SIMULATION OF CHERENKOV DIFFRACTION RADIATION FOR VARIOUS RADIATOR DESIGNS

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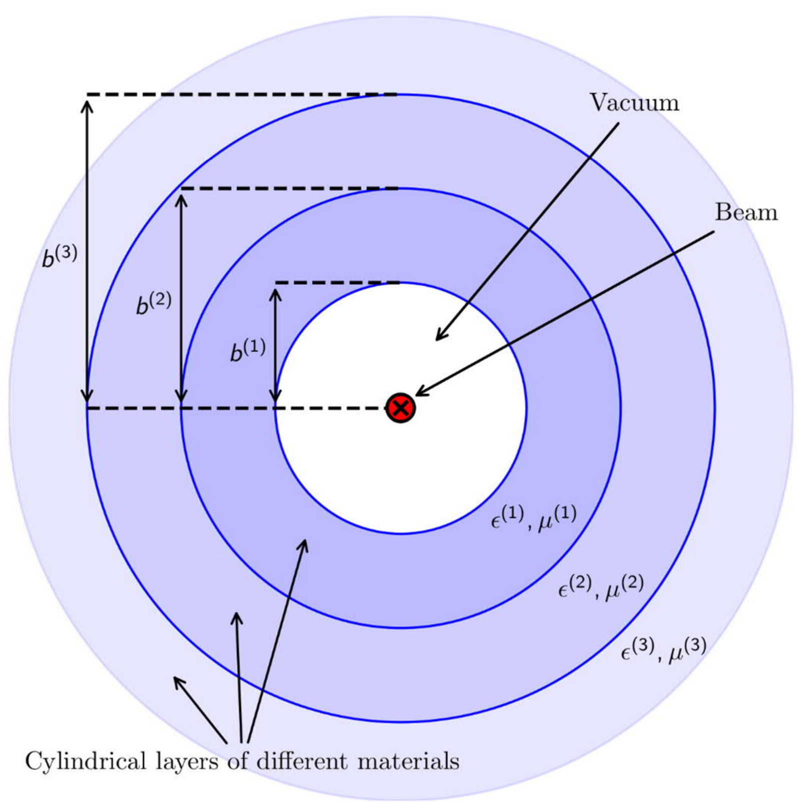
Introduction

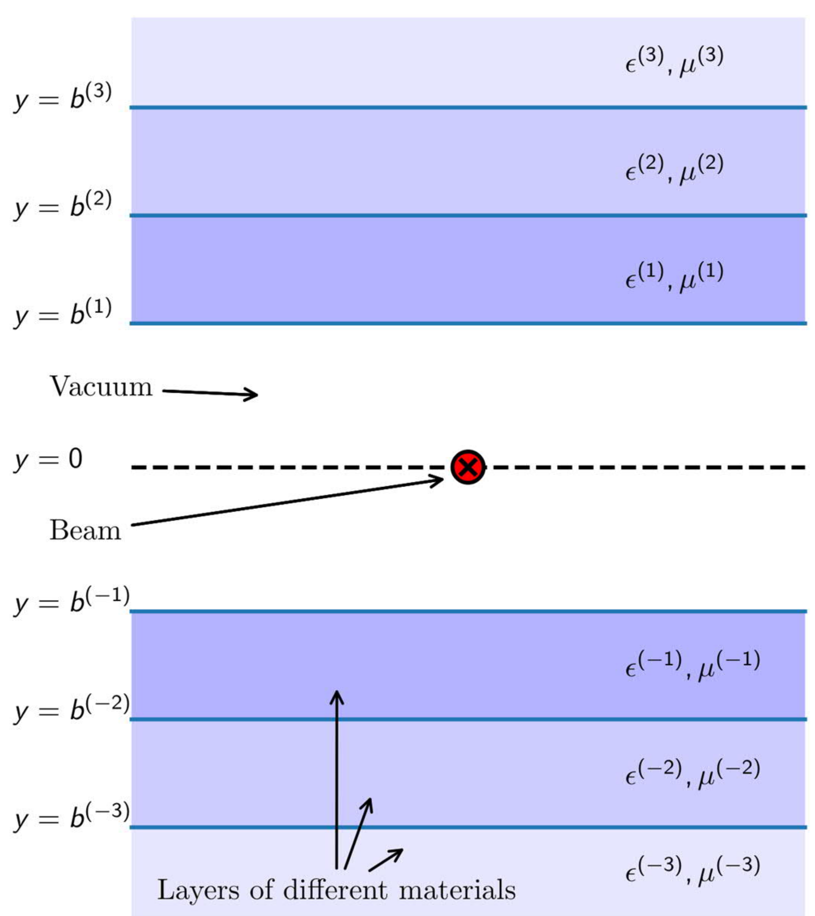
The aim of this contribution is to present a semi-analytical approach to Cherenkov Diffraction Radiation (ChDR) simulations. It is based on numerical calculations of the beam field propagating across surrounding materials, according to constraints set by the Maxwell equations. The presented procedure describes radiators infinite in the direction of beam propagation, but gives the possibility of studying complex multilayer structures orthogonal to the direction of beam propagation. The proposed method should be treated as a natural extension of a framework for beam impedance calculations, developed at CERN [1].

Cylindrical Geometry

We shall start from considering the geometry presented in the figure on the right, which is described using cylindrical coordinates r, θ and s. A charged particle travels with the velocity $v = \beta c$ along the s axis in the centre of an axisymmetric structure, consisting of an arbitrary number of layers. Each layer has a distinct permittivity ε_i and permeability μ_i, which may be frequency dependent. The central layer is constrained to be vacuum, but the subsequent layers may be any material, with the outermost layer extending to infinity.



Flat Geometry



The next geometry considered is a flat geometry described using Cartesian coordinates x, y and s. It consists of a series of infinitely long (in s direction) and wide (in x direction) plates, each having its own thickness, permittivity ε_i and permeability μ_i. A charged particle travels in s direction inside the central layer, which again we constraint to be vacuum. It is also assumed that the top and bottom outermost layers are infinitely thick. An example of such a structure is presented on the left.

Cherenkov Diffraction Radiation

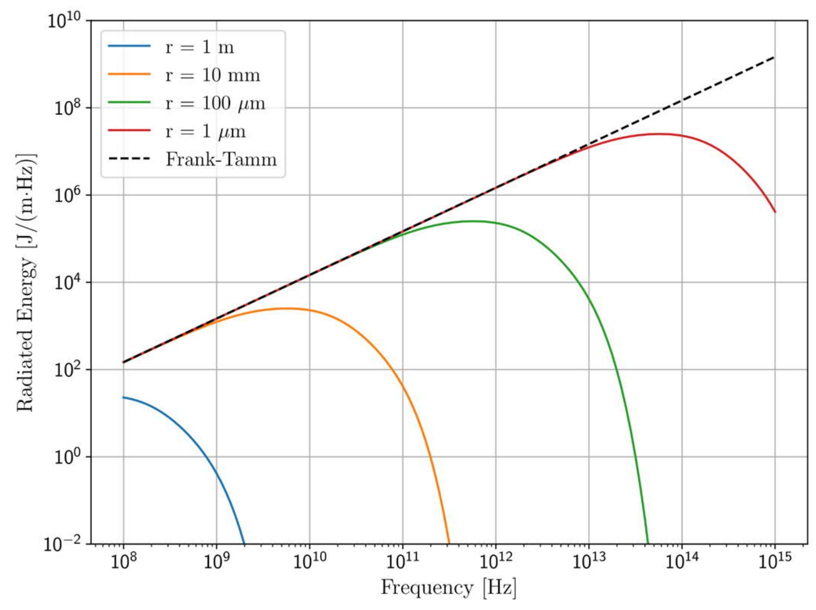
The two discussed geometries are suitable to study the properties of ChDR. To do this we choose the outermost layer to be a dielectric and place the probe point at a given depth inside this layer. The dielectric layer is set to be infinitely thick in order to avoid reflections from its outermost surface. The theory presented in [1] provides the possibility to calculate all the components of the EM field in frequency domain for a probe point located anywhere inside described geometries. If we create a grid of probe points, we are able to estimate either a total radiated energy, or the spatial distribution of the radiation by applying the following relation for radiated energy:

$$\Delta E = \frac{1}{2\pi} \int d\omega \oiint_{\partial V} \vec{P}(\omega) \cdot d\mathbf{A},$$

where

$$\vec{P}(\omega) = \Re \left[\vec{E}(\omega) \times \vec{H}^{*}(\omega) \right].$$

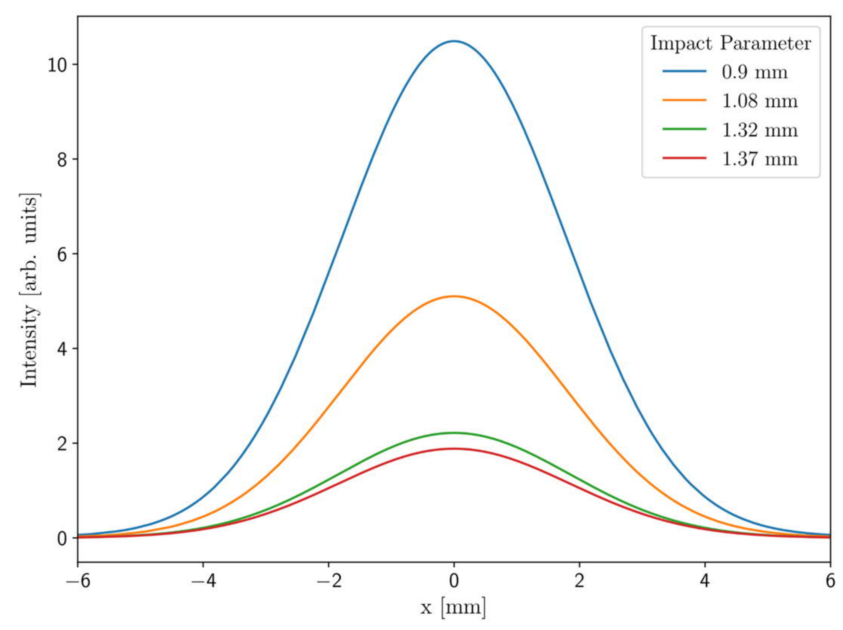
Results



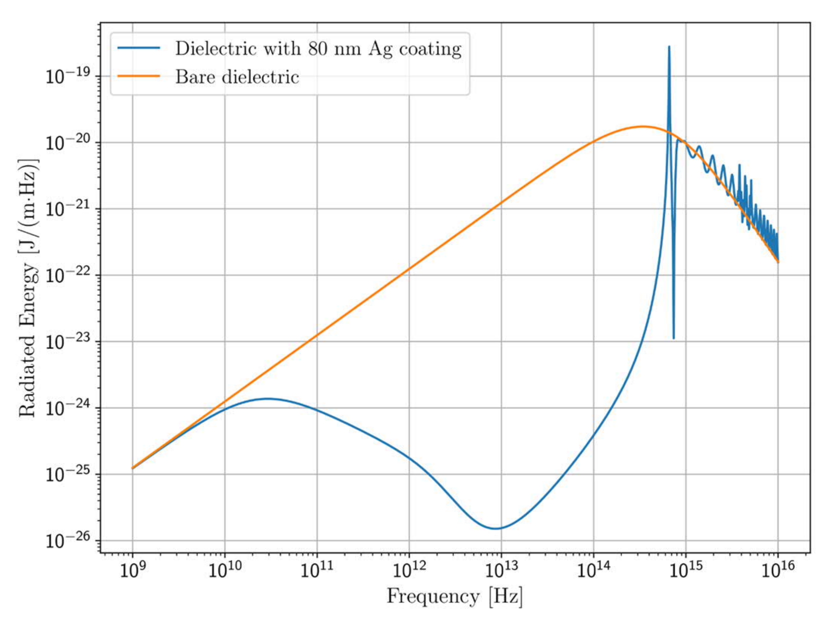
In order to validate the presented approach we compare it with the well-establised Frank-Tamm formula for a particle passing directly through the medium [2]. We calculate the radiation emitted by a particle travelling inside a cylindrical tunnel cut inside the infinite dielectric. By reducing the radius of the cylinder we converge to the distribution given by the Frank-Tamm model.

Spatial Distribution of ChDR

A dense grid of probe points, in which we calculate electromagnetic field components, allows us to estimate the radiation spatial distribution and monitor which parts of the radiator effectively interact with the beam. This study corresponds to the experimental results reported in [3]. On the right we see a horizontal profile of ChDR (600 THz) at 2 mm depth inside the flat dielectric.



Metallic Nanolayers



The presence of a thin metallic layer between the beam and the dielectric may lead to the excitation of Surface Plasmon Polaritons (SPP) on the metal-vacuum and metal-dielectric intersection. As a consequence, one observes the creation of monochromatic ChDR with significantly enhanced intensity for particular frequencies [4]. The plot on the left shows a possible SPP resonance in a geometry compatible with an Dielectic Laser Accelerator described in [5].

Conclusion

The approach presented in this contribution facilitates calculation of ChDR spectral distributions. In particular, it enables the effect of using multilayer radiators composed of various materials (metals, dielectrics, lossy media) to be studied. It has been implemented in the form of C++ code with a Python wrapper included. In addition, actions toward integrating it with Polarisation Currents Approach (PCA) [6] to form a single, independent simulation package are ongoing.

Bibliography

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