Study of drift tube linac stabilization with post couplers.

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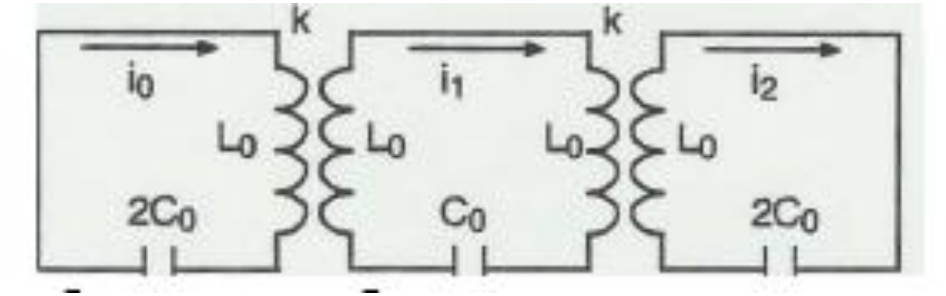
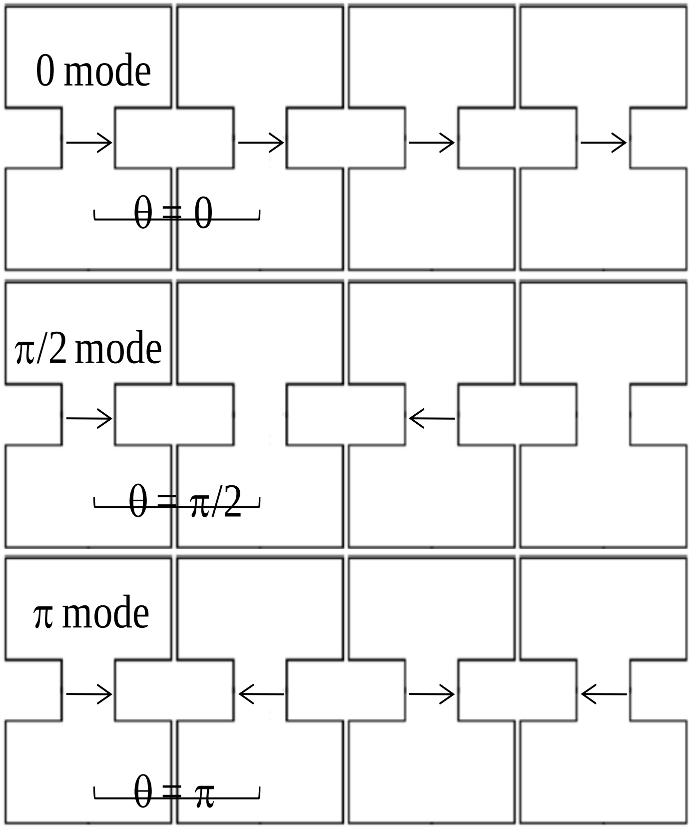
The resonant coupling



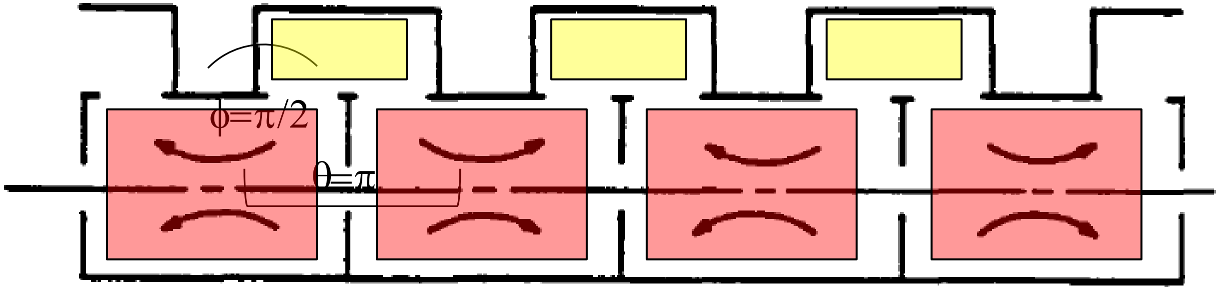
Perturbations (**δC0, δL0, δk**,…) → δω0

π/2 mode **more solid** with respect to perturbations (central oscillator unexcited and the frequency located in the middle of the dispersion curve)



The resonant coupling

Accelerating mode ↔ π/2 mode less sensitive to perturbations

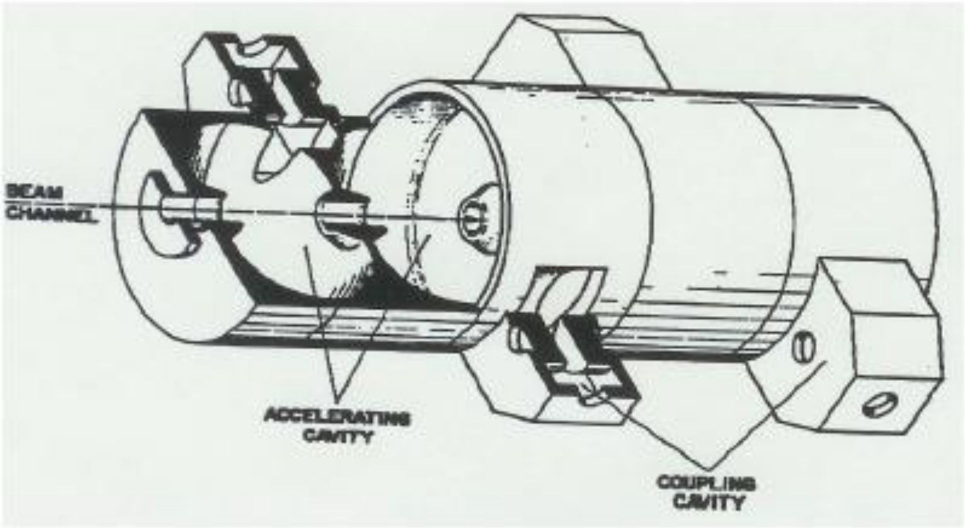


Coupling cells

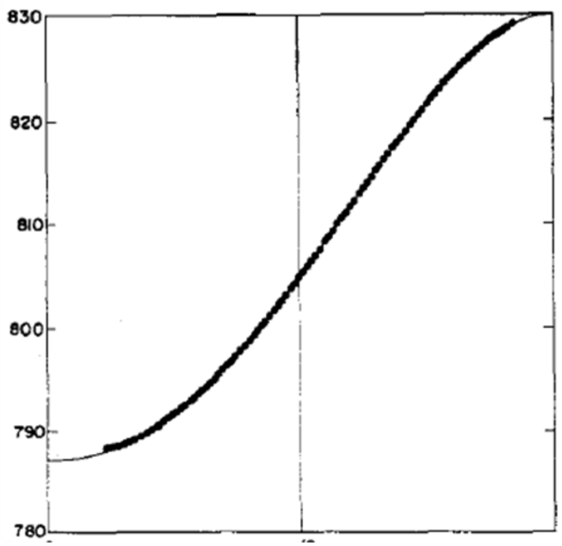
- out beam axis
- unexcited

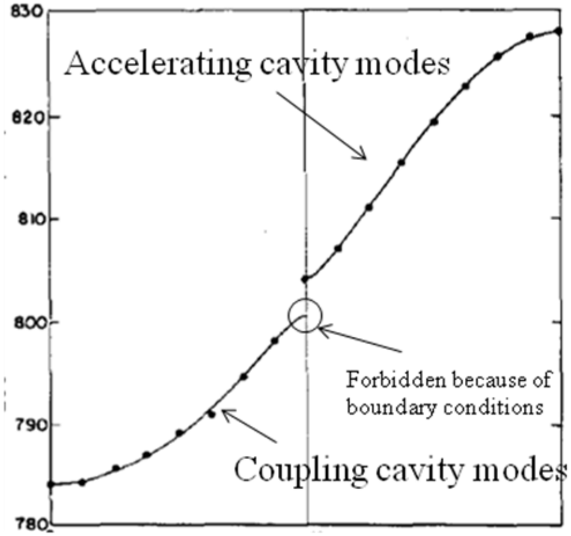
Accelerating cells

- on beam axis
- excited



The resonant coupling

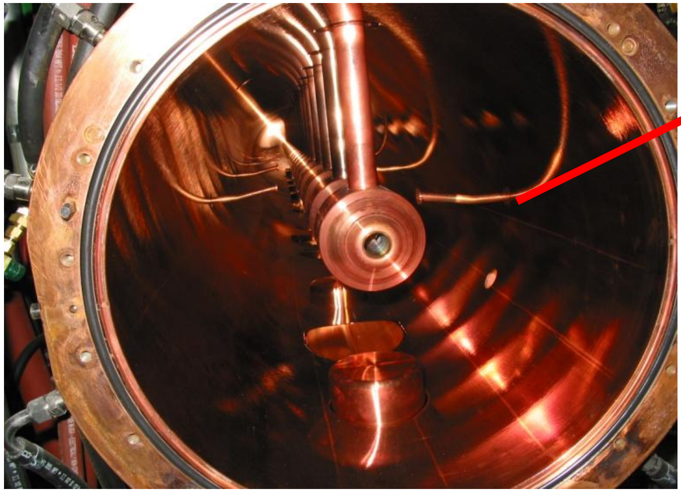




- dispersion curve has now 2 passbands, separated by a stopband
- cavities are tuned in order to remove the stopband: confluence point.
- only the accelerating cavity mode can be excited at the confluence point, the coupling cavity mode being forbidden because of boundary conditions

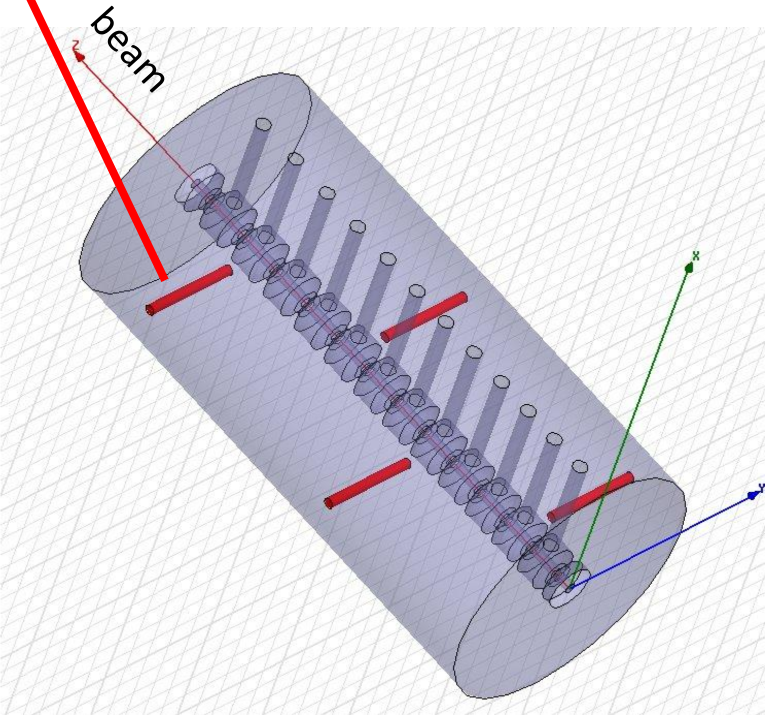
Structure	Coupling element	Mode at confluence
Side Coupled Linac	Side cavity	π
Multistem DTL	Stems	0
Post Coupled DTL	Post couplers	0
Segmented RFQ	Coupling cell	0

Resonant coupling for a DTL: post couplers



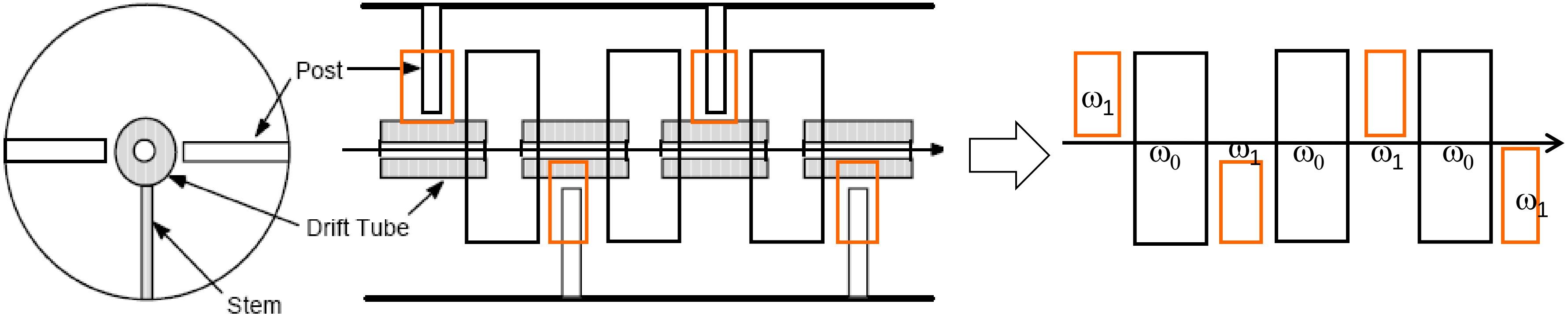
Post Coupler

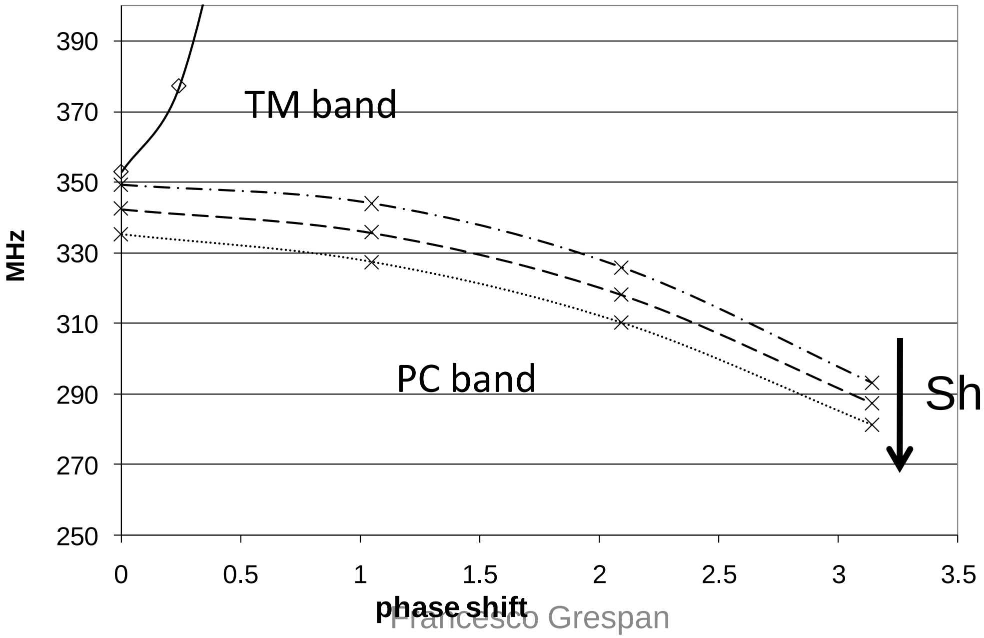
Addition of internal bars on both sides of the tanks



Post coupler forms a resonator with the opposing drift tube.

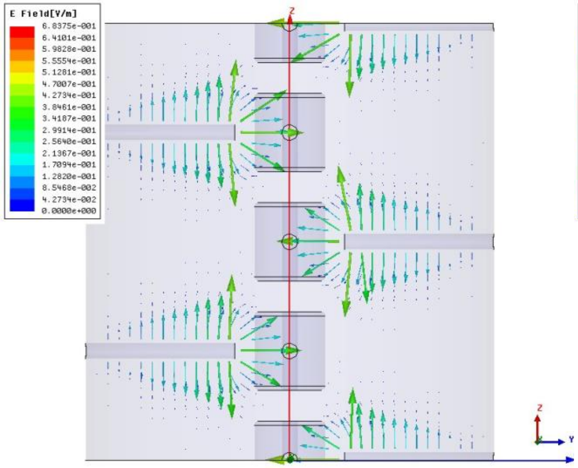
Resonant coupling for a DTL: post couplers

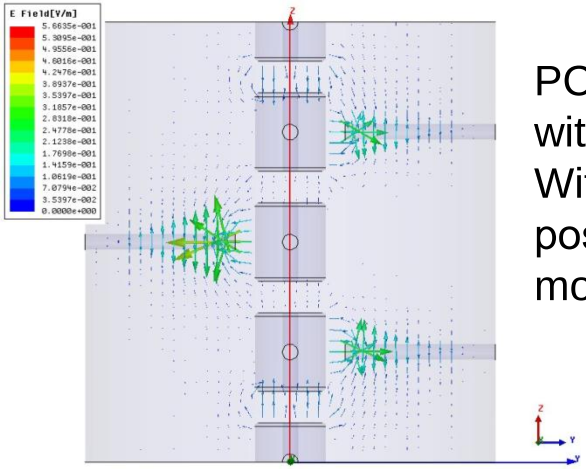




Shifted by PC length

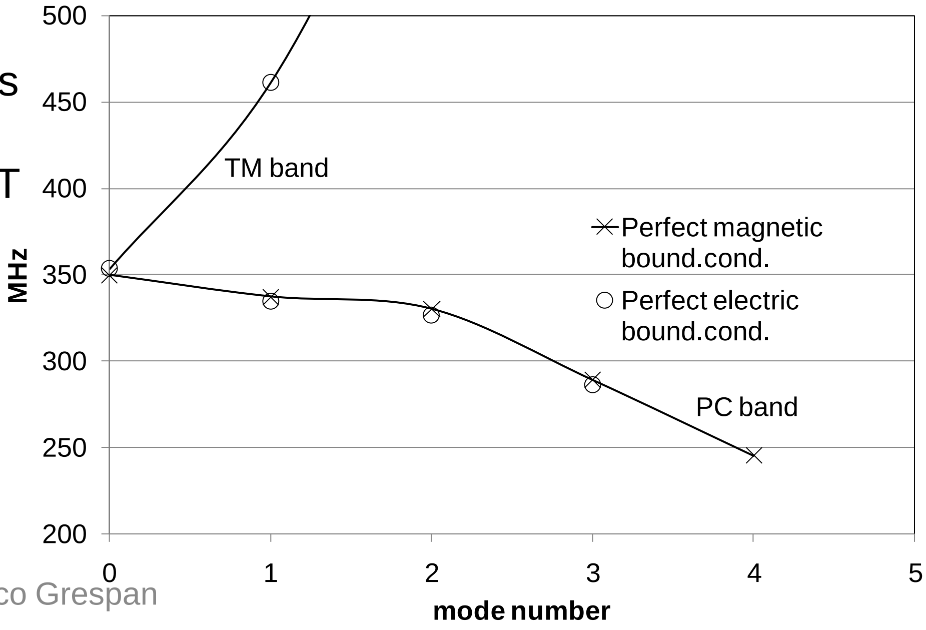
Resonant coupling for a DTL: post couplers





PC 0 mode can be simulated only with perfect magnetic end walls. With metallic end walls it is not possible to excite a "pure" PC 0 mode.

- coupling post couplers - DTL accelerating cells by the capacitance Cp
- coupling is stronger if the gap between PCs-DT is small.
- tuning of the PCs resonance is influenced the distance between post couplers
- Once this parameter is determined, it is still possible to tune the PC frequency by the gap PC-DT



Post coupler study

Objectives:

- Theoretical characterization of post couplers
- Strategy to set post coupler length in a DTL

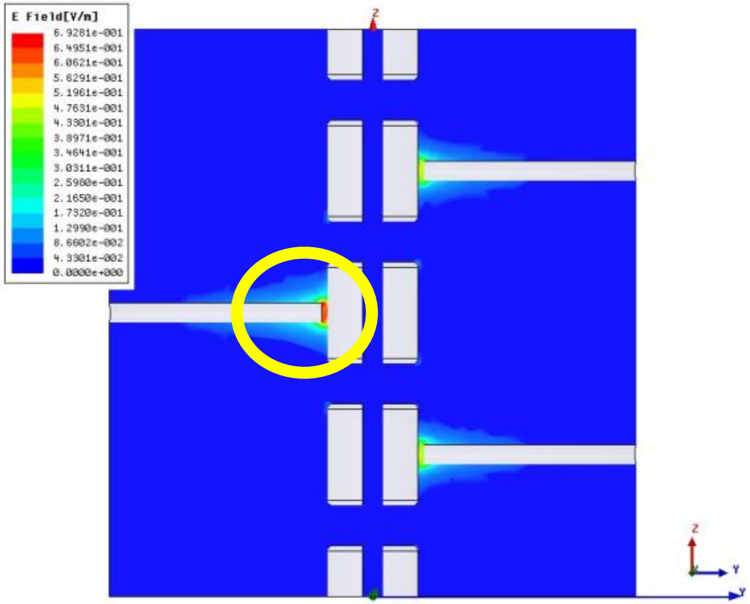
Steps:

- Simulation analysis
- Equivalent circuit for DTL
- A new procedure for post coupler setting based on equivalent circuit
- Experimental check: low power measurements and high power test

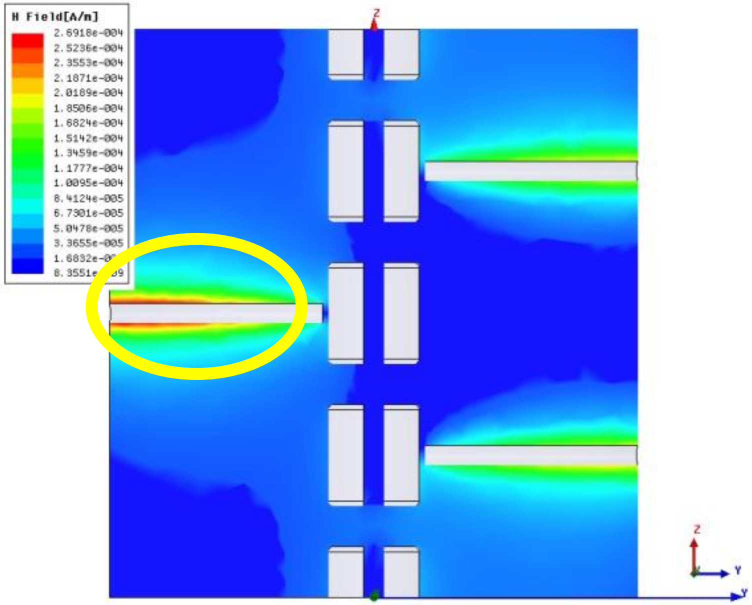
Circuital view of post couplers

3D simulations → pattern of post coupler mode

E field zone → Cp



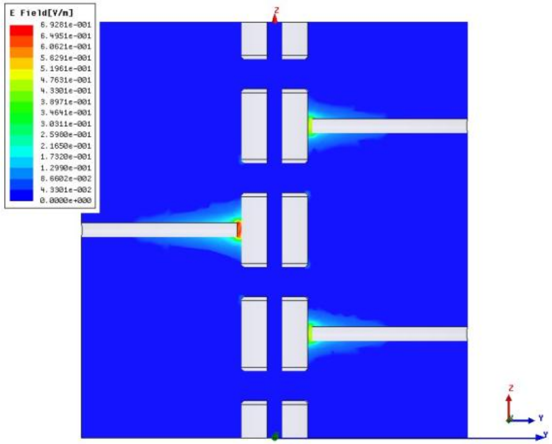
H field zone → Lp



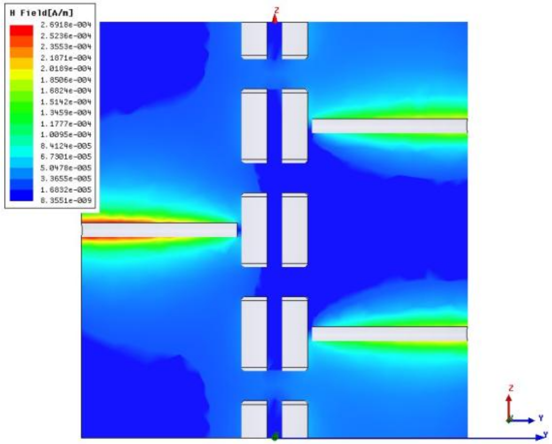
Circuital view of post couplers

3D simulations → calculation of parameter values

E field zone → Cp



H field zone → Lp



$$C_p = \frac{2U}{V^2}$$

$$L_p = \frac{1}{(2\pi f_p)^2 \overline{C_p}}$$

$$V = \int_a^b \overline{E} \cdot d\overline{s}$$

$$U = \frac{\varepsilon_0}{2} \int_V \left| \overline{E}(x,y,z) \right|^2 dV$$

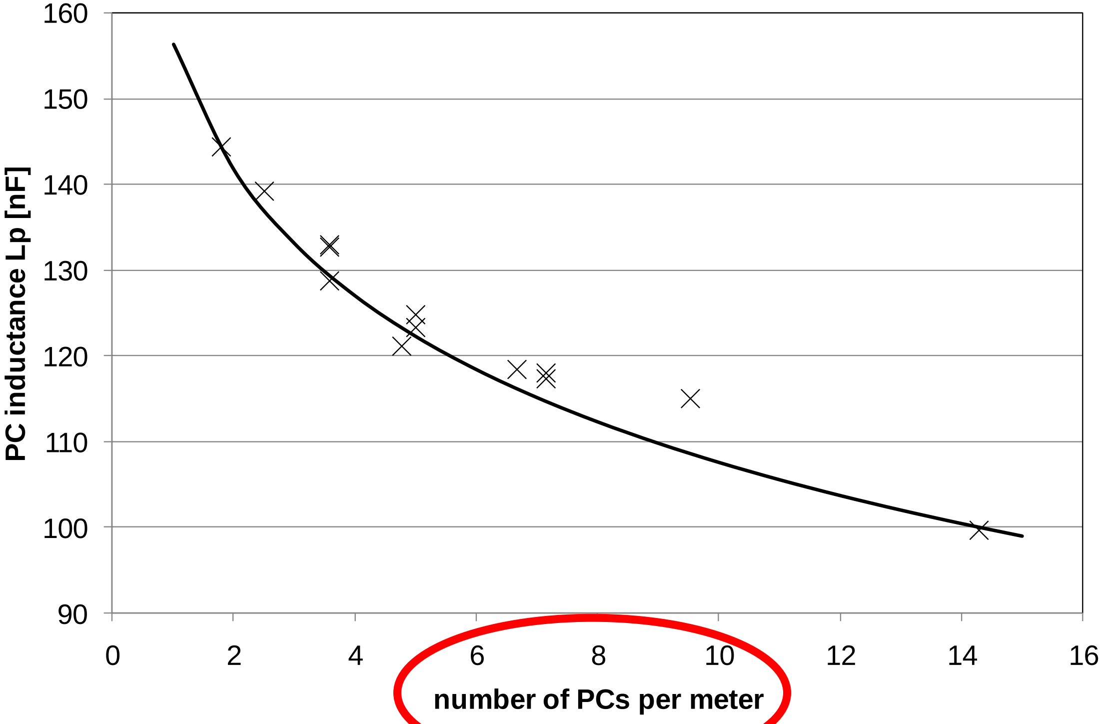
(quasi-static approximation)

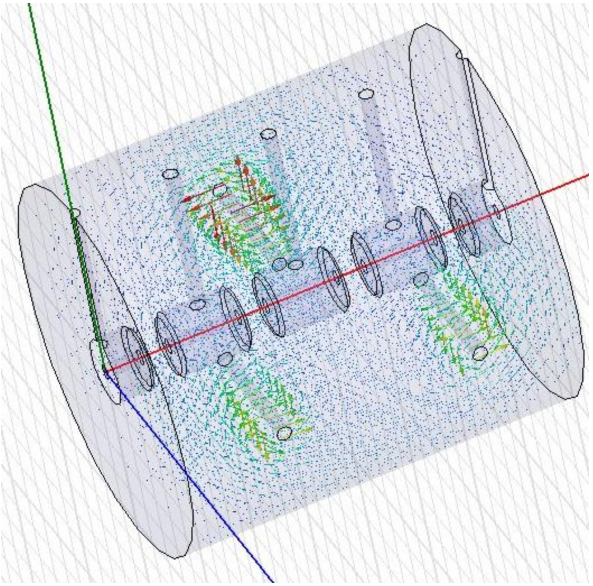
Parameter estimation

Inductance ~ coaxial $L_p = 2\cdot 10^{-7} \ln\left(\frac{D_{eq}}{d_{PC}}\right)\cdot l_{PC}$

- distance between post couplers
- post coupler length
- post coupler diameter

$$D_{eq} = D_{tank}\sqrt{\frac{L_{tank}}{2\cdot N^{o}_{PCs}\cdot l_{PC}}}$$

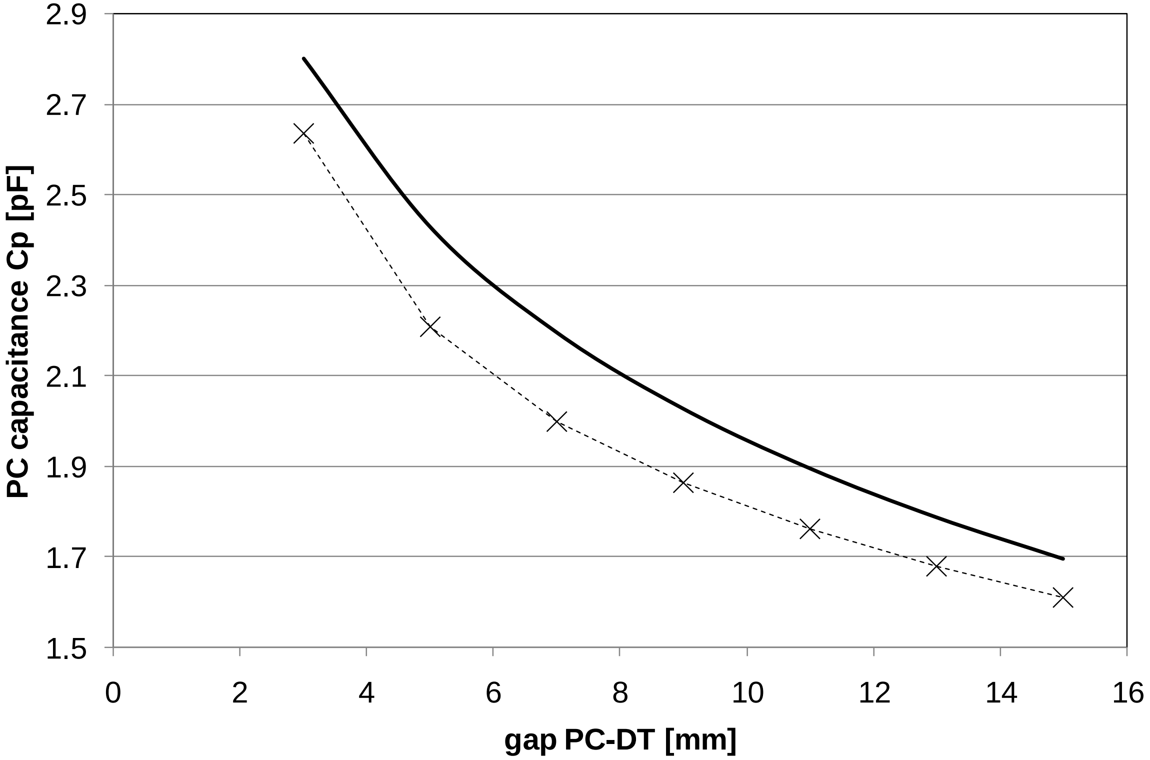


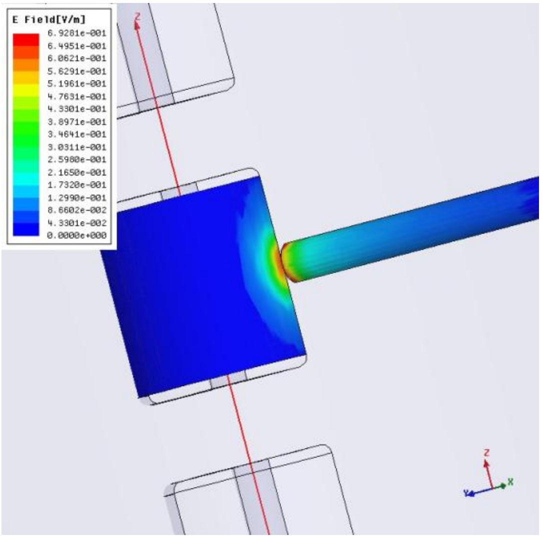


Parameter estimation

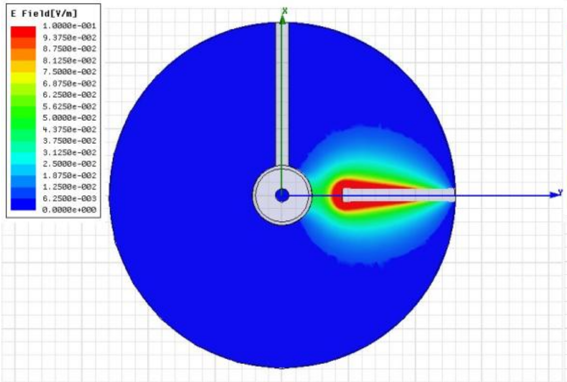
$$C_p = \varepsilon_0 \frac{A_Q}{g_{av}} = \varepsilon_0 \frac{\pi \cdot x_{tg} \cdot d_{DT} \arccos(2y_{tg} / d_{DT})}{\frac{d_{DT}}{2} + 2g - y_{tg}}$$

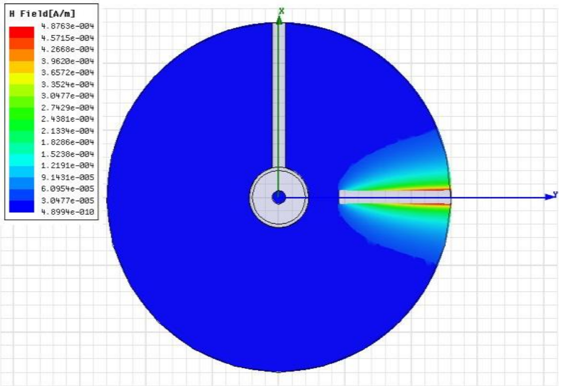
- drift tube diameter
- post coupler length
- tank diameter

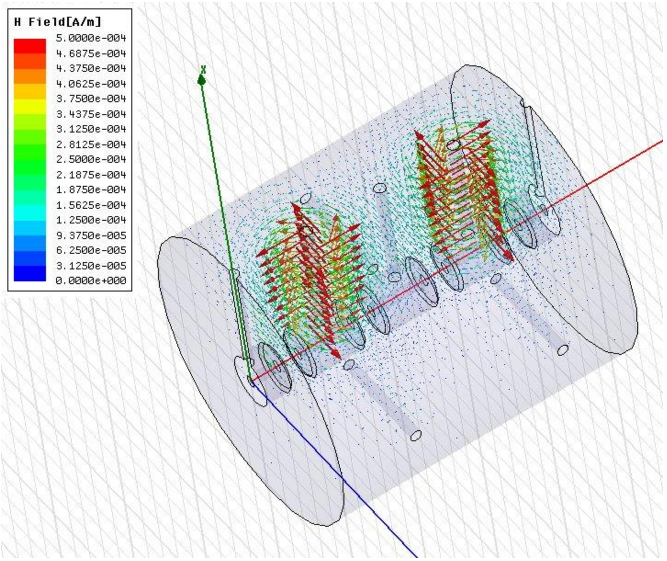


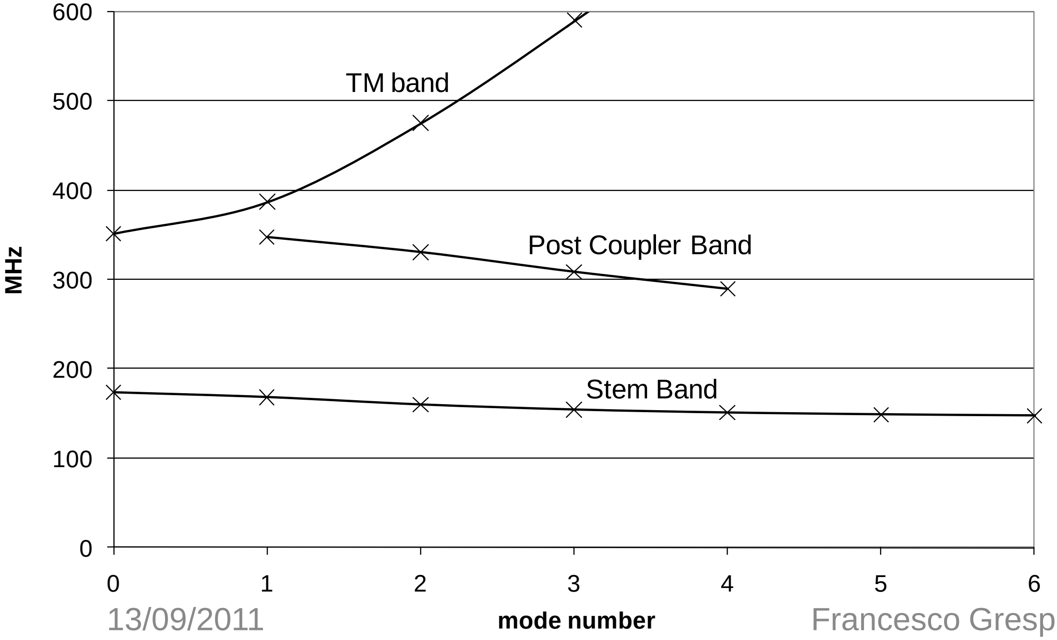


Stems and Post Couplers







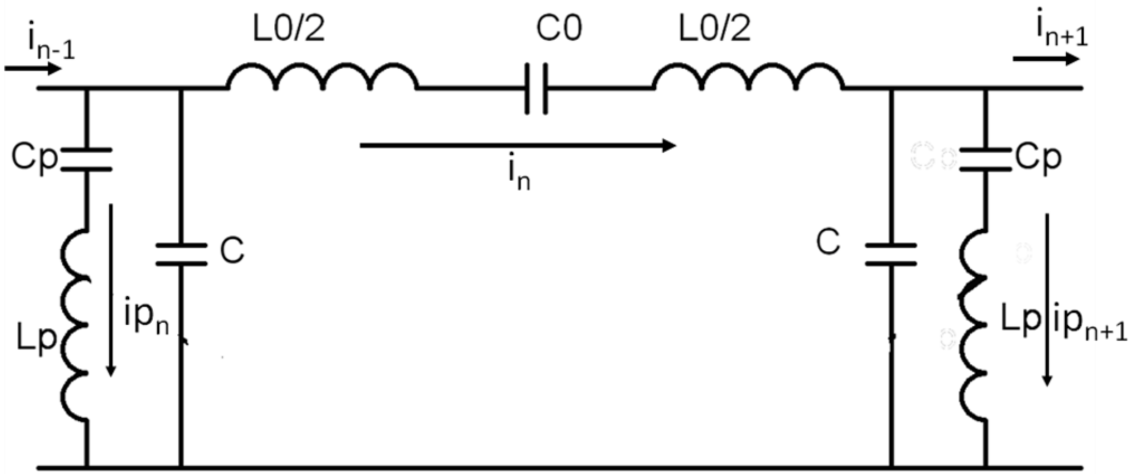


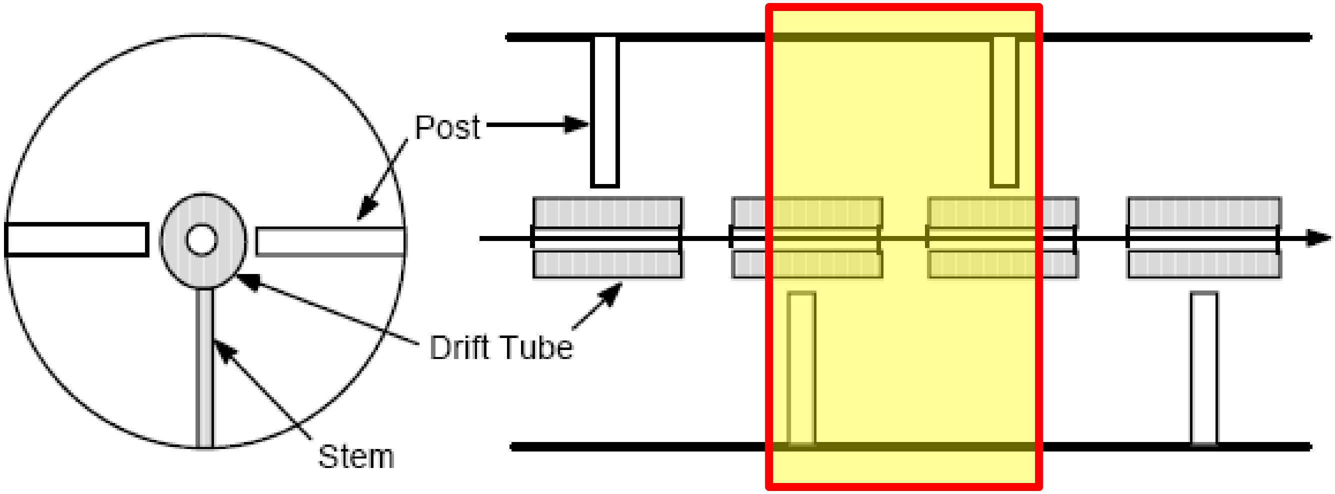
Stem modes

- RF measurements: much lower frequencies
- 3D view of stem mode magnetic field, showing weak coupling between stems and PCs

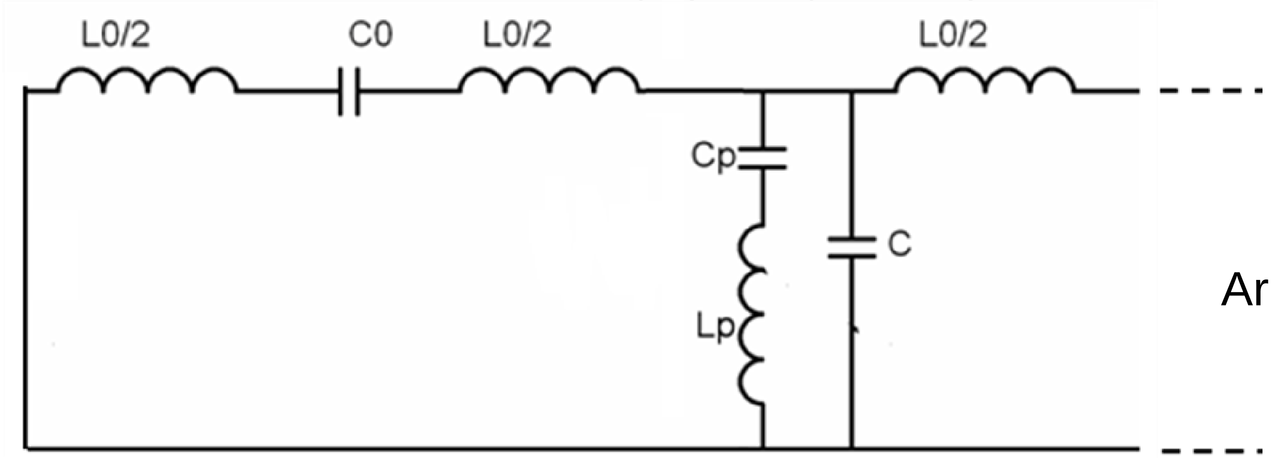
Equivalent circuit for DTL

Accelerating field $E_0 \rightarrow i_n$



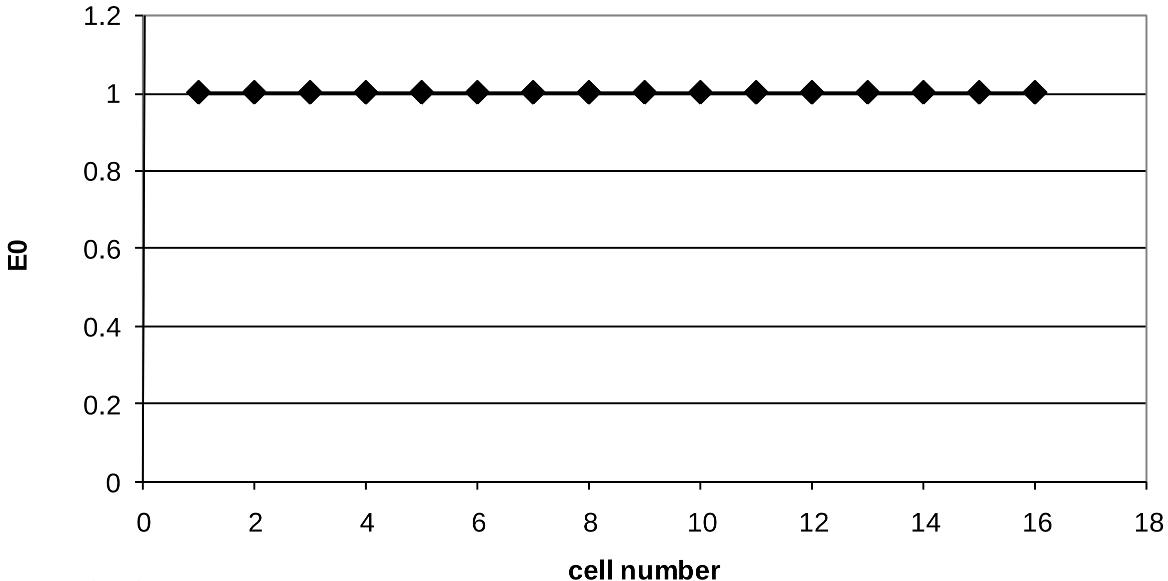


The stabilizing post coupler condition

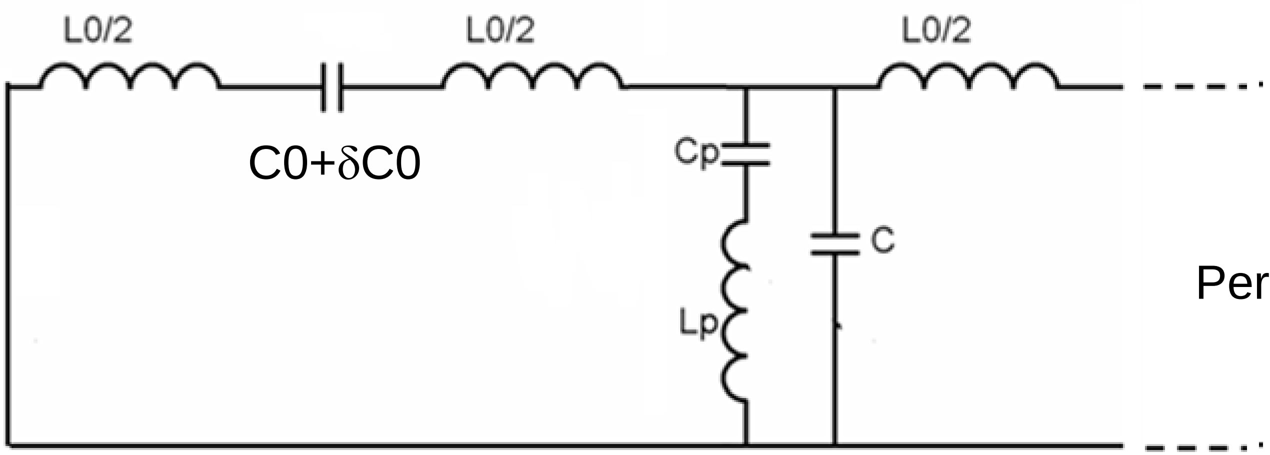


Array of all identical cells

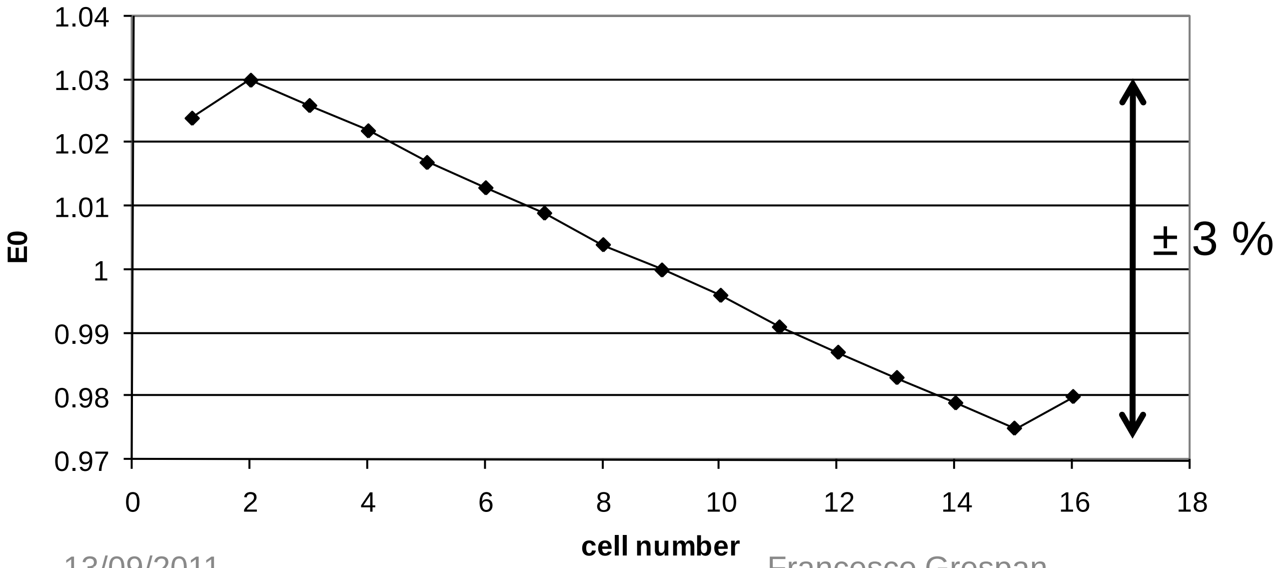
Constant field (nominal)



The stabilizing post coupler condition



Perturbation of end cells



Perturbed field

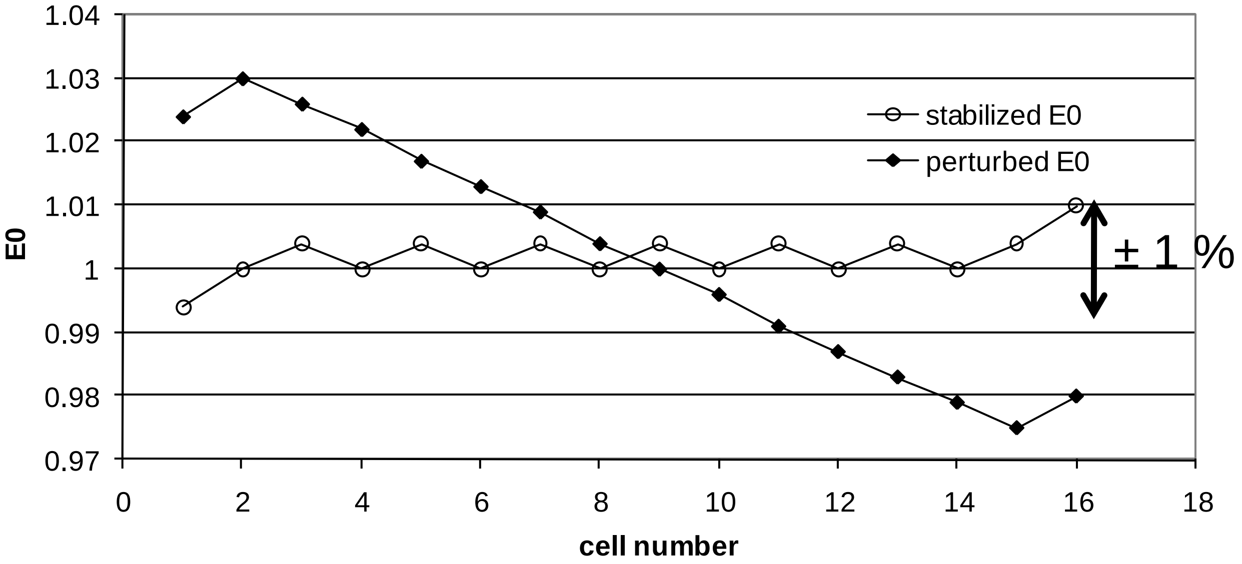
The stabilizing post coupler condition

$$I_2 \equiv \left(1+\frac{C}{C_0}(d-1)\right)I_0 + \left[\frac{C}{C_0}(d-1)+\frac{C_p}{C_0}(d-1)\left(\frac{\omega_p^2}{\omega_p^2-\omega_0^2}\right)\right]I_0 = I_0$$

$$\boxed{\omega_p^2 = \frac{\omega_0^2}{1+\frac{n\cdot C_p}{C}}}$$

$$\boxed{C_p^{stab} = \frac{C}{CL_p\omega_0^2 - n}}$$

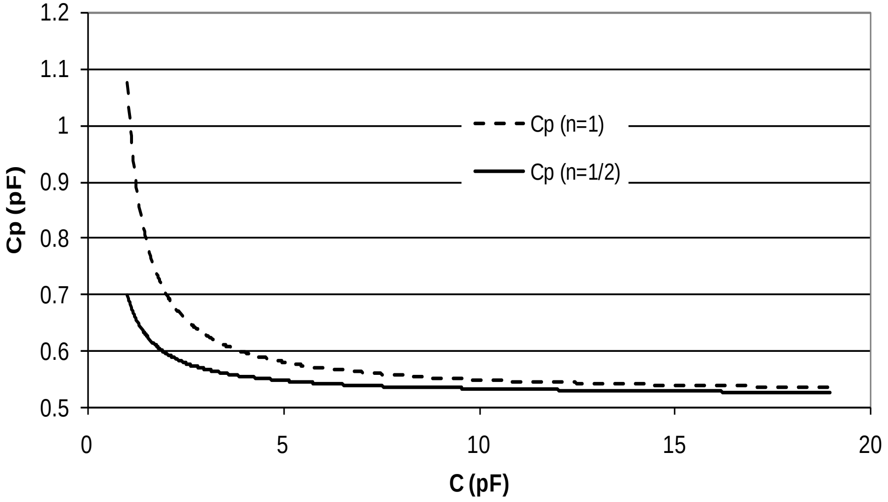
$$n = \frac{number-post-couplers}{number-cells}$$



ω_p and C_p functions of the post coupler length.

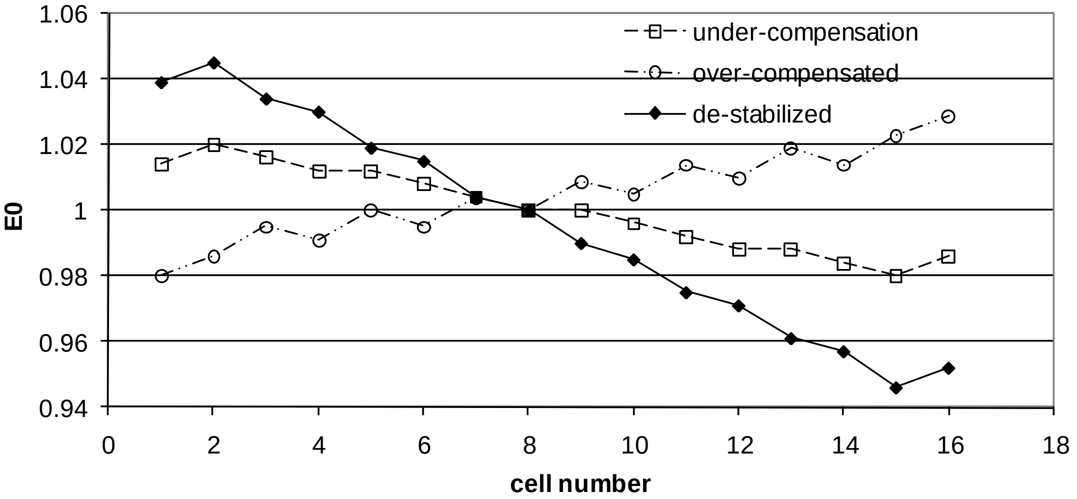
→ there is an optimum post coupler length…

The stabilizing post coupler condition

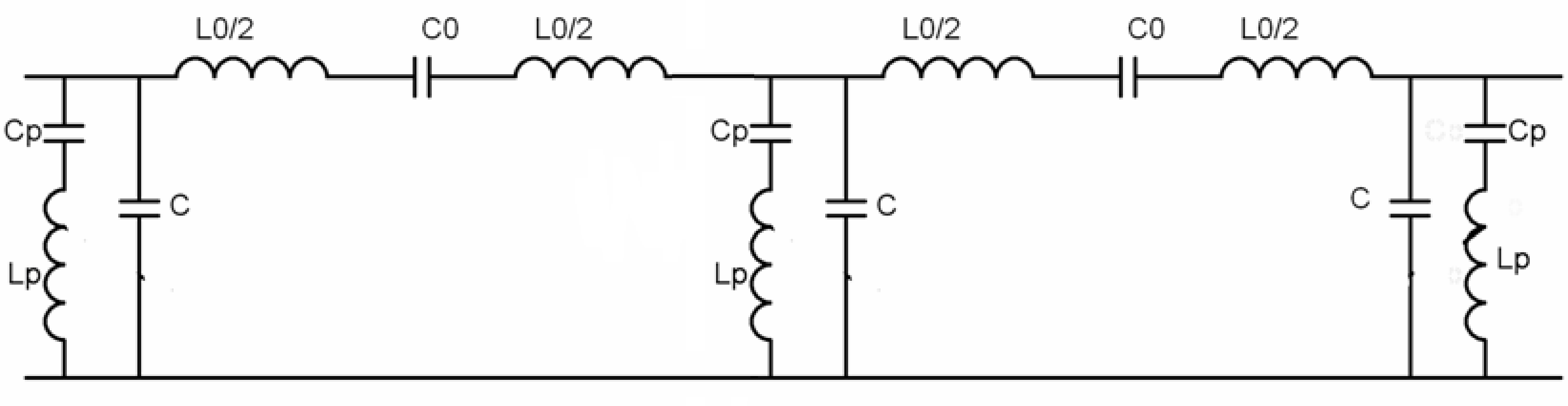


The optimum value of C_p for stabilization decreases as function of the capacitance C : where DTs are longer, gap PC-DT must be larger; where DTs are shorter, gap PC-DT must be smaller.

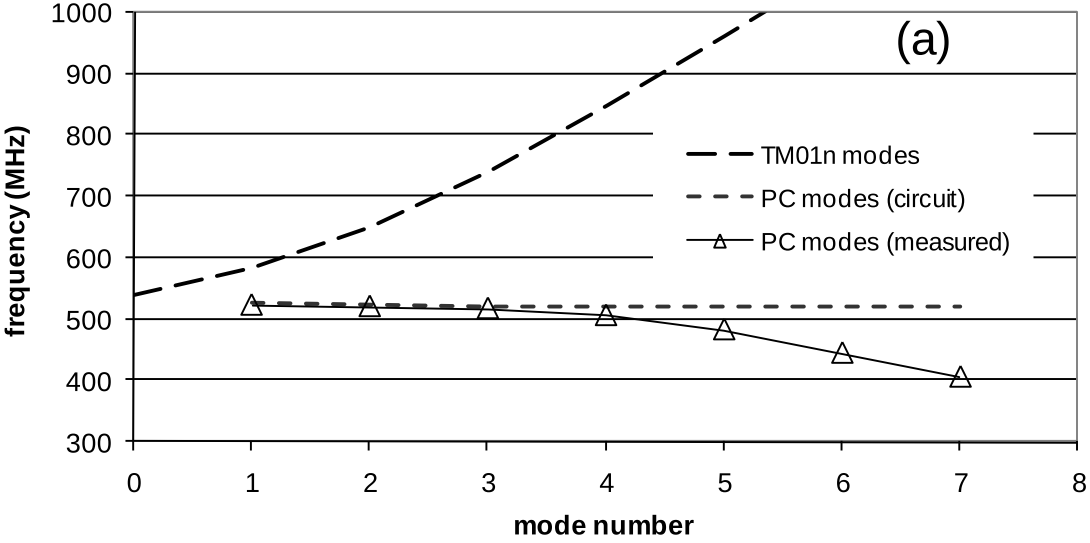
1. gap is too short: PCs can compensate the perturbation, but not completely;
2. gap is slightly larger than the stab. condition: over-compensation that changes the slope with respect to the perturbation;
3. gap is much larger than the stabilizing condition, the PC effect is de-stabilizing.

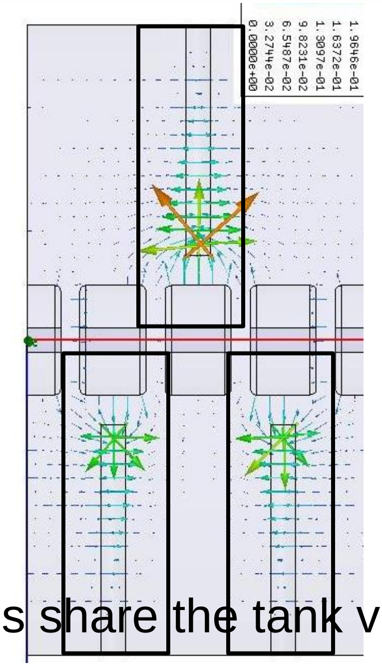


Magnetic couplings between post couplers



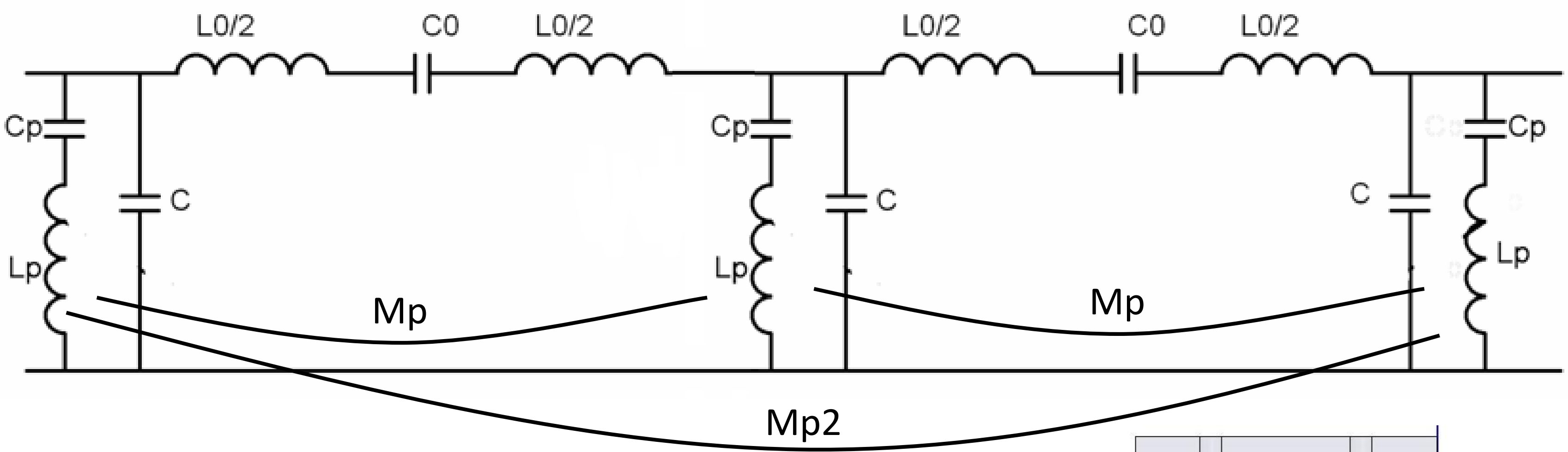
dispersion curves are different

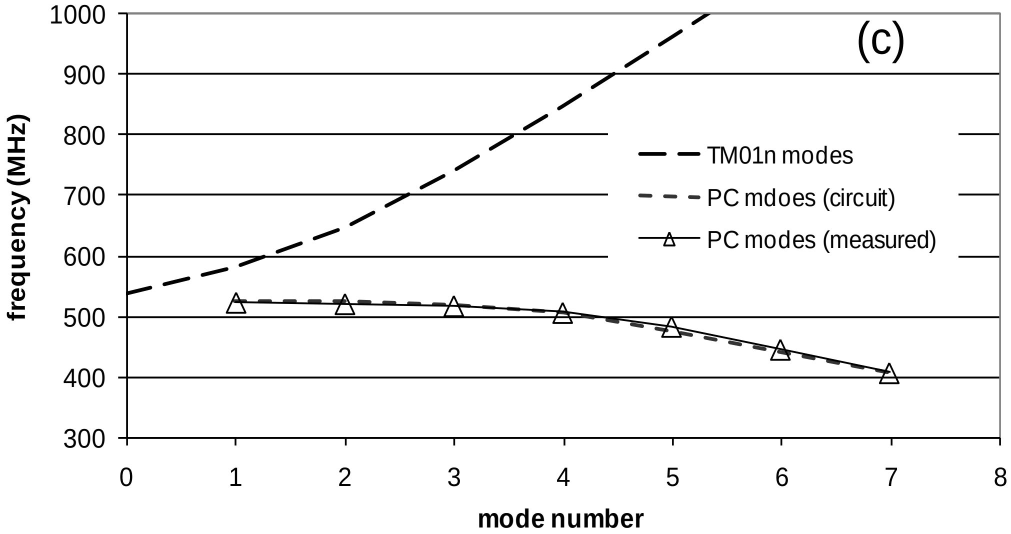


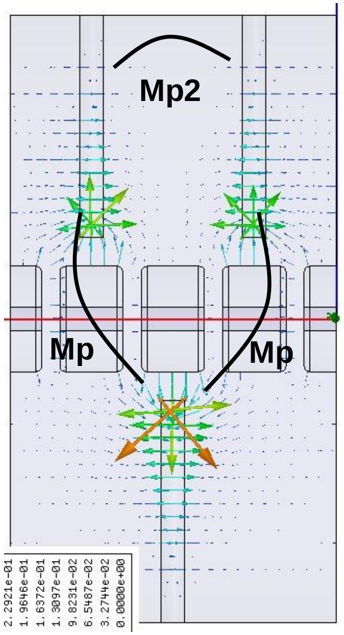


PCs share the tank volume

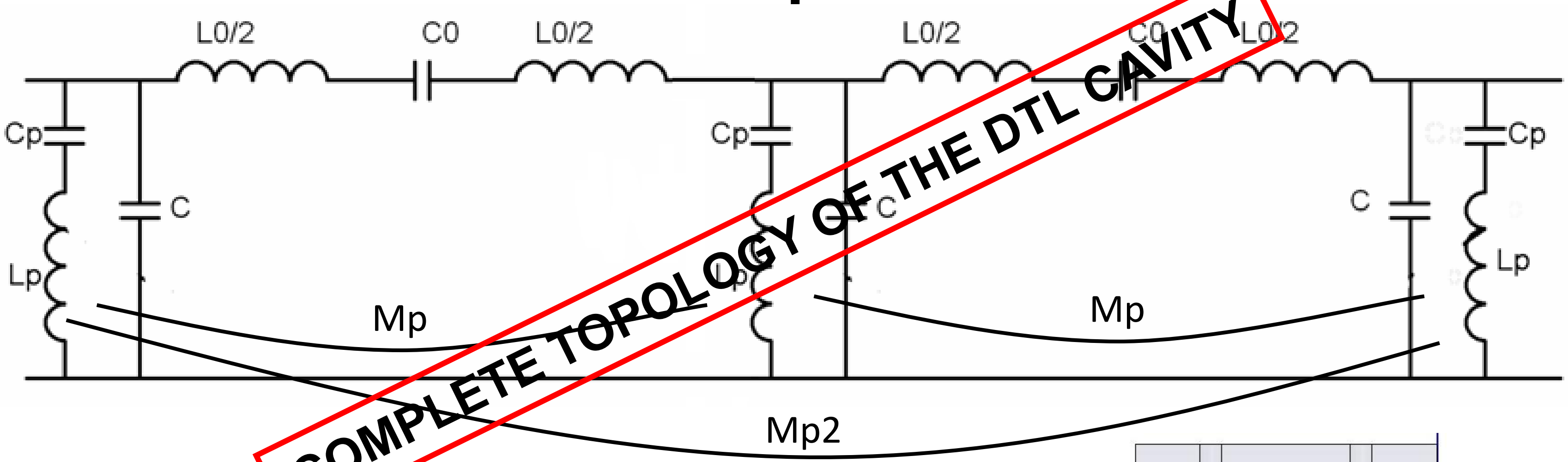
Magnetic couplings between post couplers



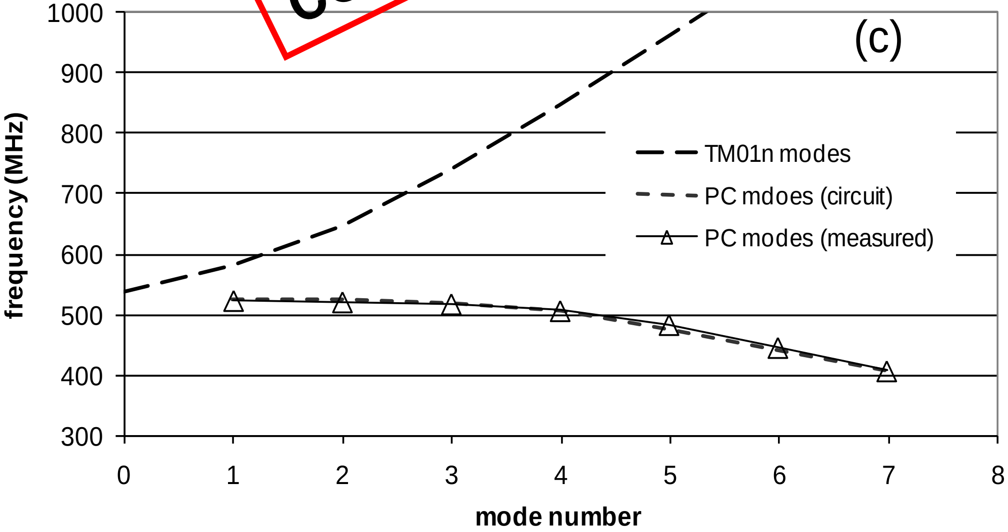


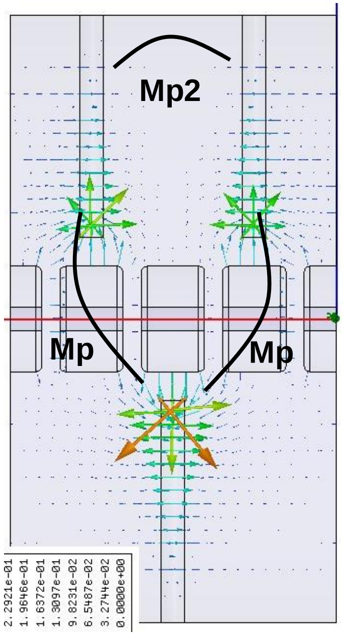


Magnetic couplings between post couplers



COMPLETE TOPOLOGY OF THE DTL CAVITY





Matrix of the DTL equivalent circuit

$$\begin{bmatrix}
C_0\omega_0^2\left(\frac{1}{C}+\frac{1}{C_0}\right) & -\frac{C_p\omega_p^2}{C} & -\frac{C_0\omega_0^2}{C} & 0 & 0 & 0 & 0 \\
-\frac{C_0\omega_0^2}{C} & C_p\omega_p^2\left(\frac{1}{C}+\frac{1}{C_p}\right) & \frac{C_0\omega_0^2}{C} & k_{p1} & 0 & k_{p2} & 0 \\
-\frac{C_0\omega_0^2}{C} & \frac{C_p\omega_p^2}{C} & C_0\omega_0^2\left(\frac{2}{C}+\frac{1}{C_0}\right) & -\frac{C_p\omega_p^2}{C} & -\frac{C_0\omega_0^2}{C} & 0 & 0 \\
0 & k_{p1} & -\frac{C_0\omega_0^2}{C} & C_p\omega_p^2\left(\frac{1}{C}+\frac{1}{C_p}\right) & \frac{C_0\omega_0^2}{C} & k_{p1} & 0 \\
0 & 0 & -\frac{C_0\omega_0^2}{C} & -\frac{C_p\omega_p^2}{C} & C_0\omega_0^2\left(\frac{2}{C}+\frac{1}{C_0}\right) & -\frac{C_p\omega_p^2}{C} & -\frac{C_0\omega_0^2}{C} \\
0 & k_{p2} & 0 & k_{p1} & -\frac{C_0\omega_0^2}{C} & C_p\omega_p^2\left(\frac{1}{C}+\frac{1}{C_p}\right) & \frac{C_0\omega_0^2}{C} \\
0 & 0 & 0 & 0 & -\frac{C_0\omega_0^2}{C} & \frac{C_p\omega_p^2}{C} & C_0\omega_0^2\left(\frac{1}{C}+\frac{1}{C_0}\right)
\end{bmatrix}$$

- resonant frequencies
- field on gaps

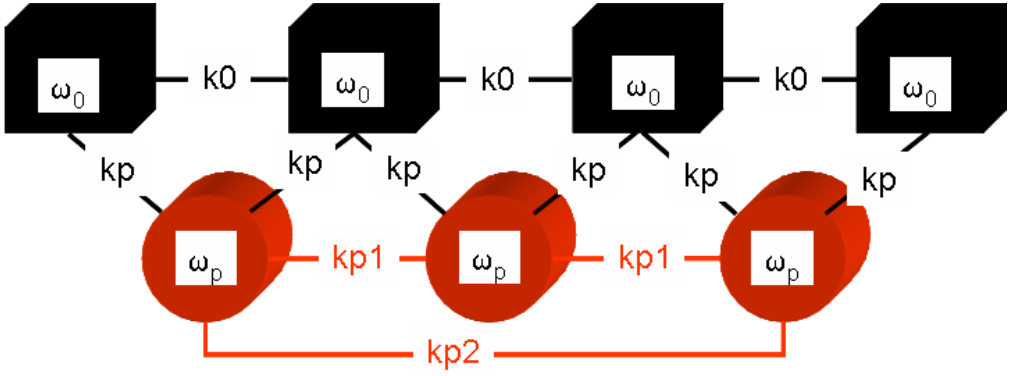
Matrix of the DTL equivalent circuit

6 parameters: 2 frequencies, 4 coupling constants.

$$\begin{bmatrix} k_0+\omega_0^2 & -k_p & -k_0 & 0 & 0 & 0 & 0 \\ -k_0 & k_p+\omega_p^2 & k_0 & k_{p1} & 0 & k_{p2} & 0 \\ -k_0 & k_p & k_0+\omega_0^2 & -k_p & -k_0 & 0 & 0 \\ 0 & k_{p1} & -k_0 & k_p+\omega_p^2 & k_0 & k_{p1} & 0 \\ 0 & 0 & -k_0 & -k_p & k_0+\omega_0^2 & -k_p & -k_0 \\ 0 & k_{p2} & 0 & k_{p1} & -k_0 & k_p+\omega_p^2 & k_0 \\ 0 & 0 & 0 & 0 & -k_0 & k_p & k_0+\omega_0^2 \end{bmatrix}$$

➢ ω_0, k_0
- constant
- calculated by simulation

➢ ω_p, k_p, k_{p1}, k_{p2}
- functions of post coupler length
- fit from measurements

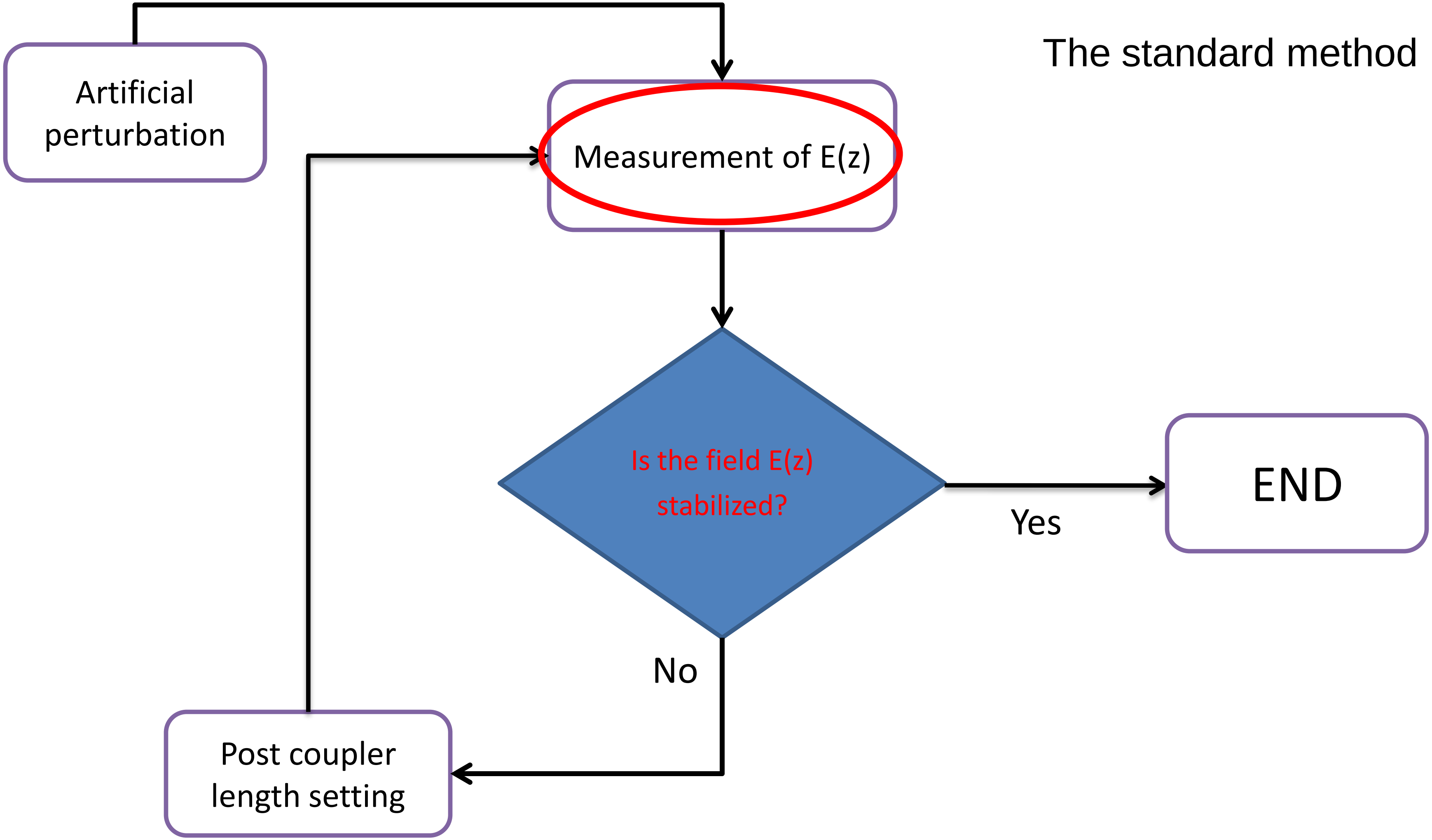


k_0/ω_0^2	k_p/ω_0^2	k_{p1}/ω_0^2	k_{p2}/ω_0^2
2.5	0.25	0.076	-0.031

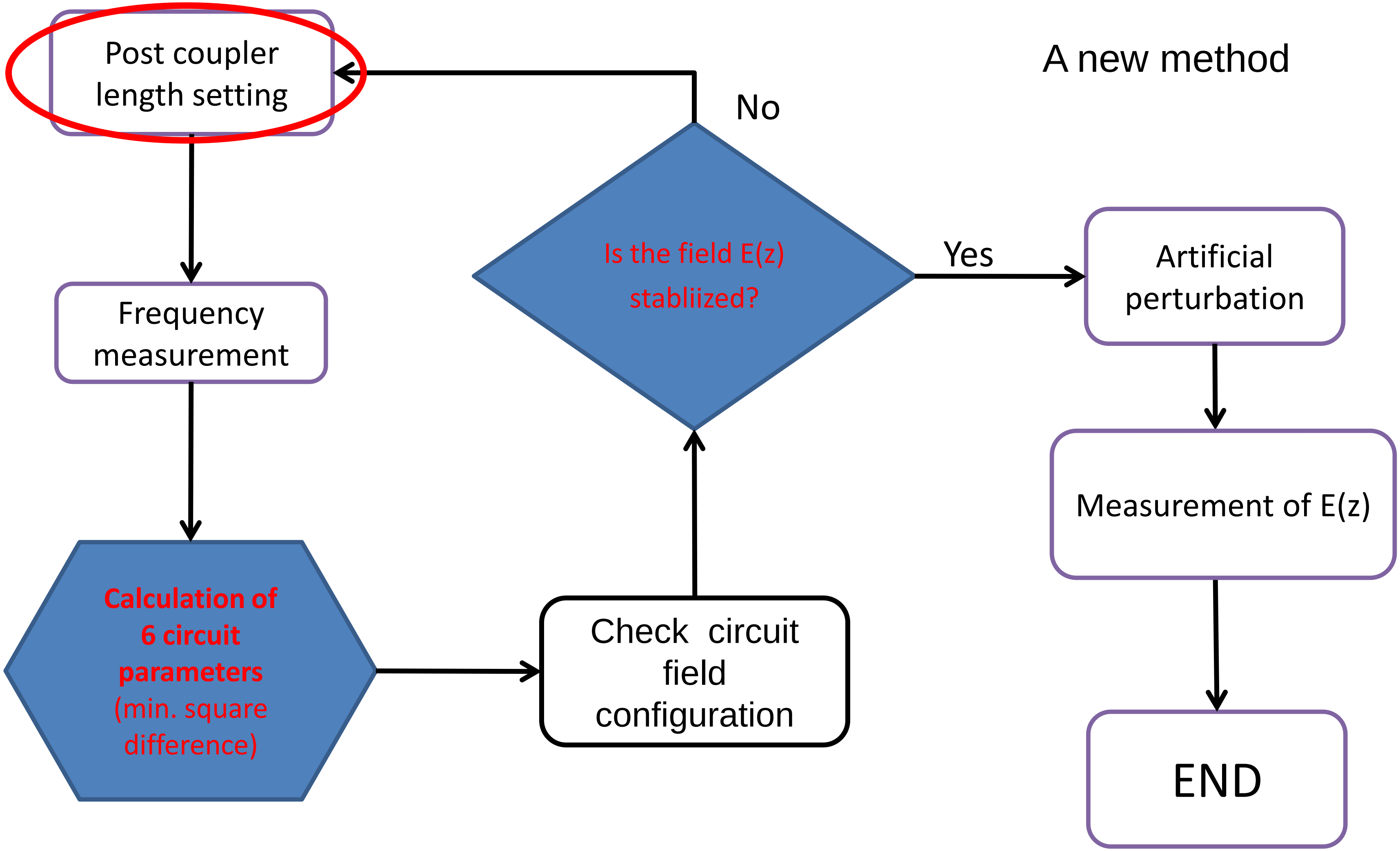
gap PC-DT = 25 mm

Procedure for post coupler length setting

The standard method



Procedure for post coupler length setting



Post coupler length setting

Frequency measurement

Calculation of 6 circuit parameters (min. square difference)

Check circuit field configuration

Is the field E(z) stabliized?

No

Yes

A new method

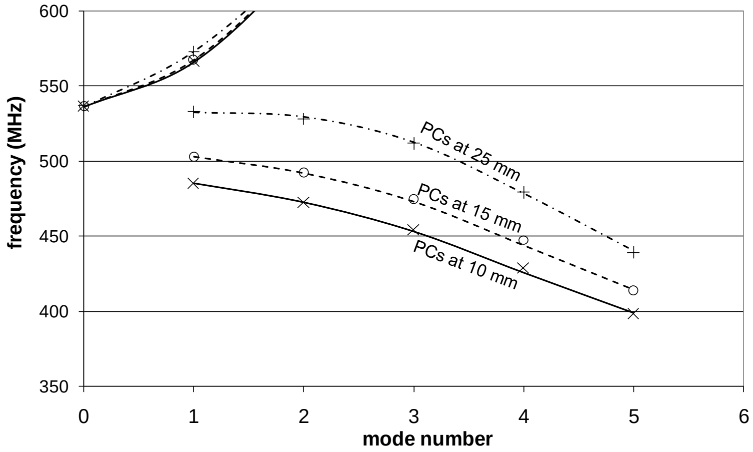
Artificial perturbation

Measurement of E(z)

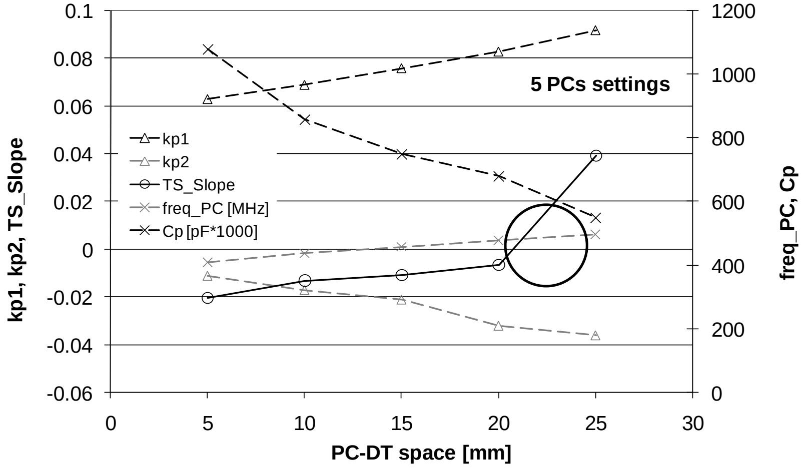
END

Measurement: DTL cold model

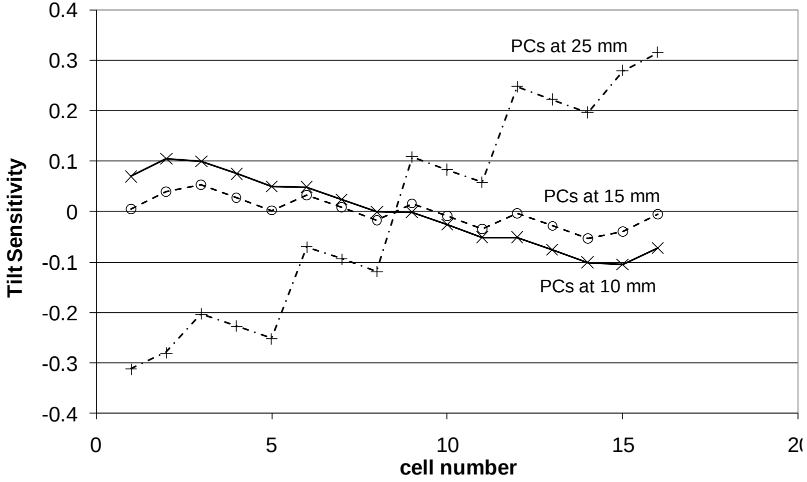
1.Frequencies at different post coupler lengths



2. Circuit parameter calculation

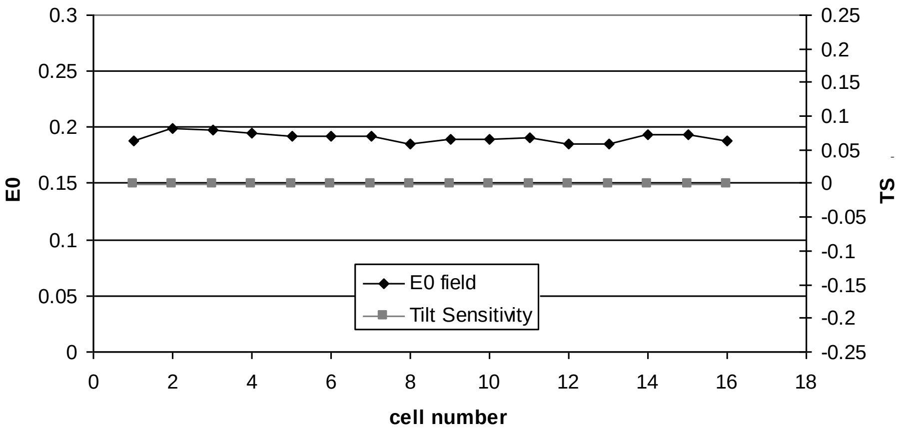


3. Field configuration check

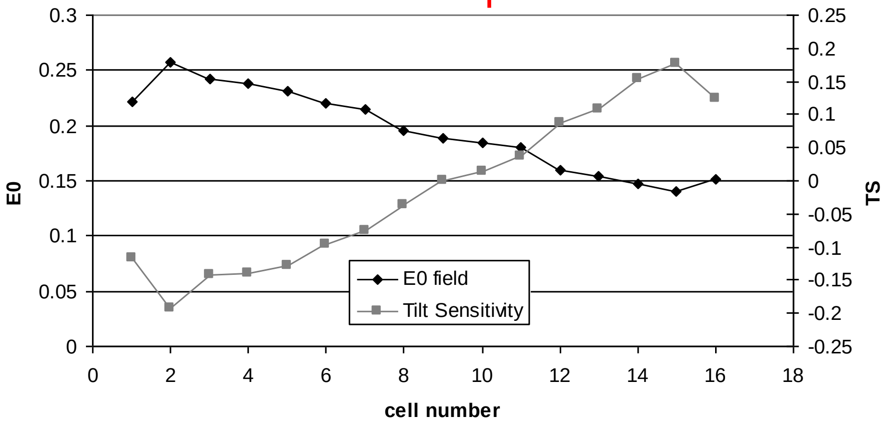


4. Optimum post coupler length: 11.8 cm

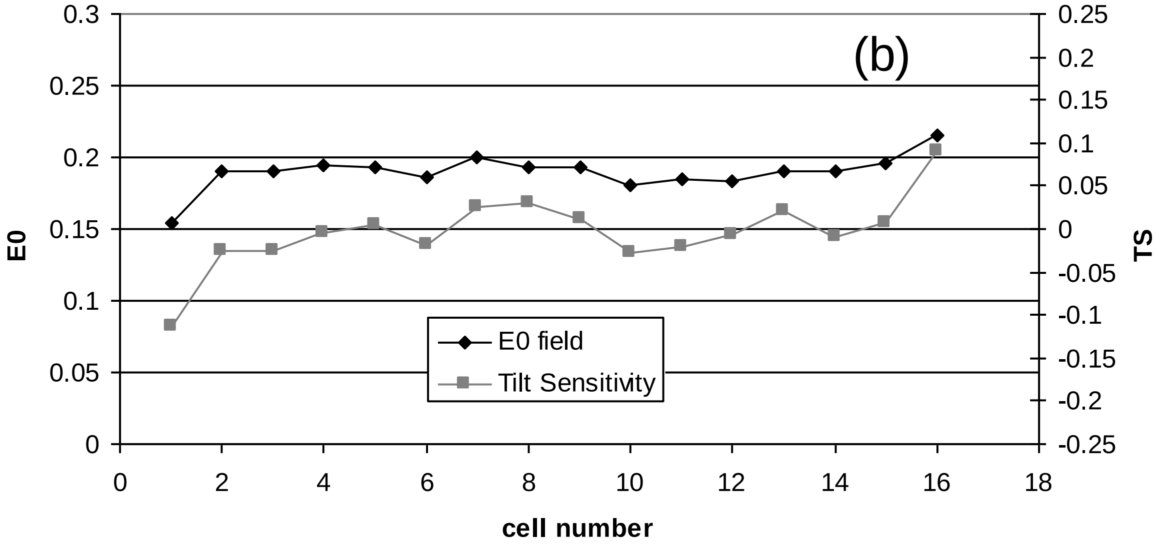
Measurements: DTL cold model



5. Nominal field



6. Artificial perturbation



7. Field stabilized by post couplers

THANK YOU!