Modeling Interaction of e-cloud & Microwaves

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Outline

- Objectives
- Radiation problem inside uniform waveguides
- Simulation setup
- Simulation results

Objectives

- Compute modes of LHC beam-pipe
- Implement microwave field using true beam pipe geometry in ecloud
- Excite LHC beam-pipe with microwave field
- Analyze em field radiated by the e^{-}-cloud

Radiation problem inside uniform waveguides

Observation:

- We deal with an arbitrary motion of charged particles (electrons)
- The em field associated with a particle is the Green function subject to the boundary conditions of the problem
- To take into account the images of the electron cloud, the modes of the waveguide are used. Especially useful when the cross-section is of non-canonical form.

$\Longrightarrow$ use time-domain Greens function based on a modal expansion.

Radiation problem inside uniform waveguides

Applying the Lorenz Gauge:

$$\nabla^2\phi - \frac{1}{c^2}\frac{\partial^2}{\partial t^2}\phi = -\frac{\rho(\vec{r},t)}{\varepsilon_0}\,, \tag{1a}$$

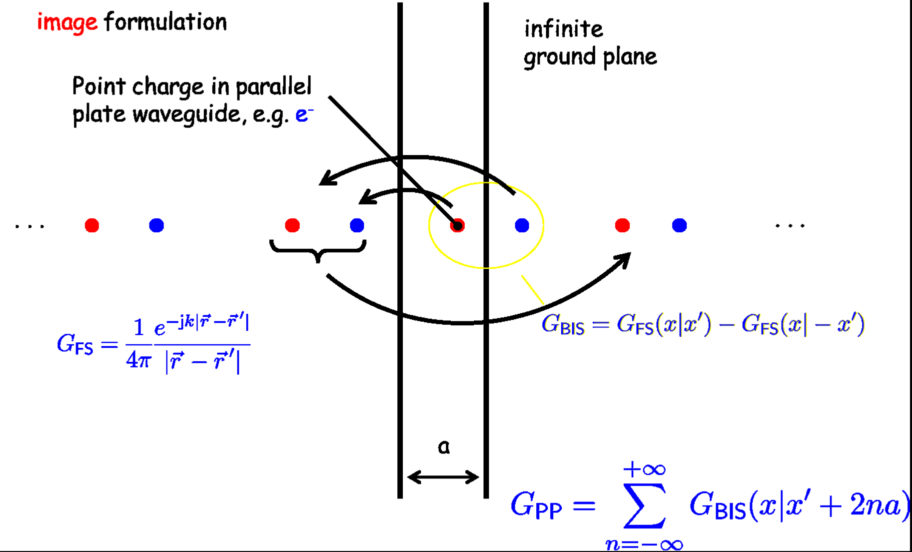
$$\nabla^2\mathcal{A} - \frac{1}{c^2}\frac{\partial^2}{\partial t^2}\mathcal{A} = -\mu_0\jmath(\vec{r},t)\,. \tag{1b}$$

By means of the Green functions, the solution can be expressed as

$$\phi(\vec{r},t) = -\frac{1}{\varepsilon_0}\int g(\vec{r},t\,|\,\vec{r}',t')\,\rho(\vec{r}',t')\,\mathrm{d}t'\mathrm{d}^3r'\,, \tag{2a}$$

$$\mathcal{A}(\vec{r},t) = -\mu_0\int \overleftrightarrow{G}_{\mathrm{A}}(\vec{r},t\,|\,\vec{r}',t')\,\jmath(\vec{r}',t')\,\mathrm{d}t'\mathrm{d}^3r'\,. \tag{2b}$$

Intermezzo - Green function of a parallel plate wg



Intermezzo - Green function of a parallel plate wg

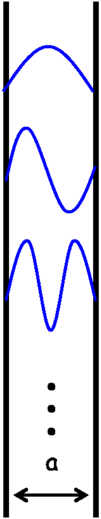
modal formulation

$$\phi_1(x) = \sin\frac{\pi x}{a}$$

$$\phi_2(x) = \sin\frac{2\pi x}{a}$$

$$\phi_3(x) = \sin\frac{3\pi x}{a}$$

$$\vdots$$



$$G_{\mathrm{PP}} = \sum_{n=-\infty}^{+\infty} g_n\,\phi_n(x)\cdot\phi_n(x')$$

Radiation problem inside uniform waveguides

The Green functions are defined by

$$\nabla^2 g - \frac{1}{c^2}\frac{\partial^2}{\partial t^2} g = 1 \cdot \delta(\vec{r} - \vec{r}')\delta(t - t')\,, \tag{3a}$$

$$\nabla^2 \overleftrightarrow{G}_{\mathrm{A}} - \frac{1}{c^2}\frac{\partial^2}{\partial t^2} \overleftrightarrow{G}_{\mathrm{A}} = \overleftrightarrow{I} \cdot \delta(\vec{r} - \vec{r}')\delta(t - t')\,. \tag{3b}$$

$+$ boundary conditions of the em field.

Radiation problem inside uniform waveguides

The waveguide problem can be solved by separating

- the transverse problem ⟶ boundary value problem, and
- the longitudinal problem ⟶ radiation/propagation problem.

Applying the Fourier Transform to the longitudinal variable z and the time t yields 2D Helmholtz equations for the transverse problem in the spectral-frequency (β - ω) domain

$$(\nabla_t^2 + k_c^2)\,\hat{g}(\vec{r}_t|\vec{r}_t') = 1 \cdot \delta(\vec{r}_t - \vec{r}_t')\,, \tag{4a}$$

$$(\nabla_t^2 + k_c^2)\,\overleftrightarrow{\hat{G}}_{\mathrm{A}}(\vec{r}_t|\vec{r}_t') = \overleftrightarrow{I}_t \cdot \delta(\vec{r}_t - \vec{r}_t')\,. \tag{4b}$$

$$k_c^2 = k_0^2 - \beta^2 \qquad k_0 = \frac{\omega}{c_0}$$

Radiation problem inside uniform waveguides

The transverse part can be expressed as infinite series of eigen solutions

$$\hat{g}(\vec{r}_t|\vec{r}_t') = \sum_l \frac{1}{k_c^2 - k_l^2} \hat{g}_l(\vec{r}_t)\hat{g}_l(\vec{r}_t'), \qquad \text{(5a)}$$

$$\overleftrightarrow{\hat{G}}_A(\vec{r}_t|\vec{r}_t') = \sum_l \frac{1}{k_c^2 - k_l^2} \hat{A}_l(\vec{r}_t)\hat{A}_l^{tr}(\vec{r}_t'). \qquad \text{(5b)}$$

Note, $k_c = k_c(\beta, \omega)$, thus the (z,t)-dependent part is isolated in the coefficients of the infinite series.

Radiation problem inside uniform waveguides

The longitudinal- (z) and time- (t) -dependency is obtained by applying the inverse Fourier transform

$$\Lambda(k_l, z-z', t-t') := \mathcal{F}^{-1}_{2\mathrm{D}}\left\{\frac{1}{k_c^2 - k_l^2}\right\} = \frac{c_0}{2}\begin{cases} \mathrm{J}_0\left(k_l\sqrt{c_0\,(t-t') - |z-z'|}\right), & c_0\,(t-t') > |z-z'| \\ 0, & \text{otherwise} \end{cases} \tag{6}$$

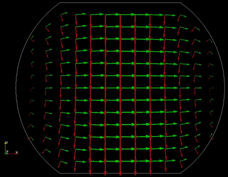
$$g(\vec{r}, t|\vec{r}', t') = \sum_l \Lambda(k_l, z-z', t-t')\,\hat{g}_l(\vec{r}_t)\hat{g}_l^{\mathrm{tr}}(\vec{r}_t'), \tag{7a}$$

$$\overleftrightarrow{G}_{\mathrm{A}}(\vec{r}, t|\vec{r}', t') = \sum_l \Lambda(k_l, z-z', t-t')\,\hat{A}_l(\vec{r}_t)\hat{A}_l^{\mathrm{tr}}(\vec{r}_t'). \tag{7b}$$

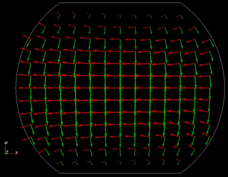
Modes of LHC beam pipe

The eigen solutions $\hat{g}$ and $\hat{G}_A$ of the LHC beam pipe are computed using the BI-RME algorithm[1]

TE_1

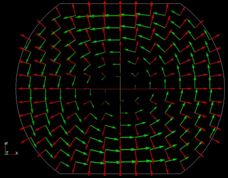


TE_2

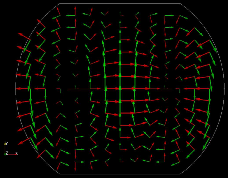


E

TM_1



TM_2



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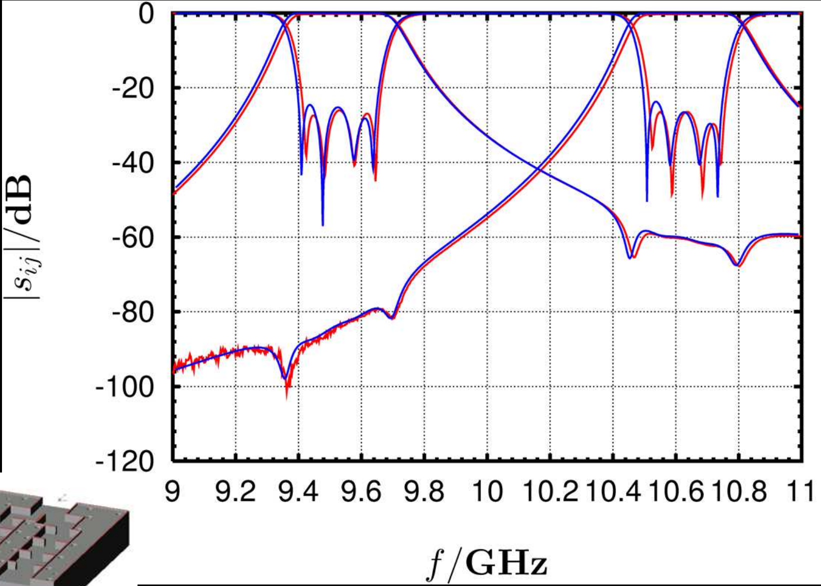
[1] Conciauro, Guglielmi, Sorrentino, *Advanced Modal Analysis*, Wiley, 1999.

Intermezzo - CEM: waveguides

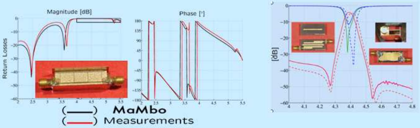


Intermezzo - CEM: planar structures

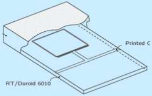
Multilayered Boxed Printed Circuits

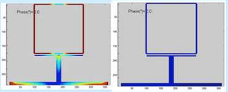
MaMbo

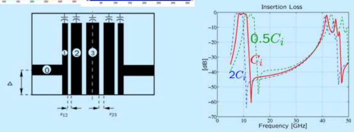
- Hybrid mesh (triangles/rectangles)
- Stable & efficient model for multilayered media
- Complete losses model



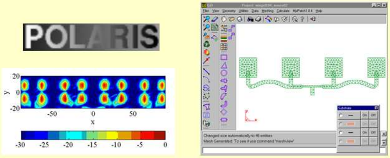
- Lumped elements
- Coax-type and waveguide ports



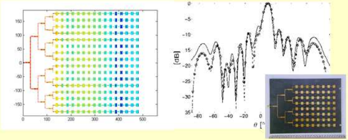




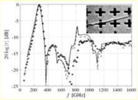
Multilayered Planar Antennas

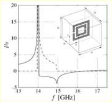


- Efficient treatment of large structures
- Computation of Input impedance and Near & Far field

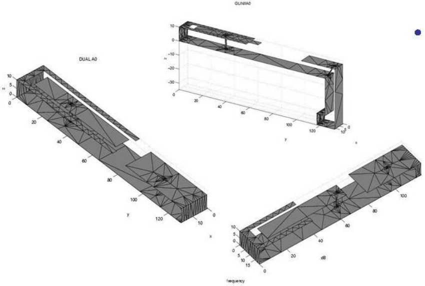


- Planar Periodic Structures, FSS and metamaterials





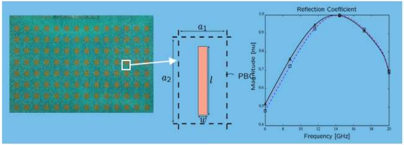
Intermezzo - CEM: 3D and periodic structures

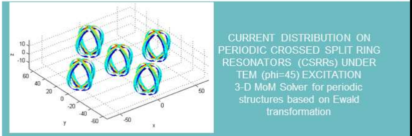


- Modelling and optimizing 3D antennas for mobile applications like GSM

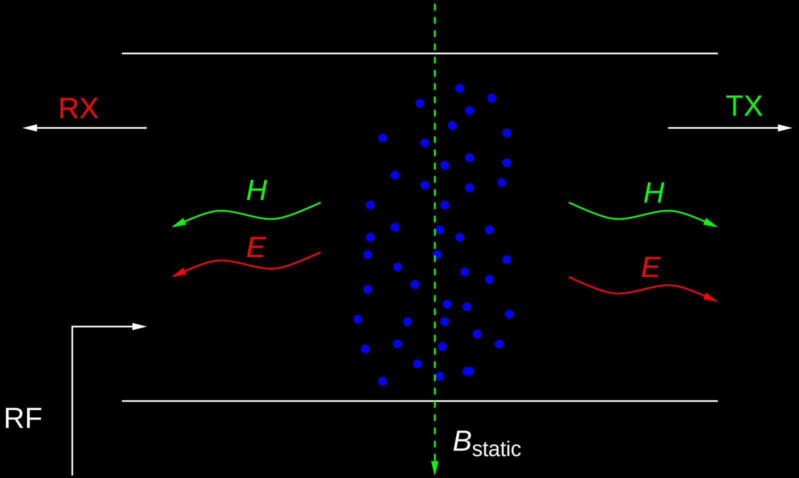
… in periodic structures

- Planar periodic structures (FSS, antenna arrays, …)
- 3D objects in a 2D/3D periodic lattice SIE-MoM procedure
- An improved retrieval procedure of artificial materials under oblique plane-wave incidence



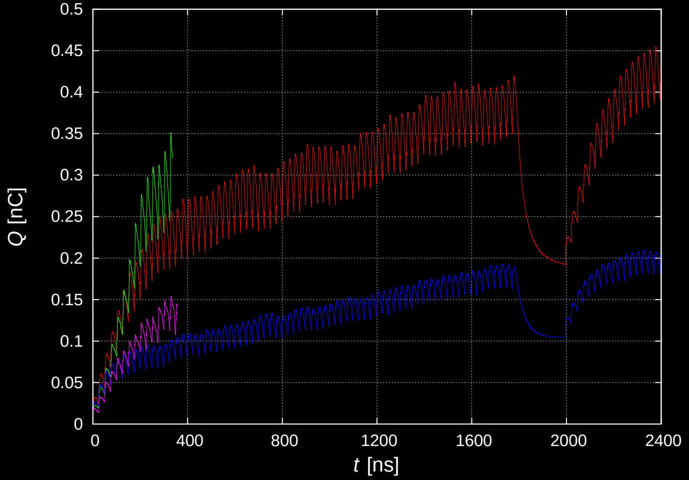


Simulation setup



RF: fundamental mode of beam-pipe is used to excite microwave field and to measure the radiated field of the e^--cloud.

Results - ecloud build up



no external field

$B_{\text{static}} = 8.33\,\text{T}$

$f_0 = 4100\,\text{MHz}$
$V_{\text{RF}} = 10\,\text{kV}$, $E_{\text{RF}} = 355\,\text{kV/m}$
$P_{\text{rms}} = 148\,\text{kW}$

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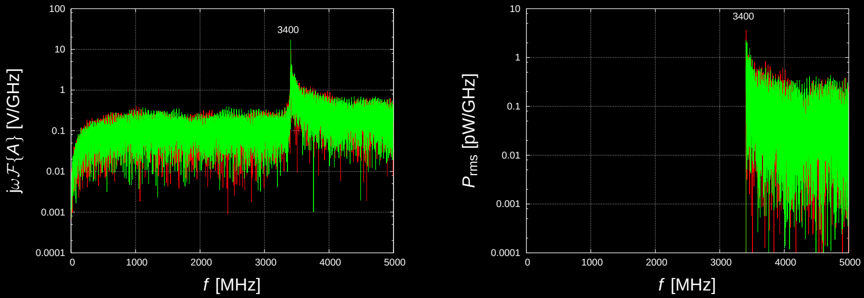
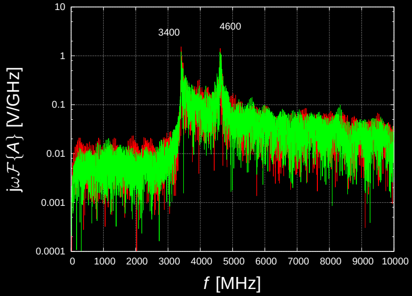
Results - no external field

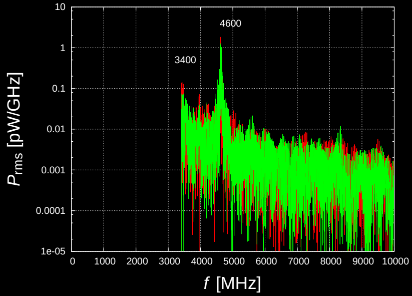


RX TX

Results - static magnetic field

$$B_{\text{static}} = 8.33\,\text{T}$$

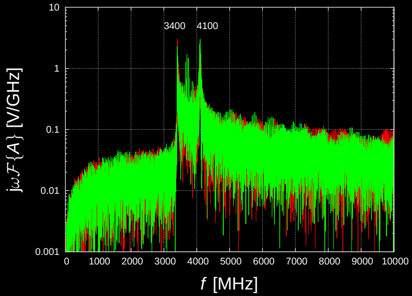


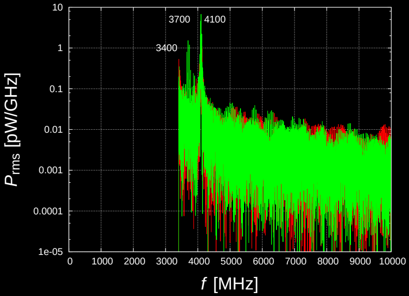


RX TX

Results - microwave field

$$f_0 = 4100\,\text{MHz},\ V_{\text{RF}} = 10\,\text{kV},\ E_{\text{RF}} = 355\,\text{kV/m},\ P_{\text{rms}} = 148\,\text{kW}$$



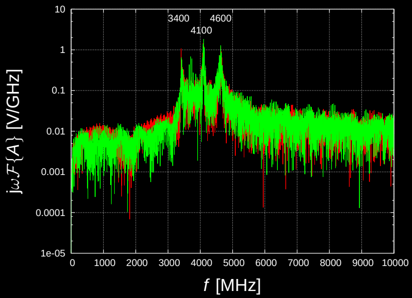


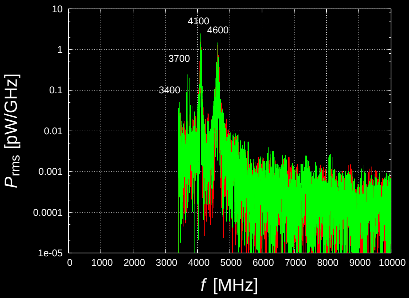
RX TX

Results - microwave & static magnetic field

$$f_0 = 4100\,\text{MHz},\ V_{\text{RF}} = 10\,\text{kV},\ E_{\text{RF}} = 355\,\text{kV/m},\ P_{\text{rms}} = 148\,\text{kW}$$

$$B_{\text{static}} = 8.33\,\text{T}$$





RX TX

Summary & Future Work

- ecloud includes microwave field excitation using beam pipe geometry
- em field radiated by e^{-}-cloud can be analyzed
- The contributions in the spectrum at 3700 MHz and 4600 MHz remain unclear for the moment. Further analysis is necessary: Dependency on
  - field strength of microwave and static magnetic field
  - microwave frequency
  - polarization of microwave field
- Excite beam pipe with a micorwave field having horizontal polarization (perpendicular to B_{static}) to check for Synchrotron effect.

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