Dielectric-Loaded Accelerating (DLA) Structures

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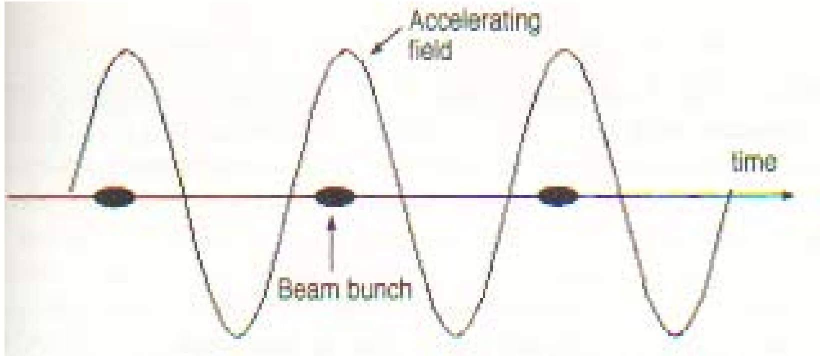
Contents

- Why Dielectric-Loaded Accelerating Structure?
  ____theory, varieties, history, etc.
- How to Make it?
  ____ EM simulation, engineering design, fabrication, etc.
- Does It Work Well?
  ____ challenges found out of the experiments.
- More advanced topics
  ____ multipactor suppression, multilayerred DLA, transverse mode damping, frequency tuning, etc.

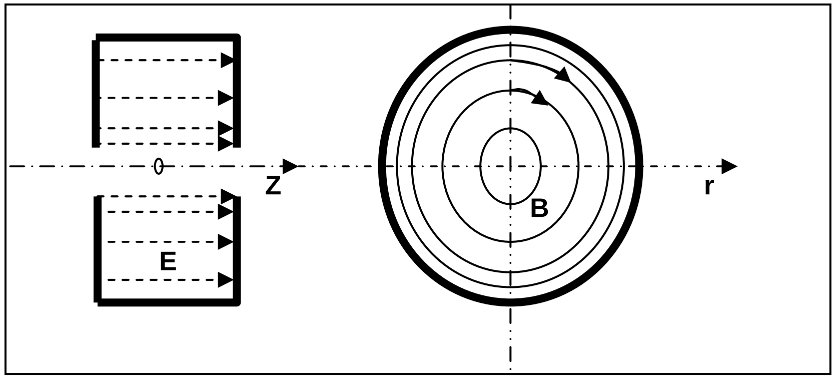
Part I: Why Dielectric-Loaded Accelerating Structure? --- theory, history, varieties, etc.

RF Driven Linear Accelerator

Using a sinusoidally varying electric field for acceleration, particle can either gain or lose energy, depending on the beam phase relative to the crest of the wave. (synchronization)



The electric and magnetic field pattern in a simple cylindrical cavity operated in a TM mode. Such a mode is characterized by a longitudinal electric field on axis, which is ideal for acceleration of a charged particle beam.



Resonant linear accelerators are usually single-pass machines. Charged particles traverse each section only once; therefore, the kinetic energy of the beam is limited by the length of the accelerator. Strong accelerating electric fields are desirable to achieve the maximum kinetic energy in the shortest length.

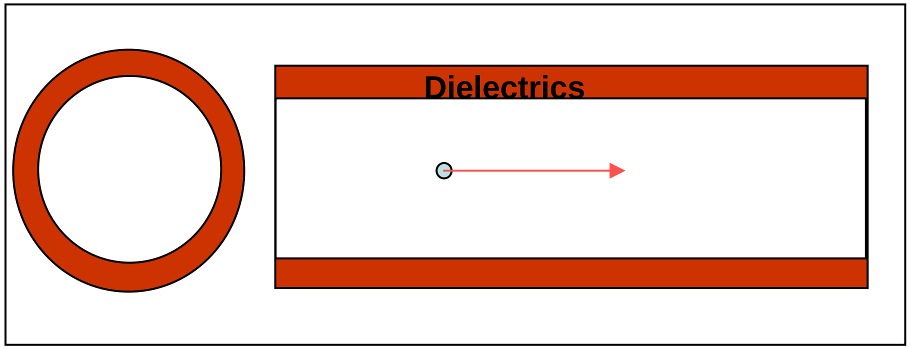
Want: Maximum accelerating gradient for a given RF power input.

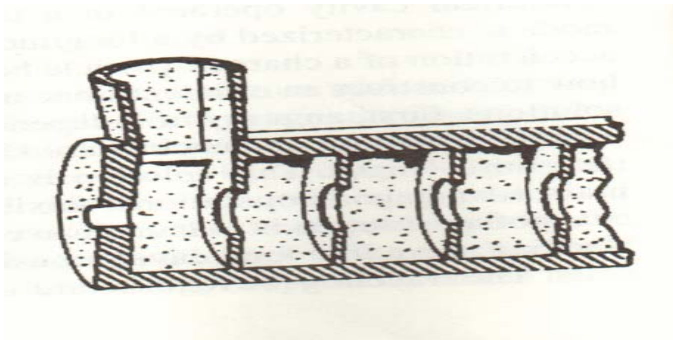
***Dielectric loaded waveguide can slow the RF wave for acceleration.**

***Low-loss dielectric materials bring promise to this kind of structure.**

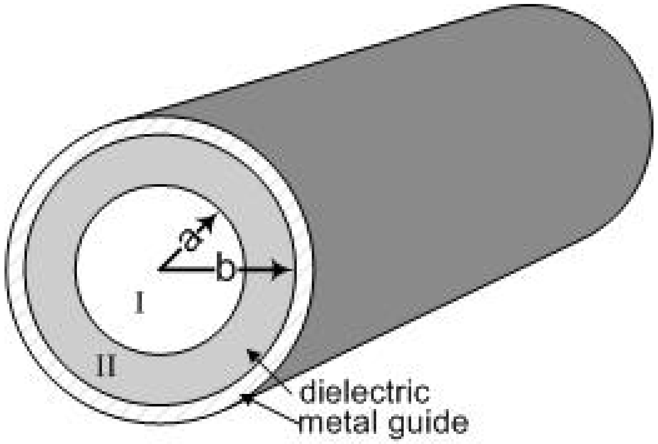
$$v_g v_p = \frac{1}{\mu \varepsilon}$$

- Advantages: simplicity of fabrication
  potentially higher breakdown threshold
  Easy deflecting mode damping
- Challenges: multipactor, broadband coupling

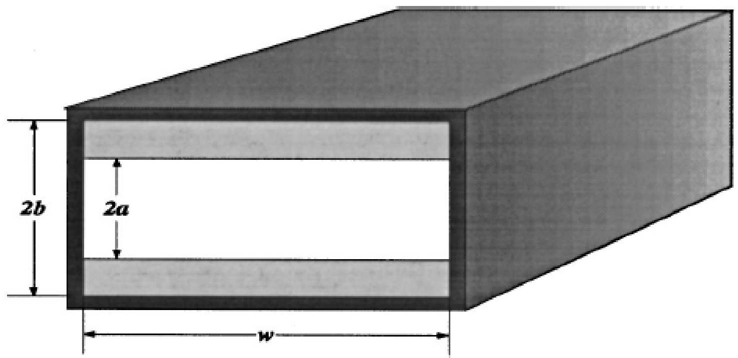




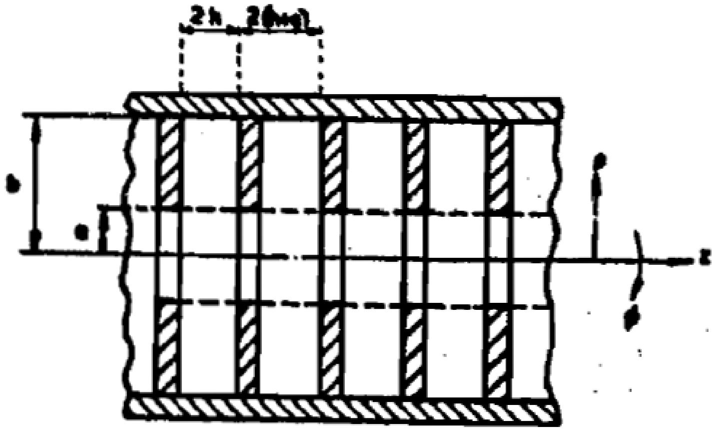
Geometrical Varieties:



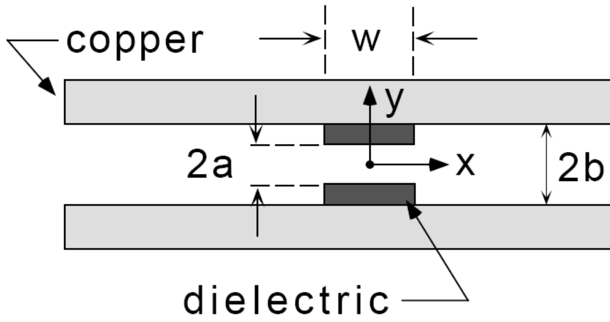
[ref1] Flesher, G., and G. Cohn. “Dielectric Loading for Waveguide Linear Accelerators.” *AIEE Transactions* 70 (1951):887-93.



[ref2] Xiao, L., W. Gai, and X. Sun, “Field Analysis of a Dielectric-loaded Rectangular Waveguide accelerating Structure.” *Physical Review E* 65 (2001): 016505.

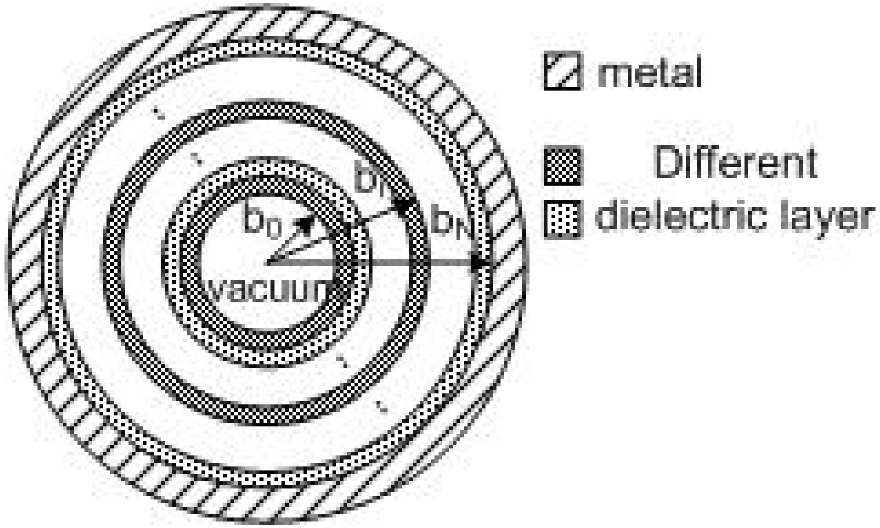


[ref3]. R.B. R.-Shersby-Harvie,etc., *Proc. I.E.E. B.*, **104** (1957) 273



[ref4] Marc E. Hill, SLAC-R-560 (2000).

A little bit of EM theory of a general case



Refer to D. Pozar's Microwave Engineering (page 117-126), or any other EM textbook.

General solutions of longitudinal component of electric and magnetic fields for the ith dielectric layer are:

$$E_{zi}(z,r,\phi) = [A_i J_n(k_i r) + B_i Y_n(k_i r)] e^{jn\phi} e^{j(\omega t - \beta z)}$$

$$H_{zi}(z,r,\phi) = [C_i J_n(k_i r) + D_i Y_n(k_i r)] e^{jn\phi} e^{j(\omega t - \beta z)}$$

$$k_i = \omega \sqrt{\frac{\mu_{ri}\varepsilon_{ri}}{c^2} - \frac{1}{v_p^{\ 2}}}$$

$$\beta^2 = \omega^2 \mu_0 \varepsilon_0 \mu_{ri} \varepsilon_{ri} - k_i^{\ 2}$$

v_p is the phase velocity of the wave, c is speed of light in vacuum,

k_i is the transverse wave number in the i^{th} layer,

β is the propagation constant along the z axis, and

$\mu_{ri}\varepsilon_{ri}$ are the relative permeability and permittivity for the i^{th} layer respectively.

In a homogenous waveguide

$$E_{ri} = \frac{-j}{k_i^{\ 2}}\left(\beta \frac{\partial E_{zi}}{\partial r} + \frac{\omega\mu_i}{r}\frac{\partial H_{zi}}{\partial \phi}\right)$$

$$E_{\phi i} = \frac{-j}{k_i^{\ 2}}\left(\beta \frac{\partial E_{zi}}{\partial \phi} - \omega\mu_i \frac{\partial H_{zi}}{\partial r}\right)$$

$$H_{ri} = \frac{j}{k_i^{\ 2}}\left(\frac{\omega\varepsilon_i}{r}\frac{\partial E_{zi}}{\partial \phi} - \beta \frac{\partial H_{zi}}{\partial r}\right)$$

$$H_{\phi i} = \frac{-j}{k_i^{\ 2}}\left(\omega\varepsilon_i \frac{\partial E_{zi}}{\partial r} + \frac{\beta}{r}\frac{\partial H_{zi}}{\partial \phi}\right)$$

B.C. → Ez and Hz continuous at the boundary between the neighbor layers

recurrence relation from the ith layer to the (i+1)th layer

$$\begin{pmatrix} A_{i+1} \\ B_{i+1} \\ C_{i+1} \\ D_{i+1} \end{pmatrix} = M \begin{pmatrix} A_i \\ B_i \\ C_i \\ D_i \end{pmatrix} \qquad , i = 0, \ldots N$$

M is transfer matrix between neighbor layers

Transfer matrix M

$$
M=\begin{pmatrix}
Y_n'(k_{i+1}r)J_n(k_ir)-\frac{k_{i+1}\varepsilon_i}{k_i\varepsilon_{i+1}}Y_n(k_{i+1}r)J_n'(k_ir) & Y_n'(k_{i+1}r)Y_n(k_ir)-\frac{k_{i+1}\varepsilon_i}{k_i\varepsilon_{i+1}}Y_n(k_{i+1}r)Y_n'(k_ir) & \frac{\beta}{\omega\varepsilon_{i+1}}\left(\frac{1}{k_{i+1}r}-\frac{k_{i+1}}{k_i^2r}\right)J_n(k_ir)Y_n(k_{i+1}r) & \frac{\beta}{\omega\varepsilon_{i+1}}\left(\frac{1}{k_{i+1}r}-\frac{k_{i+1}}{k_i^2r}\right)Y_n(k_ir)Y_n(k_{i+1}r) \\
\frac{k_{i+1}\varepsilon_i}{k_i\varepsilon_{i+1}}J_n'(k_ir)J_n(k_{i+1}r)-J_n'(k_{i+1}r)J_n(k_ir) & \frac{k_{i+1}\varepsilon_i}{k_i\varepsilon_{i+1}}J_n(k_{i+1}r)Y_n'(k_ir)-J_n'(k_{i+1}r)Y_n(k_ir) & \frac{\beta}{\omega\varepsilon_{i+1}}\left(\frac{k_{i+1}}{k_i^2r}-\frac{1}{k_{i+1}r}\right)J_n(k_ir)J_n(k_{i+1}r) & \frac{\beta}{\omega\varepsilon_{i+1}}\left(\frac{k_{i+1}}{k_i^2r}-\frac{1}{k_{i+1}r}\right)J_n(k_ir)Y_n(k_ir) \\
\frac{\beta}{\omega\mu_{i+1}}\left(\frac{1}{k_{i+1}r}-\frac{k_{i+1}}{k_i^2r}\right)Y_n(k_{i+1}r)J_n(k_ir) & \frac{\beta}{\omega\mu_{i+1}}\left(\frac{1}{k_{i+1}r}-\frac{k_{i+1}}{k_i^2r}\right)Y_n(k_ir)Y_n(k_{i+1}r) & J_i(k_ir)Y_i'(k_{i+1}r)-\frac{k_{i+1}\mu_i}{k_i\mu_{i+1}}J_n'(k_ir)Y_n(k_{i+1}r) & Y_n(k_ir)Y_n'(k_{i+1}r)-\frac{k_{i+1}\mu_i}{k_i\mu_{i+1}}Y_n(k_{i+1}r)Y_n'(k_ir) \\
\frac{\beta}{\omega\mu_{i+1}}\left(\frac{k_{i+1}}{k_i^2r}-\frac{1}{k_{i+1}r}\right)J_n(k_ir)J_n(k_{i+1}r) & \frac{\beta}{\omega\mu_{i+1}}\left(\frac{k_{i+1}}{k_i^2r}-\frac{1}{k_{i+1}r}\right)Y_n(k_ir)J_n(k_{i+1}r) & \frac{k_{i+1}\mu_i}{k_i\mu_{i+1}}J_n(k_{i+1}r)J_n'(k_ir)-J_n'(k_{i+1}r)J_n(k_ir) & \frac{k_{i+1}\mu_i}{k_i\mu_{i+1}}J_n(k_{i+1}r)Y_n'(k_ir)-J_n'(k_{i+1}r)Y_n(k_ir)
\end{pmatrix}
$$

Where, J_n, Y_n, J_n', Y_n' are n^{th} order Bessel functions and their derivatives.

k_i, k_{i+1} transverse cut-off wave number in i^{th} and $i+1^{th}$ respectively.

N-layer structure with metal jacket

$$\begin{pmatrix} A_N \\ B_N \\ C_N \\ D_N \end{pmatrix} = M_{N-1} \cdots M_1 M_0 \begin{pmatrix} A_0 \\ 0 \\ C_0 \\ 0 \end{pmatrix}$$

Reality tells us that B0 and D0 have to be Zeros.

with

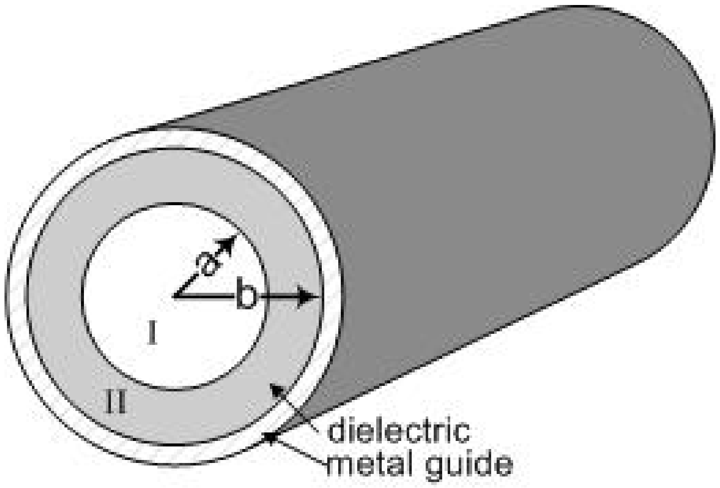
Ez=0 & Hr=0 @metal surface

$$\begin{cases} A_N J_n(k_N b_N) + B_N Y_n(k_N b_N) = 0 \\ C_N J_n'(k_N b_N) + D_N Y_n'(k_N b_N) = 0 \end{cases}$$

The conditions for a non-trivial solution of the above equations will determine the dispersion relation of this waveguide.

Now, it comes to what we care most:

Fields components and dispersion relation for TM01 mode in a single layer dielectric-loaded structure



$$k_1 = \omega\sqrt{\frac{1}{c^2} - \frac{1}{v_p^{\,2}}}$$

$$k_2 = \omega\sqrt{\frac{\varepsilon_r}{c^2} - \frac{1}{v_p^{\,2}}}$$

$$\beta^2 = k_0^{\,2} - k_1^{\,2} = \varepsilon_r k_0^{\,2} - k_2^{\,2}$$

$$k_0^{\,2} = \omega^2 \mu_0 \varepsilon_0$$

$$E_z = \begin{cases} B_1 J_0(k_1 r) e^{j(\omega t - \beta z)} & 0 \le r < a \\ B_2 \left[F_{00}(k_2 r)\right] e^{j(\omega t - \beta z)} & a \le r \le b \end{cases}$$

$$E_r = \begin{cases} -\dfrac{j\beta}{k_1} B_1 J_0{}'(k_1 r) e^{j(\omega t - \beta z)} & 0 \le r < a \\ -\dfrac{j\beta}{k_2} B_2 F_{00}{}'(k_2 r) e^{j(\omega t - \beta z)} & a < r \le b \end{cases}$$

$$H_\phi = \begin{cases} -\dfrac{j\omega\varepsilon_0}{k_1} B_1 J_0{}'(k_1 r) e^{j(\omega t - \beta z)} & 0 \le r < a \\ -\dfrac{j\omega\varepsilon_r\varepsilon_0}{k_2} B_2 F_{00}{}'(k_2 r) e^{j(\omega t - \beta z)} & a < r \le b \end{cases}$$

$$\left[\frac{1}{k_1}\frac{J_0{}'(k_1 a)}{J_0(k_1 a)} - \frac{\varepsilon_r}{k_2}\frac{F_{00}{}'(k_2 a)}{F_{00}(k_2 a)}\right] = 0$$

where

$$F_{00}(k_2 a) = J_0(k_2 a) - \frac{J_0(k_2 b)}{Y_0(k_2 b)} Y_0(k_2 a)$$

$$F_{00}'(k_2 a) = J_0'(k_2 a) - \frac{J_0'(k_2 b)}{Y_0'(k_2 b)} Y_0{}'(k_2 a)$$

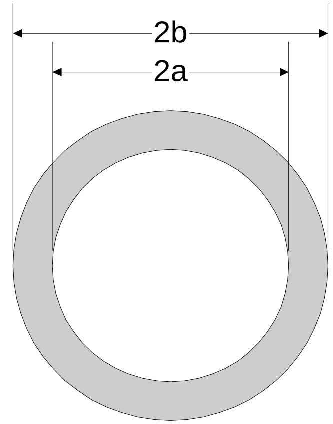
Example:

The operation frequency: f=11.424GHz

The dielectric constant of ceramic is 20

The inner radius of dielectric ceramic: a= 3mm

The phase velocity of TM_{01} mode: $v_p = c$.



Using the equations of TM_{01} mode, the solution of the outer radius b of dielectric ceramic can be found

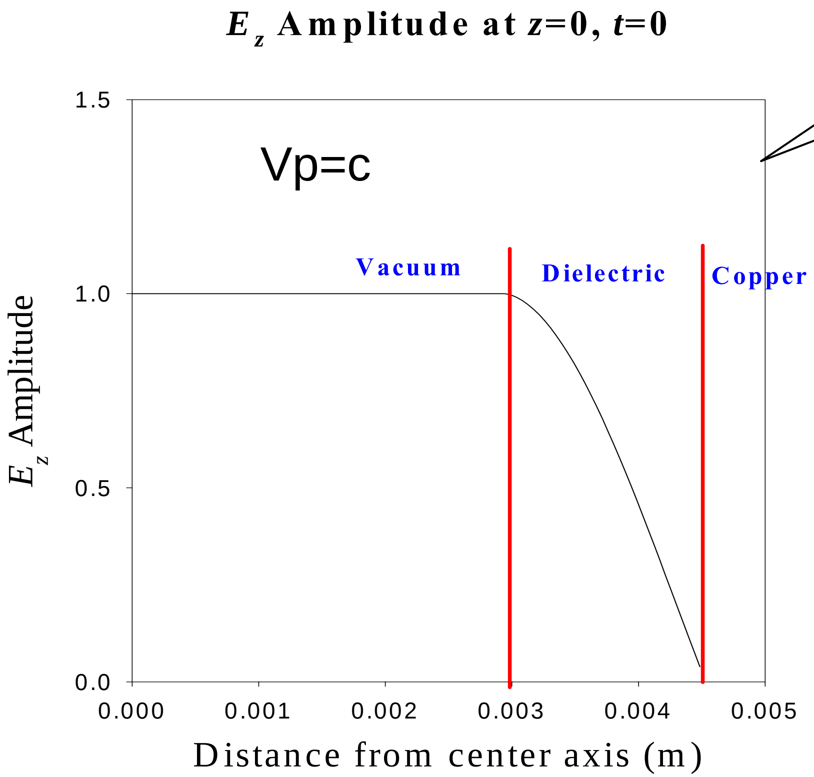
b=4.56mm.

Homework1: if a=2mm, what is the b? (You may use Matlab/MathCAD to solve the dispersion relation, or use CST MWS)

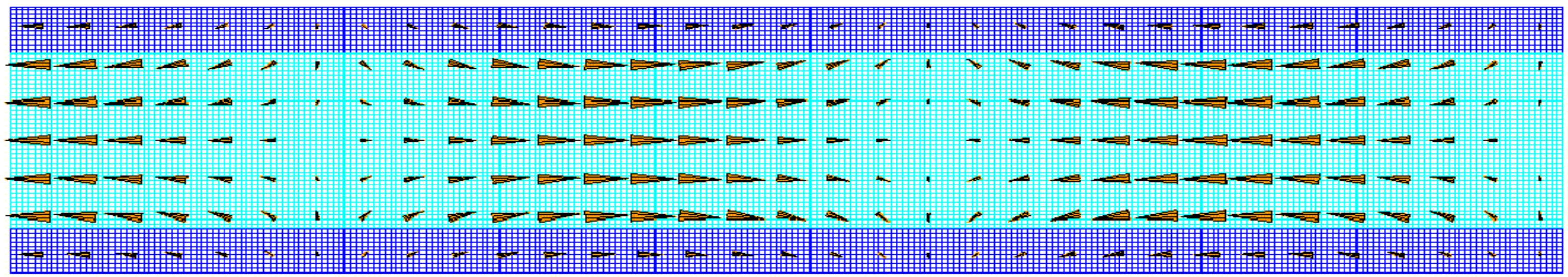
*Computer Lab: modeling using CST MWS→field pattern, accelerating parameters, etc.

Field Pattern Inside the Dielectric-lined Waveguide

Homework2: make a similar plot for Er



Homework3: DLA structure can be made either TW or SW. For TW case, is it const. impedance or const. gradient (assumptions: uniform geometry and linear material)? For SW case, what is the extra eqn. to determine the length?



Dispersion Curves

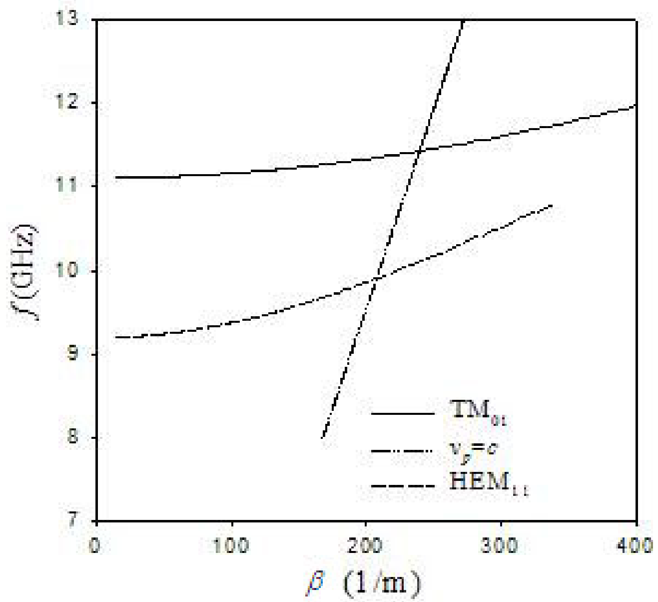
The general dispersion relation

$$\left[\frac{\mu_0}{k_1 a}\frac{J_n'(k_1 a)}{J_n(k_1 a)} - \frac{\mu_0}{k_2 a}\frac{G_{nn}'(k_2 a)}{G_{nn}(k_2 a)}\right]\left[\frac{\varepsilon_0}{k_1 a}\frac{J_n'(k_1 a)}{J_n(k_1 a)} - \frac{\varepsilon_r \varepsilon_0}{k_2 a}\frac{F_{nn}'(k_2 a)}{F_{nn}(k_2 a)}\right]$$

$$= \frac{(\beta n \omega)^2}{(k_1 k_2 a)^4}(\mu_0 \varepsilon_r \varepsilon_0 - \mu_0 \varepsilon_0)^2$$

The dispersion curves of TM_{01} mode and HEM_{11} mode

β vs. Frequency for TM_{01} and HEM_{11} modes



Homework4: make a similar plot use CST MWS for a comparison

Acceleration Parameters

You know the field expressions.
You can calculate everything.

$$\begin{cases} P = \dfrac{1}{2}\oint_S \vec{E}\times\vec{H}^*\cdot d\vec{s} \\ U = \dfrac{\varepsilon}{4}\mathrm{Re}\left(\int_V \vec{E}\times\vec{E}^* dv\right) + \dfrac{\mu}{4}\mathrm{Re}\left(\int_V \vec{H}\times\vec{H}^* dv\right) \end{cases}$$

$$Q = \frac{\omega U}{P_{loss}}$$

$$P_{loss} = \frac{R_s}{2}\int_S \left|H_\perp\right|^2_{r=b} ds + \frac{1}{2}\int_{\substack{Dielectric \\ UnitLength}} \omega\varepsilon_r\varepsilon_0 \tan\delta_l E^2 dV$$

$$R_s = \sqrt{\frac{\mu_0\omega}{2\sigma}}$$

$$\Rightarrow$$

$$\begin{cases} v_g = \dfrac{d\omega}{d\beta} = \dfrac{P}{U} \\ \dfrac{r}{Q} = \dfrac{E_a^{\,2}}{\omega U} \\ r = \dfrac{E_a^{\,2}}{-\,dP/dz} \\ \alpha_0 = \dfrac{\omega}{2Qv_g} \end{cases}$$

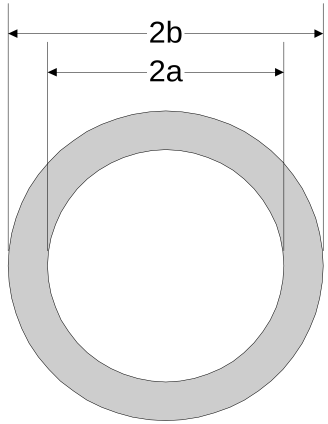
Example:

The operation frequency: f=11.424GHz

The dielectric constant of ceramic is 20, no loss

The inner radius of dielectric ceramic: a= 3mm

b=4.567mm.



PARAMETERS	**MgCaTi based DLA structure**
Group Velocity	0.057c
R/Q	8.8kΩ/m
Shunt Impedance	25.1 MΩ/m
Q	2865
Power ATTN	6.6dB/m
RF power needed to support 1MV/m gradient	27kW

*Computer Lab: you can use CST MWS to get accelerating parameters too.

Now, let's dig out some history

Experimental Studies of Dielectric Loaded Accelerator (1950s)

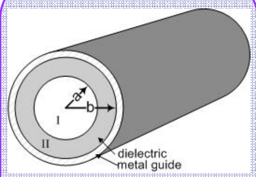
Major Research Group	**Scientists**	**References**	**Research Scope**
Atomic Energy Research Establishment (AERE), UK	R.B. R.-Shersby-Harvie, etc.	*1*. R.B. R.-Shersby-Harvie, *Nature*, **162** (1948) 890. *2*. R.B. R.-Shersby-Harvie,etc., *Proc. I.E.E. B.*, **104** (1957) 273.	Constructed and Tested a 4MeV Traveling wave Dielectric Disk Loaded Accelerator. Beam Acceleration. Discovered Multipactor in DLA.
Queen Mary College, Uni. of London, UK	G.B. Walker, etc.	*1*. G.B.Walker and N.D.West, *Proc. I.E.E. C.*, **104** (1957) 381. *2*. G.B.Walker and E.L.Lewis, *Nature*, **181** (1958) 38.	Constructed and Tested Dielectric Disk Loaded Wavguide Cavities. Tested Dielectric Breakdown.
IIT, USA	G.I. Cohn and G.T. Flesher	*1*. G.T.Flesher and G.I.Cohn, *A.I.E.E. C.*, **70** (1951) 887. *2*. G.I.Cohn and G.T.Flesher, *IIT Report*, **2** (1952).	Constructed and Tested a Quartz Tube Based Dielectric Loaded Accelerator.

Part II: How to Make it?

--- EM simulation, engineering design, fabrication, etc.

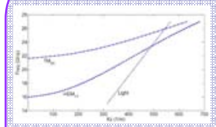
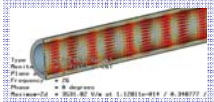
How do we design a DLA structure using CST MWS?

Analytical Solutions

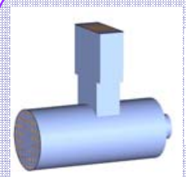
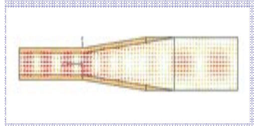


Calculate f, *a, b, L, Q, R/Q, Vg, G, P, etc.*

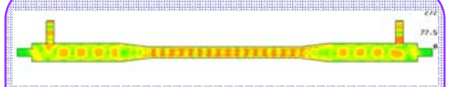
CST MW Studio

Verify, modes dispersion curves, EM fields, Q, etc.

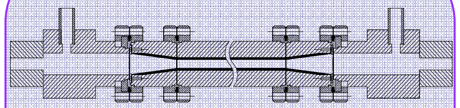



Coupler and matching Design



Full structure simulation

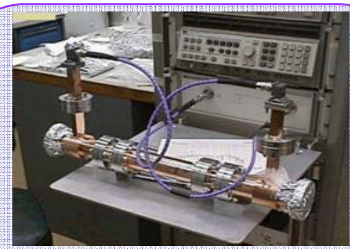
Engineering Design &Fabrication



More practical considerations, like vacuum, assembly, machining tolerance, etc.

Fabrication, assembly, *leak test.*

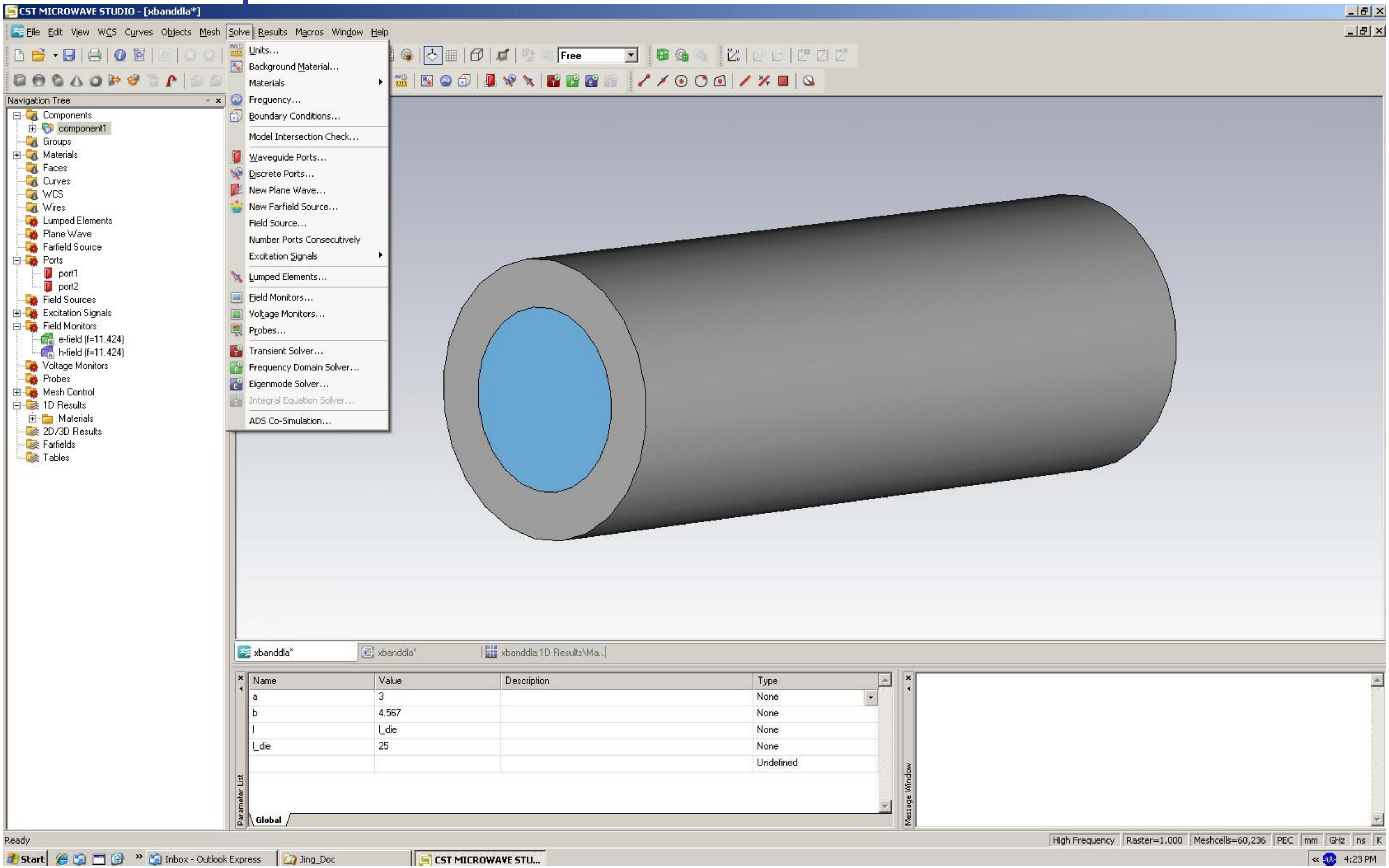
Tests



Bench tests, including S-parameters, beadpull, etc.

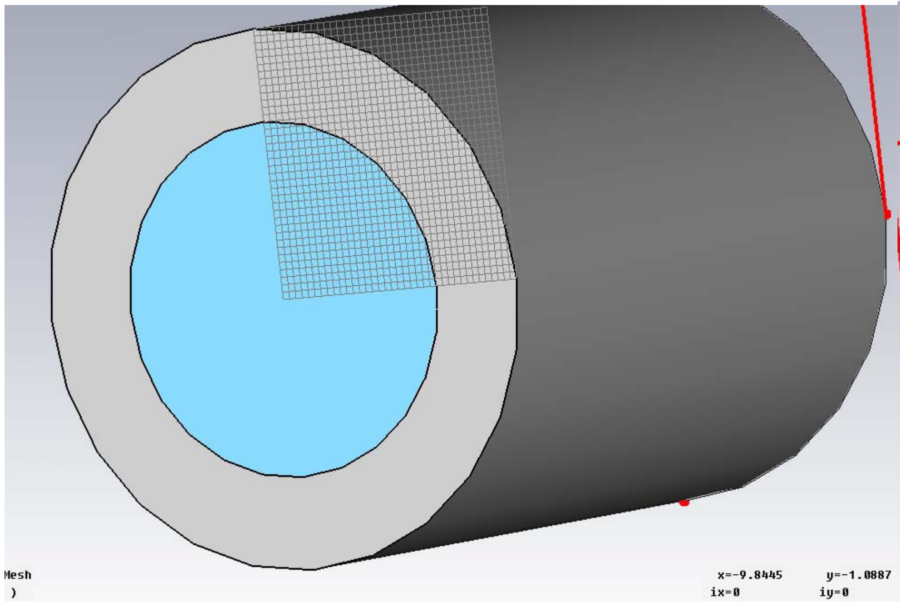
High power rf test.

EM simulation of a DLA structure (I) ---set up a model

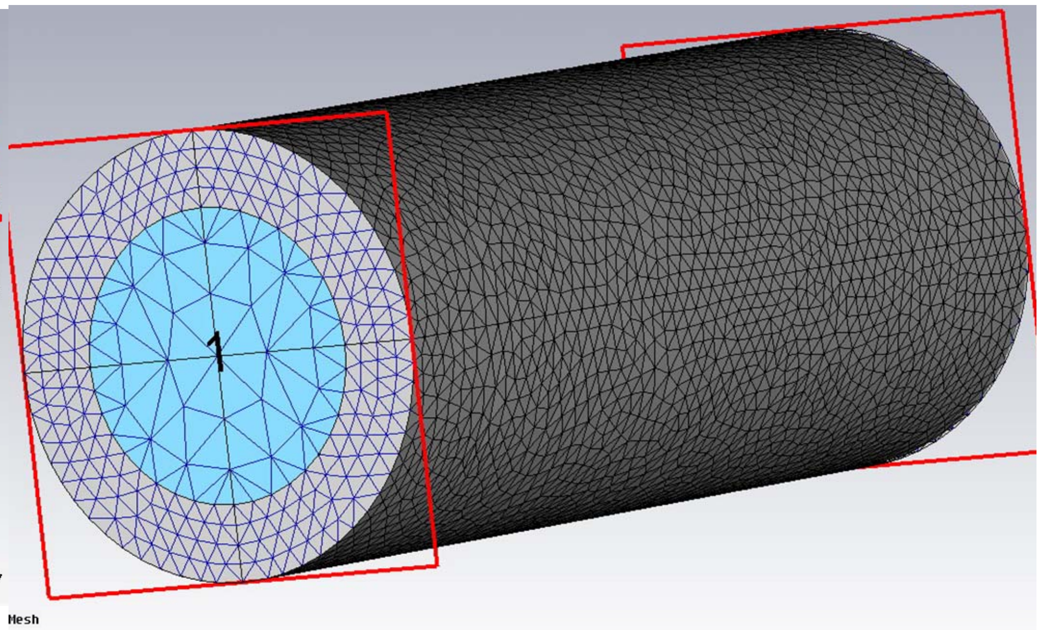


EM simulation of a DLA structure (II) ---mesh

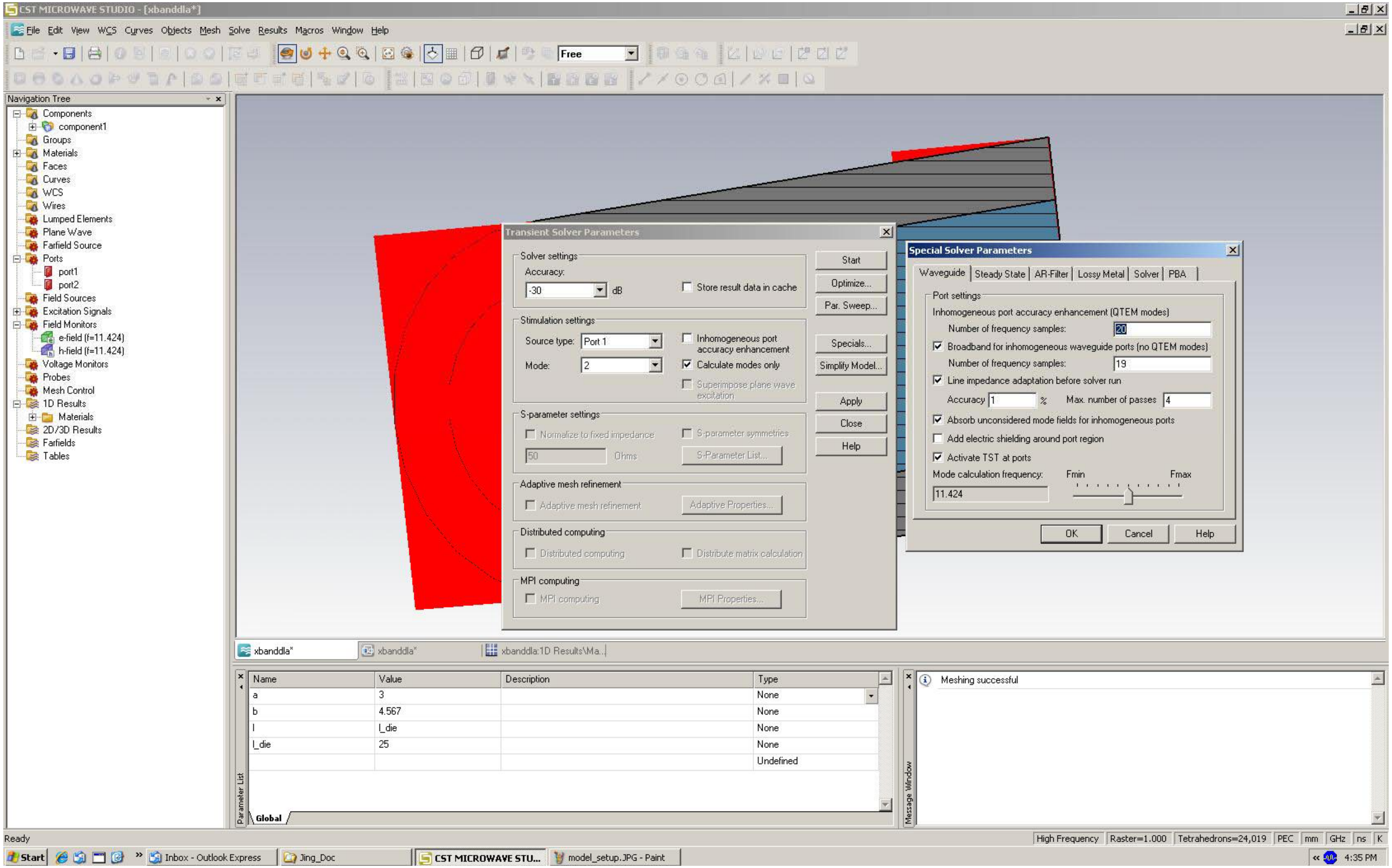
hexahedral mesh (TD)



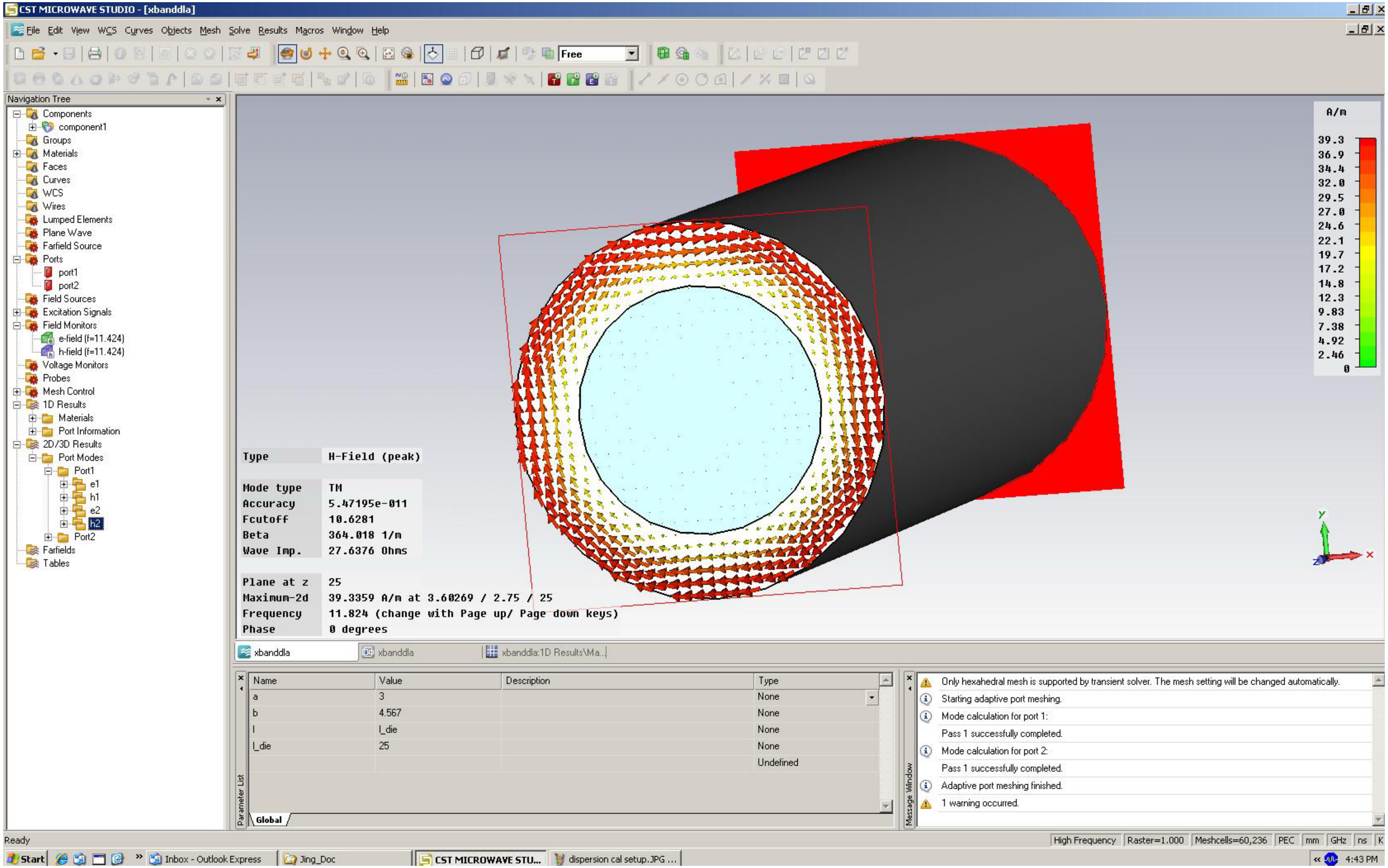
Tetrahedral mesh (FD)



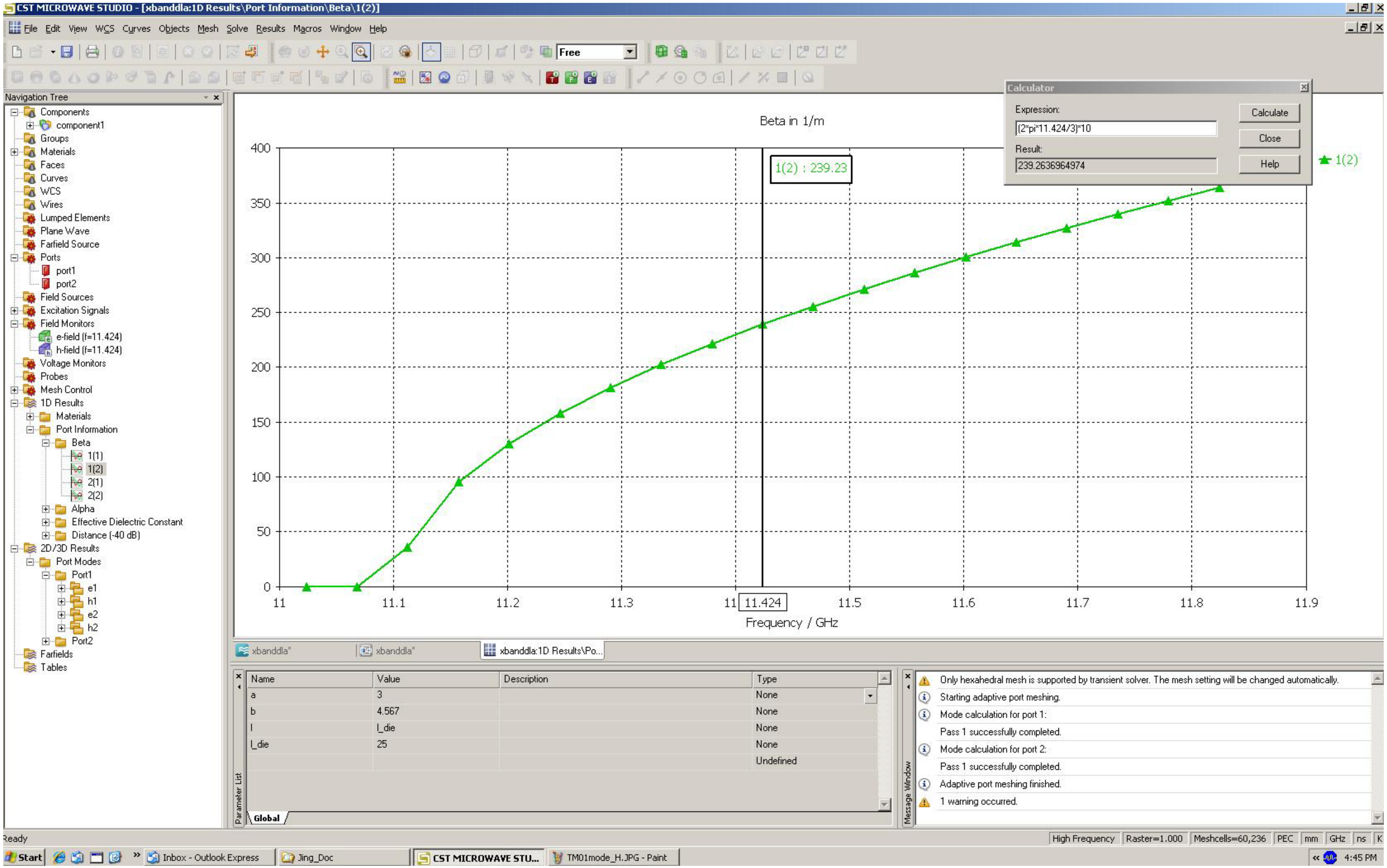
EM simulation of a DLA structure (III)
---set up the mode and dispersion cal



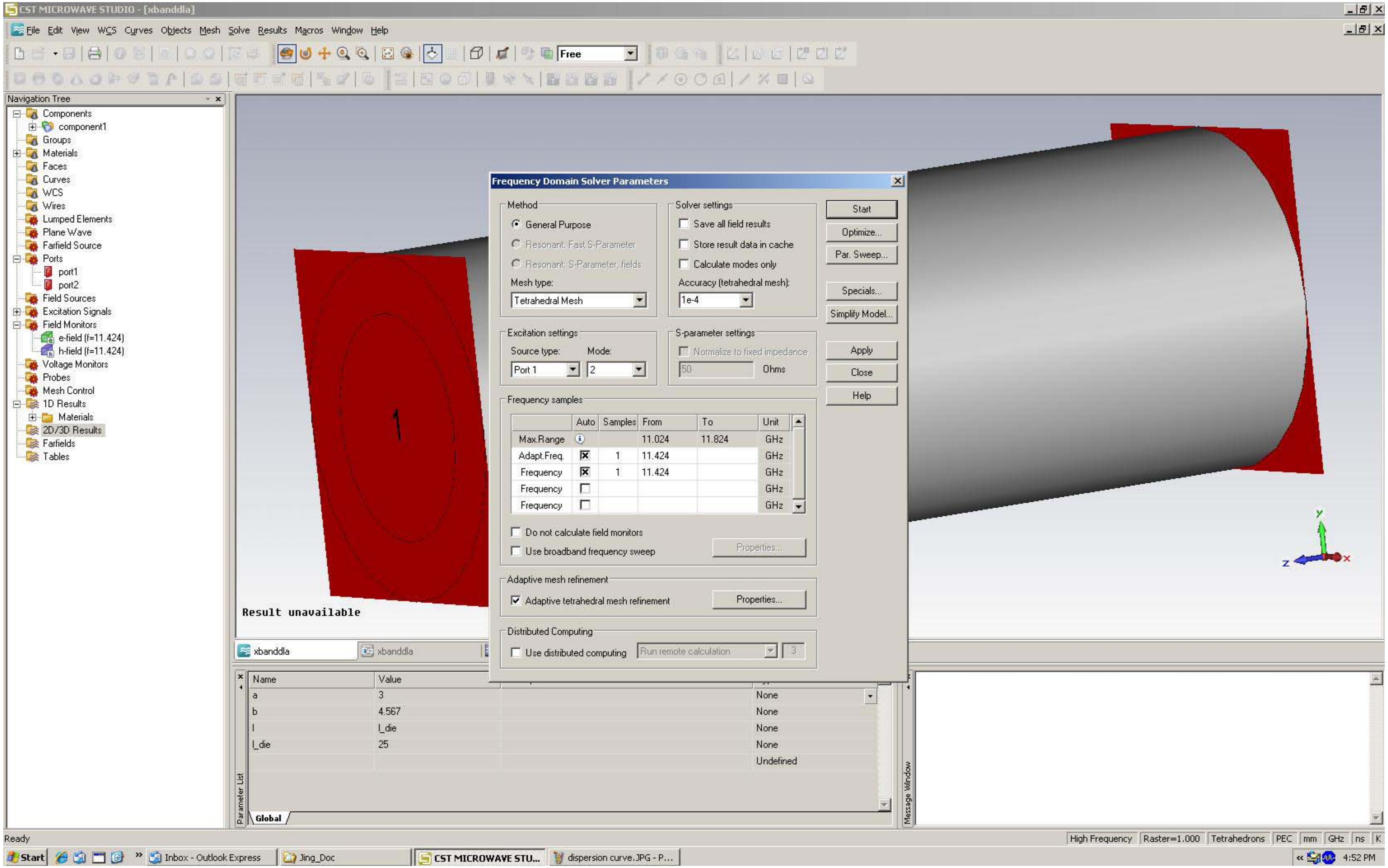
EM simulation of a DLA structure (III) ---mode



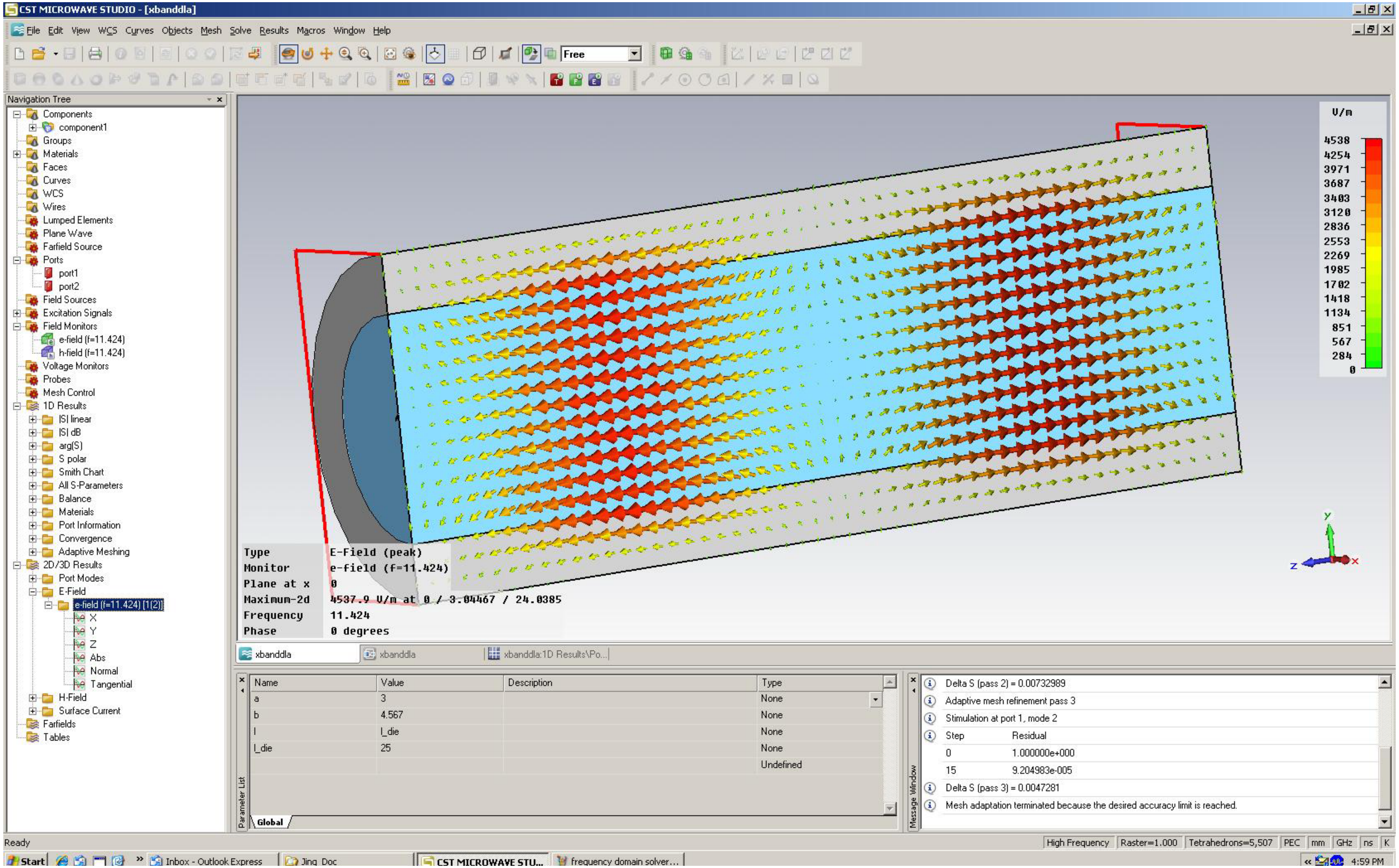
EM simulation of a DLA structure (III) ---dispersion



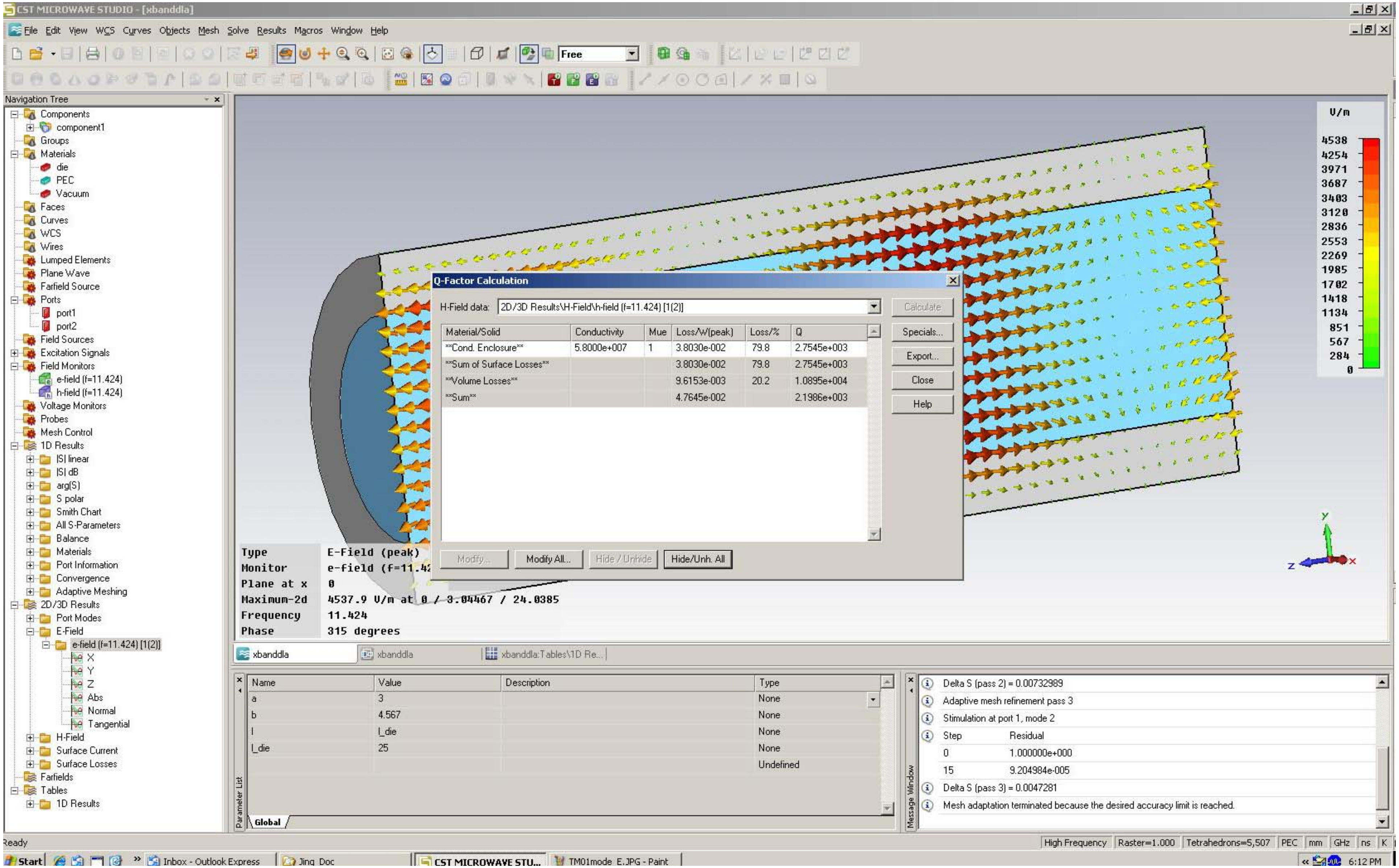
EM simulation of a DLA structure (IV) ---EM field simulation in FD



EM simulation of a DLA structure (IV) ---EM field simulation in FD

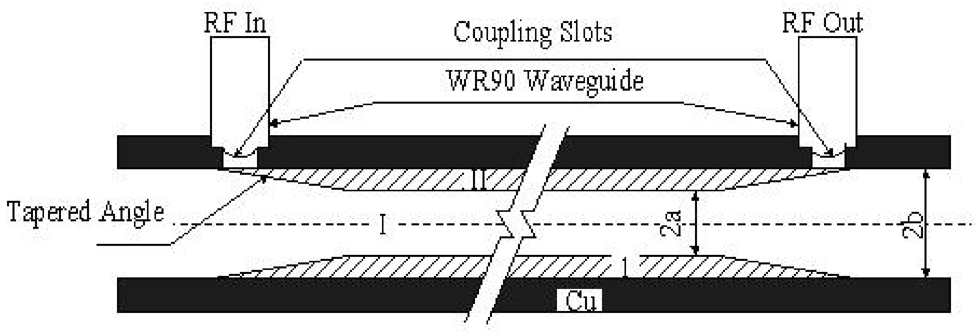


EM simulation of a DLA structure (IV) ---calculate acceleration parameters

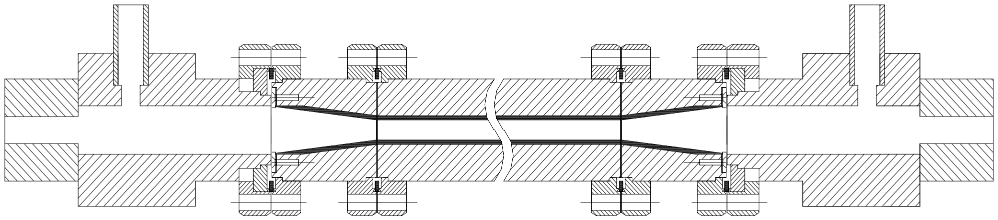


Now, we need figure out how to coupling the high power rf into the DLA structure.

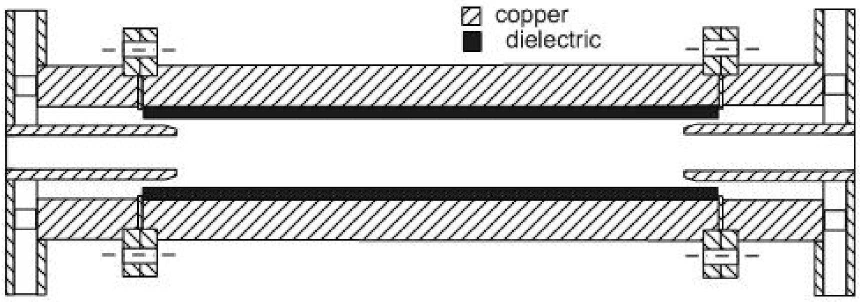
RF Coupling schemes--- TW (I)



Direct coupling

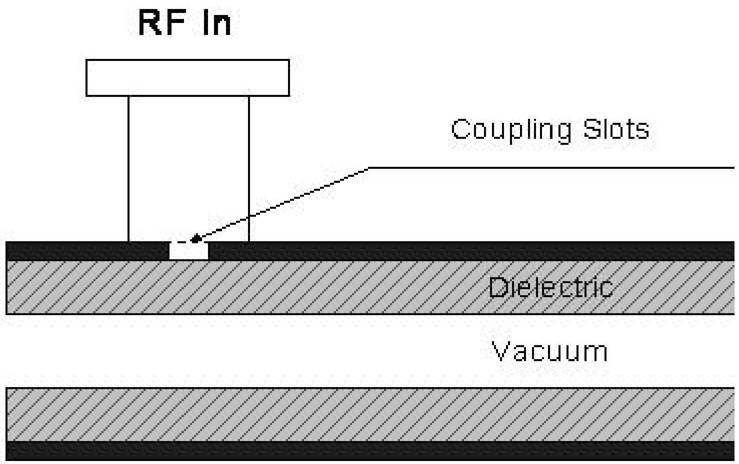


Mode launcher + impedance matching

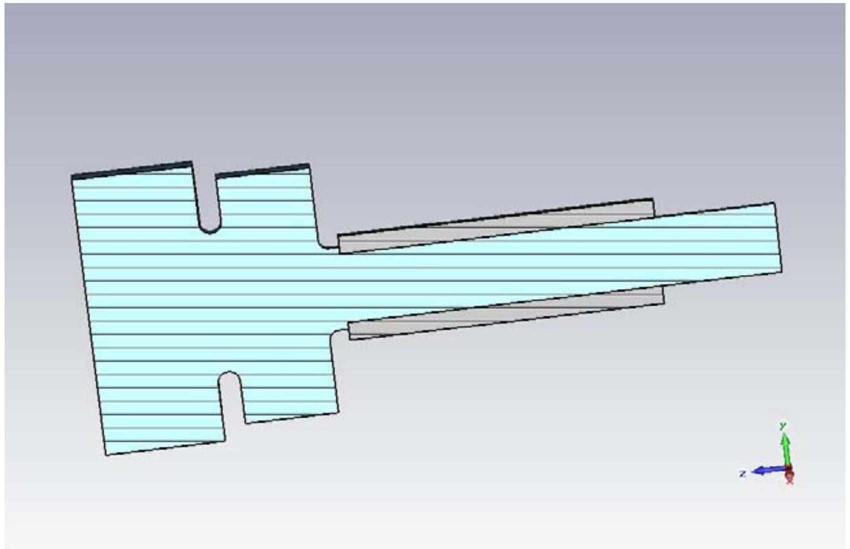


Coaxial type coupler

RF Coupling schemes--- SW



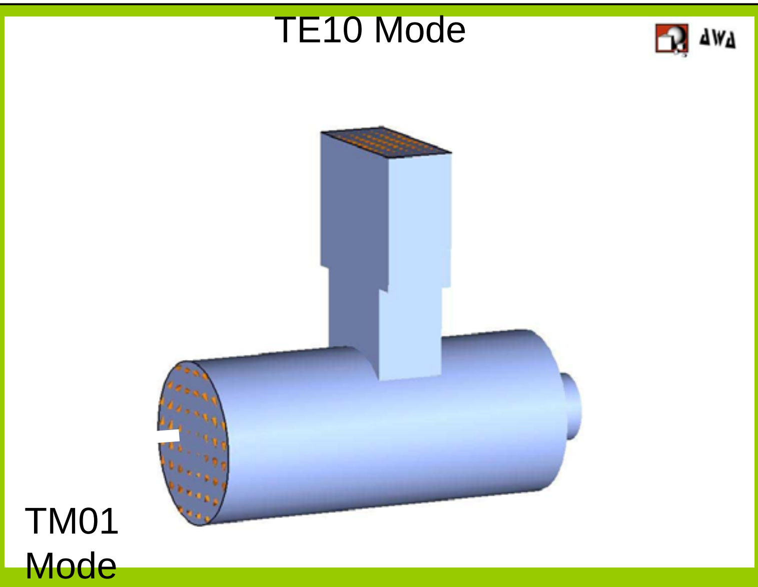
Side coupling

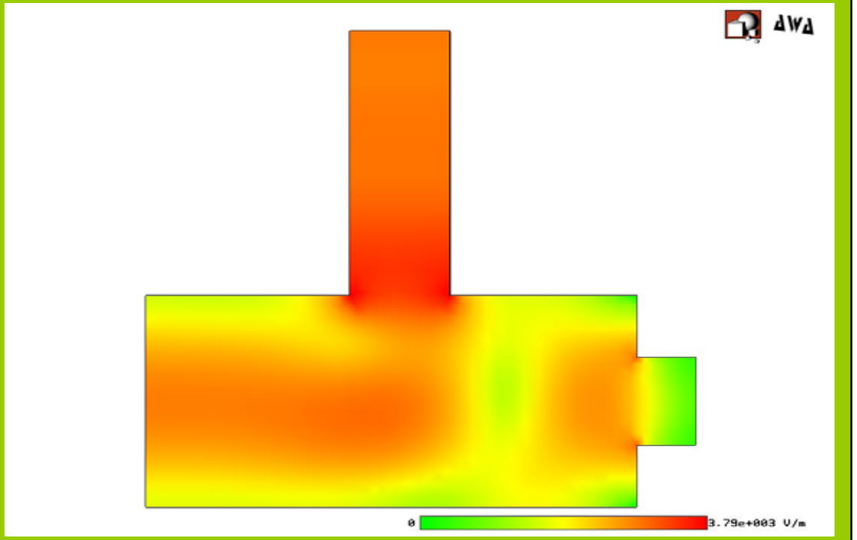


Axial coupling

Example: modular structure design

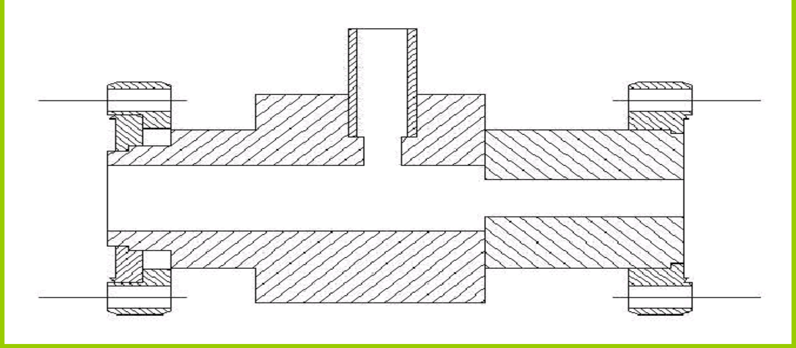
Coupler Simulation





E-field in Coupler

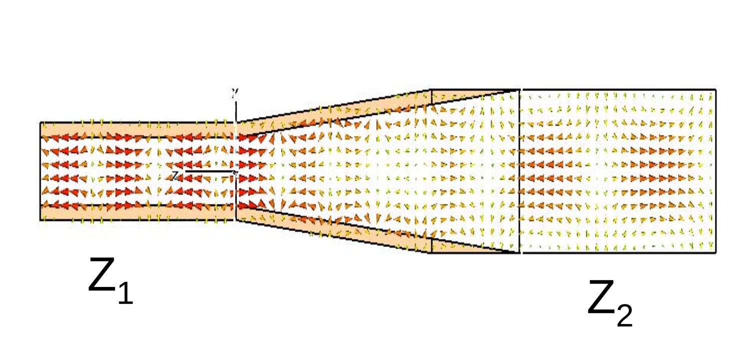
Peak electrical fields around the corners (blended at a radius of 2mm) of the coupling slot are to be less than 40 MV/m for 100 MW RF power, which is well below the copper surface breakdown threshold.



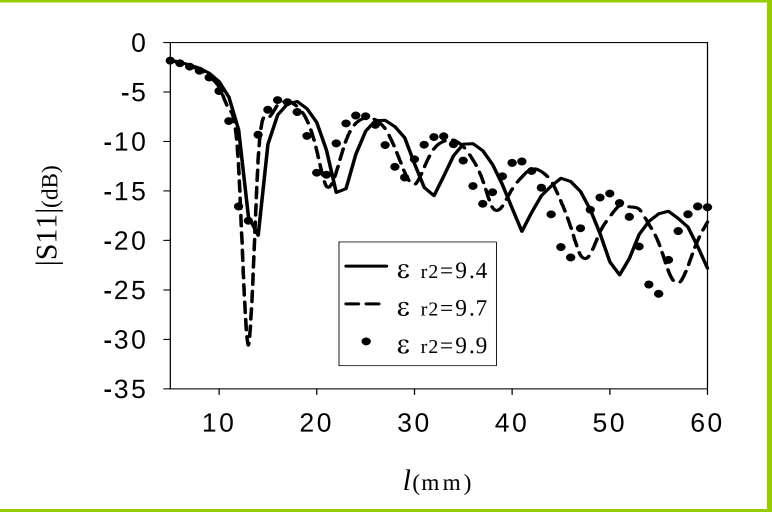
Mechanic Drawing

Matching Section Simulation and Making

Purpose of the tapered matching section is to match the wave impedance between the dielectric loaded circular waveguide (dielectric loaded accelerator section) and the regular circular waveguide where the RF coupling structure is implemented, thus achieve high transmissions.



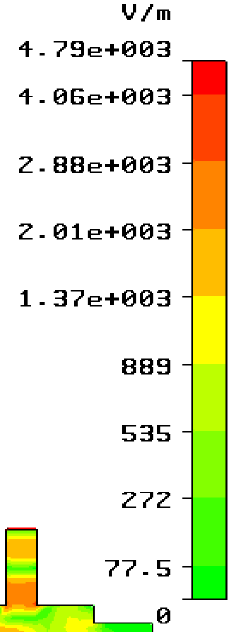
E-field pattern for taper section

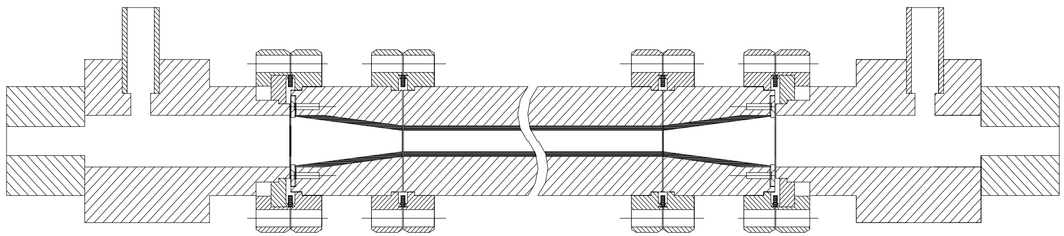


Length vs. Performance (S11)

E-Field of Dielectric-Loaded Accelerator structure

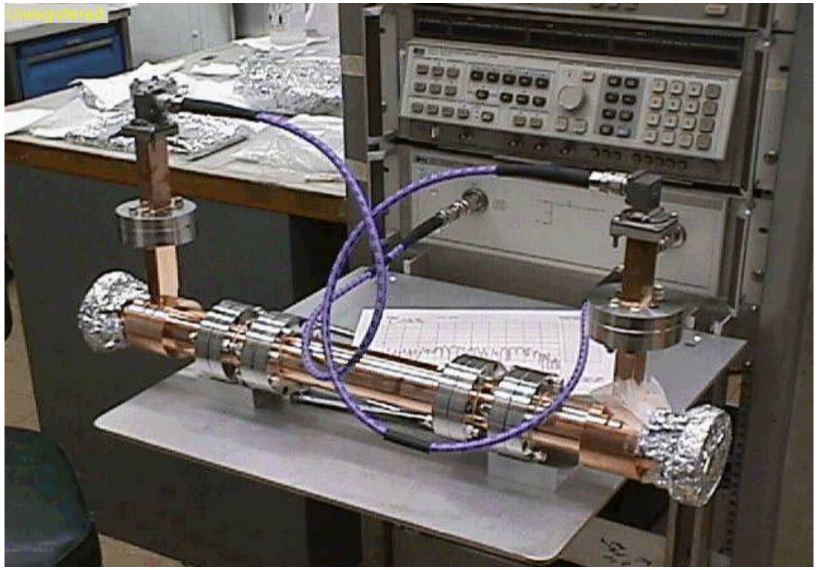
With a carefully designed coupler and taper, almost all of the microwave energy goes through the dielectric loaded traveling wave accelerating structure.

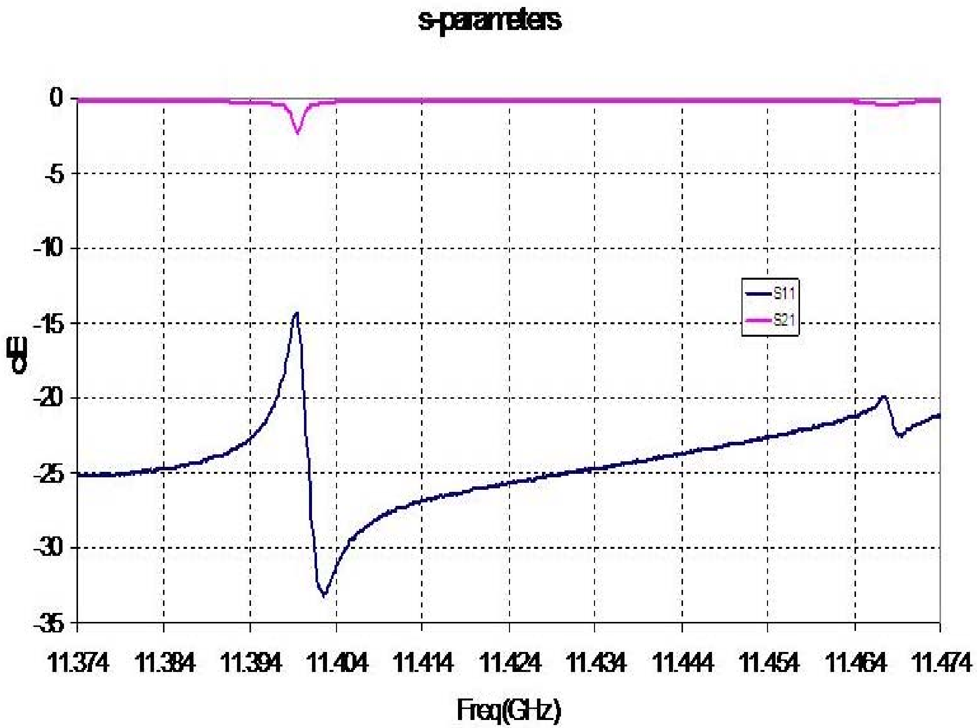




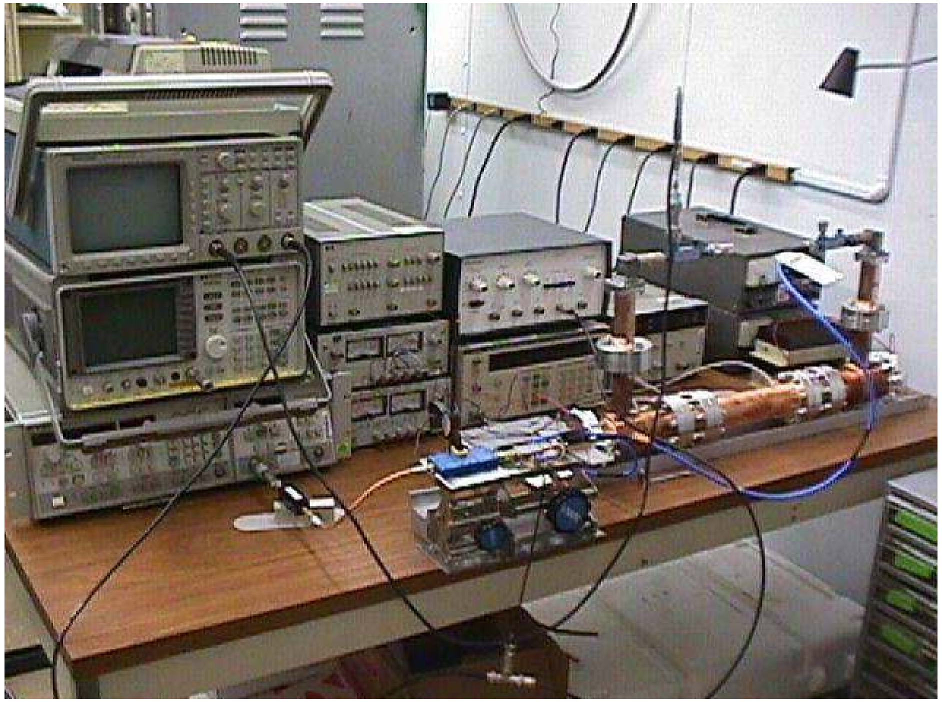
With properly selected dielectric constant and loading geometry, the wave in the dielectric loaded accelerating structure will travel at the speed of light and its pattern is good for accelerating the particles at the given frequency, here, 11.424GHz

Bench Test: S-parameter measurement.

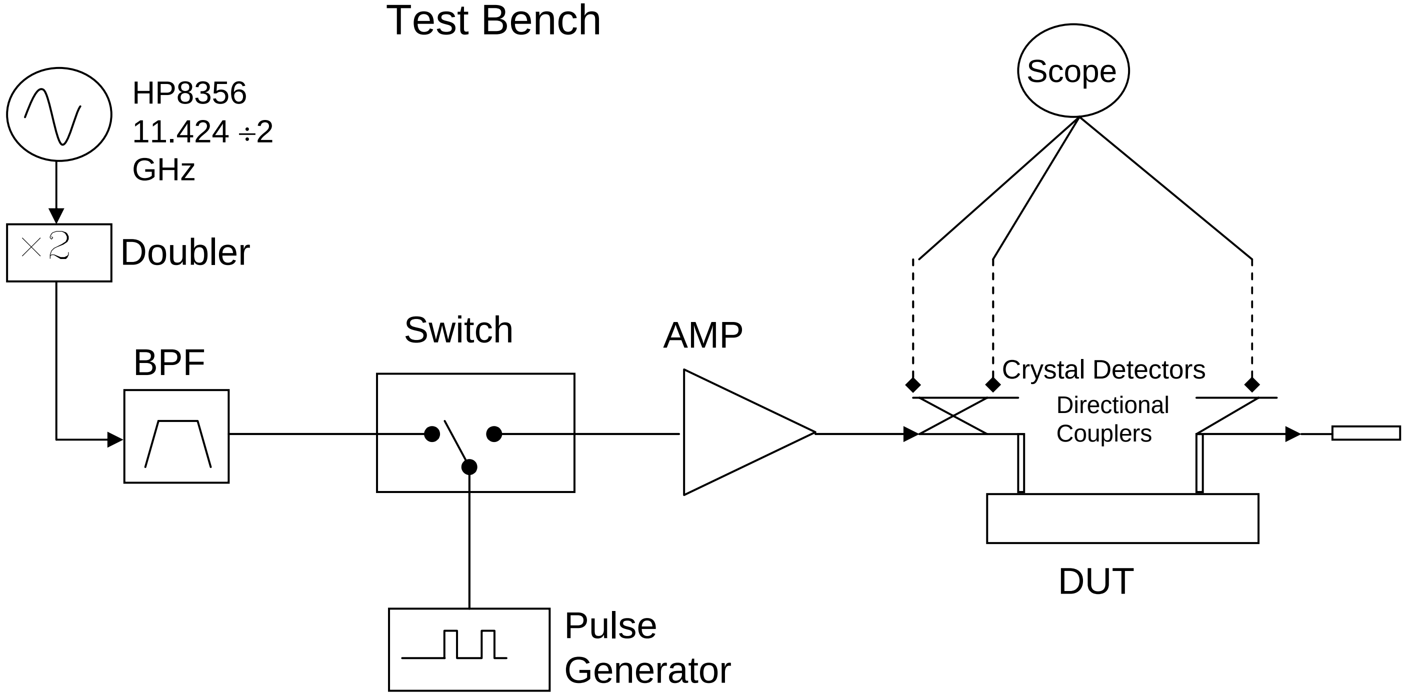




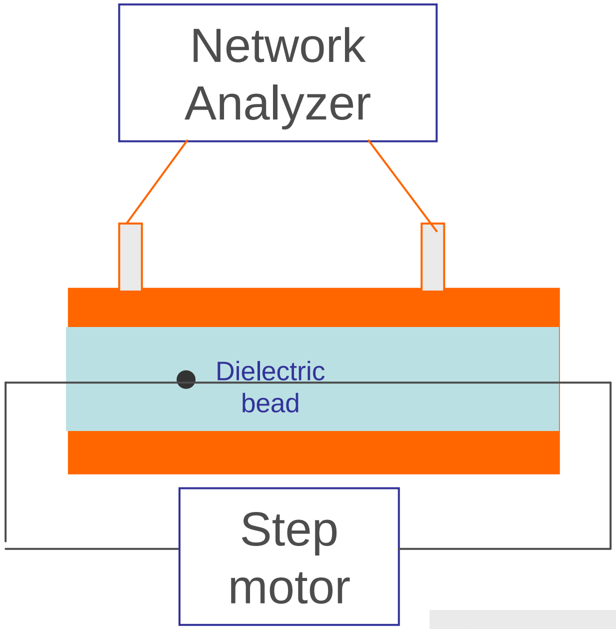
Bench Test: Low power pulsed rf bench test on X-band DLA structure

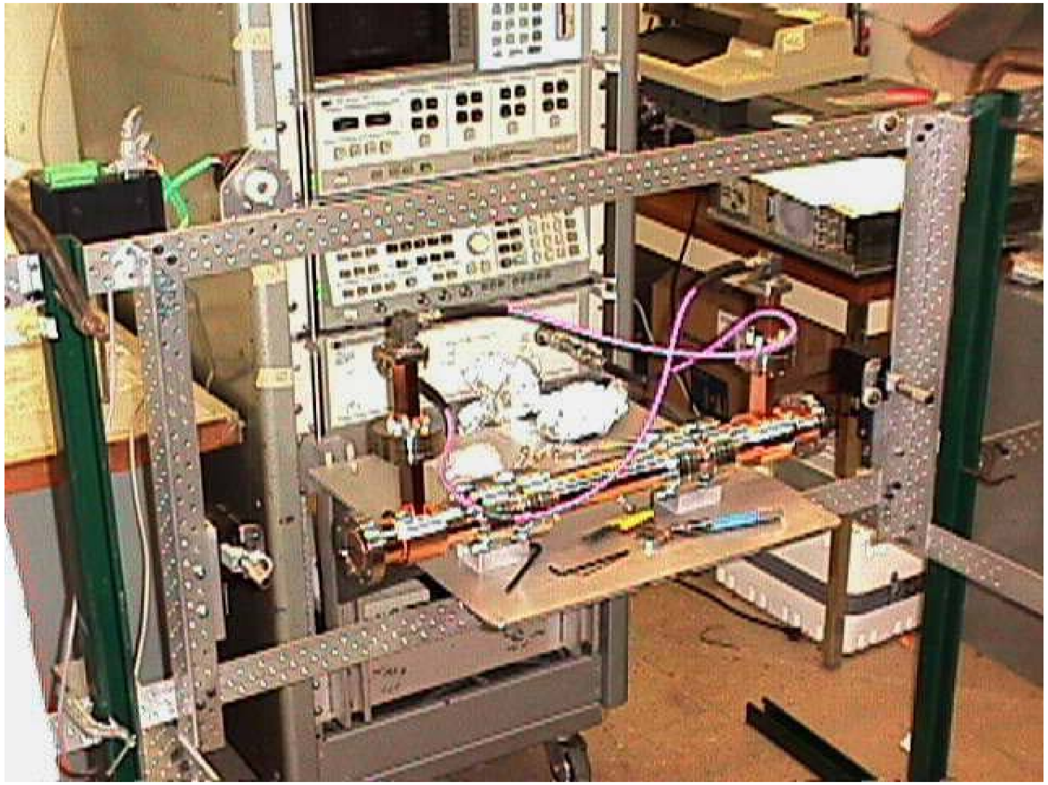


11.424GHz Time Response Test Bench



Bench Test: Beadpull experiment to obtain the profile of accelerating field.





Standing Wave Case

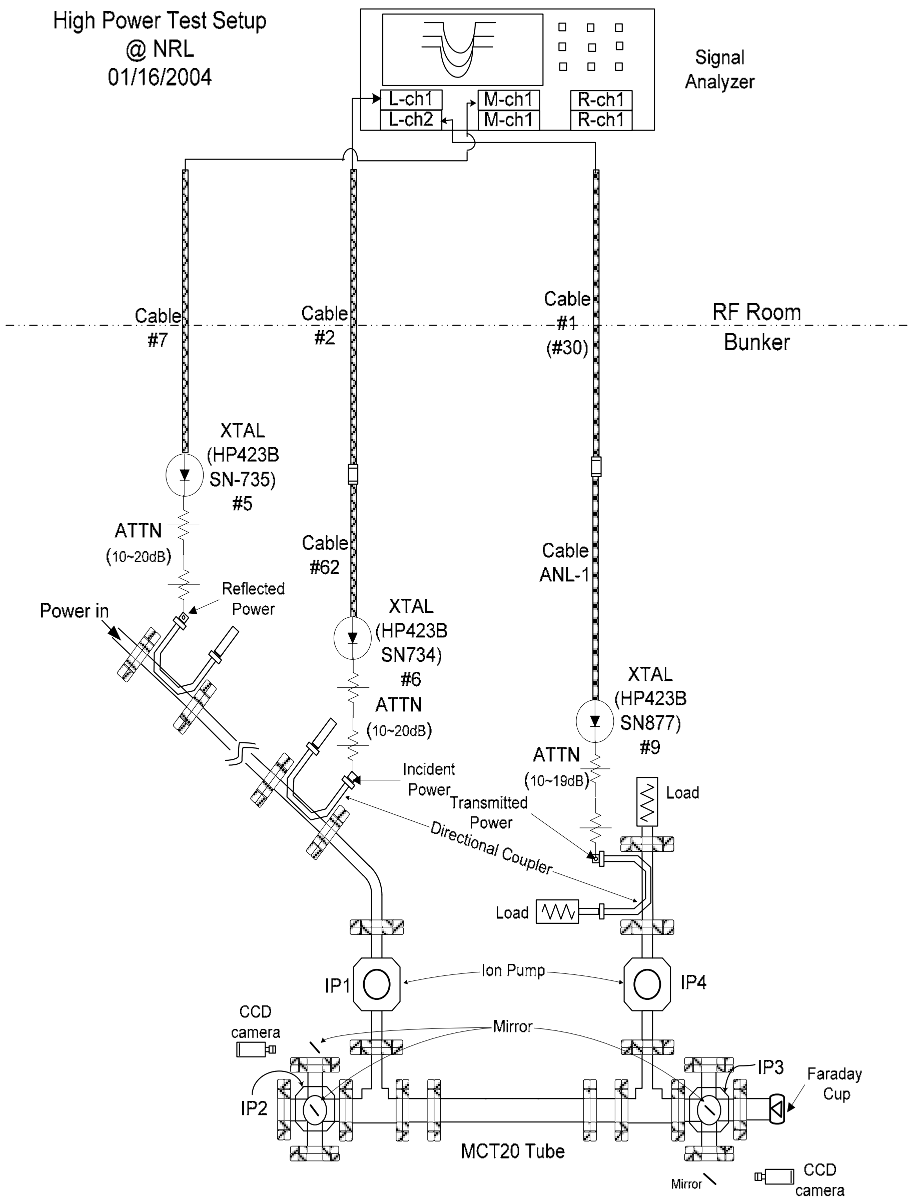
$$\frac{\Delta\omega}{\omega} = -\frac{\varepsilon\alpha_e}{4U}|E|^2$$

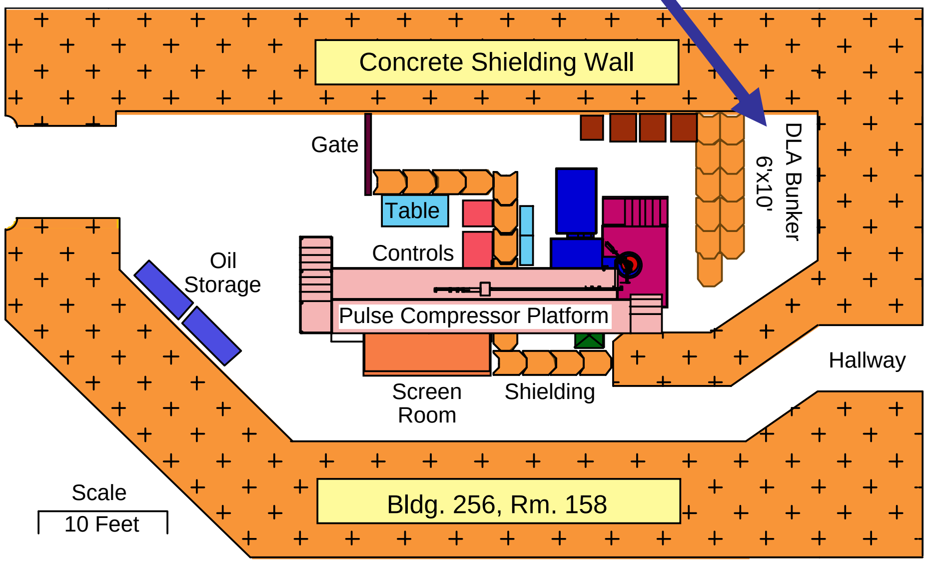
Traveling Wave Case

$$\Delta S_{11} = -\frac{j\omega}{2P_i}(\varepsilon\alpha_e|E|^2 - \mu\alpha_m|H|^2)e^{j2\varphi}$$

For dielectric bead $\alpha_e = 4\pi r^3$, $\alpha_m = 0$

High Power rf Test



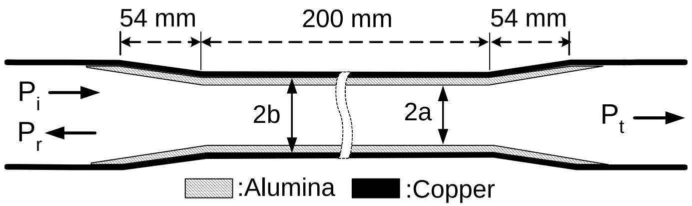


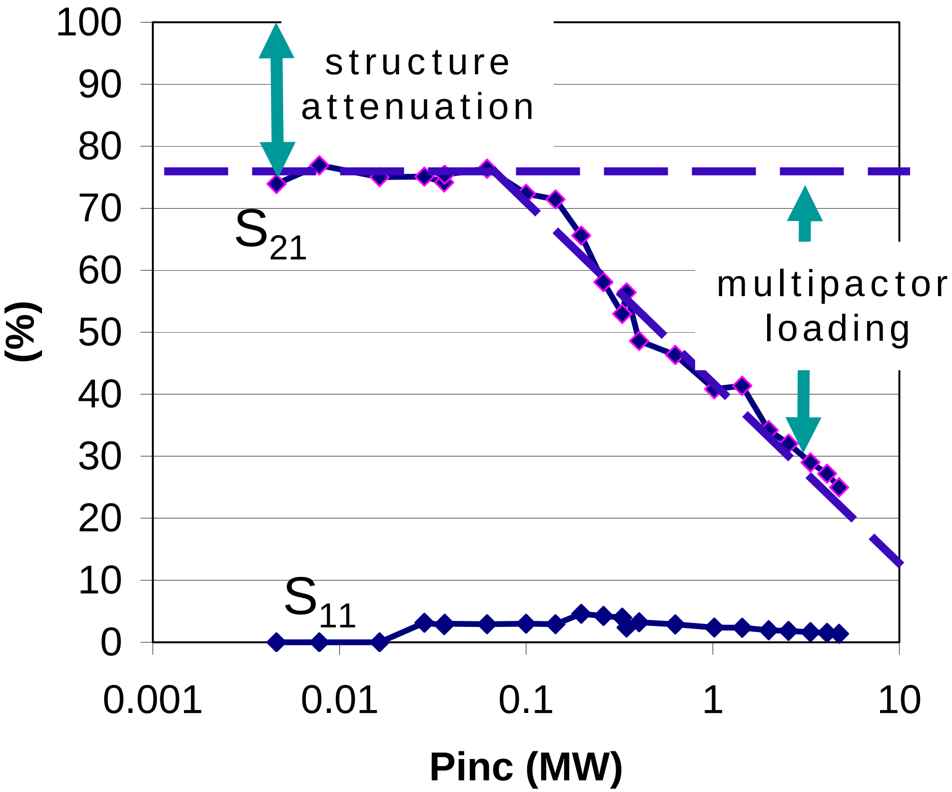
Part III: Does It Work Well?

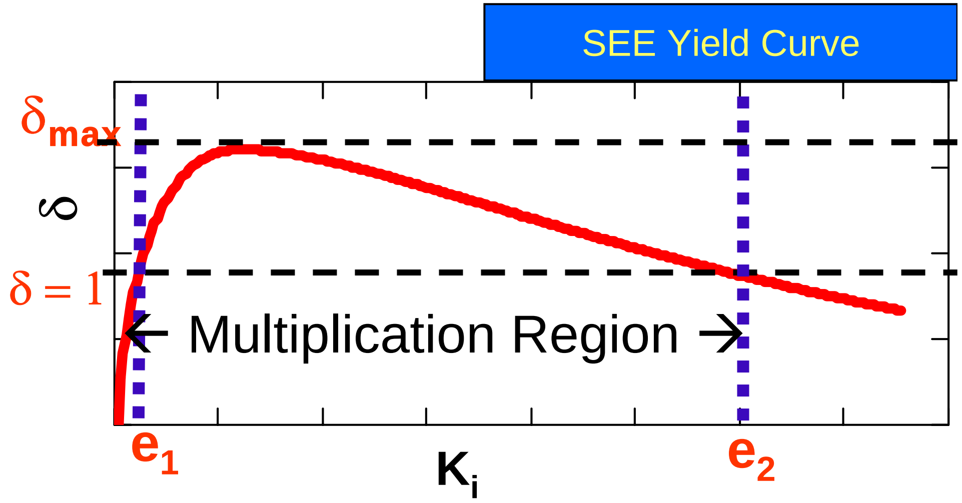
____ challenges found out of the experiments

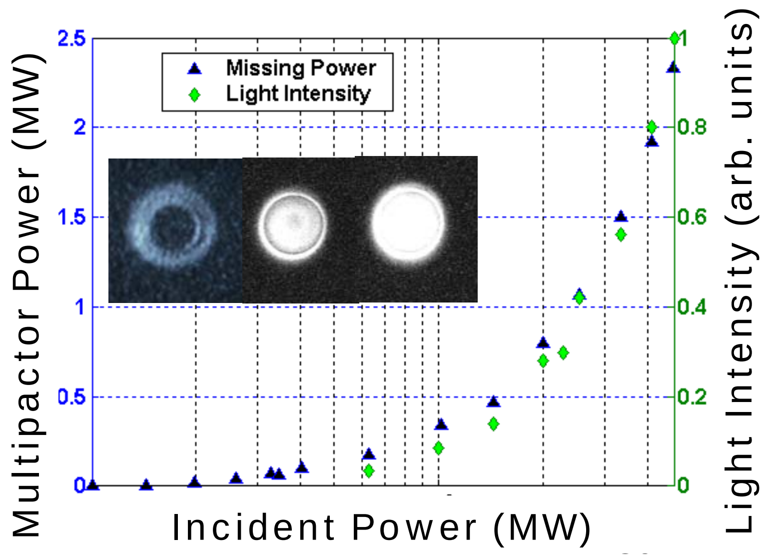
Multipactor

[ref5]. J.G. Power, et al. Phy. Rev. Lett. 92, 16, 2004, pp. 164801 (2004).



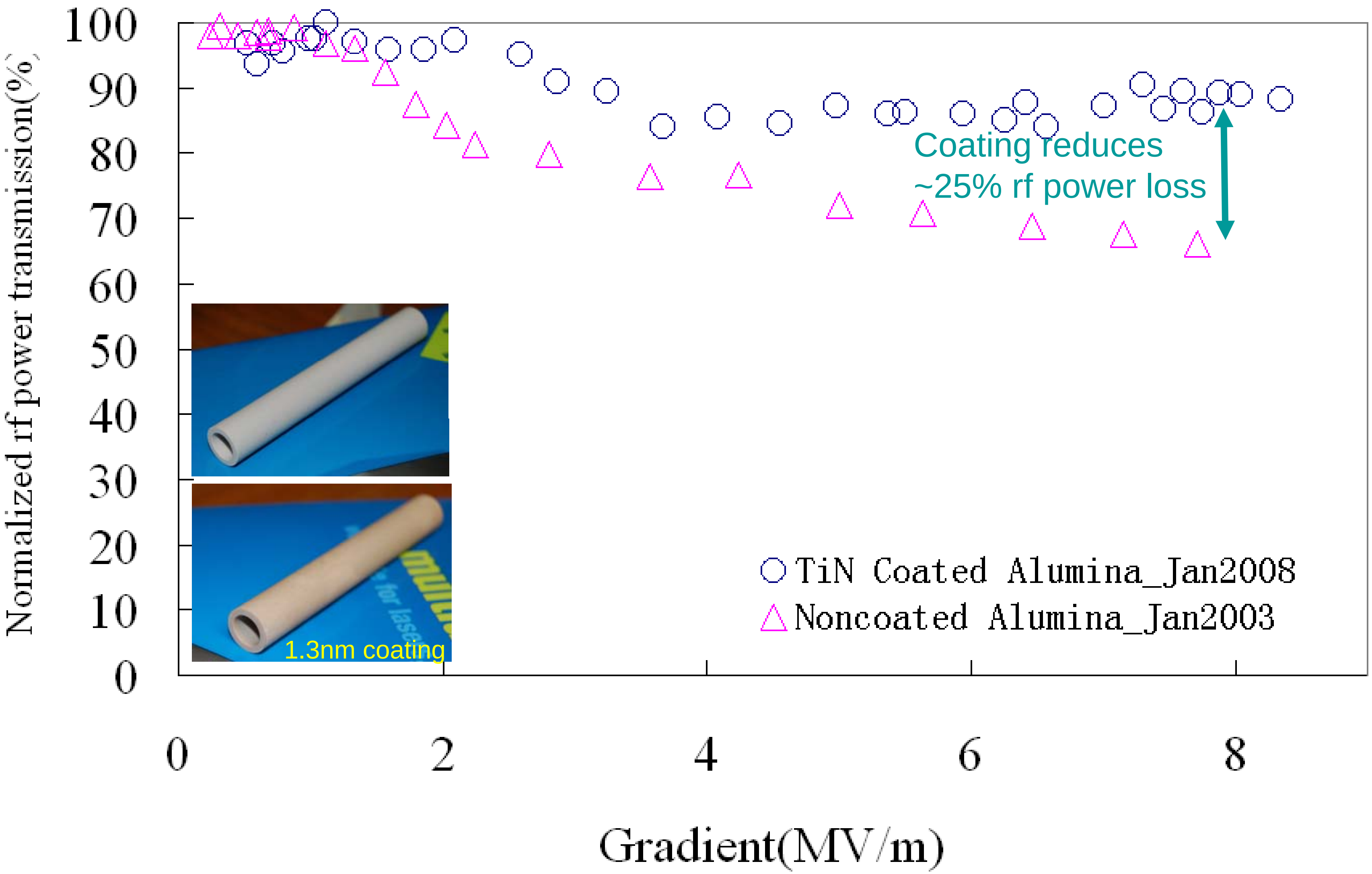






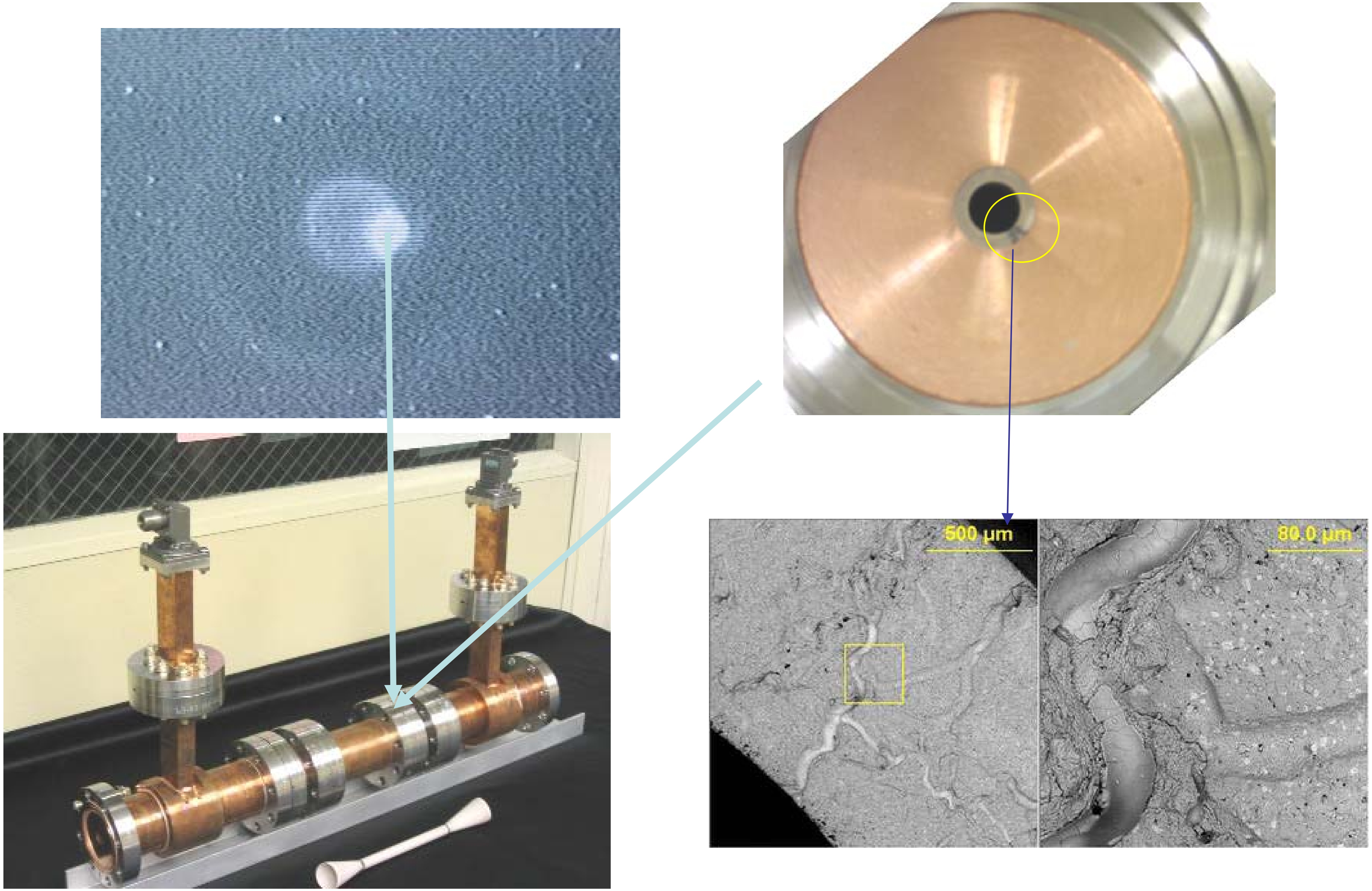
Multipactor suppression

Coating/ better material/ geometrical factor, like grooves

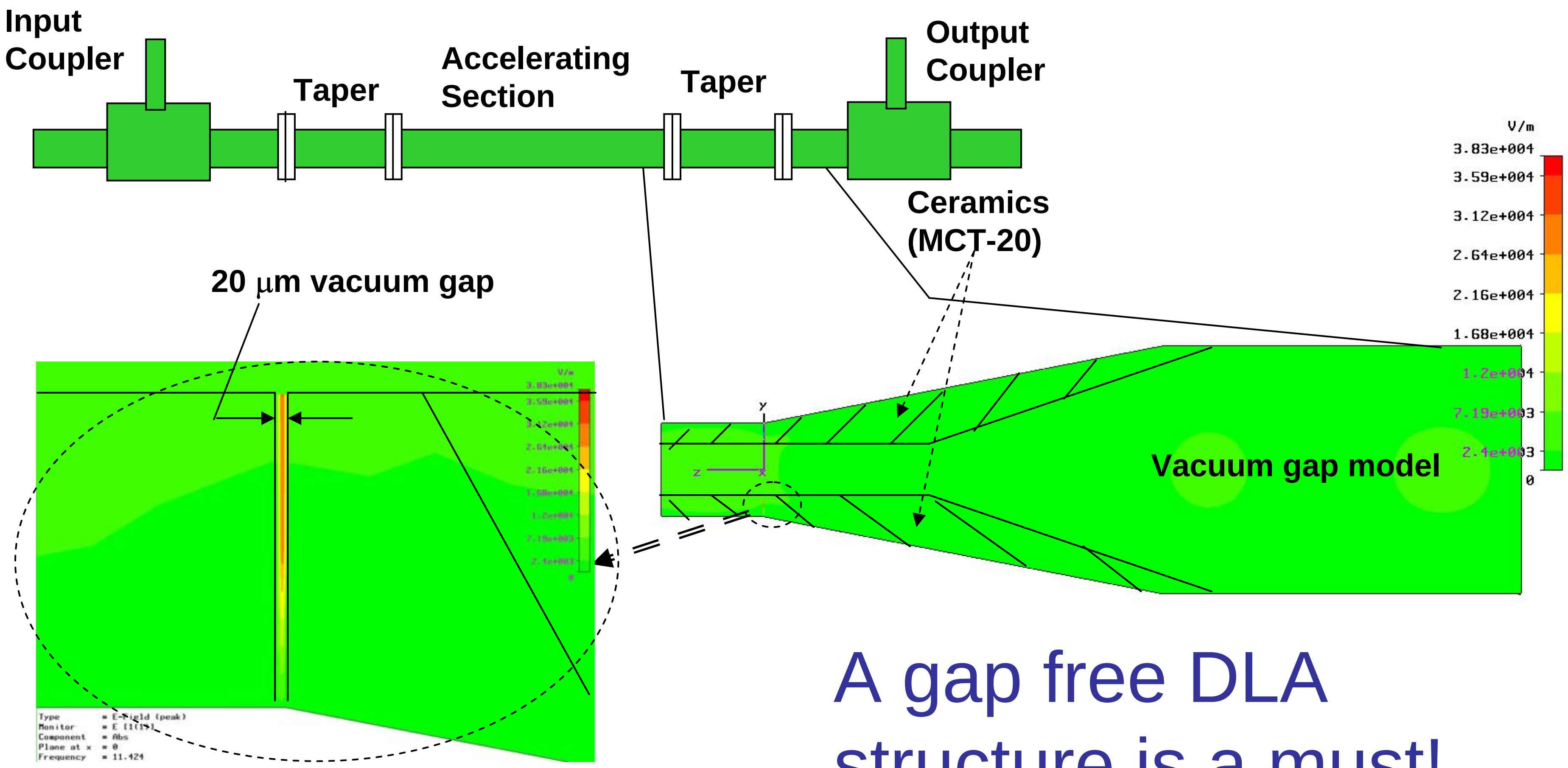


Dielectric BD @ the joint

[ref6]. C. Jing, et al.   IEEE, Trans. PS, vol.33 No.4, Aug. 2005, pp.1155-1160.



Simulation on E-field enhancement from introduced air gap by Microwave Studio®

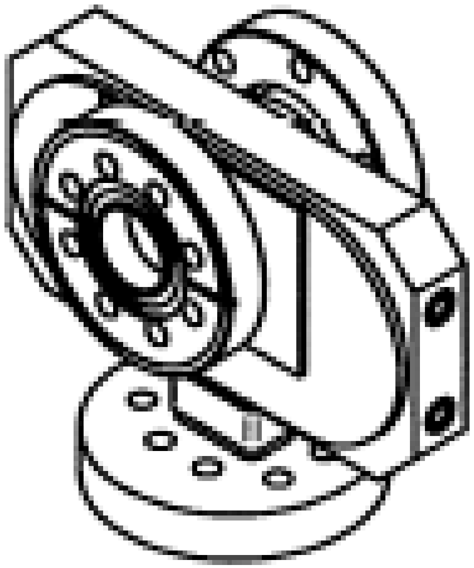


A gap free DLA structure is a must!

Compared to normal case (no air gap), at that position, the electrical field at the edge of the gap increased >20 times.

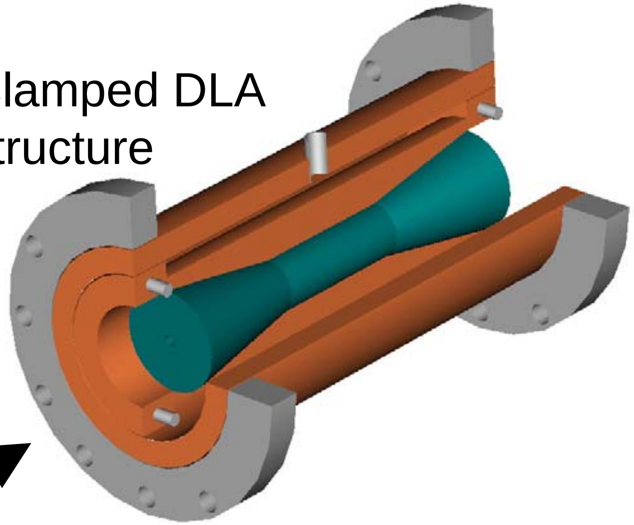
Gap Free DLA structures

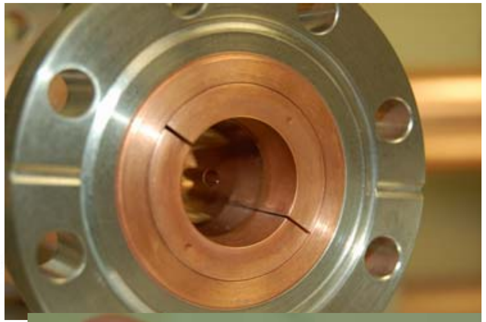
Well tested mode launcher

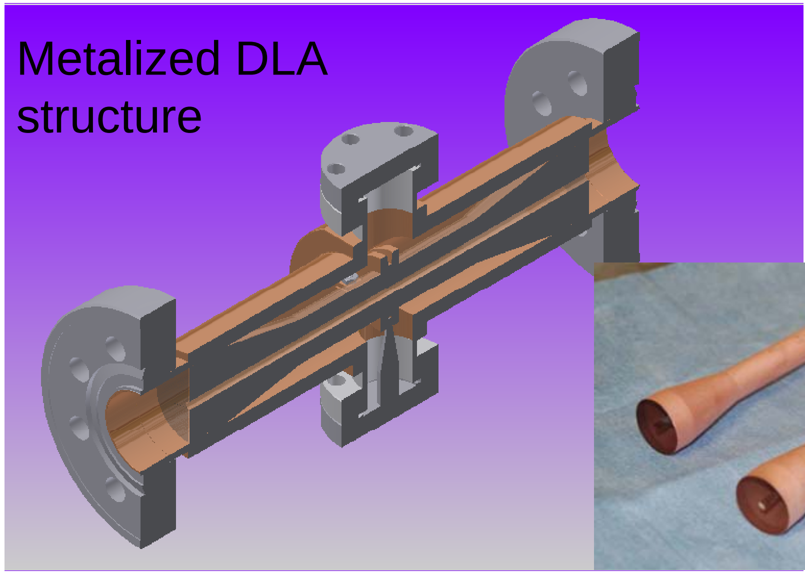


+

Clamped DLA structure







Part IV: More advanced topics

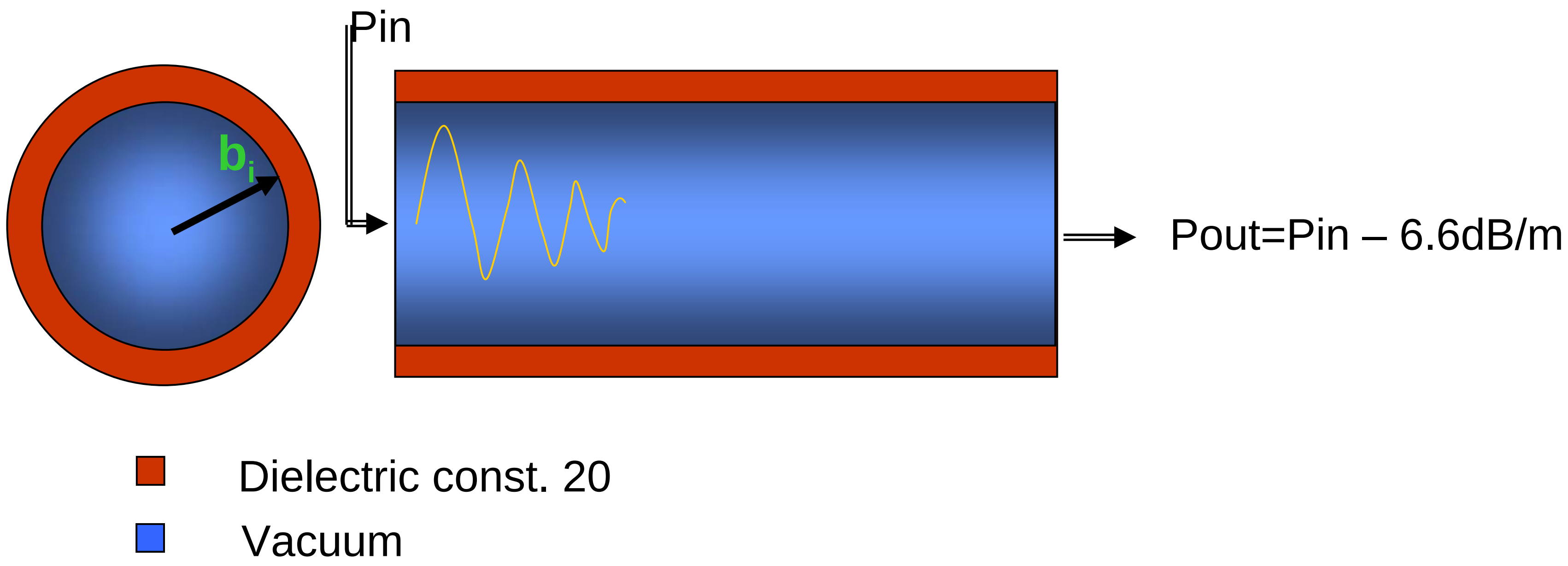
____multilayered DLA, transverse mode damping, frequency tuning, hybrid DLA, etc.

1. Multilayer Dielectric-Loaded Accelerating Structure

[ref7]. C. Jing, et al. Nuclear Instr. Metho. in Phy. Research A,Vol.539, Mar. 2005, pp.445-454.

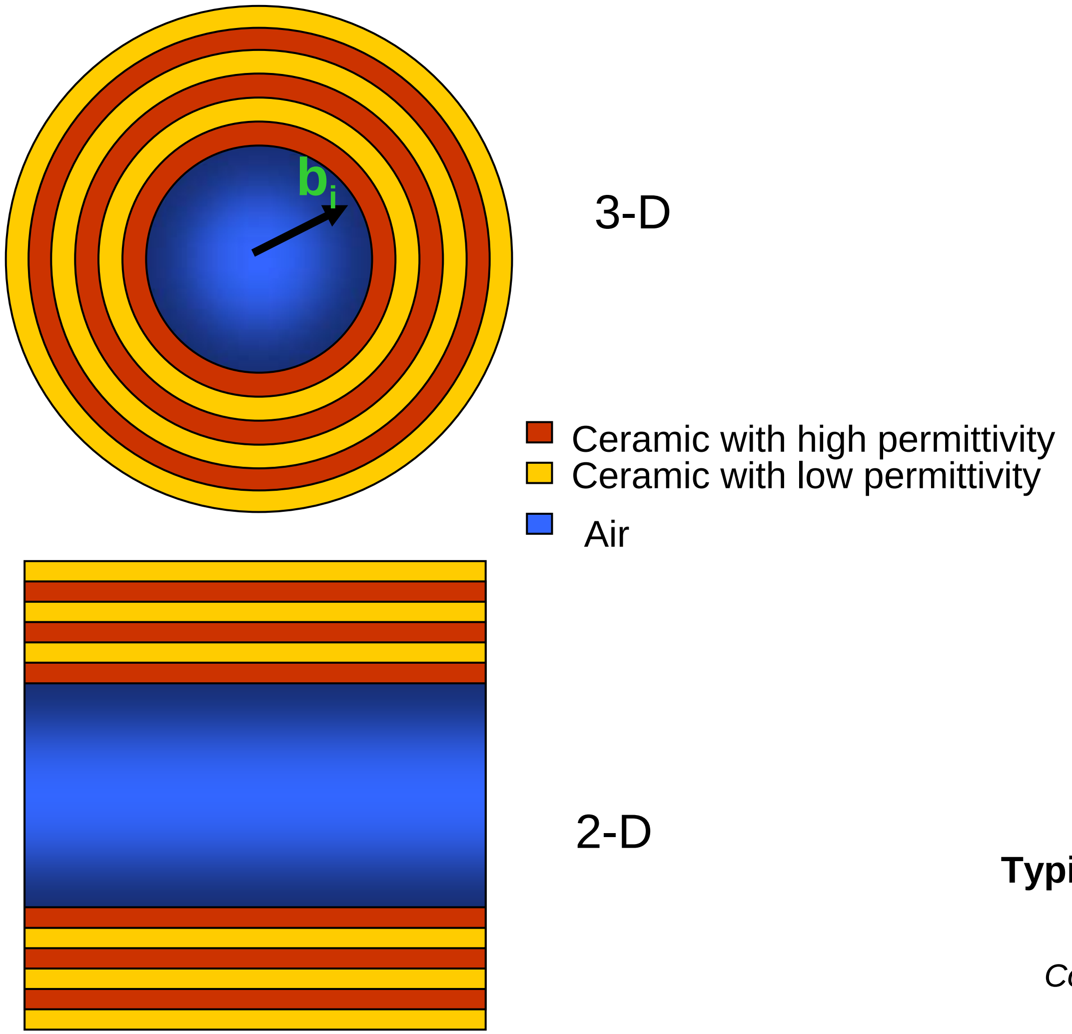
Motivation

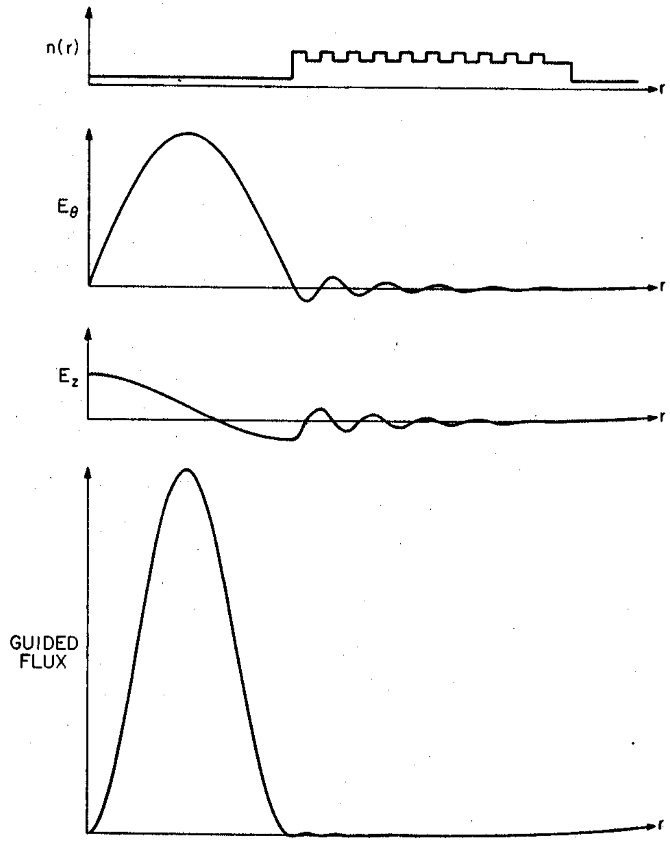
- Well-developed single layer dielectric-loaded accelerating (DLA) structure has trouble in large RF power attenuation along the structure.



Benefit from theory of Bragg fiber

Field is confined by radial periodical ceramic layers



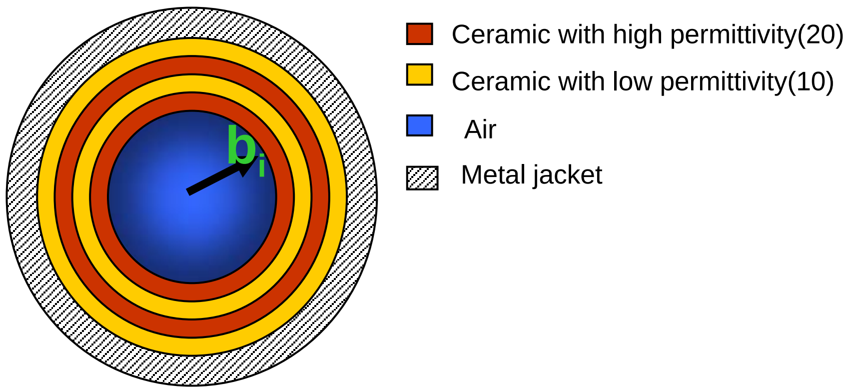


Typical Field distribution and guided flux in a bragg fiber

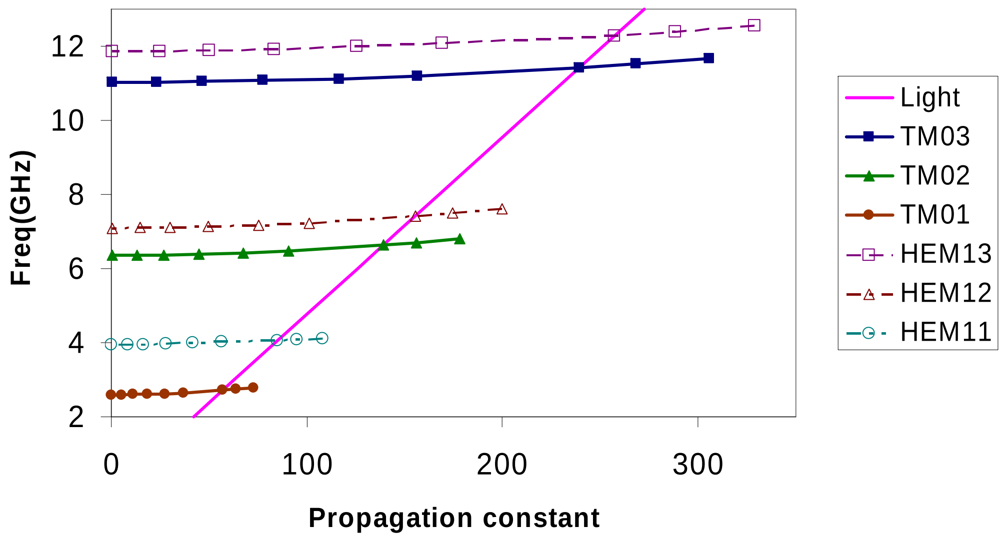
Courtesy of P.Yeh J. Opt. Soc. Am Vol.68 1978

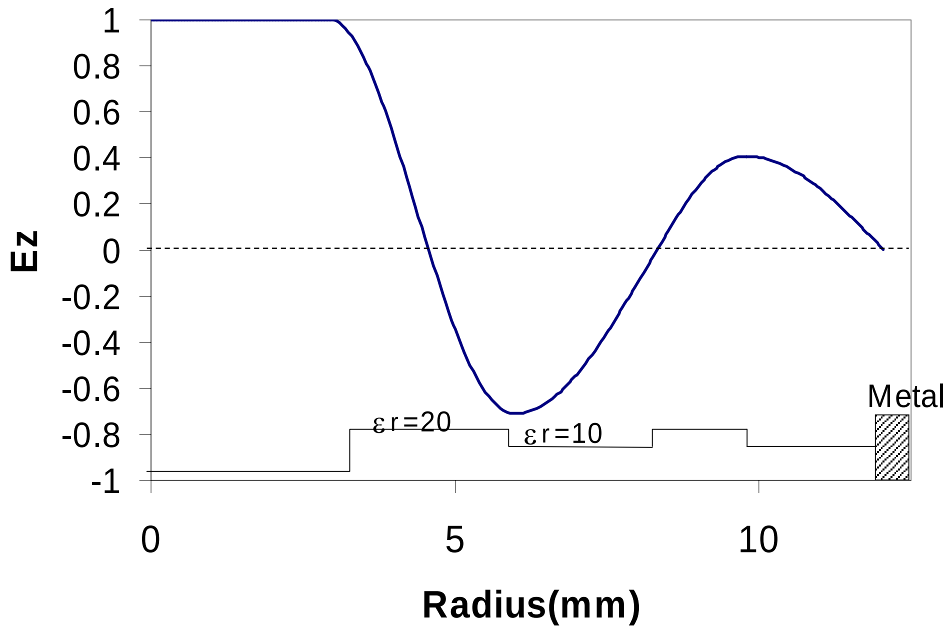
Mode Analysis

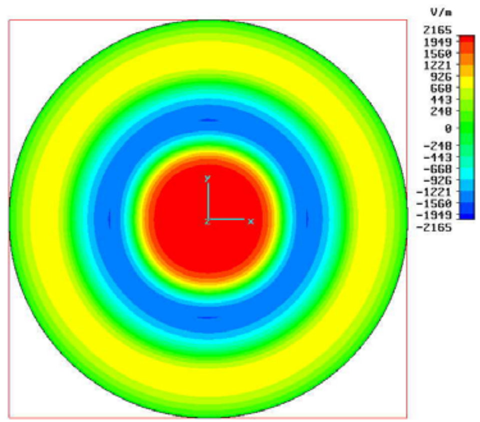
---example: 4-layer structure



Dispersion characteristics



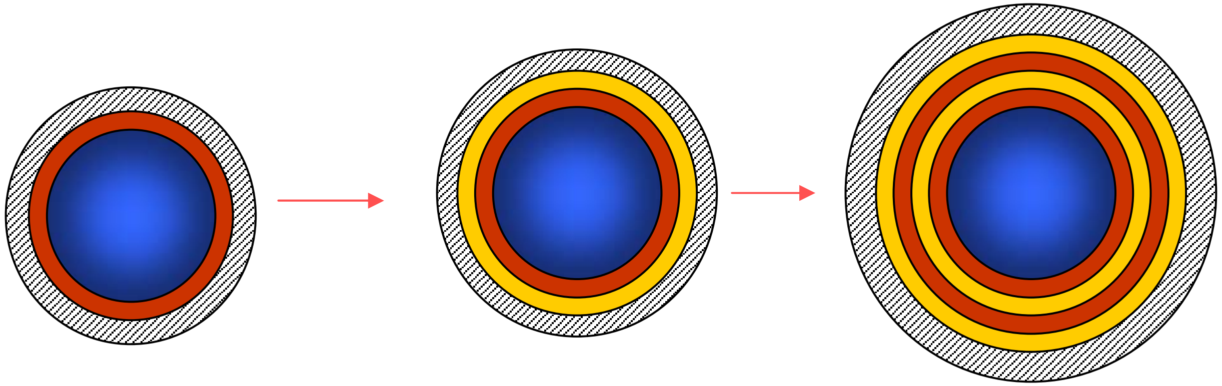




Accelerating properties

---different cases comparison

Ceramic with high permittivity(20)
Ceramic with low permittivity(10)
Air
Metal jacket

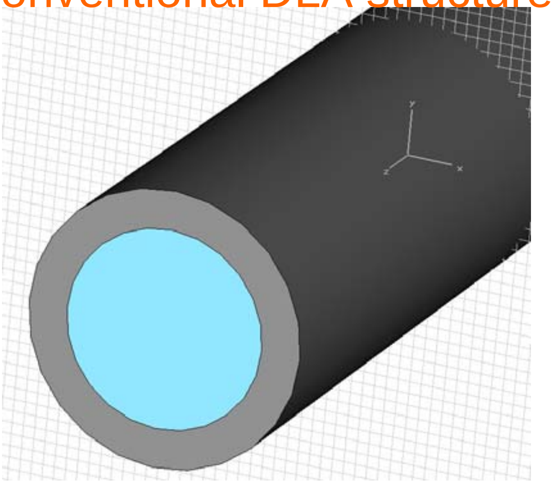


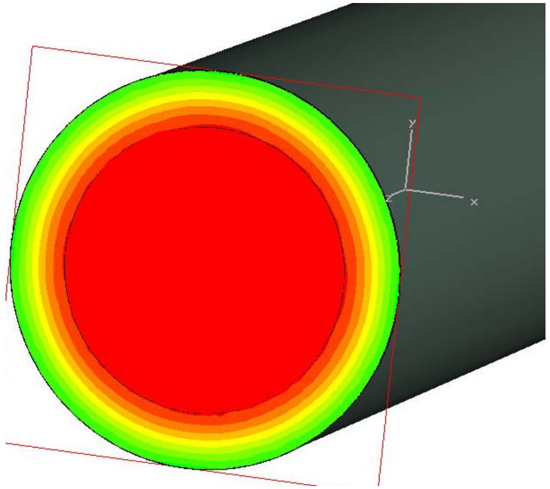
Accel. mode	radius	Cut-off freq.	Group velocity	Qw	R(MΩ/m)	R/Q (Ω/m)	Power Attn (dB/m).
One layer	b0=3mm b1=4.56mm	11.1GHz	5.5%c	2865	25.1	8756	-6.6
Two layers	b0=3mm b1=5.99mm b2=8.3mm	11.04GHz	6.7%c	13454	47	3504	-1.16
Four layers	b0=3mm b1=5.99mm b2=8.3mm b3=9.8mm b4=12.1mm	11.03GHz	6.8%c	33451	89	2658	-0.45
NLC			5.1%c~1.1%c	9055~8093	81.2	9000~10000	-2~-5dB

2. Transverse mode damping

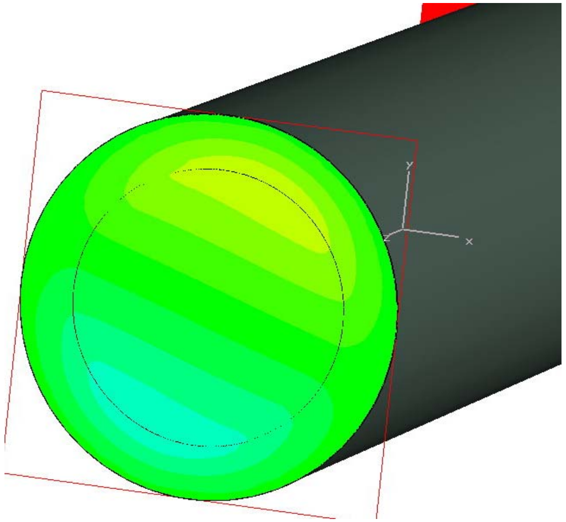
[ref8]. W.Gai and C. Ho. J. Appl. Phys. 70(7). 1991, pp.3955-3957.

Conventional DLA structure

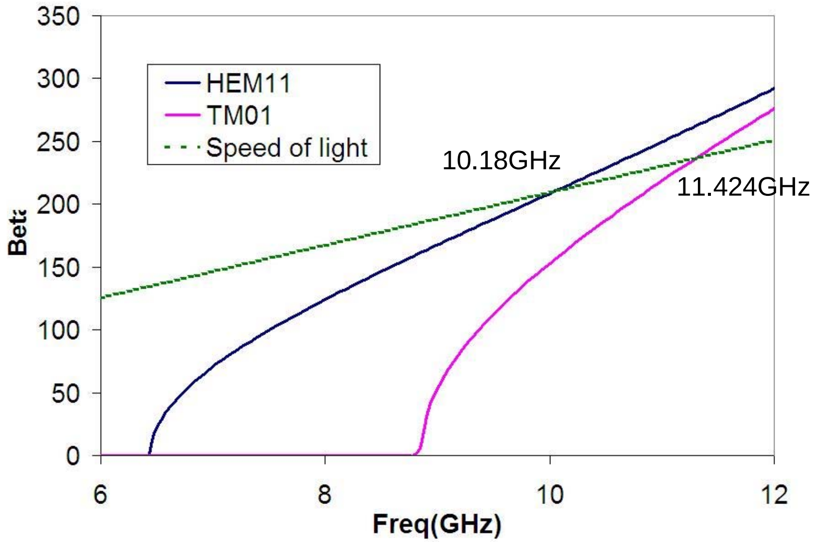




TM01 mode Ez

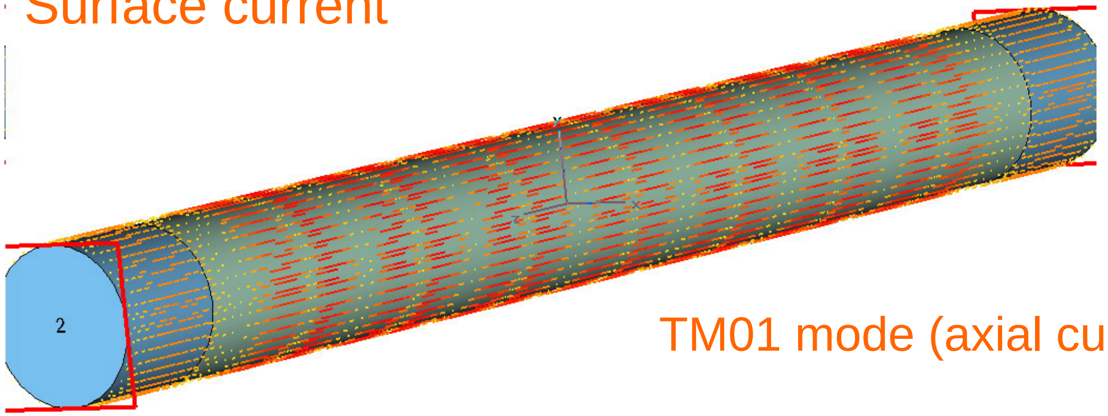


HEM11 mode Ez

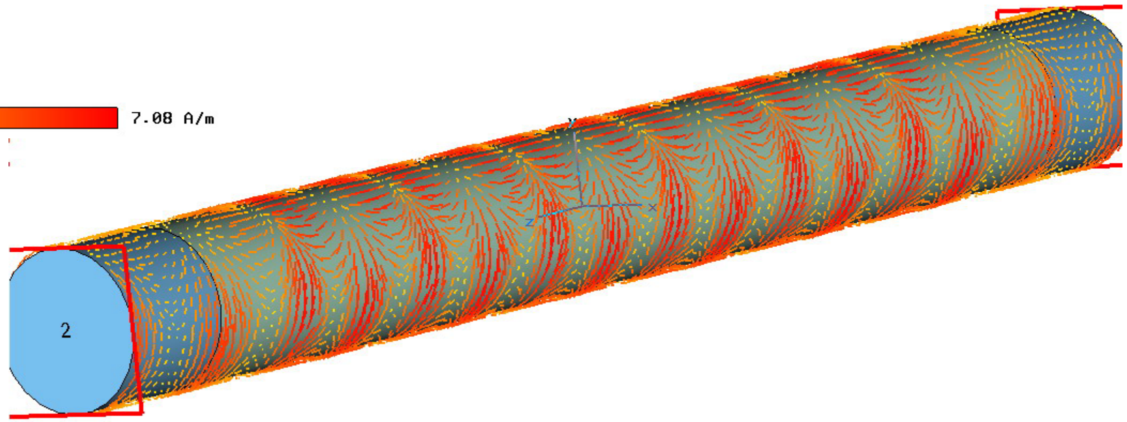


Surface current distributions for different modes

Surface current



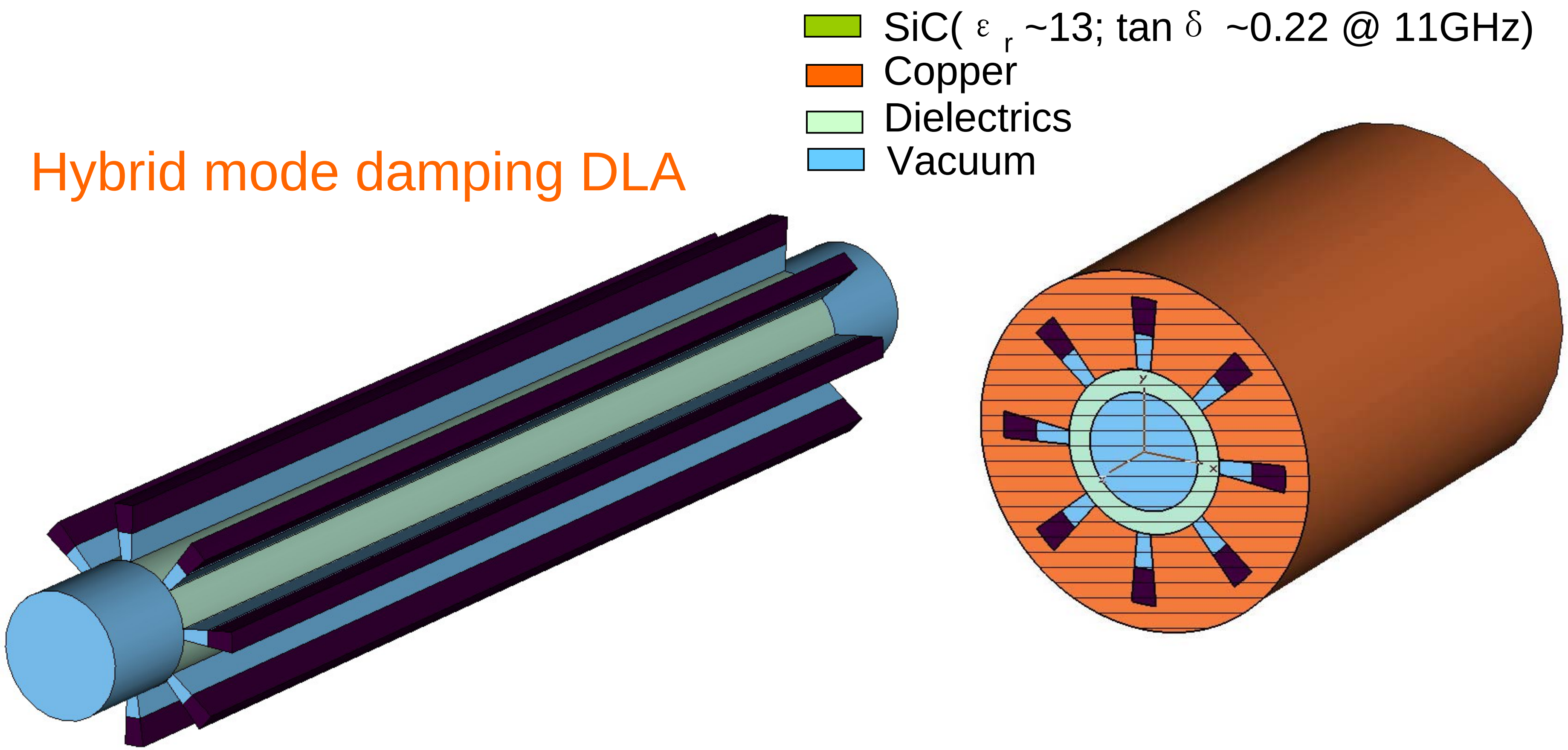
TM01 mode (axial current only)



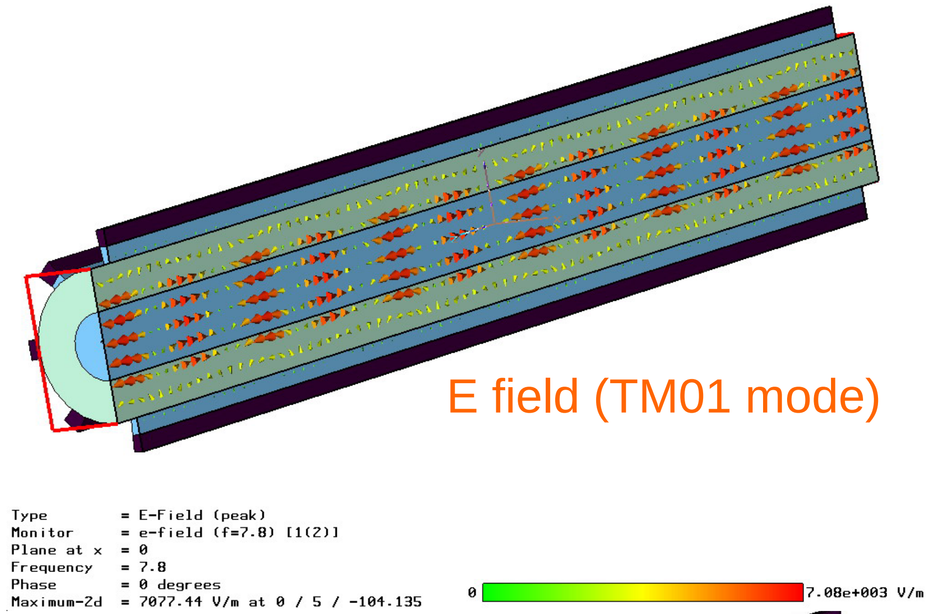
HEM11 mode (azimuthal current included)

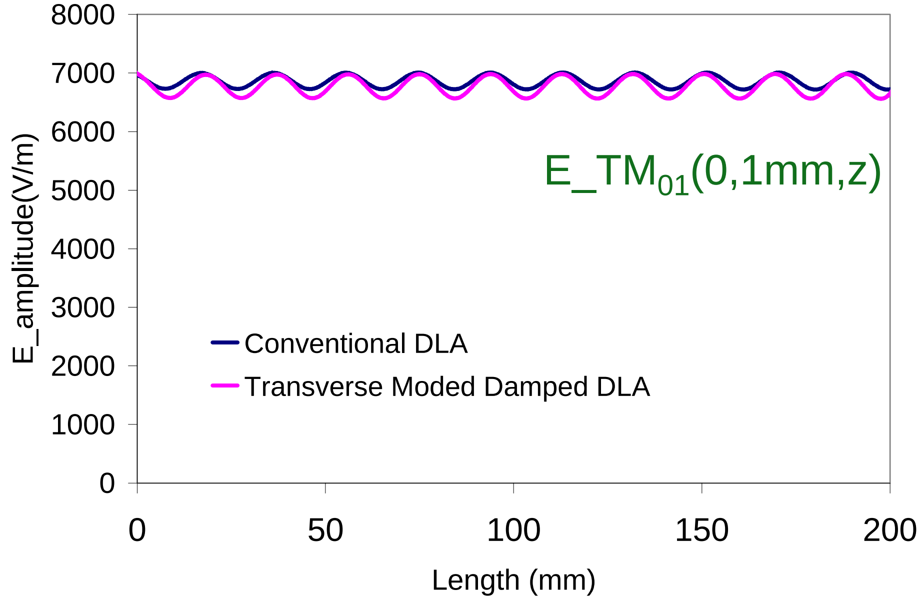
Design of transverse mode damping structure

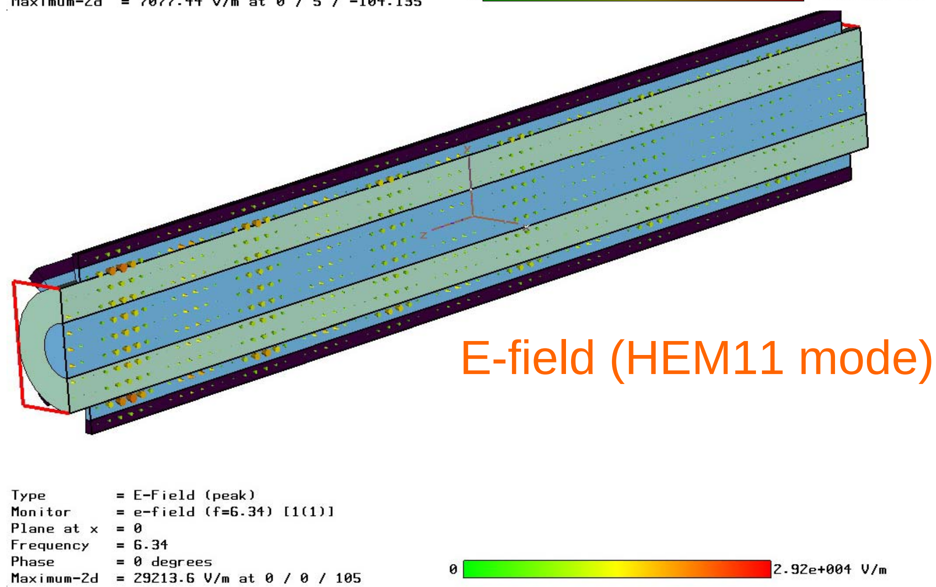
Hybrid mode damping DLA

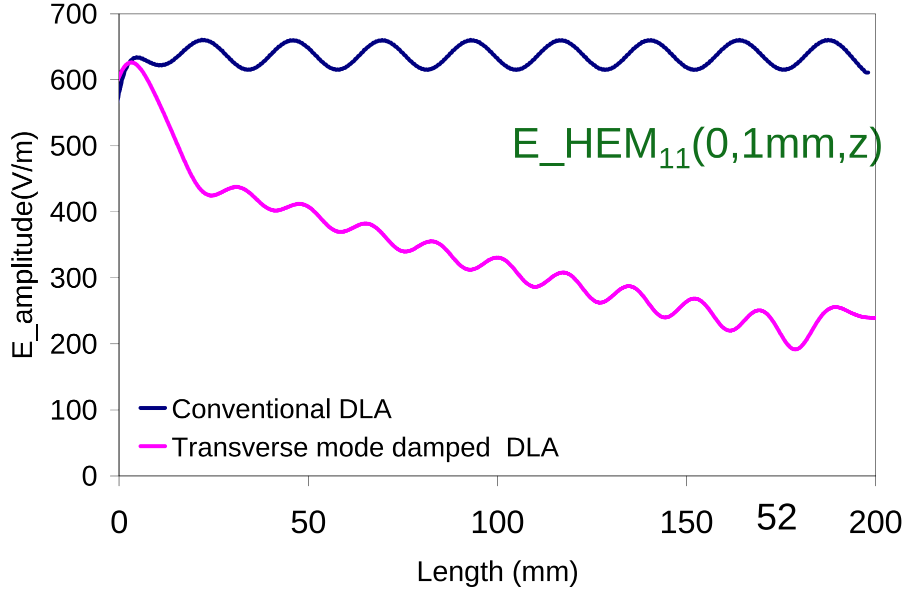


Simulations







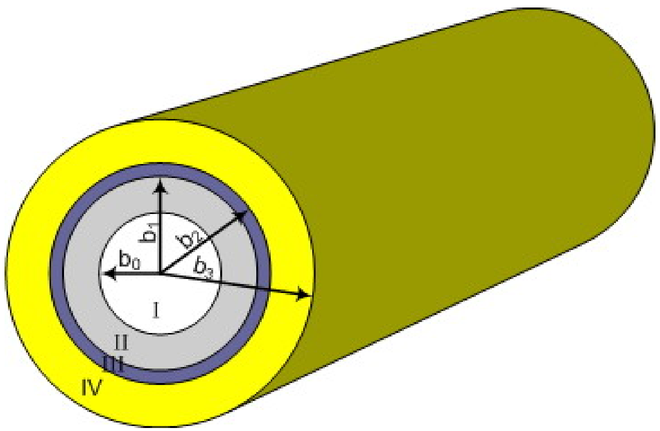


Simulated parameters

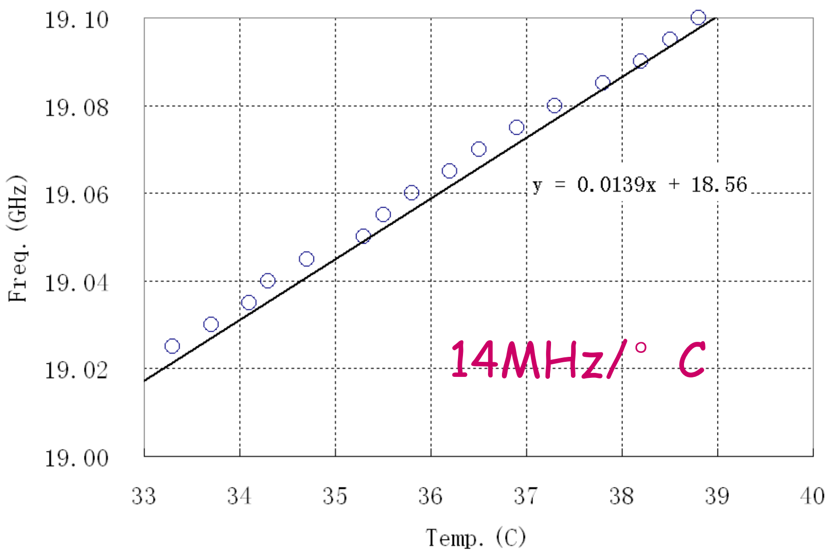
Comparison of the 7.8GHz Conventional and the Transverse mode Damped DLA structure.			
	Freq.	**Q in conventional DLA structure**	**Q in transverse modes damped DLA structure**
Accelerating mode (TM_{01})	7.8GHz	6964*	6738*
Transverse modes (HEM_{11})	6.34GHz	6866*	23*

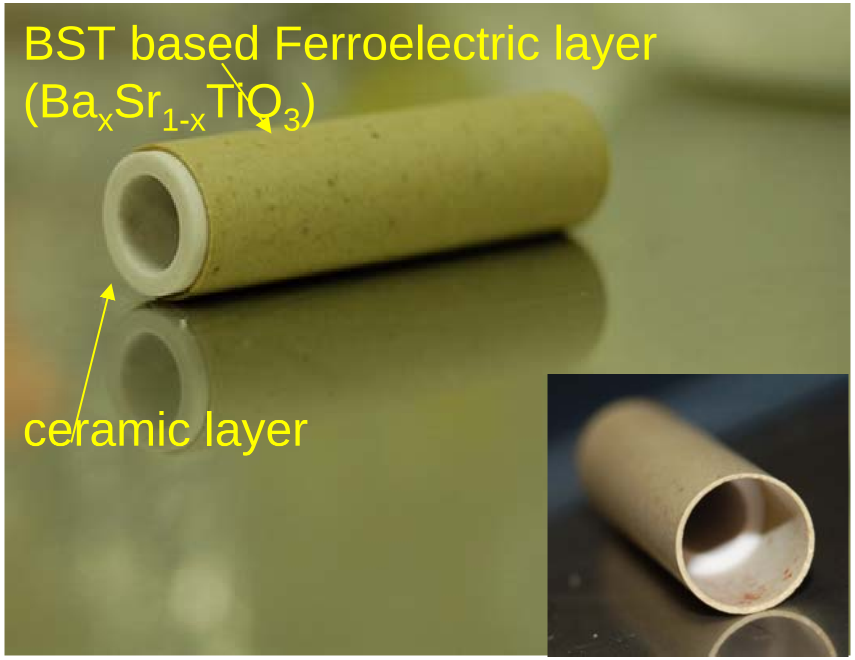
*In the desired frequency band, SiC (ε r = 13; tan δ = 0.22) and quartz (ε r =3.78; tan δ = 0.5×104) are used in the calculations. ; Slots / circumference = 22%.

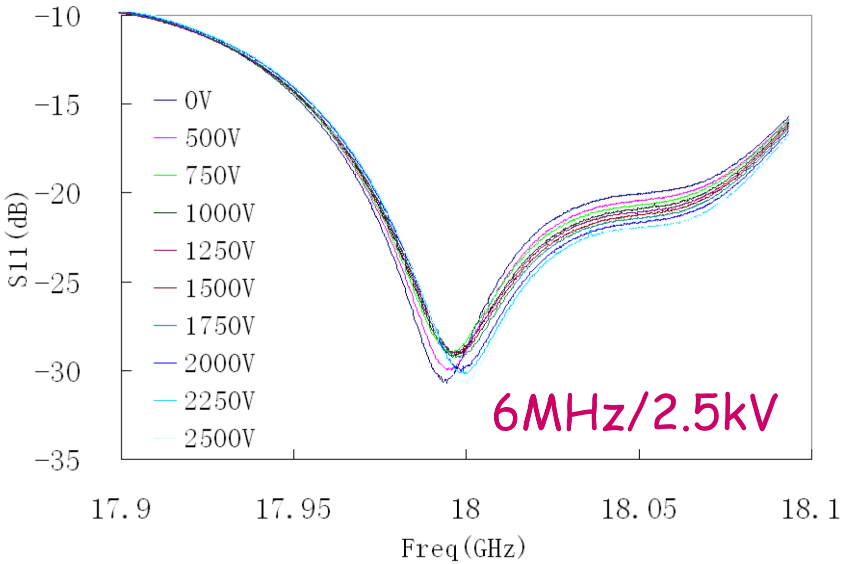
3. Frequency tuning



Configuration of the tunable DLA structure: Region I---vacuum; Region II---dielectric tube; Region III---ferroelectric tube; Region IV---copper.







4. Hybrid Dielectric-Iris-Loaded Accelerating Structure

[ref9]. P. Zou, et al. J. Appl. Phys., 2001,. 90(4): 2017—2023.

Purpose: To reduce the high ratio of the peak surface electric field to the accelerating gradient for the conventional disk-loaded metal structure, meanwhile increase the shunt impedance and Q for the single layer pure dielectric-loaded accelerating structure.