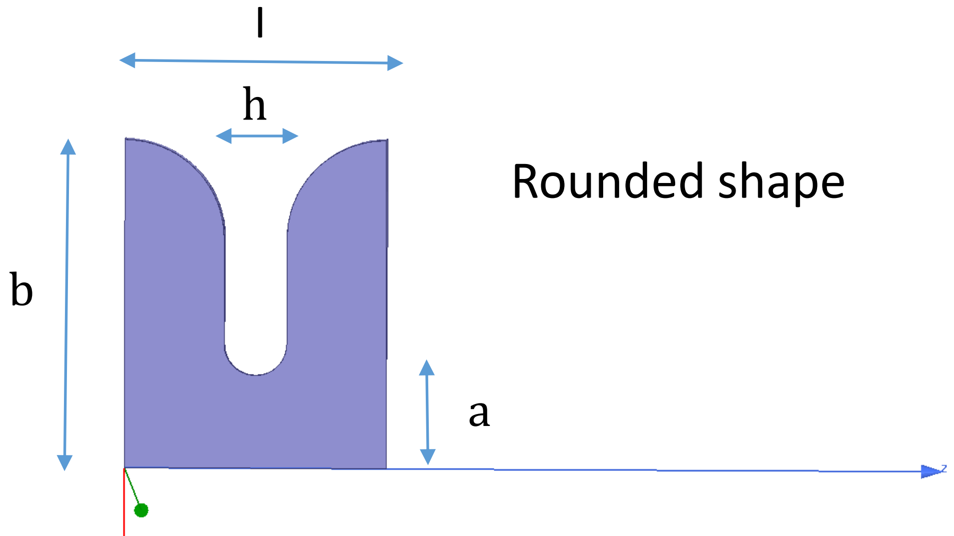
Comparison between analytical and numerical of the group velocity

Accelerating electric field estimation

TW cavity shape for the 2π/3 mode



Hard edge shape



Rounded shape

l = cell lenght $\lambda/3$

b = cavity radius

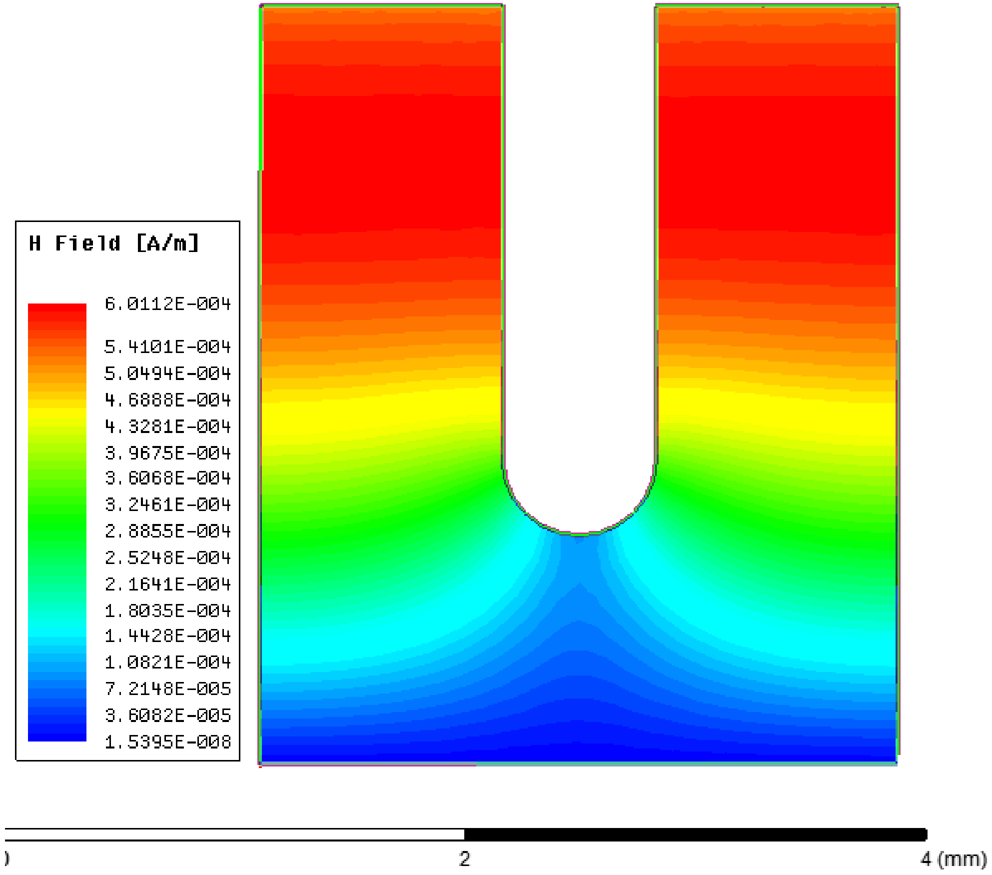
a = iris radius

h = iris thickness

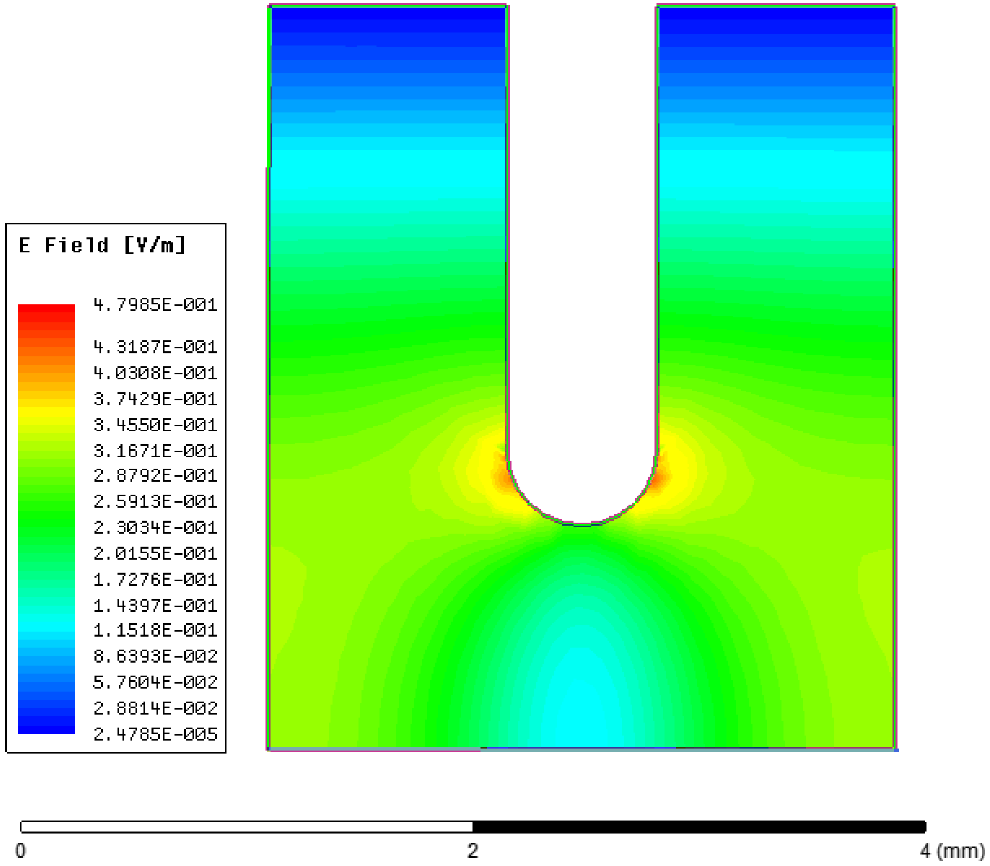
$$\frac{v_{gr}}{c} = \frac{1}{c}\frac{d\omega}{d\Phi}$$

$$\Phi = phase\ advance$$

‘Hard edge’ TW cavity shape for the 2π/3 mode simulated with HFSS software

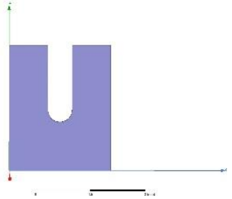


Magnetic field distribution of the TM_{010} mode



Electric field distribution of the TM_{010} mode

Group velocity analytical estimation of the hard edge shape



From Thomas P. Wangler , the group velocity is given by :

$$\frac{v_{gr}}{c} = k\, sin\,\psi\, \frac{a^2}{b^2}\, e^{-\alpha h}$$

$$\alpha = \sqrt{\left(\frac{2.405}{a}\right)^2 - \left(\frac{\omega}{c}\right)^2} \approx \frac{2.405}{a}$$

Ψ = phase advance per cell of the traveling wave structure

α = attenuation per unit lenght of the field for theTM_{01} waveguide mode through a hole in a wall of thickness h

K = constant **h = iris thickness** **a = iris radius** **b = cavity radius**

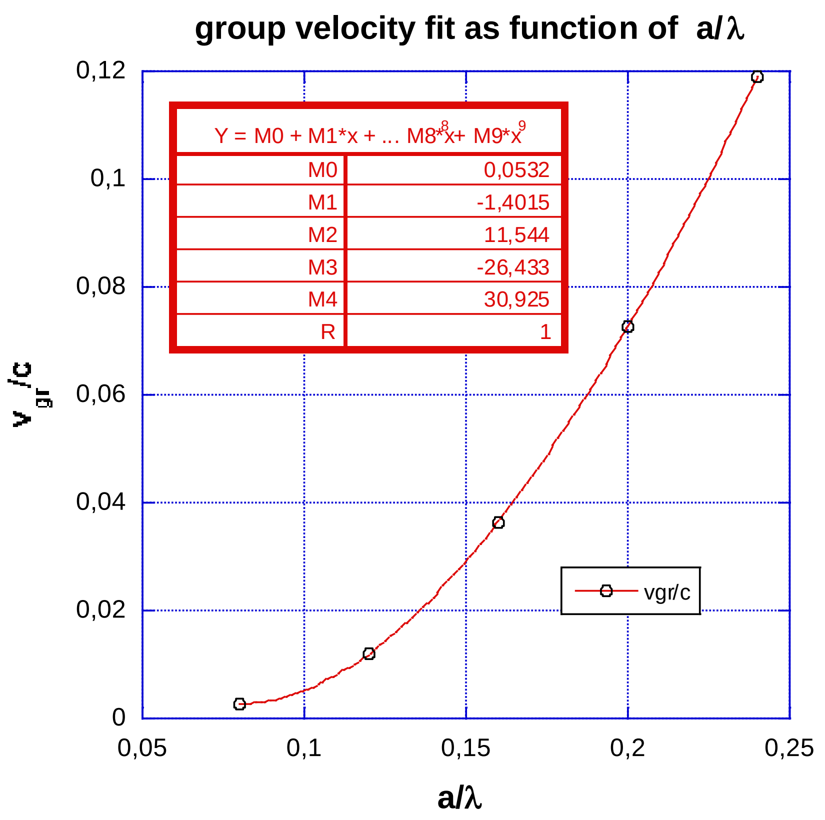
By using the Taylor expansion of the term $e^{-\alpha h}$ assuming h = 0.08 λ after some manipulations, we get the analytical equations of the group velocity :

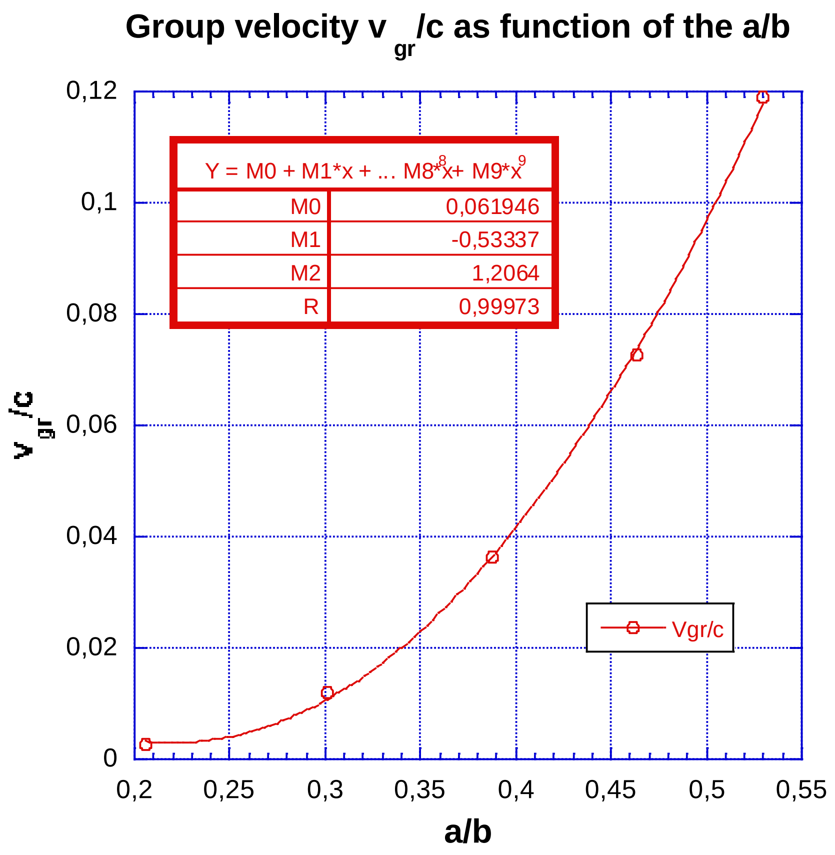
$$\frac{v_{gr}}{c} = k \sin\psi \left[\frac{a^3}{\lambda^3} - 0.19\frac{a^2}{\lambda^2} + 0.185\frac{a}{\lambda} + 0.000057\frac{\lambda}{a} - 0.0012\right]$$

$$\frac{v_{gr}}{c} = k \sin\psi \left[\frac{a^3}{b^3} - 0.496\frac{a^2}{b^2} + 0.126\frac{a}{b} + 0.0026\frac{b}{a} - 0.0213\right]$$

Group velocity v_{gr}/c of function of a/λ and a/b estimated with HFSS

The simulations have been carried out at a constant frequency (or F = 35.988 GHz)

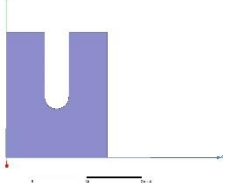


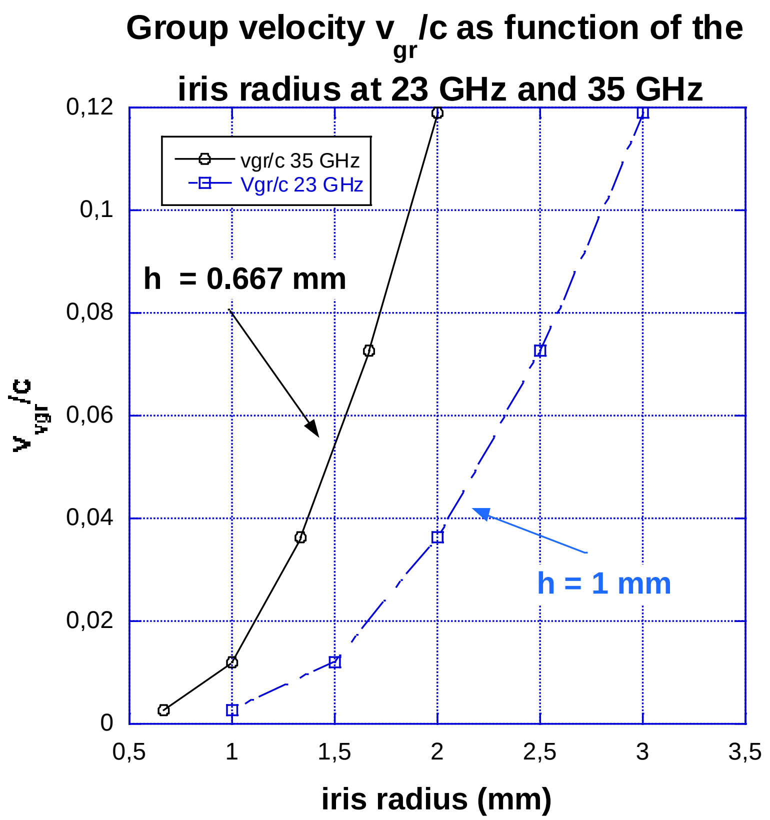


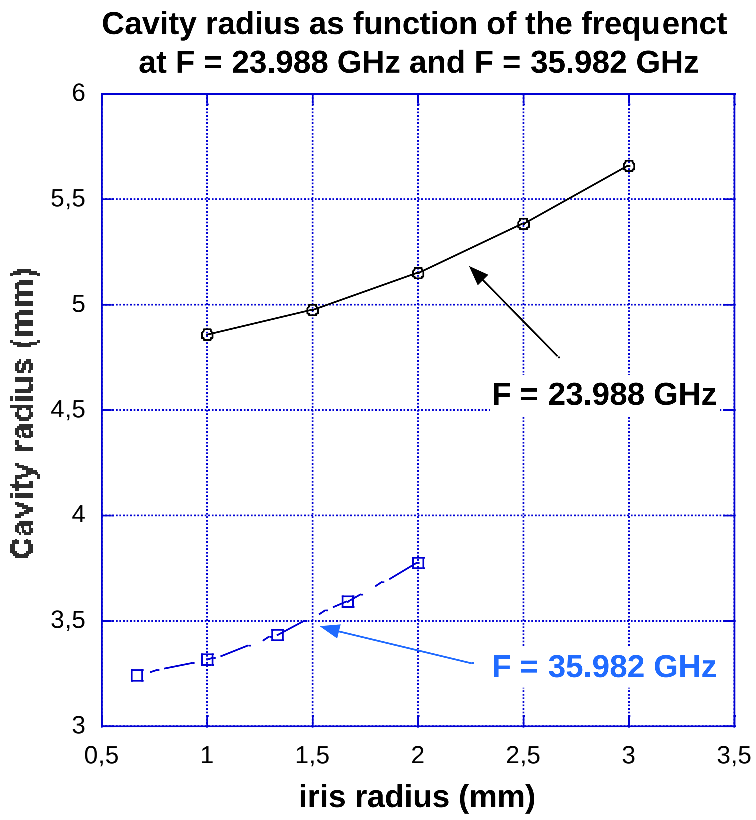
As an example by assuming $a/\lambda = 0.16$:

v_{gr}/c = 0.0365 **a/b = 0.388**

23.988 GHz and 35.982 GHz cavity dimensions







As an example, by assuming $\lambda = 8.3375$ mm

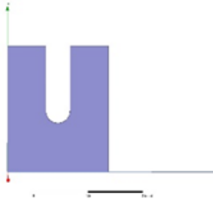
$v_{gr}/c = 0.0365$ iris radius = 1.333 mm cavity radius = 3.435 mm thickness iris h = 0.667 mm

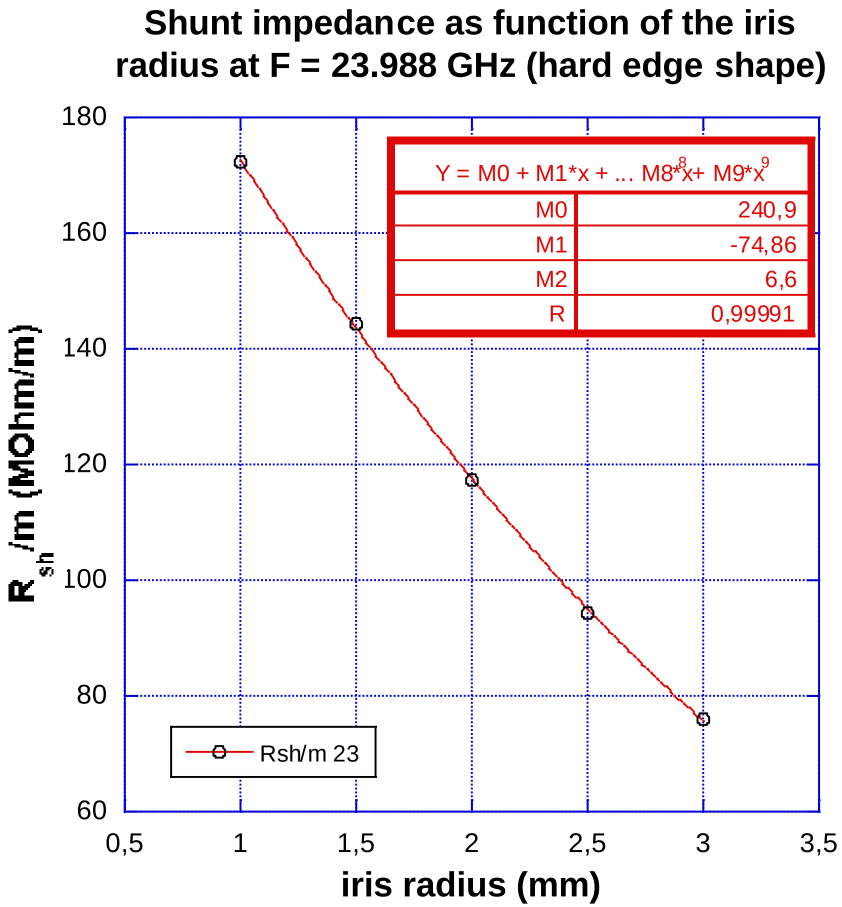
with $\lambda = 12.506$ mm

$v_{gr}/c = 0.0365$ iris radius = 2 mm cavity radius = 5.153 mm thickness iris h = 1 mm

These dimensions are perfectly consistent with the 110 Ghz structure by scaling law with frequency aleady tested at SLAC

Shunt impedance as function of the iris radius a F = 23.988 GHz and F = 35.982 GHz (hard edge shape)





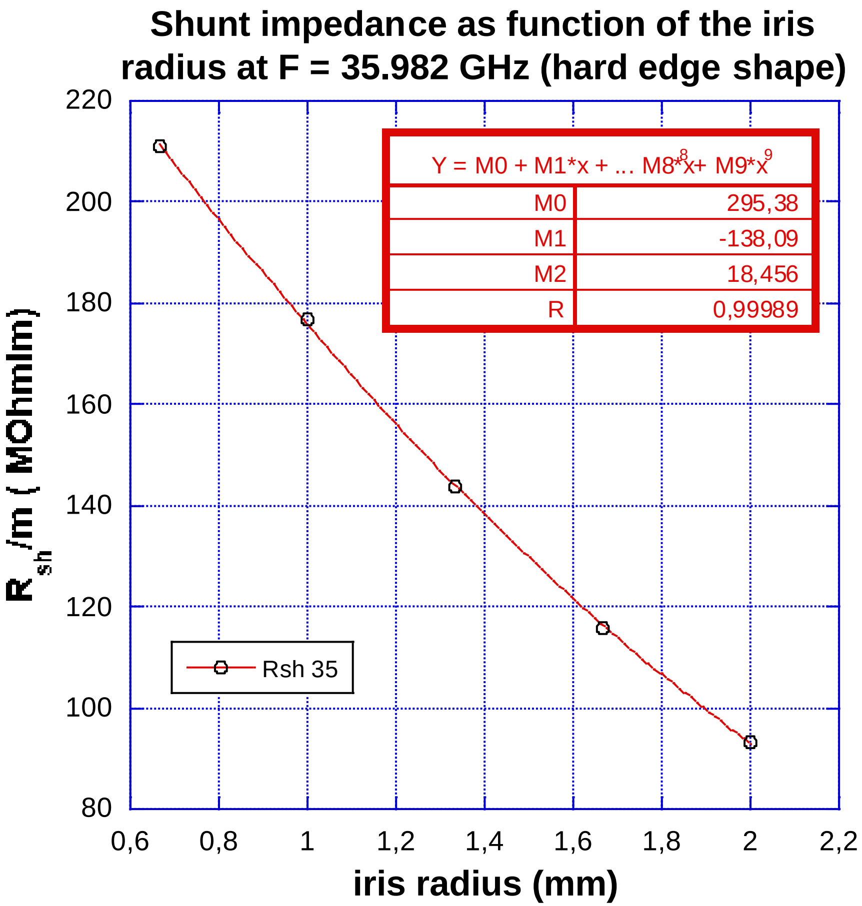
F = 23.988 GHz

iris radius a = 2 mm

thickness iris h = 1 mm

v_{gr}/c = 0.0365

R_{sh} / m = 117 MΩ /m



F = 35.982 GHz

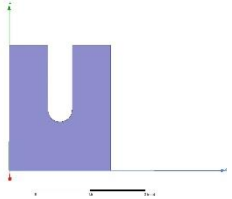
iris radius = 1.333 mm

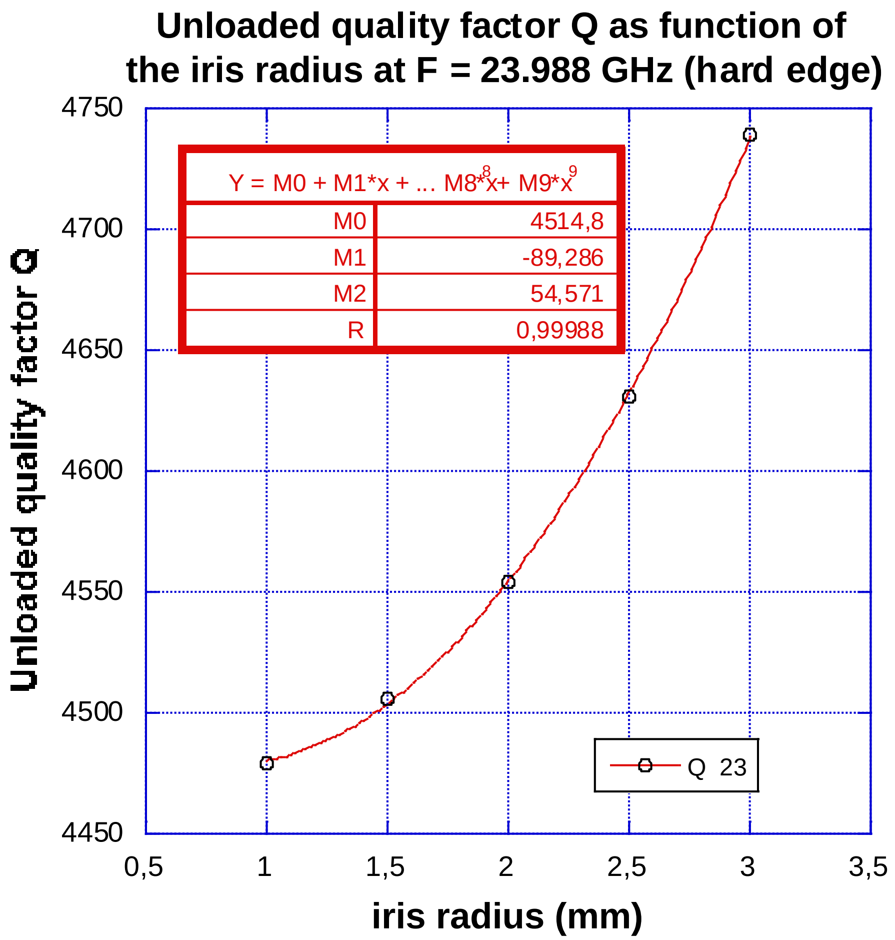
thickness iris h = 0.667 mm

v_{gr}/c = 0.0365

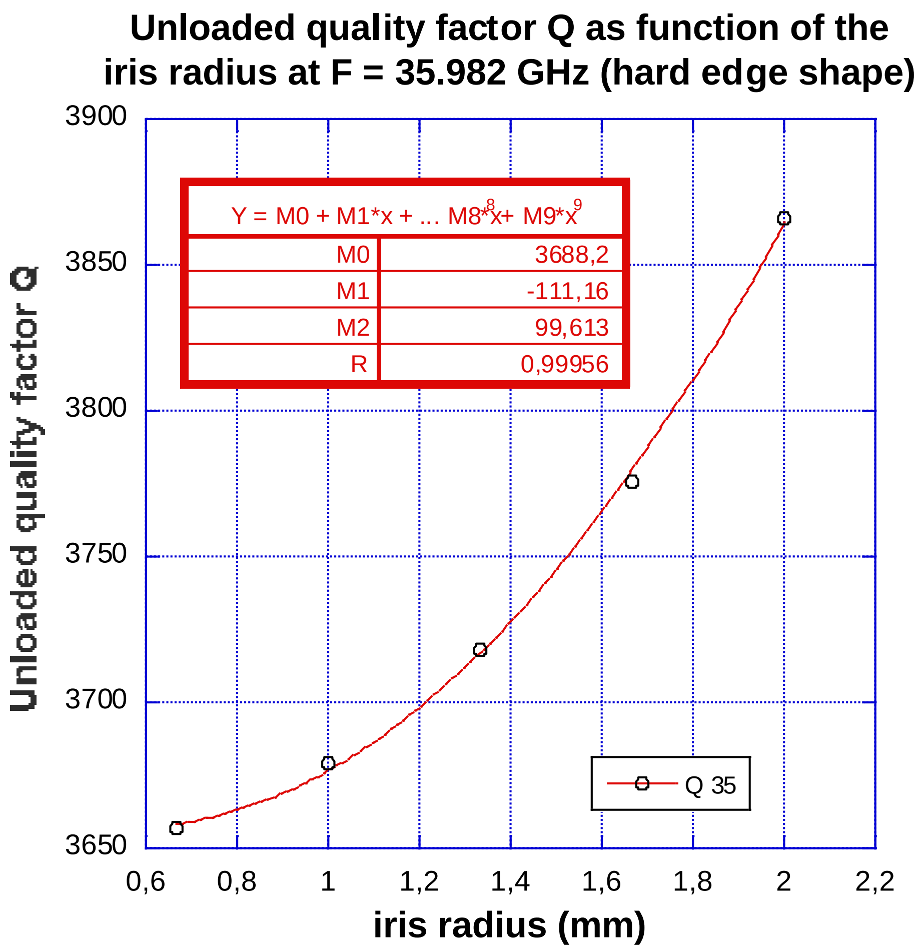
R_{sh} / m = 144 MΩ /m

Unloaded quality factor Q as function of the iris radius at F = 23.988 GHz and F = 36.982 GHz (hard edge shape)





F = 23.988 GHz



F = 35.988 GHz

iris radius a = 2 mm

v_{gr}/c = 0.0365

thickness iris h = 1 mm

Q = 4554

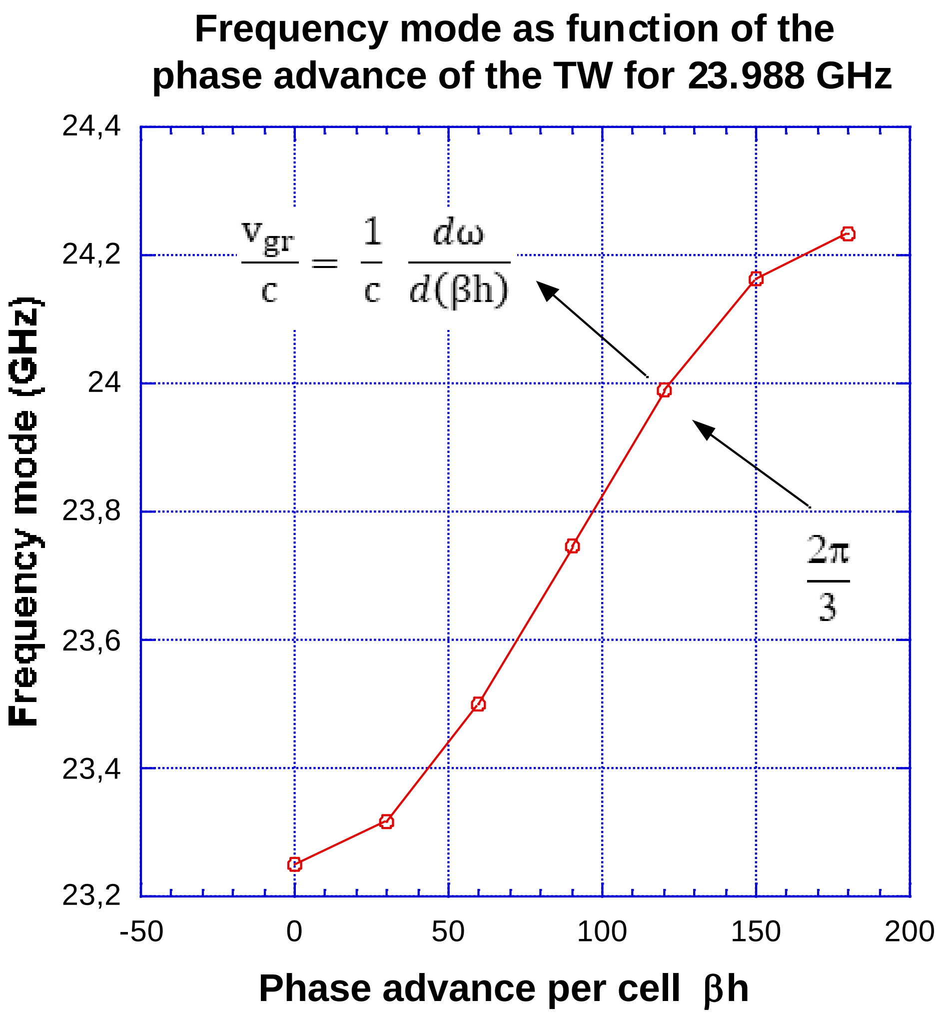
iris radius a = 1.333 mm

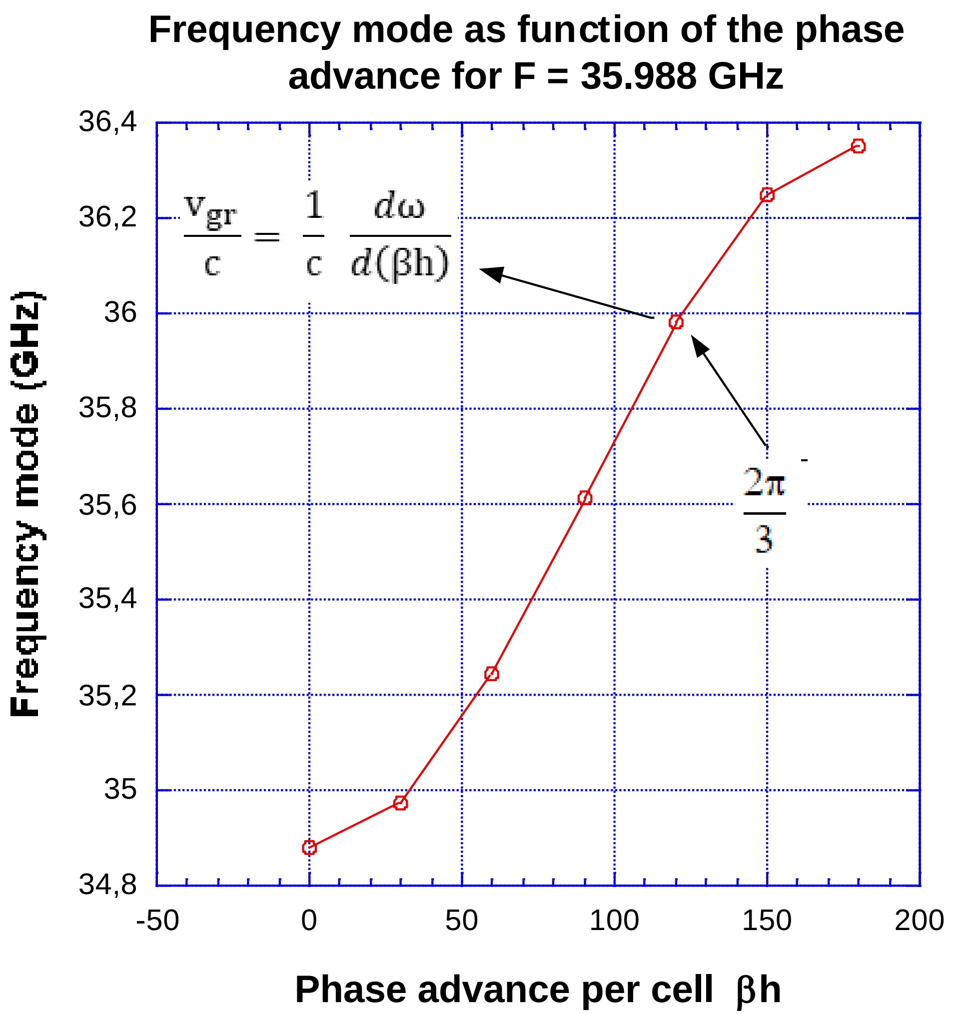
v_{gr}/c = 0.0365

thickness iris h = 0.667 mm

Q = 3718

Dispersion relation at F = 23.988 GHz and F = 35.983 GHz





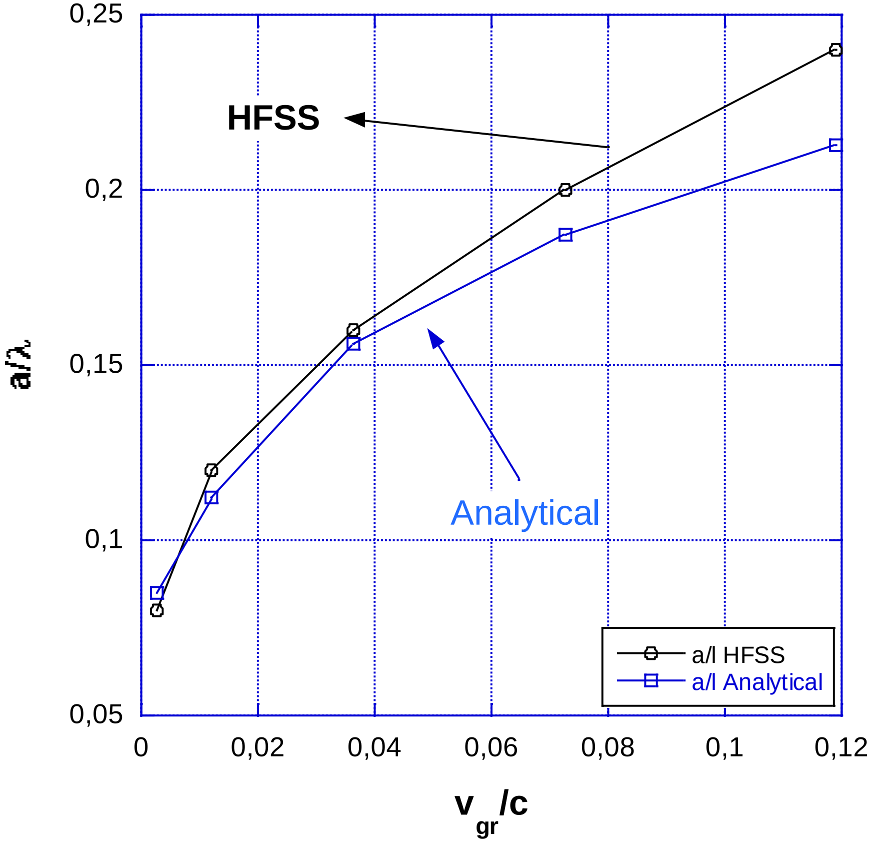
a = 2 mm, h = 1 mm, b = 5.153 mm, K = 4 %

a = 1.333 mm, h = 0.667 mm, b = 3.435 mm, K = 4 %

Comparison beteween HFSS and Analytical estimations

Max error

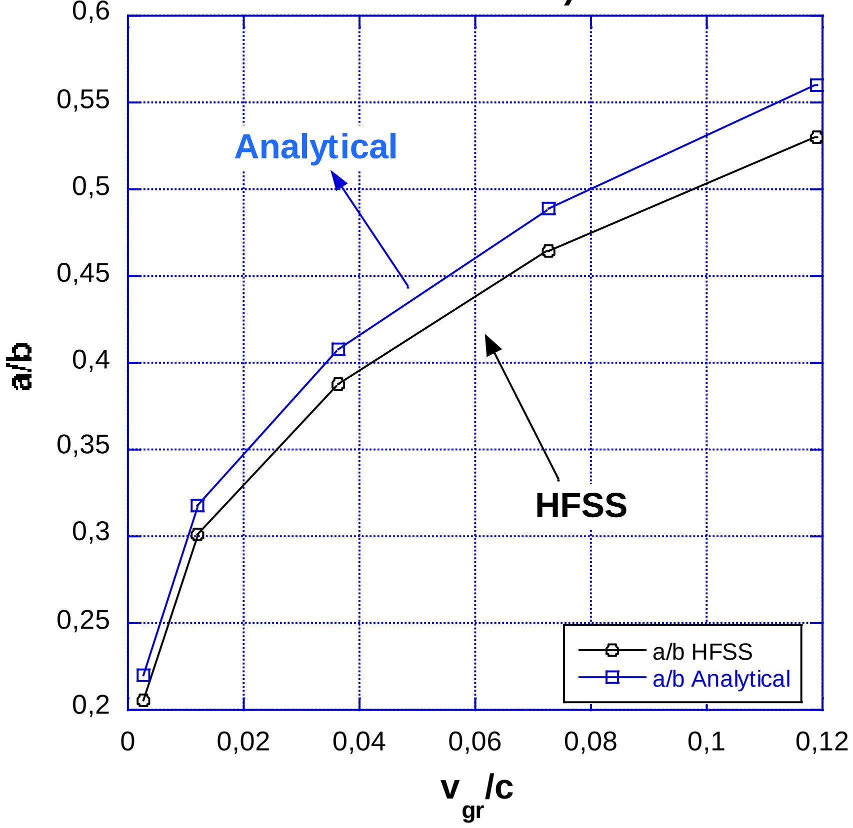
a/λ as function of the group velocity v_{gr}/c (comparison between analytical and HFSS estimations)



11.2 %

5.6%

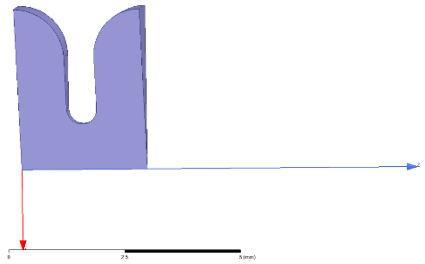
a/b as function of the group velocity v_{gr}/c (comparison betewwen analytical and HFSS estimations)

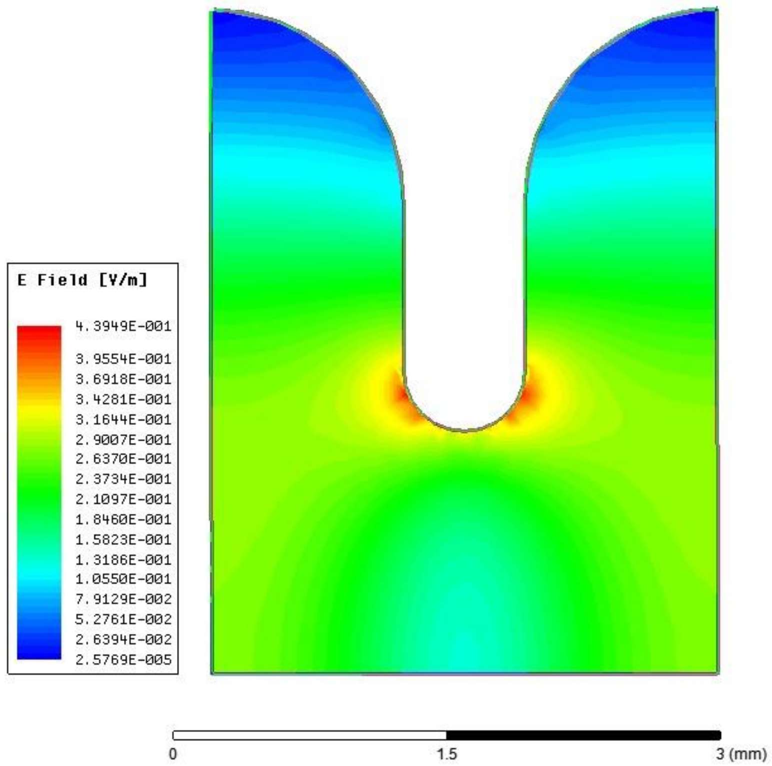


$$\frac{v_{gr}}{c} = k \sin\psi \left[\frac{a^3}{\lambda^3} - 0.19\,\frac{a^2}{\lambda^2} + 0.185\,\frac{a}{\lambda} + 0.000057\,\frac{\lambda}{a} - 0.0012 \right]$$

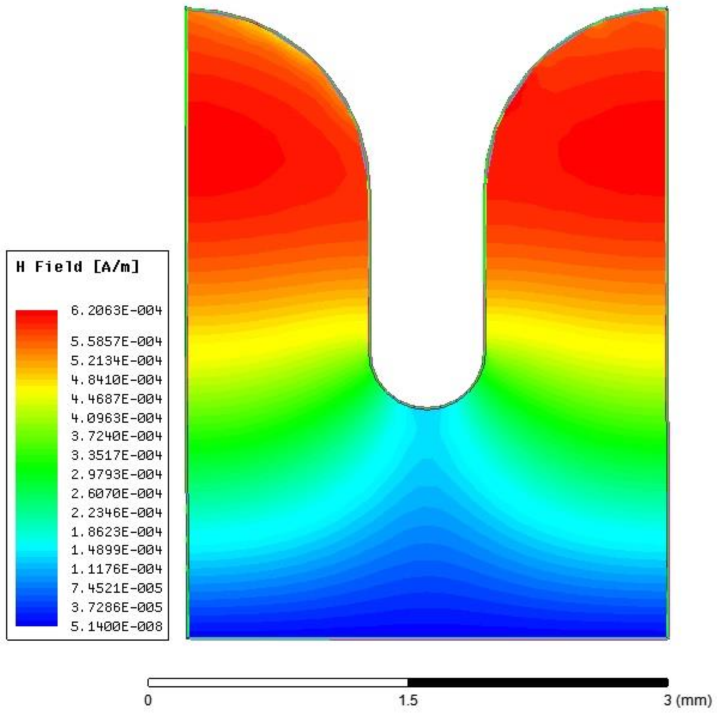
$$\frac{v_{gr}}{c} = k \sin\psi \left[\frac{a^3}{b^3} - 0.496\,\frac{a^2}{b^2} + 0.126\,\frac{a}{b} + 0.0026\,\frac{b}{a} - 0.0213 \right]$$

‘Rounded’ TW cavity shape estimations for the 2π/3 mode



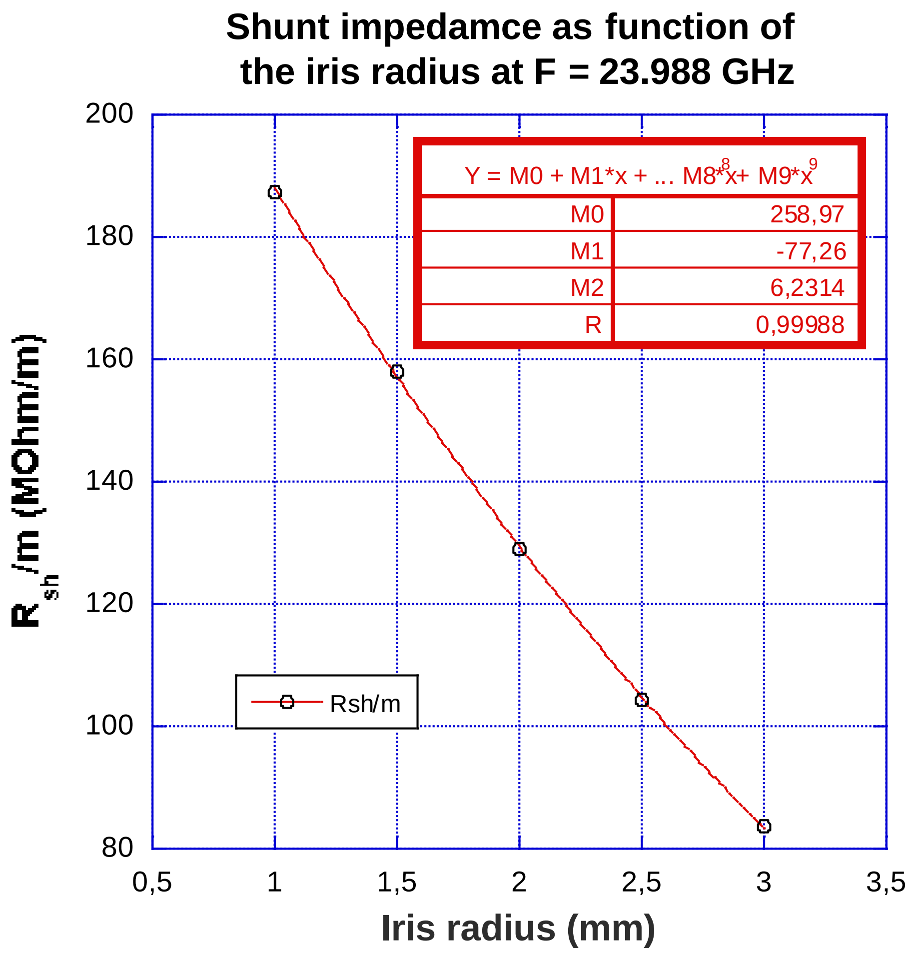


Electric field distribution of the TM_{010} mode

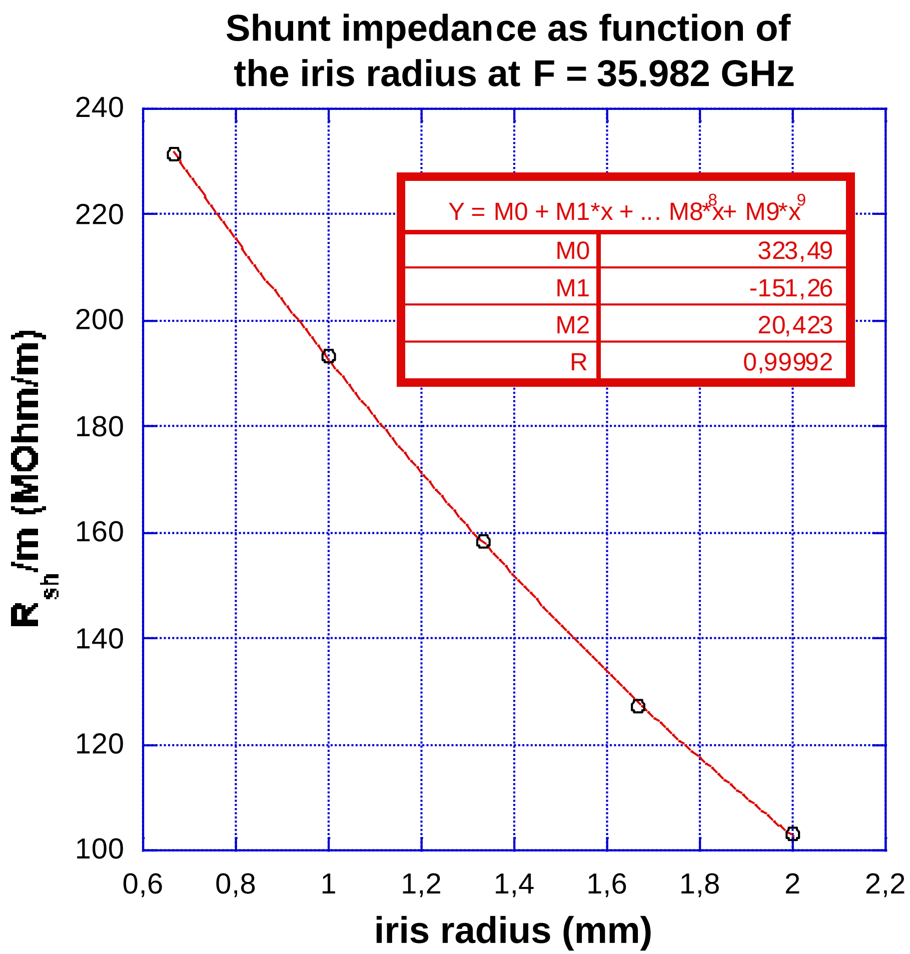


Magnetic field distribution of the TM_{010} mode

Shunt impedance estimations of the rounded shape as function of the iris radius at F = 23.988 GHz and F = 35.982 GHz of the rounded shape



F = 23.988 GHz



F = 35.982 GHz

iris radius a = 2 mm thickness iris h = 1 mm

b = 5.516 mm R_{sh} / m = 128 MΩ /m (118 hard edge)

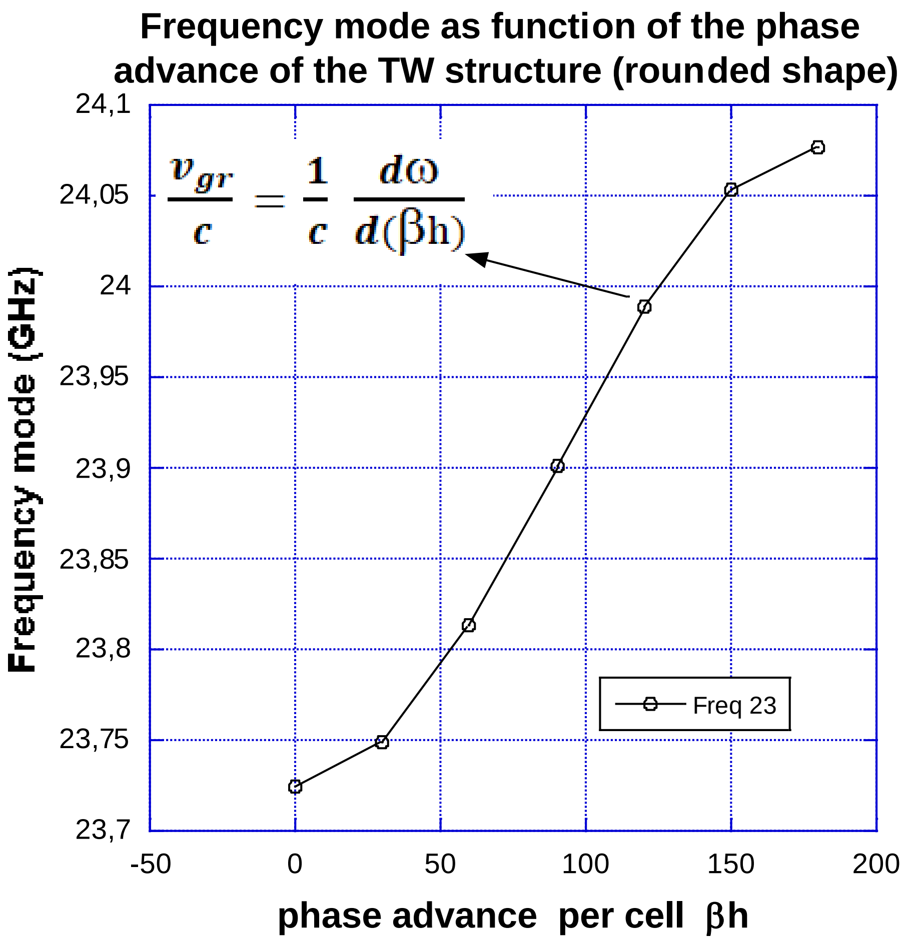
v_{gr}/c = 0.0365

iris radius a = 1.333 mm thickness iris h = 0.667 mm

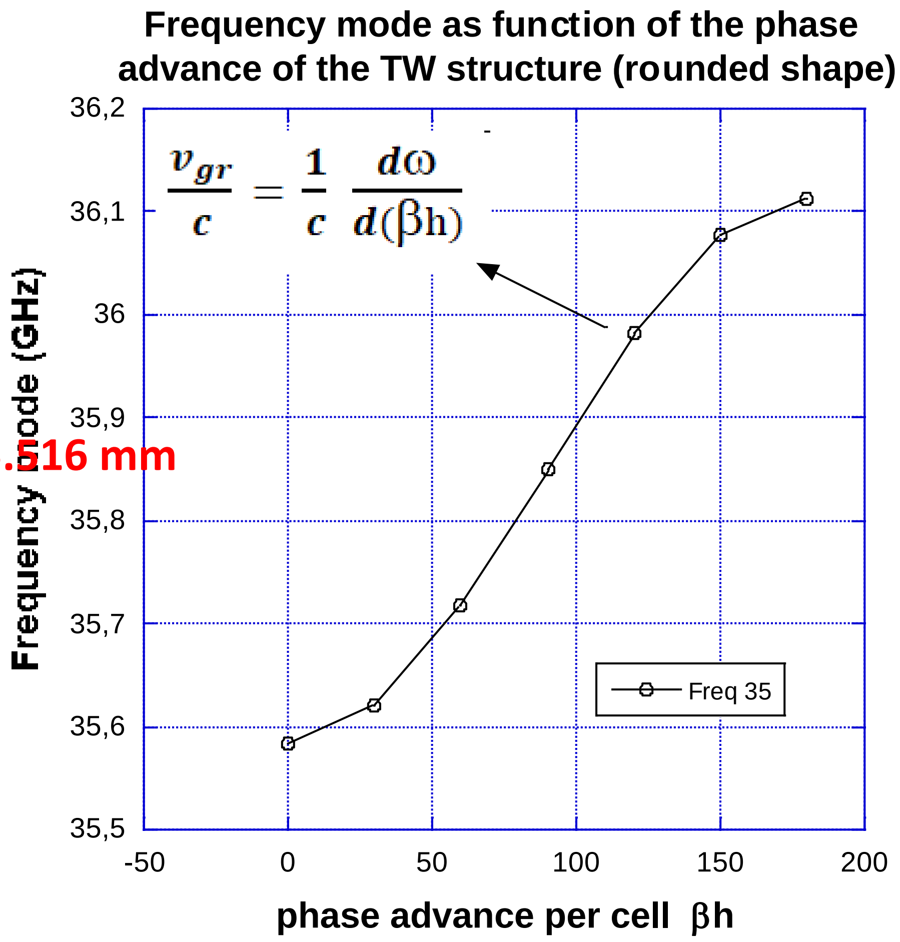
b = 3.657 mm R_{sh} / m = 158 MΩ /m (144 hard edge)

v_{gr}/c = 0.0365

Dispersion relation of the rounded shape at F = 23.988 GHz and F = 35.982 GHz



b = 5.516 mm



a = 2 mm, h = 1 mm, b = 5.516 mm

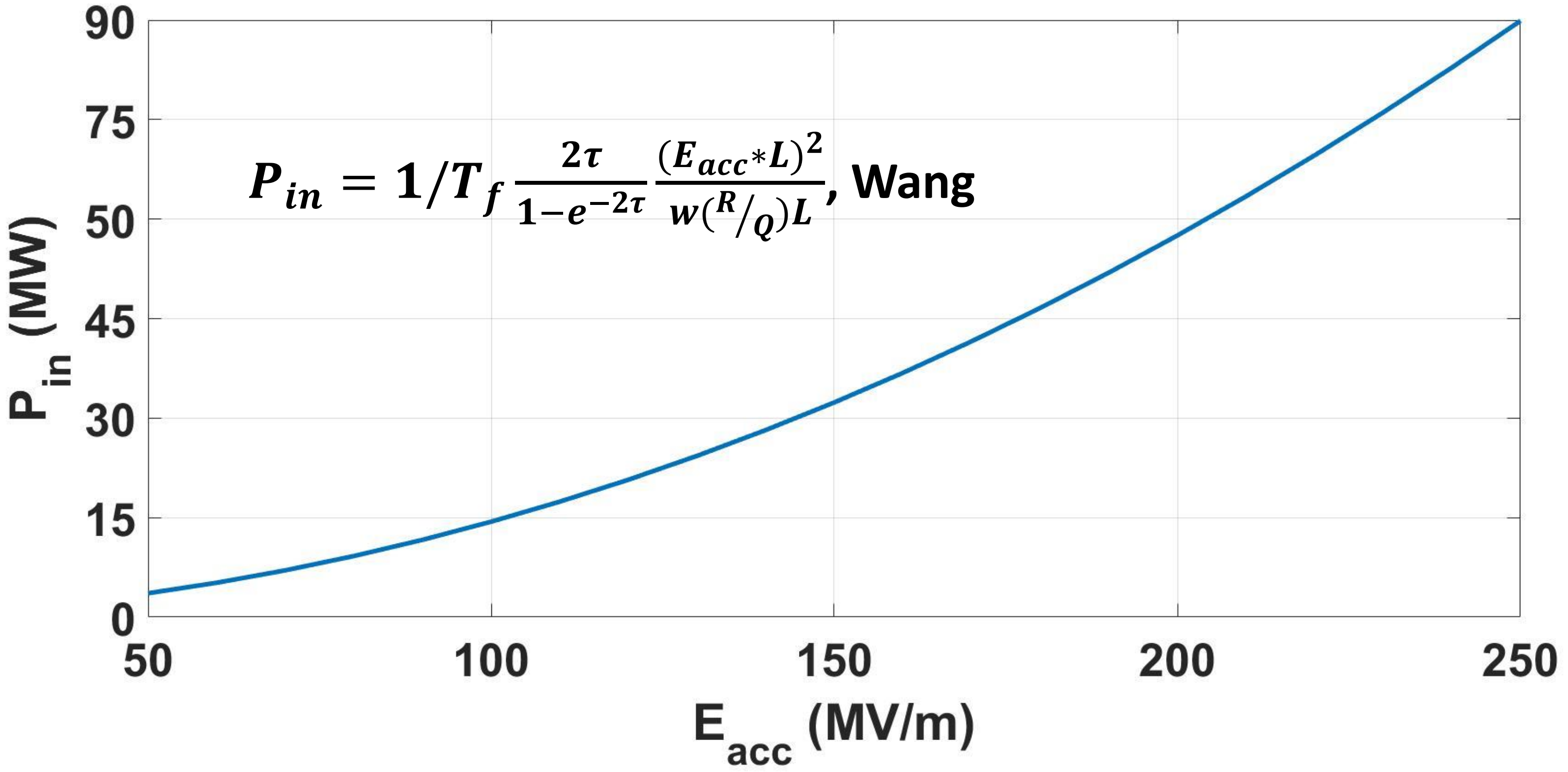
K = 1.5 % v_{gr}/c = 3.65 %

a = 1.333 mm, h = 0.667 mm mm, b = 3.657 mm

K = 1.5 % v_{gr}/c = 3.65 %

Input RF power for different gradients

Assuming a structure length L = 21 cm ,T_f = 20 ns (filling time) and τ = 0.65 (attenuation)

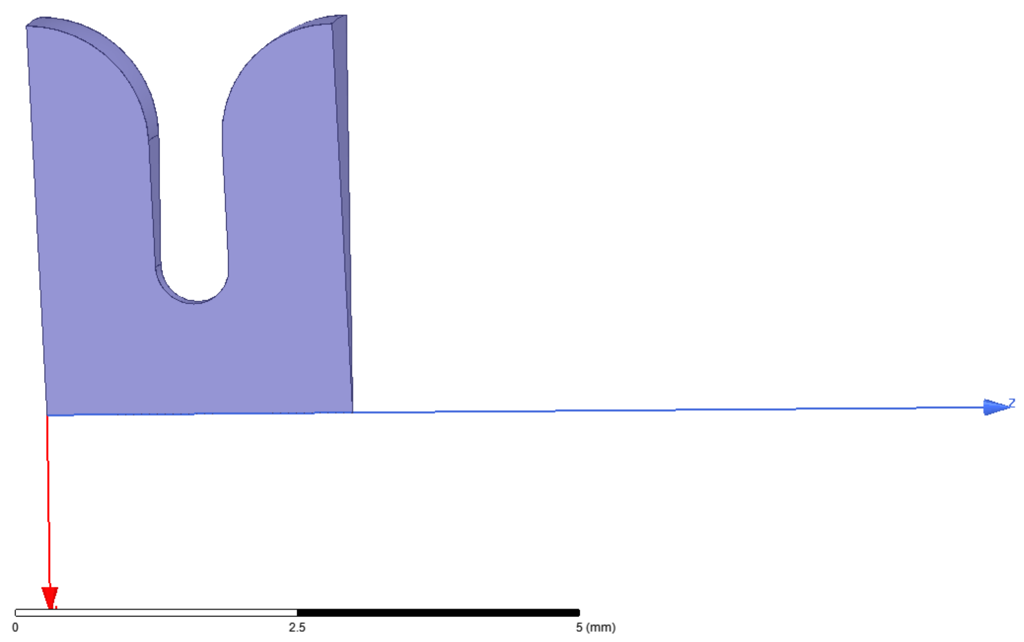


Parameter	Value
Filling Time, Tf	20 ns
L, length	21 cm
w, frequency	2pi*35.982 GHz
R/Q	57.7 kΩ/m
τ	0.65

For a CG structure: **input group velocity v_{gr_in}/c =6.2%, output group velocity v_{gr_out}/c=1.7%,**
For a CI structure : **v_{gr} = 0.035 c**

Luigi Faillace checked these estimations by using a different approach (normalized electric field method)

Rounded cavity : final RF estimations have been processed and will be discussed in a next talk



As an example at F = 35.982 GHz with a = 1 mm, h = 0.667 mm, b = 3.538 mm:

$R_{sh}/m = 195\ M\Omega/m$

Q = 4065