Computing the Shielding Effectiveness of Thin Screens by the Finite Element Method

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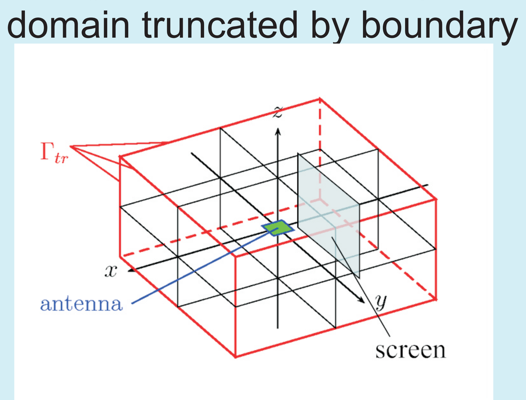
Abstract: In order to protect electronic devices and dedicated areas against exposure of RF-electromagnetic radiation very thin screening materials will be employed. Single and multi-layered metallic foils as well as meta-materials will be utilized in favor. The ambition of this contribution lies in the computation of such thin screens with the finite element (FE) method. To overcome numerical difficulties due to the very thin layers, analytical descriptions of the layers will be implemented in the FE-formulation. An improvement of the mesh truncation will be achieved by prescribing improved impedance boundary conditions containing a surface operator. A given antenna and screen arrangement has been computed and a comparison to the results, obtained with an alternative numerical model will demonstrate the efficiency and reliability of the way suggested.

Basic arrangement, antenna in point of origin, domain truncated by boundary Γ_{tr}



$$\nabla \times \vec{E} = -j\omega\mu\vec{H}, \qquad \nabla \times \vec{H} = j\omega\epsilon\vec{E}.$$

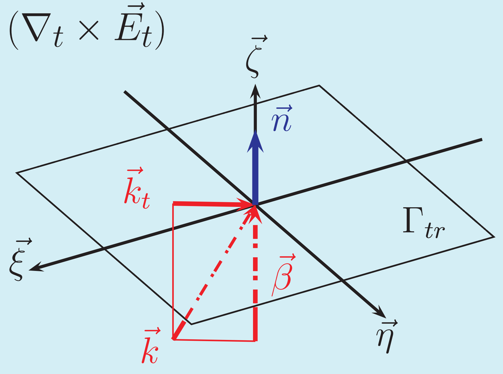
$$\vec{E} = \vec{E}_t + \vec{n}\,E_n,\ \vec{H} = \vec{H}_t + \vec{n}\,H_n,\ \nabla = \nabla_t + \frac{\partial}{\partial n}\vec{n}$$

Surface operator containing boundary conditions (SOBC)

$$\frac{\partial(\vec{n}\times\vec{E}_t)}{\partial n} = -j\omega\mu\vec{H}_t - \frac{1}{j\omega\epsilon}\nabla_t \times (\nabla_t \times \vec{H}_t)$$

$$\frac{\partial(\vec{n}\times\vec{H}_t)}{\partial n} = j\omega\epsilon\vec{E}_t + \frac{1}{j\omega\mu}\nabla_t \times (\nabla_t \times \vec{E}_t)$$

$$\vec{k} = \vec{k}_t + \vec{\beta}$$
$$\beta = \pm\sqrt{k^2 - k_t^2}$$
$$k = \omega\sqrt{\mu\epsilon}$$



$$\int_{\zeta=0}^{\infty} \vec{H}_{t_0} e^{-j\beta\zeta} d\zeta = \frac{1}{j\beta}\vec{H}_{t_0},\ \int_{\zeta=0}^{\infty} \vec{E}_{t_0} e^{-j\beta\zeta} d\zeta = \frac{1}{j\beta}\vec{E}_{t_0}$$

$$\vec{n}\times\vec{E}_{t_0} = \frac{-\omega\mu\vec{H}_{t_0}}{\sqrt{k^2-k_t^2}} + \frac{\nabla_t \times (\nabla_t \times \vec{H}_{t_0})}{\omega\epsilon\sqrt{k^2-k_t^2}}$$

$$\vec{n}\times\vec{H}_{t_0} = \frac{\omega\epsilon\vec{E}_{t_0}}{\sqrt{k^2-k_t^2}} - \frac{\nabla_t \times (\nabla_t \times \vec{E}_{t_0})}{\omega\mu\sqrt{k^2-k_t^2}}$$

$$\vec{n}\times\vec{E}_{t_0} = \frac{-\omega\mu\vec{H}_{t_0}}{\sqrt{k^2-k_t^2}} - \frac{\vec{k}_t \times (\vec{k}_t \times \vec{H}_{t_0})}{\omega\epsilon\sqrt{k^2-k_t^2}}$$

$$\vec{n}\times\vec{H}_{t_0} = \frac{\omega\epsilon\vec{E}_{t_0}}{\sqrt{k^2-k_t^2}} + \frac{\vec{k}_t \times (\vec{k}_t \times \vec{E}_{t_0})}{\omega\mu\sqrt{k^2-k_t^2}}$$

Galerkin equation for the A,v-formulation:

$$-\int_{\Omega} \nabla\times\vec{N}_i \cdot \frac{1}{\mu}\nabla\times\vec{A}\,d\Omega + \int_{\Gamma_H} \vec{N}_i \cdot \underbrace{(\vec{n}\times(\frac{1}{\mu}\nabla\times\vec{A}))}_{\vec{n}\times\vec{H}}\,d\Gamma$$
$$+ \int_{\Omega} \vec{N}_i \cdot (\sigma + j\omega\epsilon)j\omega(\vec{A} + \nabla v)d\Omega = 0$$

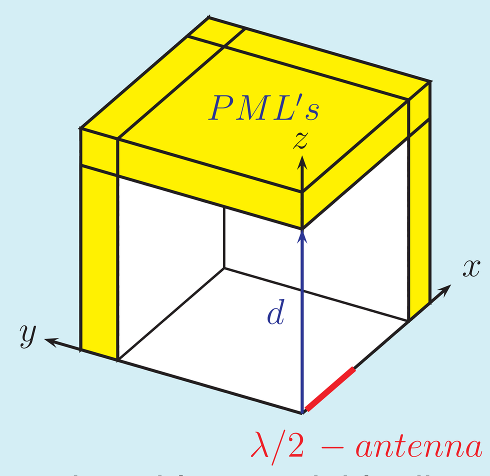
Galerkin equation for the T,F-formulation:

$$-\int_{\Omega} \nabla\times\vec{N}_i \cdot \frac{1}{\gamma}\nabla\times\vec{T}\,d\Omega + \int_{\Gamma_E} \vec{N}_i \cdot \underbrace{(\vec{n}\times(\frac{1}{\gamma}\nabla\times\vec{T}))}_{\vec{n}\times\vec{E}}\,d\Gamma$$
$$+ \int_{\Omega} \vec{N}_i \cdot j\omega\mu(\vec{T} - \nabla\Phi)d\Omega = 0$$

Surface impedance boundary conditions (SIBC)

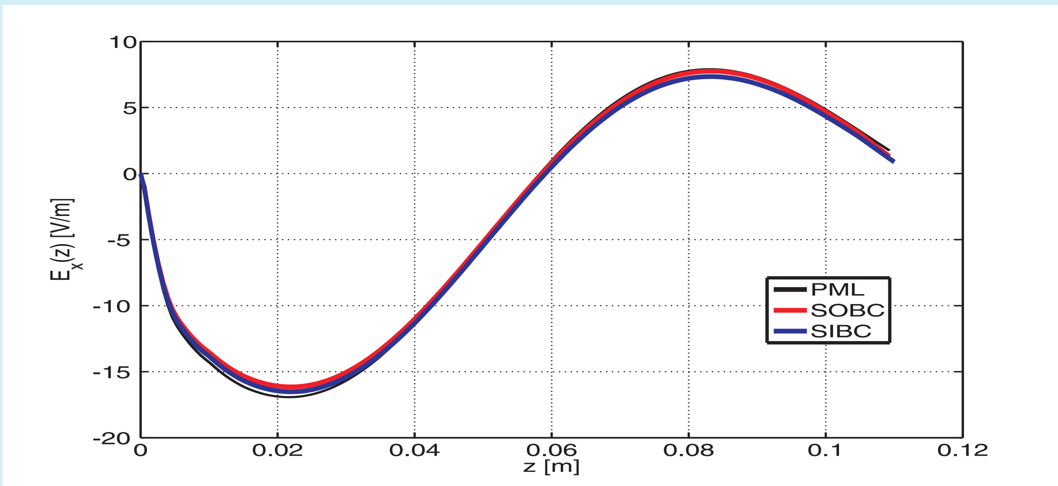
$$\vec{n}\times\vec{E}_{t_0} = \frac{-\omega\mu\vec{H}_{t_0}}{k} = -\sqrt{\frac{\mu}{\epsilon}}\vec{H}_{t_0} = -Z_0\vec{H}_{t_0}$$

$$\vec{n}\times\vec{H}_{t_0} = \frac{\omega\epsilon\vec{E}_{t_0}}{k} = \sqrt{\frac{\epsilon}{\mu}}\vec{E}_{t_0} = \frac{1}{Z_0}\vec{E}_{t_0}$$

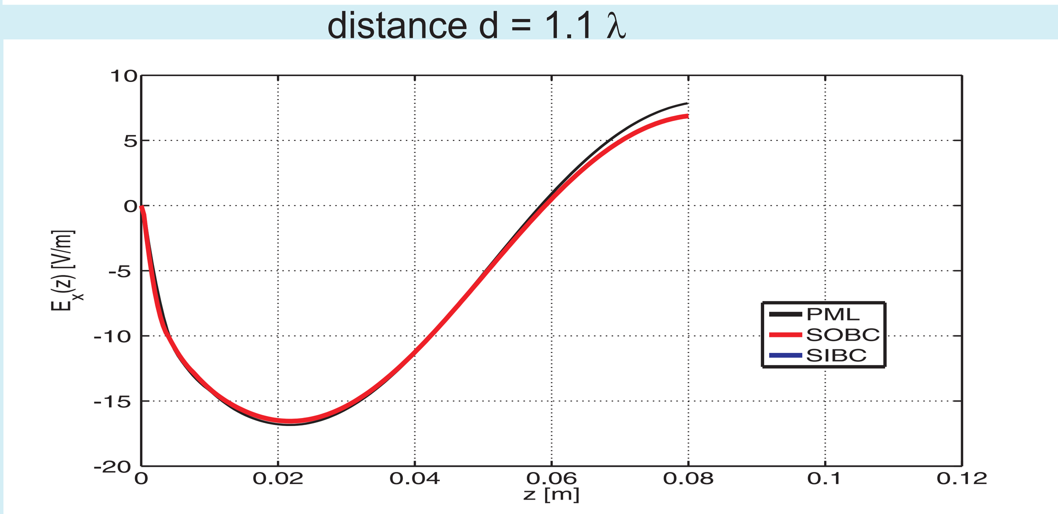


Benchmark problem, variable distance d

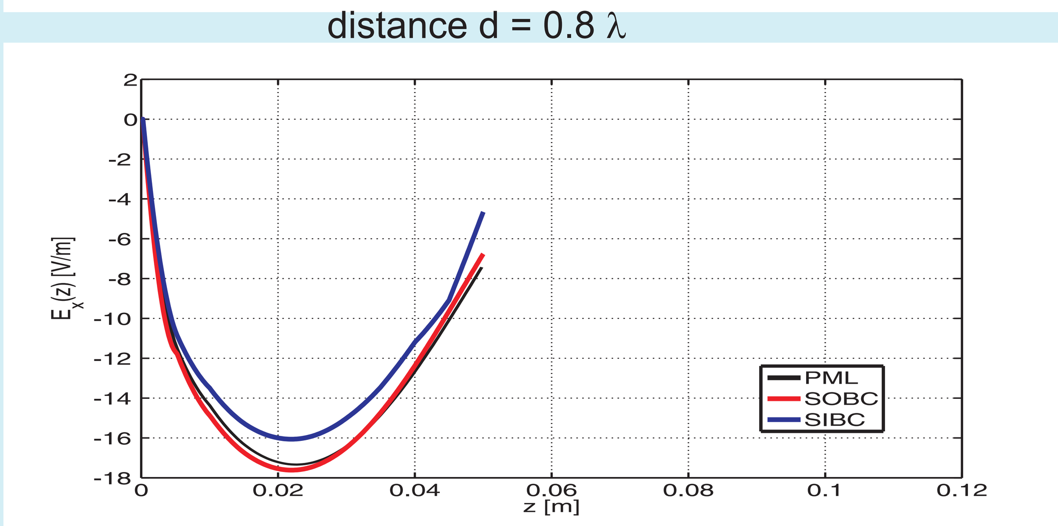
Influence of the disdance d:



distance d = 1.1 λ



distance d = 0.8 λ

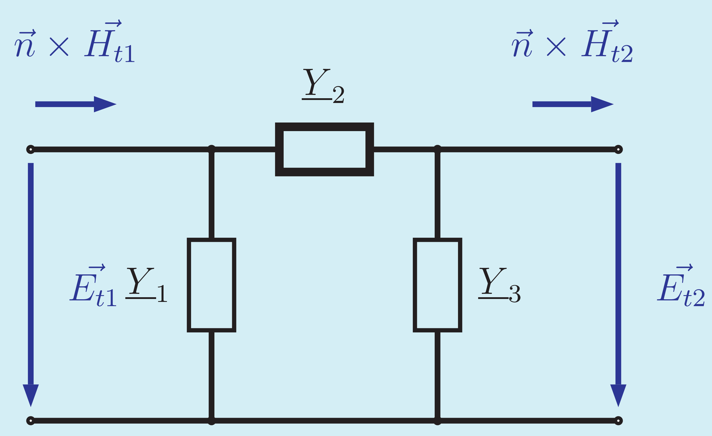


distance d = 0.5 λ

Computational effort

d	-	PML	SOBC	SIBC
1.1 λ	DOF	401.275	269.377	269.377
	NIT	7.283	2.359	2.316
	sec	5.952	1.505	1.465
0.8 λ	DOF	200.251	119.845	119.845
	NIT	4.283	1.461	1.802
	sec	1.761	368	510
0.5 λ	DOF	80.371	38.929	38.929
	NIT	1.582	684	737
	sec	252	55	71

Network circuit model of a metallic thin layer

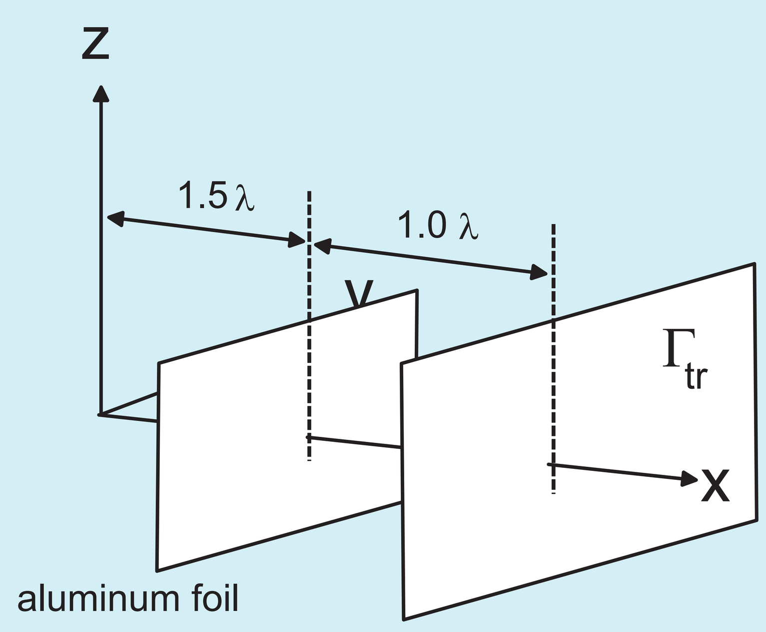


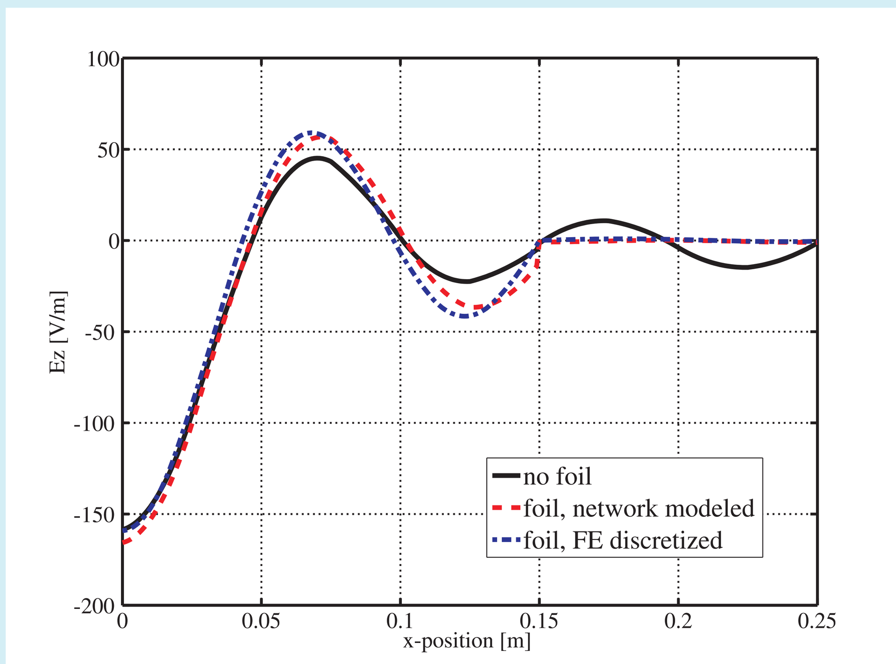
$$\left\{ \begin{array}{c} \vec{n}\times\vec{H}_{t1} \\ \vec{n}\times\vec{H}_{t2} \end{array} \right\} = \left[\begin{array}{cc} \bar{Y}_{11} & \bar{Y}_{12} \\ \bar{Y}_{21} & \bar{Y}_{22} \end{array} \right] \cdot \left\{ \begin{array}{c} \vec{E}_{t1} \\ \vec{E}_{t2} \end{array} \right\}$$

$$\bar{Y}_{11} = \underline{Y}_1 + \underline{Y}_2 \qquad \bar{Y}_{12} = -\underline{Y}_2$$
$$\bar{Y}_{21} = \underline{Y}_2 \qquad \bar{Y}_{22} = -\underline{Y}_2 - \underline{Y}_3$$

$$\underline{k} = \sqrt{\omega^2\epsilon\mu - \sigma\mu j\omega} = \sqrt{-(\sigma + j\omega\epsilon)j\omega\mu}$$

Computed arrangement





Ez along the x-axis, aluminum foil thickness 10 μm

Conclusion:

Efficient FE-mesh truncation by surface operator containing integral

No need of modeling PML’s, good conditioned system of equations

Convenient modeling of thin metallic layers with a network model