A New Spherical Pulse Compressor Working with Degenerated "Whispering Gallery" Mode

Zongbin Li (SINAP), Alexej Grudiev (CERN),

Wencheng Fang (SINAP), Qiang Gu (SINAP), Zhentang Zhao (SINAP)

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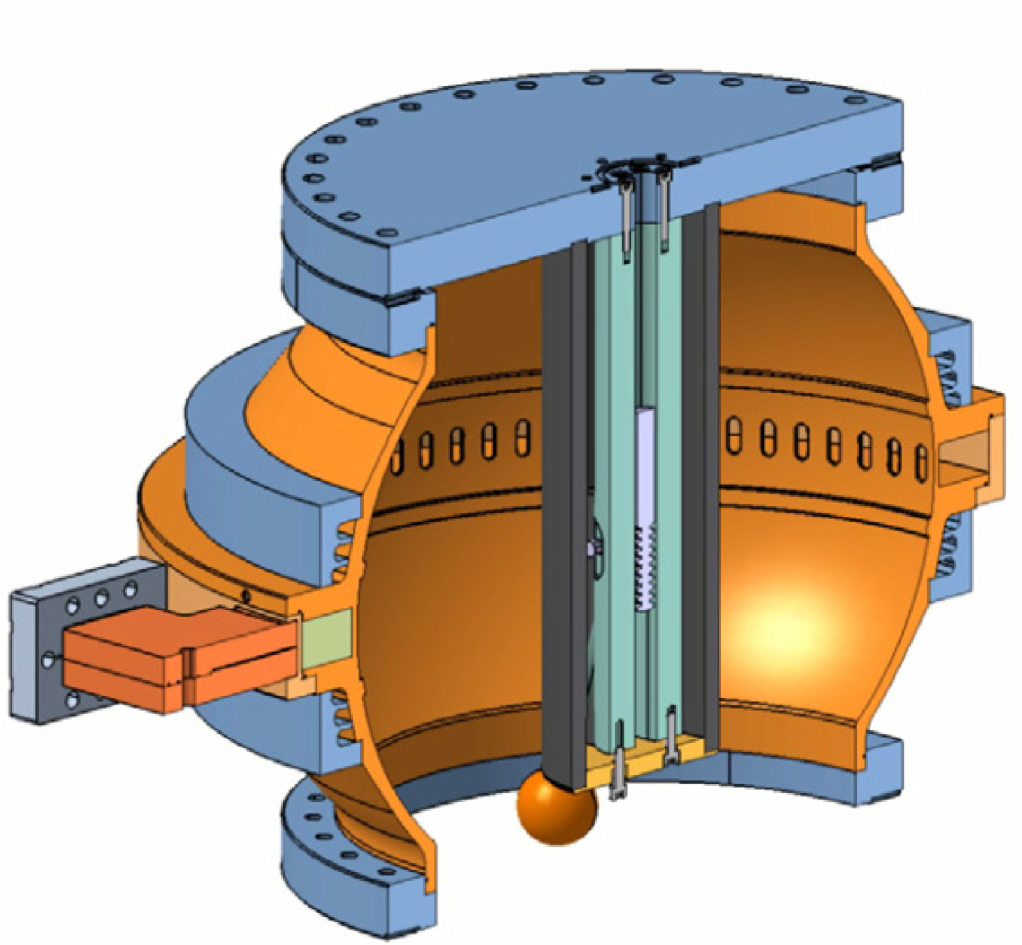
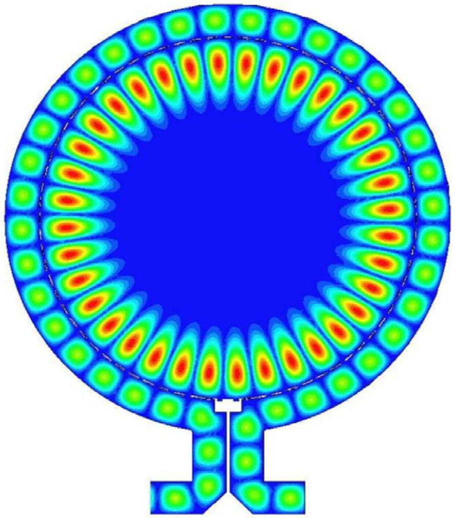
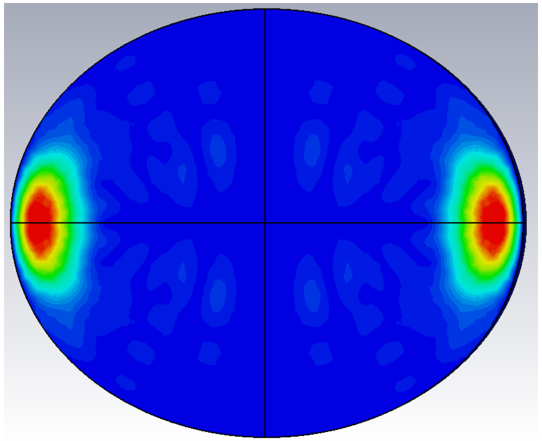


Barrel-shape Open Cavity

Working with "Whispering Gallery" mode.



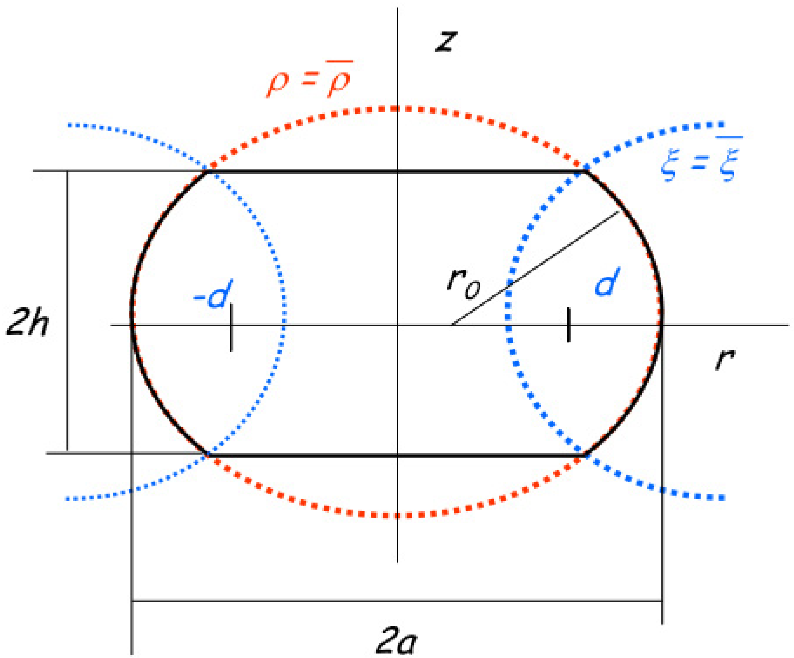
E-field: Top-view



E-field: Side-view

BOC

Barrel cavity short theory.



Cavity profile

$$z = \sqrt{a r_0 \left\{ 1 - \left(\frac{r}{a} \right)^2 \right\}}$$

Elliptical cavity

The eigen-frequency of the Barrel cavity with E_{mnq} oscillation is the solution of the next equation:

$$ka = \nu_{mn} + \frac{(q - 1/2)\alpha}{\sin\theta}$$

ν_{mn} is a root of the Bessel function that for the big *m* can be approximated as:

$$\nu^{o}_{mn} = m - \mu t^{0}_{n} \qquad (n = 1, 2, \ldots),$$

$$-t^{0}_{n} = [(n - 0.25)1.5\pi]^{2/3}, \qquad \mu = \left(\frac{m}{2} \right)^{1/3}.$$

The optimal radius r_0, when the external caustic has the smallest height comes from: $r_0 = 2a \sin^2\theta$ where α and θ are derived from:

$$\sin\alpha = \sqrt{\frac{a}{r_0}} \sin\theta \qquad \cos\theta = \frac{m}{\nu_{mn}}$$

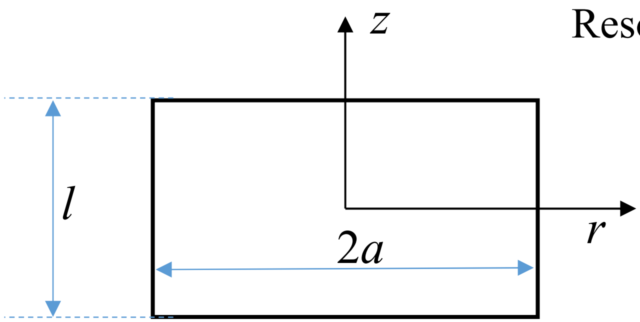
Finally the height of the external caustic and Q-factor of the cavity are:

$$z_{q-1} = 2\sqrt{(q - 1/2) \frac{a \sin\theta}{k \sin 2\alpha}}$$

$$Q_E = \frac{a}{\sigma_s}$$

I. Syratchev, *Barrel Open Cavity RF pulse compression system*, 2003

BOC

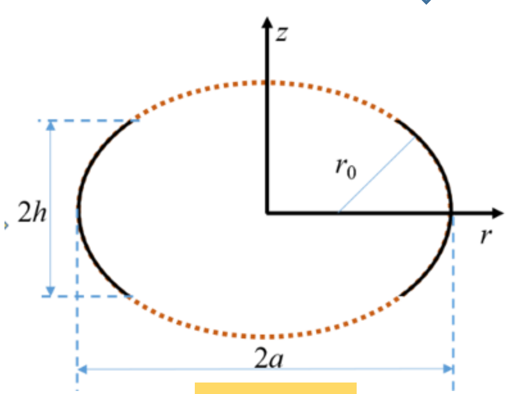


Cylindrical Cavity

Resonant frequency of TM_{mnp}:

$$k^2a^2 = \upsilon_{mn}^2 + \left(\frac{p\pi a}{l}\right)^2$$

m: φ direction (T)
n: r direction (T)
p: z direction (L)



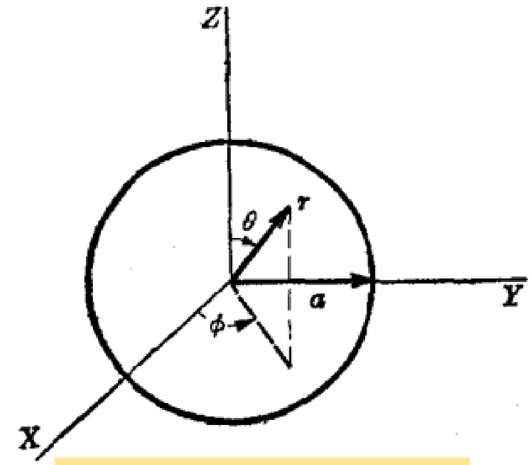
BOC

Resonant frequency of TM_{mnp}:

$$ka = \upsilon_{mn} + \frac{(p - 1/2)\alpha}{\sin\theta}$$

m: φ direction (T)
n: r direction (T)
p: z direction (L)

I. Syratchev, *The Progress of X-Band "Open" Cavity RF Pulse Compression Systems*, 1994



Spherical Cavity

Resonant frequency of TE_{mnp}:

$$f = \frac{u_{np}}{2\pi a\sqrt{\varepsilon\mu}}$$

m: φ direction (T)
n: θ direction (T)
p: r direction (L)

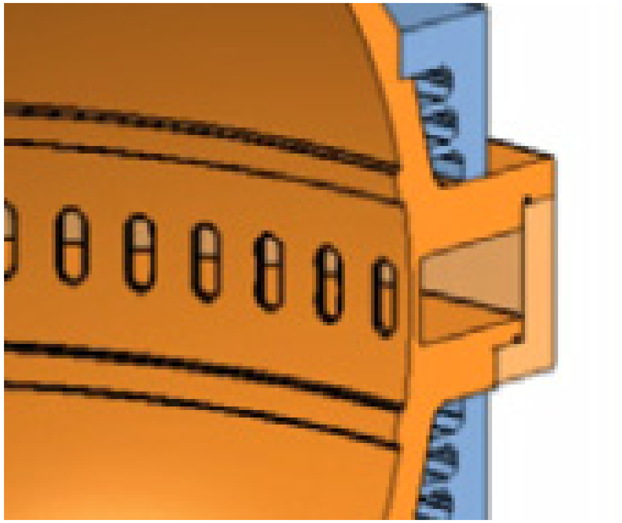
$$Q_0 = \frac{a}{\delta}$$

In this work, we use a spherical cavity, but for convenience, I will use the definitions in BOC.

Difference between two designs

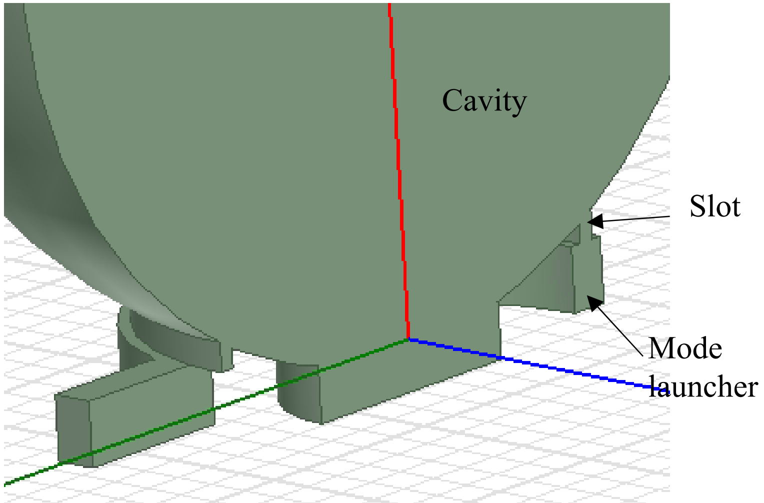
Traditional BOC:

- ❖ Cavity is surrounded by rectangular waveguide to couple power.
- ❖ Power is coupled through coupling apertures.



New design:

- ❖ We plan to use a coupling slot instead of the apertures, which can be machined more precisely.
- ❖ The cavity and the mode launcher can be designed separately, which can simplify the design.



Analysis of $TM_{24,1,1}$ mode

For Whispering Gallery mode, both BOC and SC theory can be used:

Resonant frequency of TM_{mnq} for BOC:

$$ka = \upsilon_{mn} + \frac{(p - 1/2)\alpha}{\sin\theta}$$

When m=24, n=1, q=1

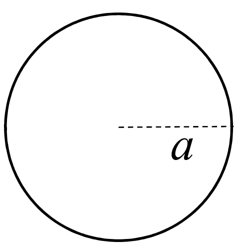
Resonant frequency of TE_{mnp} for spherical cavity:

$$f = \frac{u_{np}}{2\pi a\sqrt{\varepsilon\mu}}$$

When n=24, p=1

$$a = 120.3 \text{ mm}$$

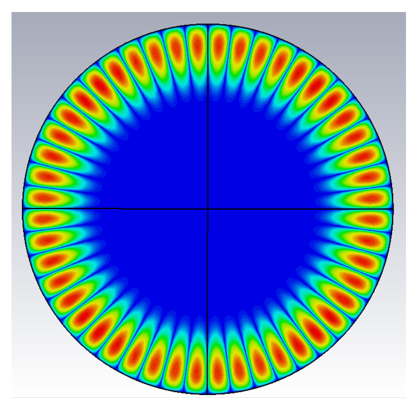
$$Q_0 = 200{,}000$$

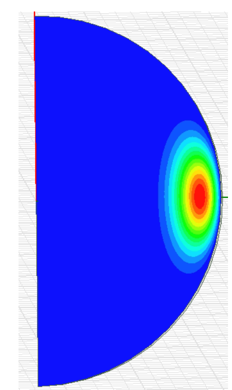


Spherical cavity

Simulation result:

$TM_{24,1,1}$	
Radius /mm	120.3
Frequency /MHz	11995.8
Q_0	199,374

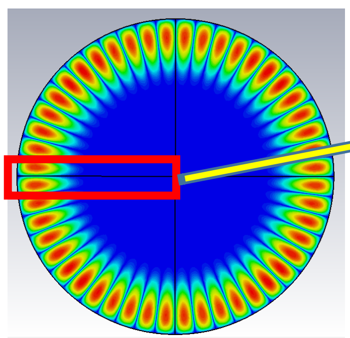


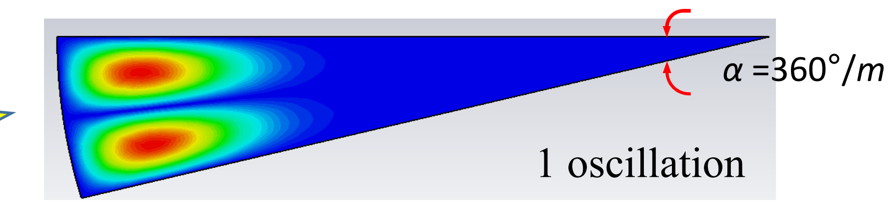


Analysis of $TM_{14,1,11}$ mode

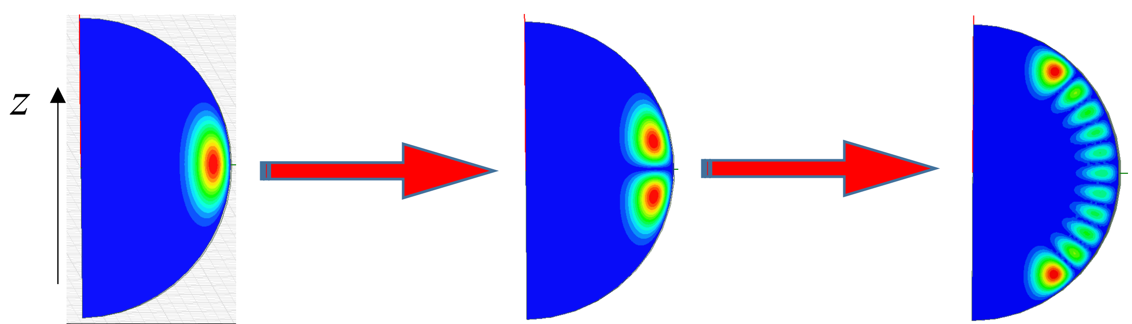
- We need to reduce the size of mode launcher, but there's a limitation because of the index *m*. For *m*=24, the minimum radius of the input port is 104.85 mm, the cut-off radius of $TE_{24,1}$ mode.
- We have to keep the Q-factor high enough, so the cavity radius should not be reduced.

The solution is to decrease the index *m*, but increase the index *p* correspondingly.



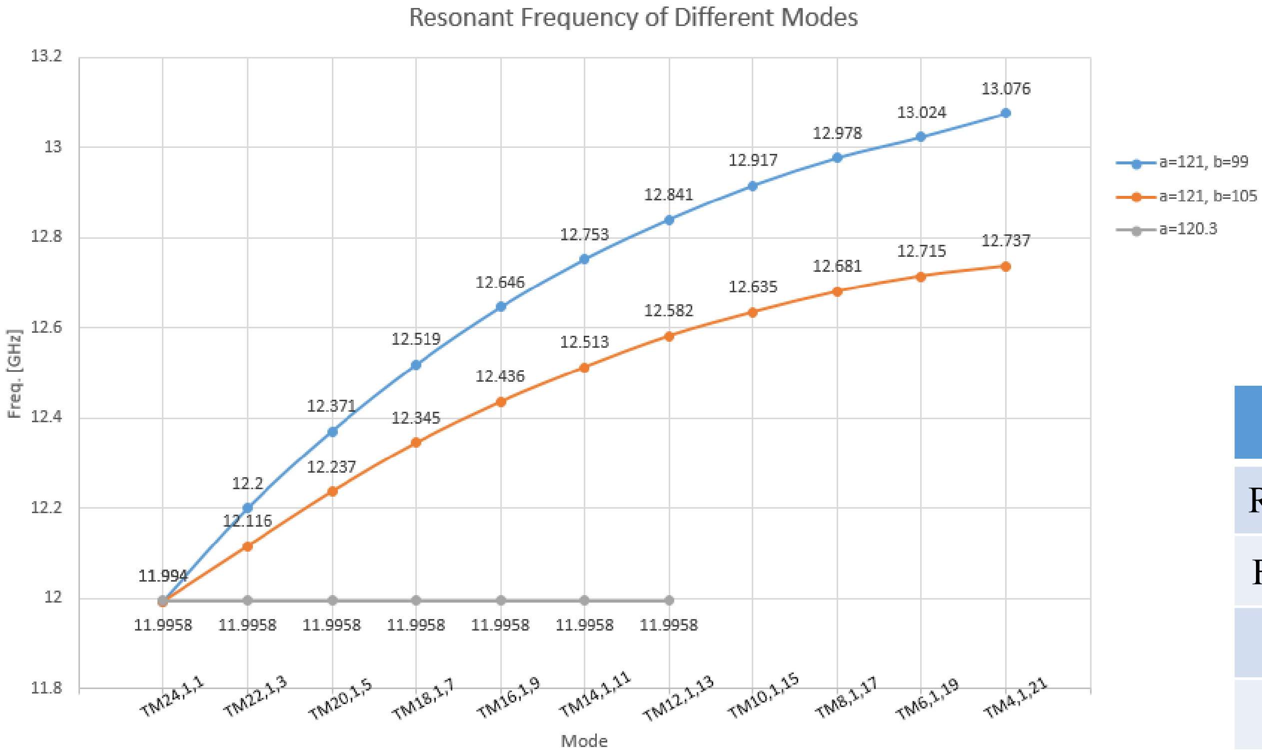


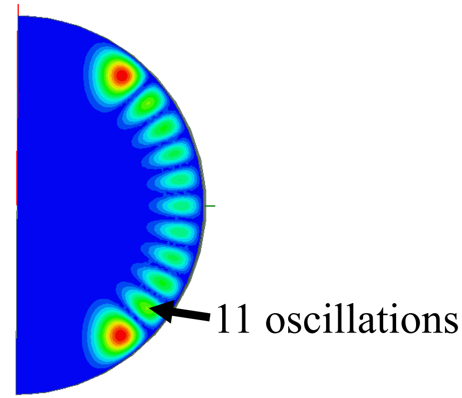
m is the number of oscillations along *φ* direction on equator plane.
p is the number of oscillations along *z* direction.



p=1 *p*=2 *p*=11

Analysis of $TM_{14,1,11}$ mode - cavity





$TM_{14,1,11}$	
Radius [mm]	120.3
Freq. [MHz]	11995.8
Q_0	199376
α	25.714°

For different modes in BOC, as long as n=1, $m+p=25$:

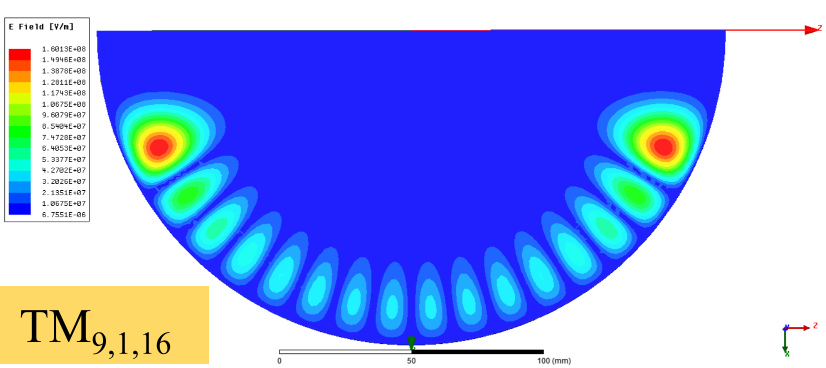
- For elliptical BOC, their frequencies are different.
- The smaller the difference between a and b is, the smaller the frequency difference will be.
- If $a=b$, the frequency difference becomes 0. All these modes are degenerated.

Analysis of $TM_{9,1,16}$ mode

The mode launcher is still too big. So we continue to reduce index *m*.
But *m* cannot be too small, otherwise the surface field in mode launcher will be too high. Besides, the smaller the index *m* is, the more degenerated high-order modes there will be.
For example:

Working mode	High-order modes
$TM_{9,1,16}$	$TM_{18,1,7}$
$TM_{8,1,17}$	$TM_{16,1,9}$, $TM_{24,1,1}$
$TM_{7,1,18}$	$TM_{14,1,11}$, $TM_{21,1,4}$
$TM_{6,1,19}$	$TM_{12,1,13}$, $TM_{18,1,7}$, $TM_{24,1,1}$
$TM_{5,1,20}$	$TM_{10,1,15}$, $TM_{15,1,10}$, $TM_{20,1,5}$

For now, index *m* of 9 is chosen:

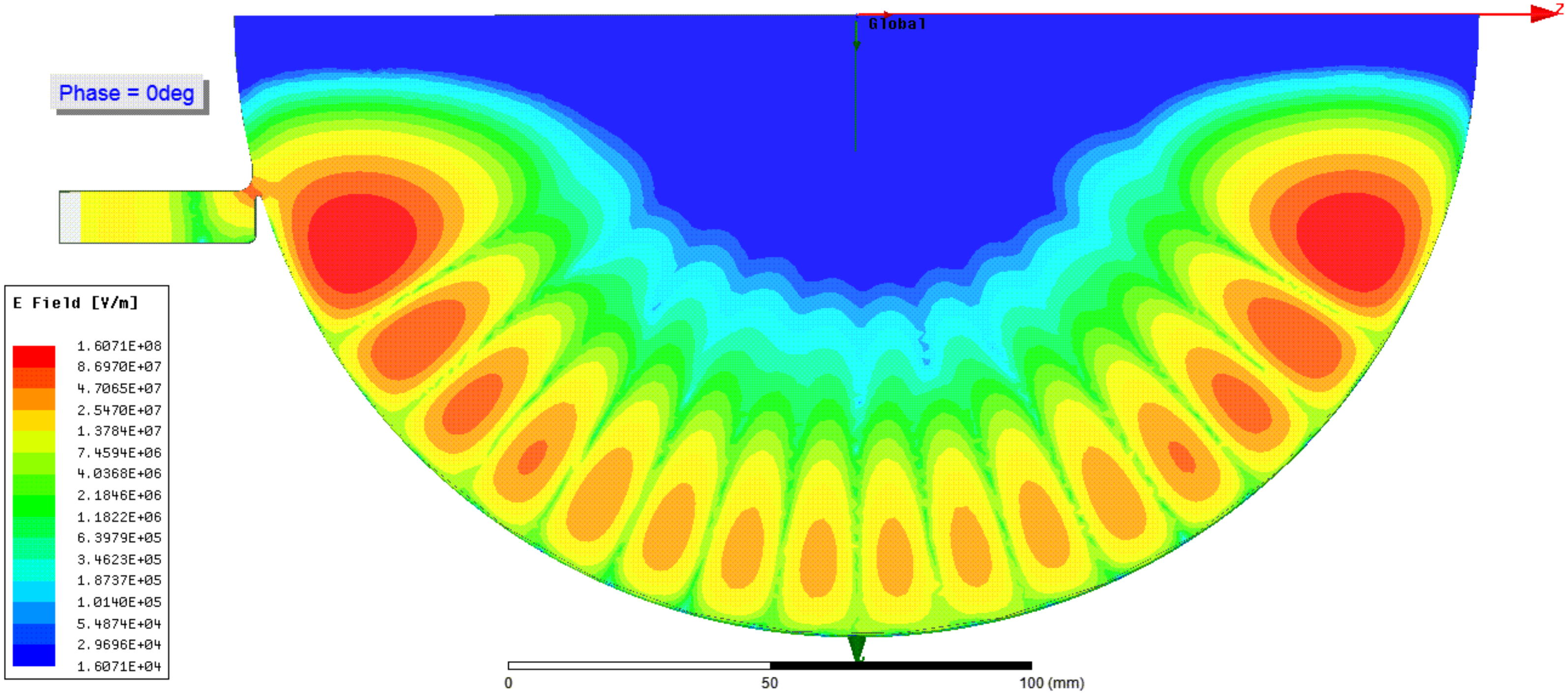


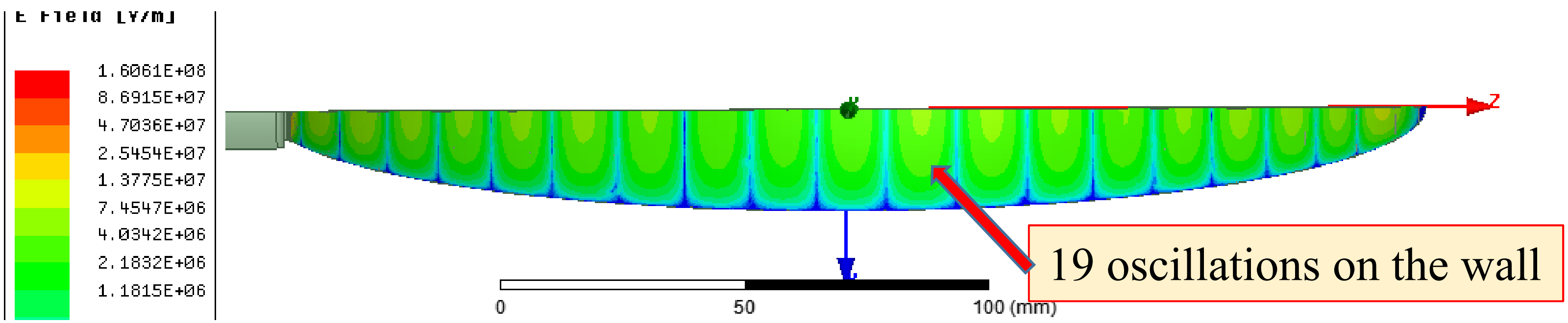
$TM_{9,1,16}$

Neighboring modes.

	Eigenmode	Frequency (GHz)	Q
	Mode 1	11.9249 +j 0.000183232	32540.4
	Mode 2	11.9249 +j 0.000183227	32541.4
	Mode 3	11.9958 +j 3.00849e-05	199365.
	Mode 4	12.0073 +j 4.80147e-05	125038.
	Mode 5	12.0490 +j 3.62833e-05	166040.

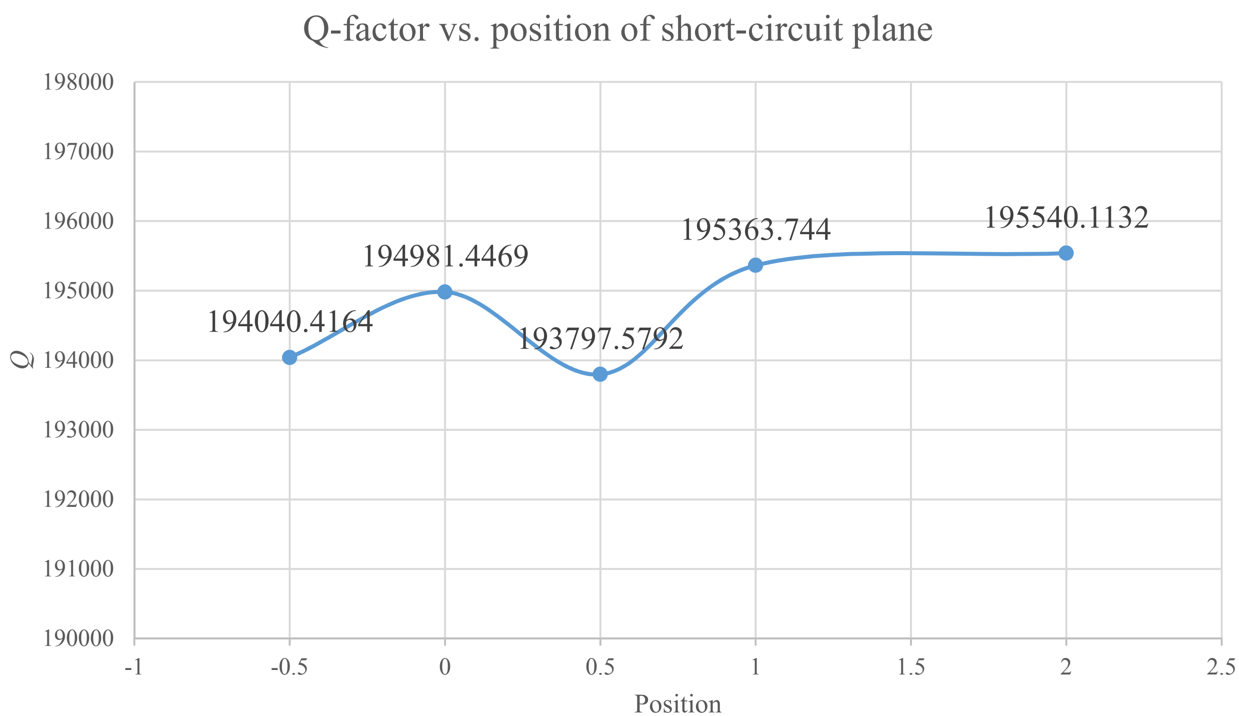
Analysis of $TM_{9,1,16}$ mode - cavity





There's some mode mixture.

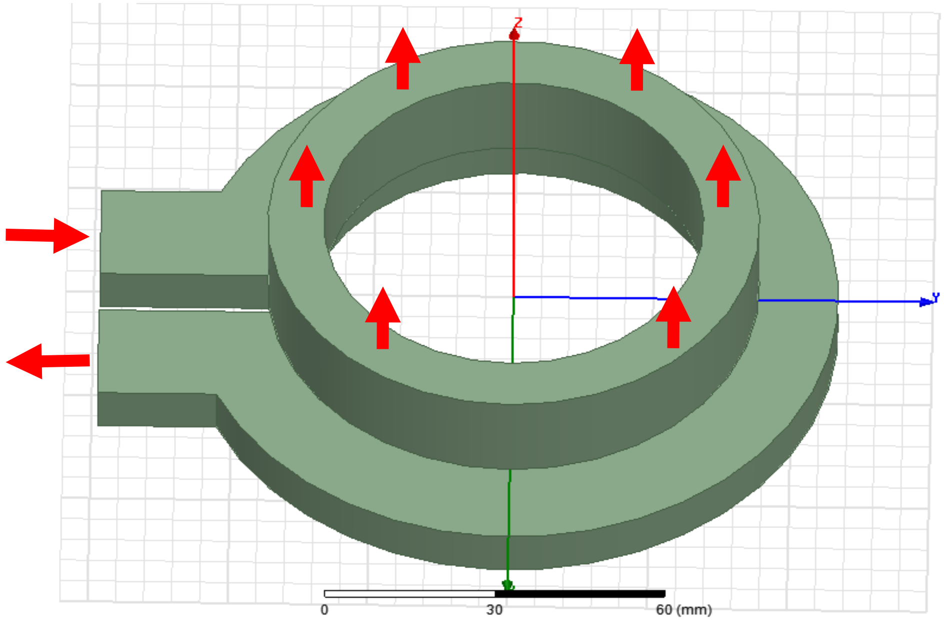
Analysis of $TM_{9,1,16}$ mode - cavity



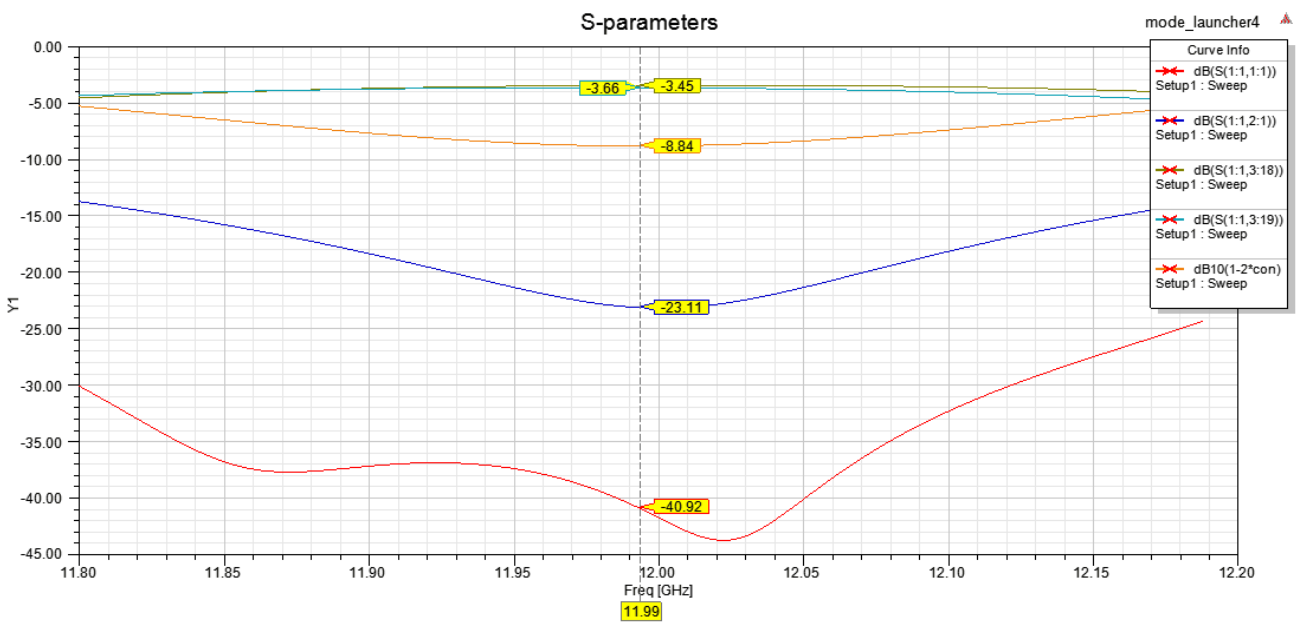
The Q-factor is around 194,000 (~2.5% reduced).

Analysis of $TM_{9,1,16}$ mode – mode launcher

Model:

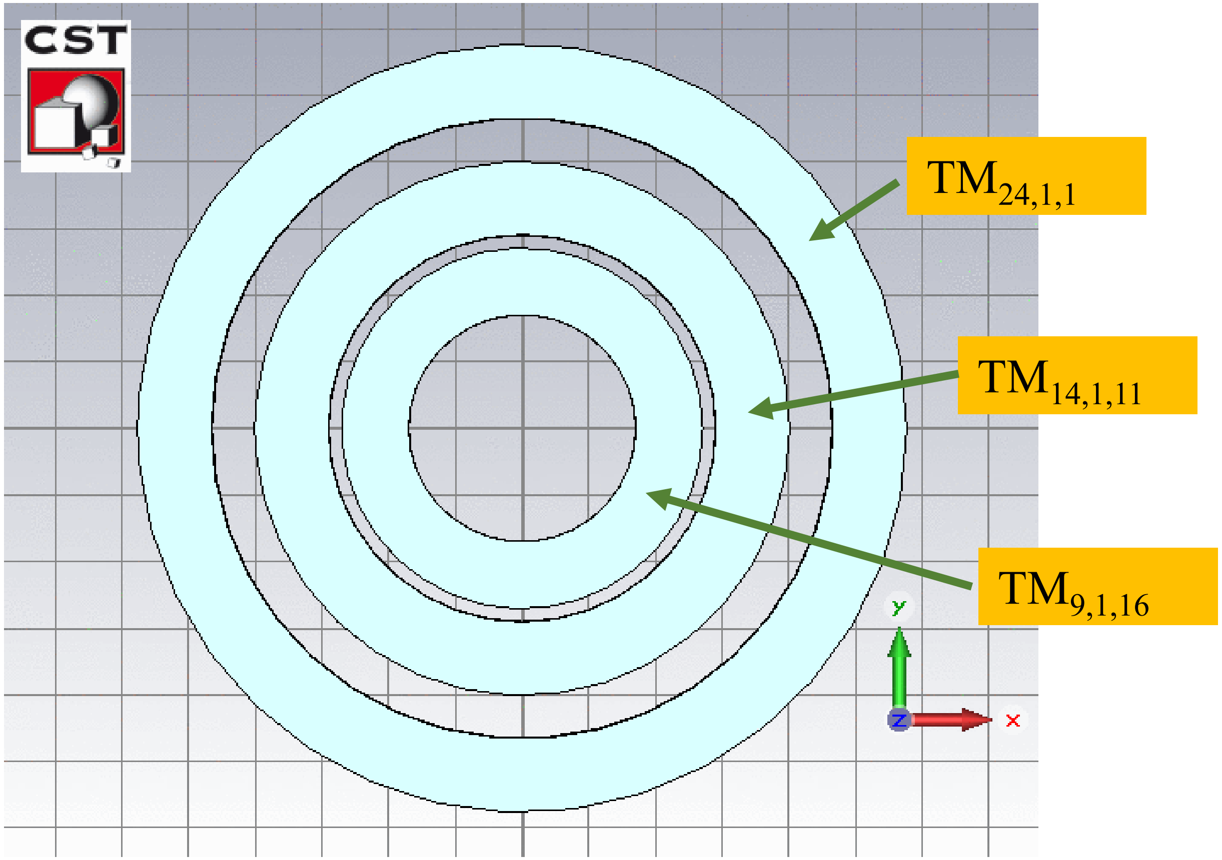


Best result for now:



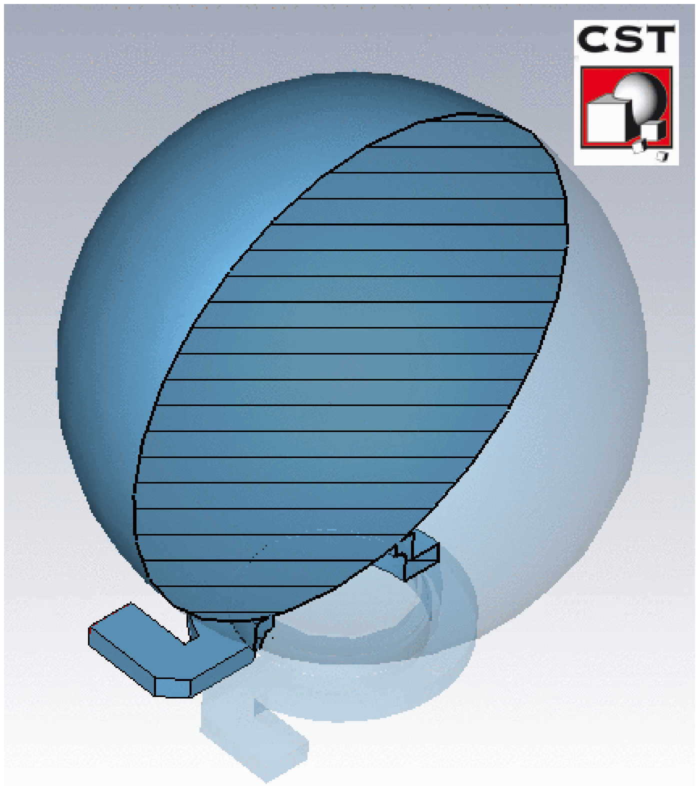
Mode launcher size comparison

Mode launcher circles of the three pulse compressor schemes:



The use of degenerated mode reduces the size of mode launcher significantly.

Summary



- This work is to design a spherical pulse compressor using degenerated "whispering gallery" mode.
- Some investigations on "whispering gallery" mode and its degenerated modes are presented.
- The structure is being designed. Some preliminary results are presented.

Thank you!

Meet me at THPO109.

Thank you!