Numerical modelling of ground penetrating radar antennas

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Numerical Modeling of Ground Penetrating Radar Antennas

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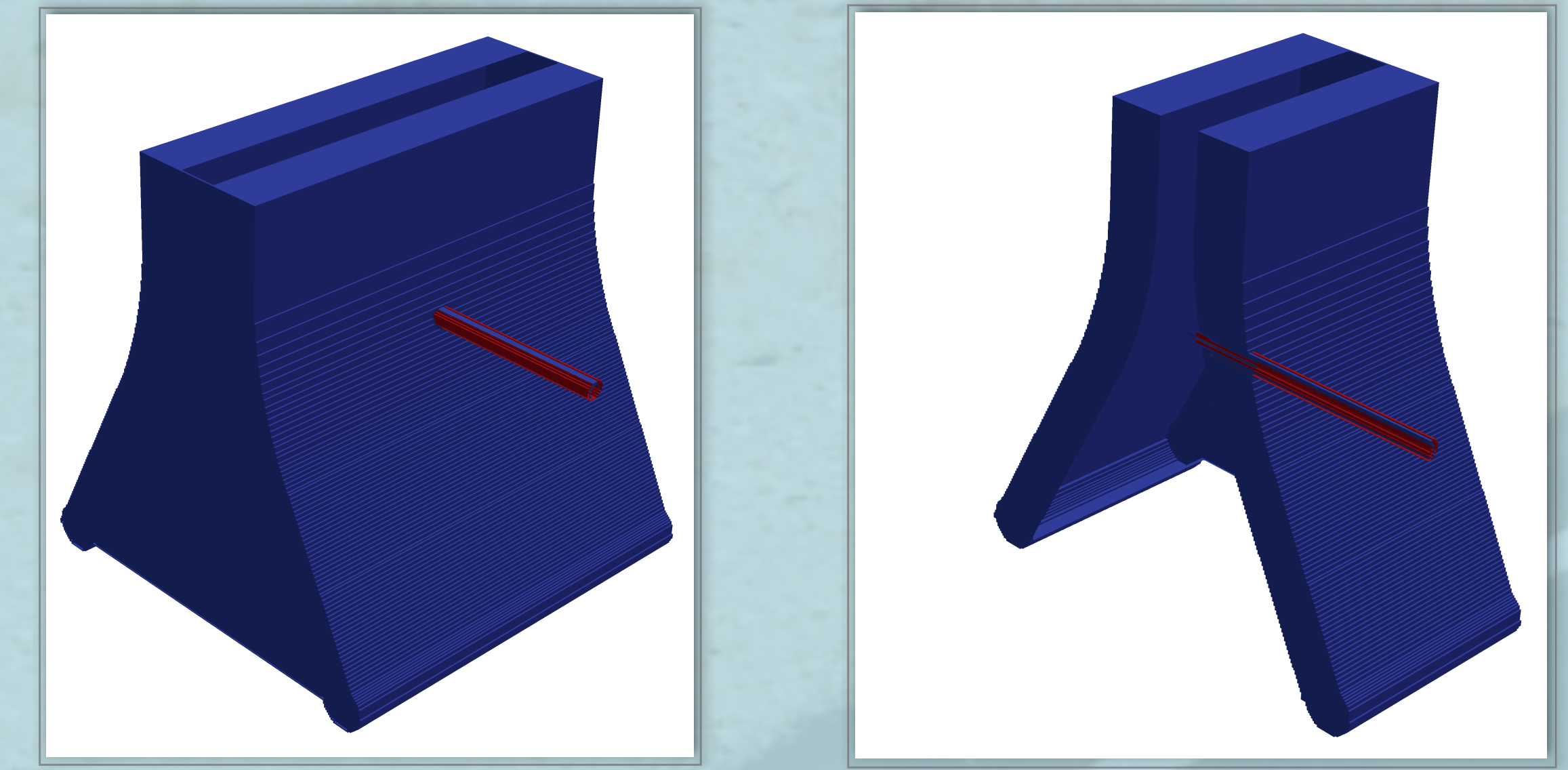
Introduction

Air coupled antennas like horn antennas have been extensively used for pavement evaluation using Ground Penetrating Radar (GPR). The main reasons for that are :

- Low spatial resolution
- Capable to detect thin layers
- Safely operates in highway speeds because it doesn't need to be close to the ground
- Easy to manufacture

A high frequency 2.6 GHz monostatic horn antenna is modeled using GprMax (Giannopoulos 2005) a free software which solves Maxwell's equations using a second order in both space and time finite difference time domain (FDTD) algorithm. The modeled antenna is numerically tested in a realistic pavement evaluation scenario.

Waveguide feed



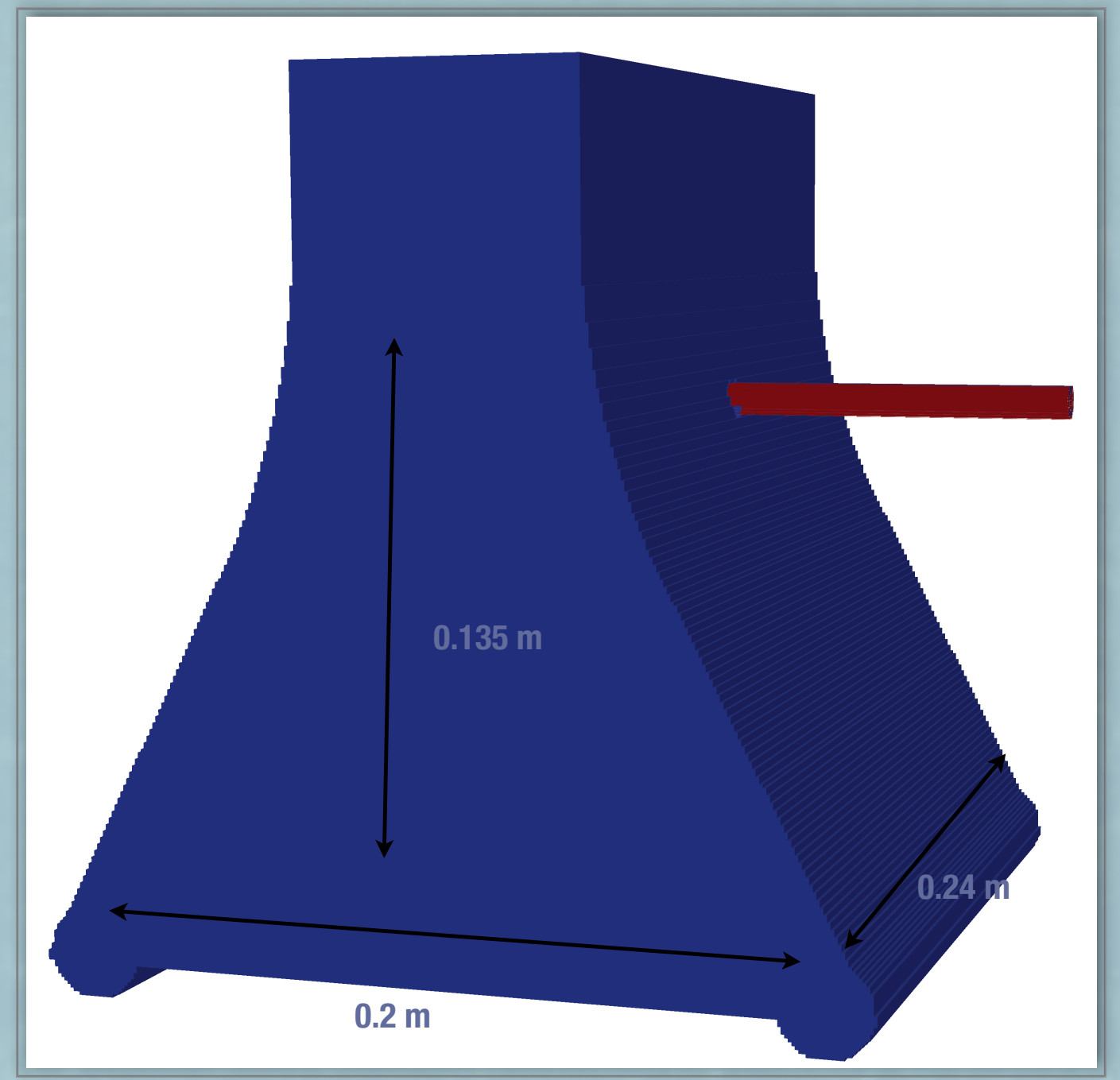
The antenna probing instrumentation is more complex and expensive when the antenna is working with multiple modes. The goal of the suggested antenna is to use a dominant TE10 mode in a frequency range of roughly 0.5 - 6 GHz.

The cutoff frequency of different modes in a rectangular waveguide is given by

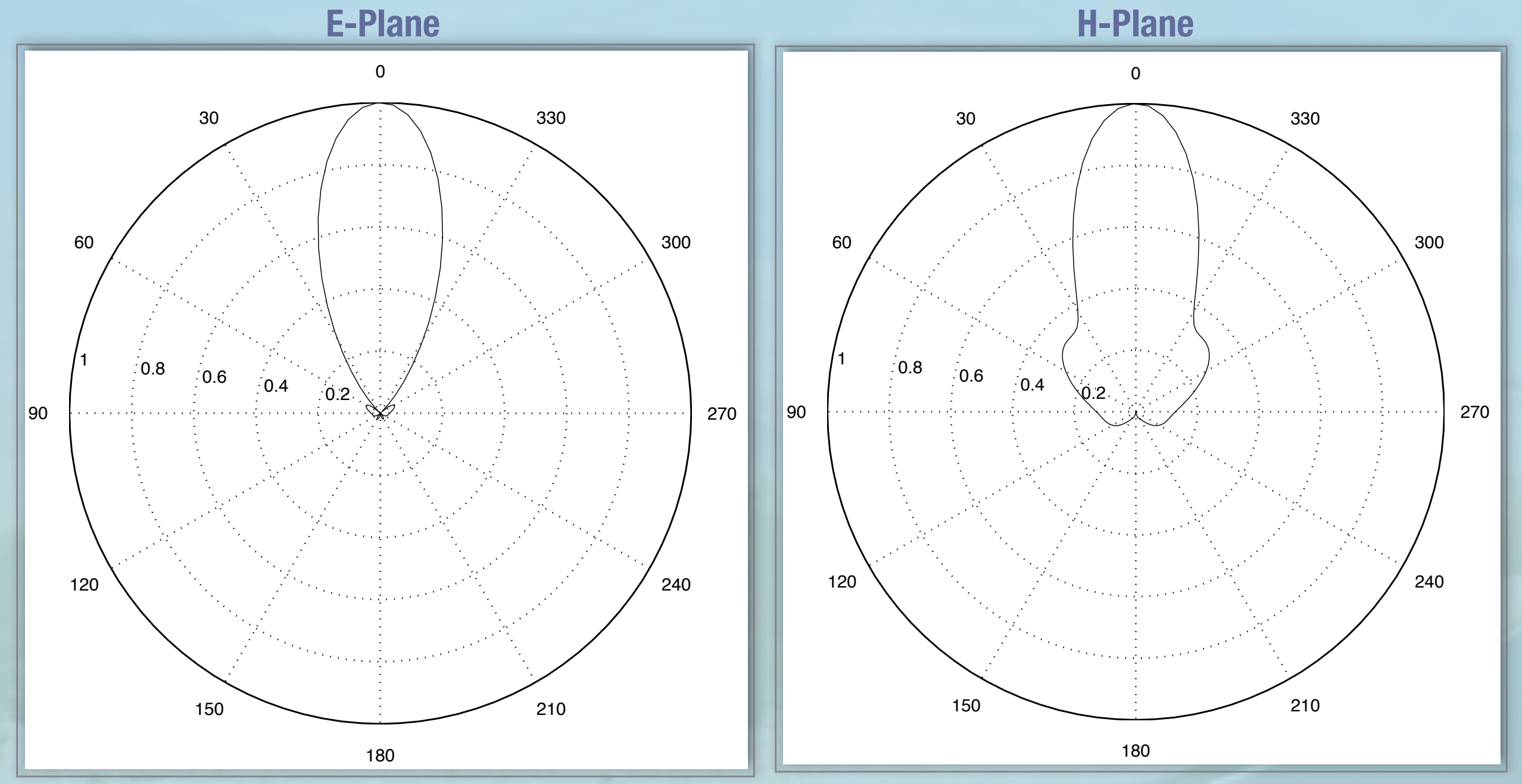
$$f_{mn} = \frac{1}{2\pi\sqrt{\mu\epsilon}}\sqrt{\left(\frac{m\pi}{\alpha}\right)^2 + \left(\frac{n\pi}{b}\right)^2}$$

Where m and n are the mode indexes, a and b are the dimensions of the waveguide. We use a rectangular waveguide with dimensions 0.25 m and 0.022 m. The suggested waveguide can act as a single mode TE10 waveguide in the frequency range 0.6 - 6.8 GHz. We use a TE10 mode with central frequency 2.6 GHz to excite the waveguide.

Field patterns

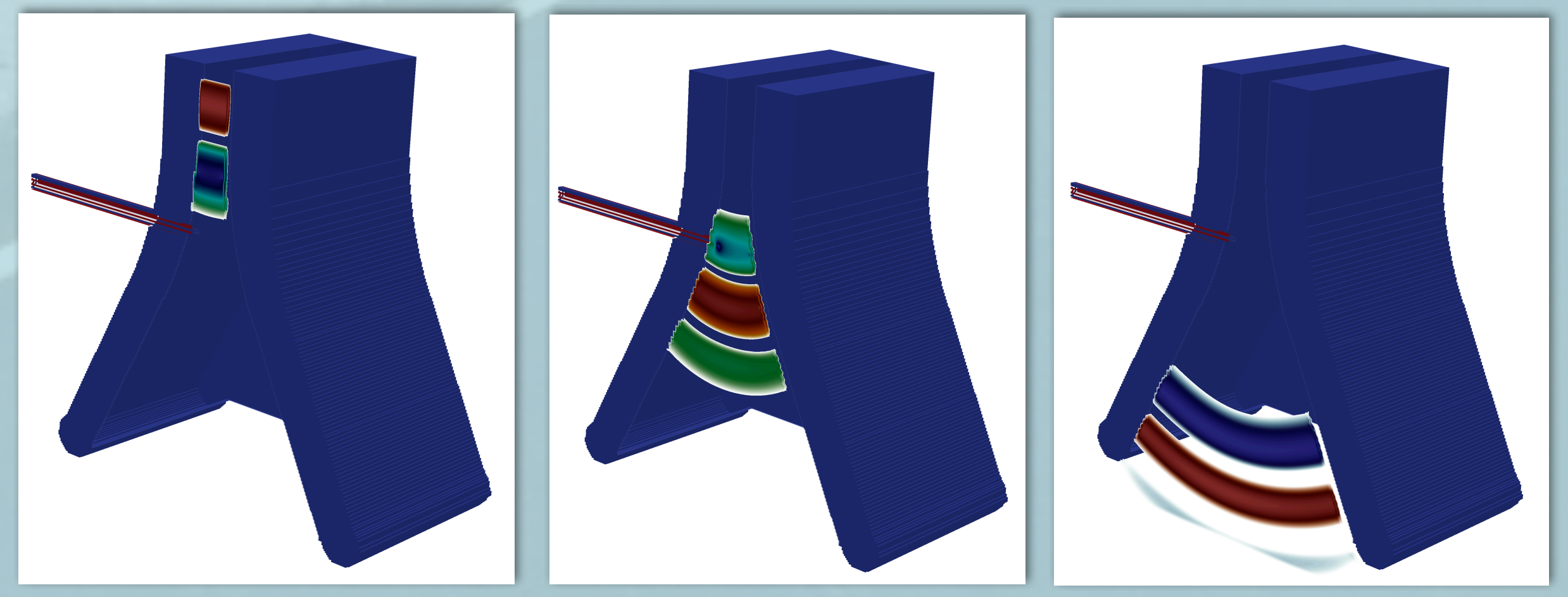


The field patterns were calculated theoretically from the geometry of the horn. They are valid for only one frequency 2.6 GHz (the central frequency of the antenna). Since the antenna is an air coupled antenna the field patterns correspond to the far field.



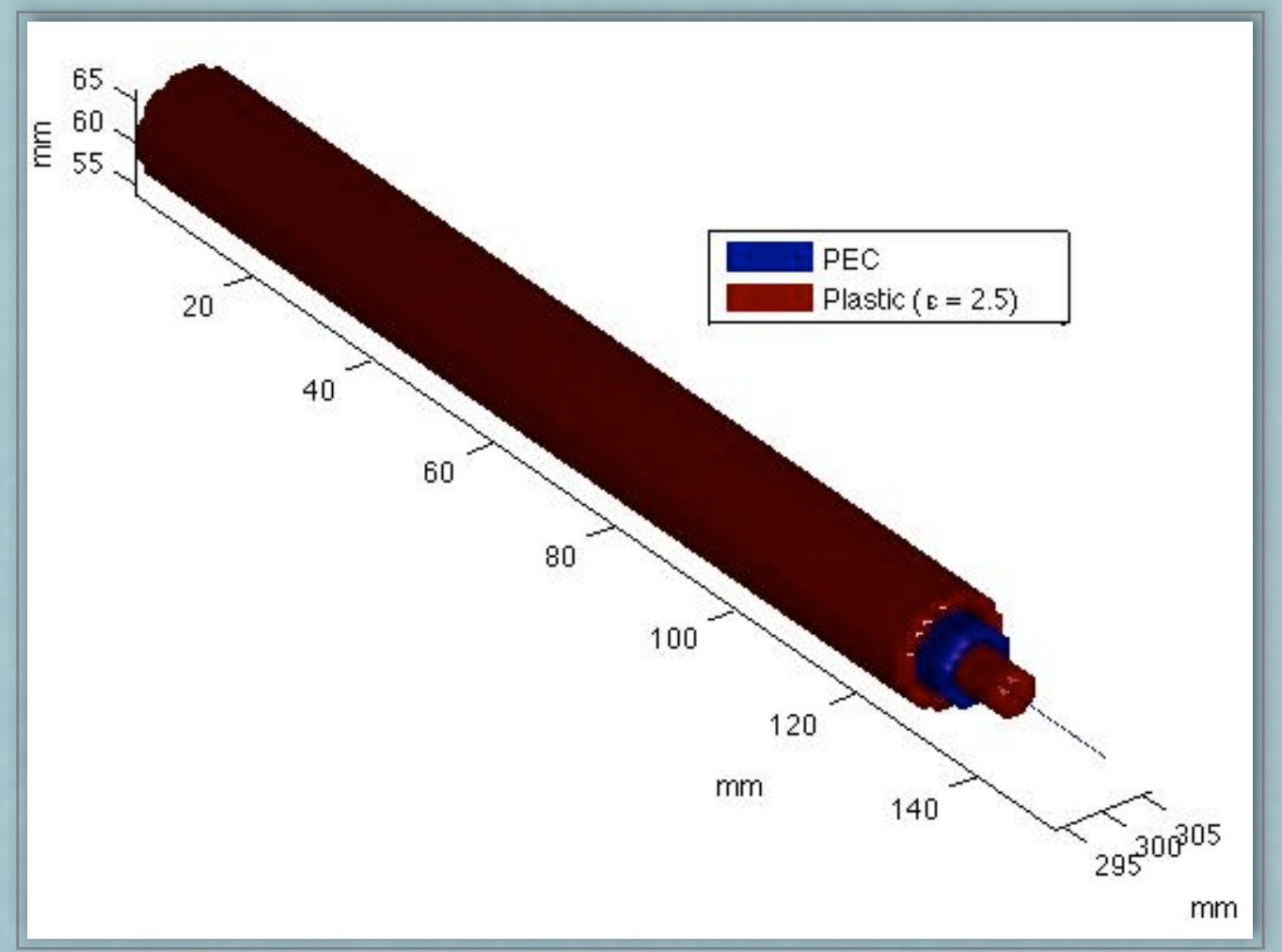
In the theoretically calculated field patterns the back lobes are not taken into account. The curved surfaces at the edges of the horn were used in order to reduce back lobes and also to minimize the reflections at the aperture.

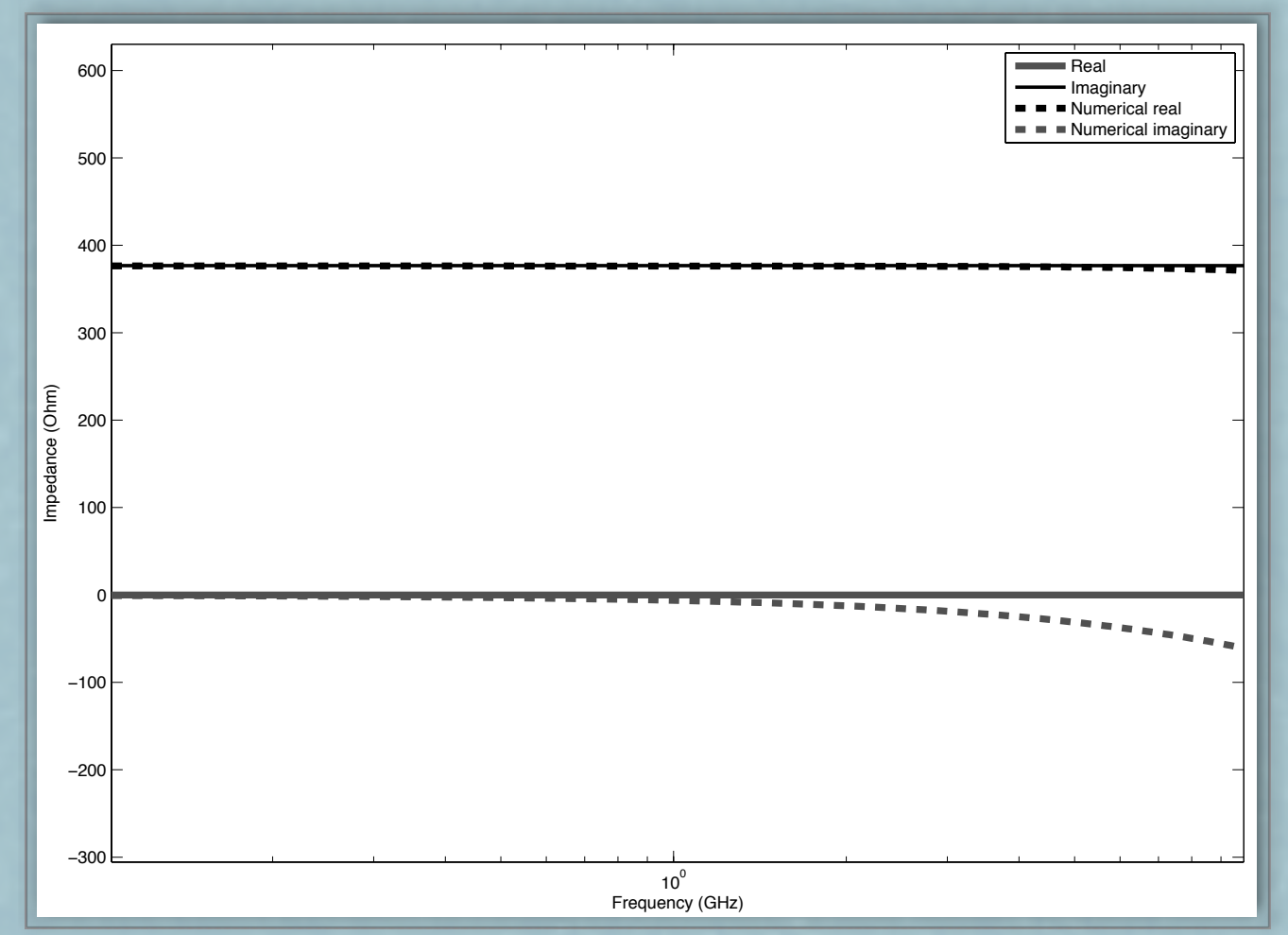
Absorber



For numerical reasons arising from constrained computational resources the absorber of the proposed antennas is not modeled. Instead of that we extend the waveguide to the perfectly matched layer (PML) in which the back traveling wave is attenuated.

Coaxial cable



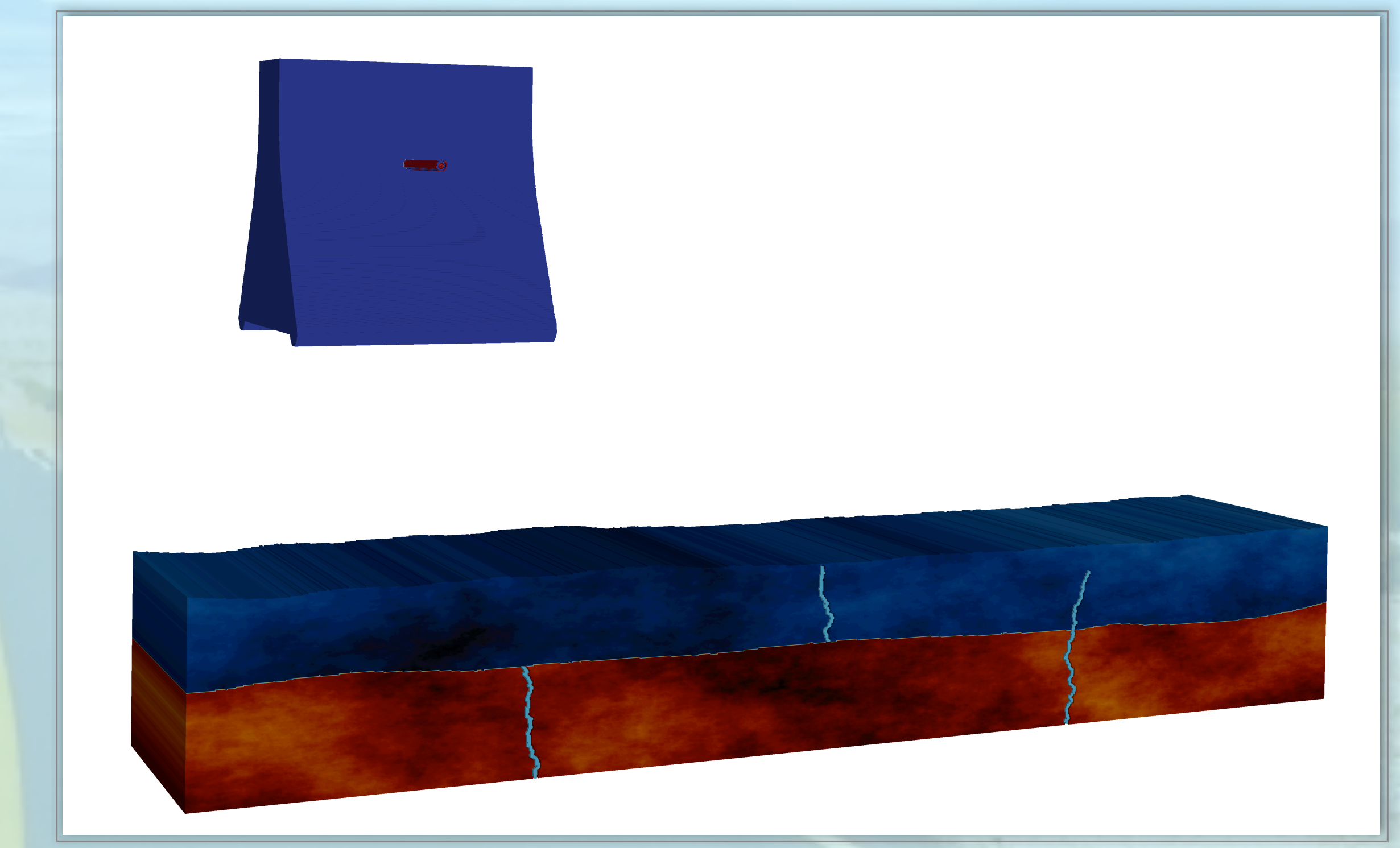


The receiving coaxial cable has a total radius of 0.5 cm. It is consisted of three layers. The first one is the protective plastic, the second one is the perfect conductor and the third one is also plastic. The inner conductor is modeled using only one Yee cell with discretization step equal 1 mm. The coaxial cable is terminated in the PML similar with the waveguide.

In order to test the validity of the modeled coaxial cable we compare the numerically calculated and the real impedance of a coaxial cable filled with air. In order to do that we excite the coaxial cable with a TEM10 mode. The results are in good agreement for the frequency range of interest.

Using a coaxial cable as a receiver in a FDTD numerical modeling, allow us to receive the current flowing in the inner conductor of the coaxial cable or the voltage difference between the inner and the outer conductor.

Pavement evaluation



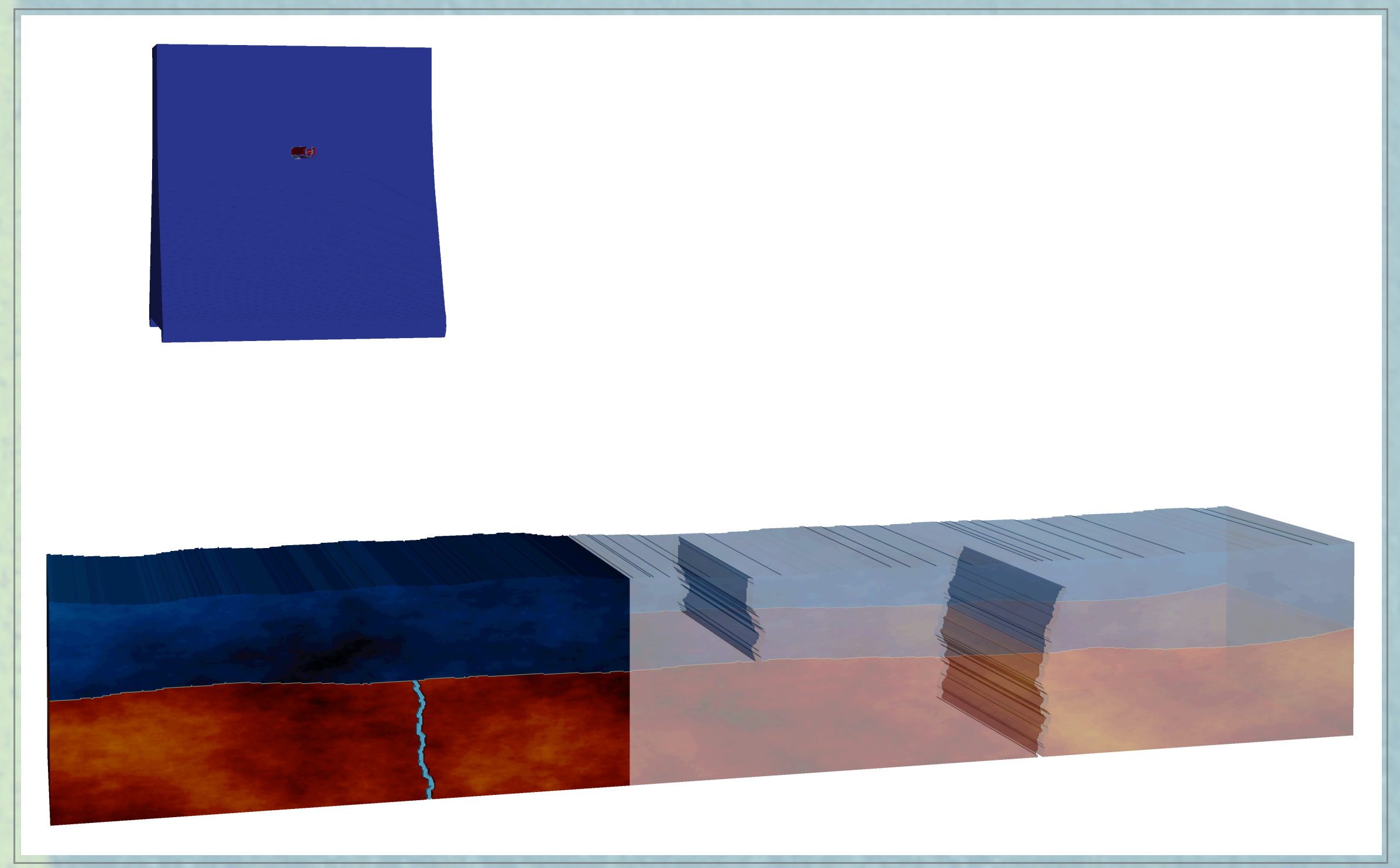
In the present case study the proposed antenna is tested in a realistic pavement evaluation scenario. The pavement is consisted with two layers, the asphalt layer and the base. The asphalt layer has a relative electrical permittivity which varies stochastically from 6-8 and the base from 10-12. The conductivity of both layers is 0.01 S/m. Fractals were used in order to create realistic variations of the dielectric properties within each layer.

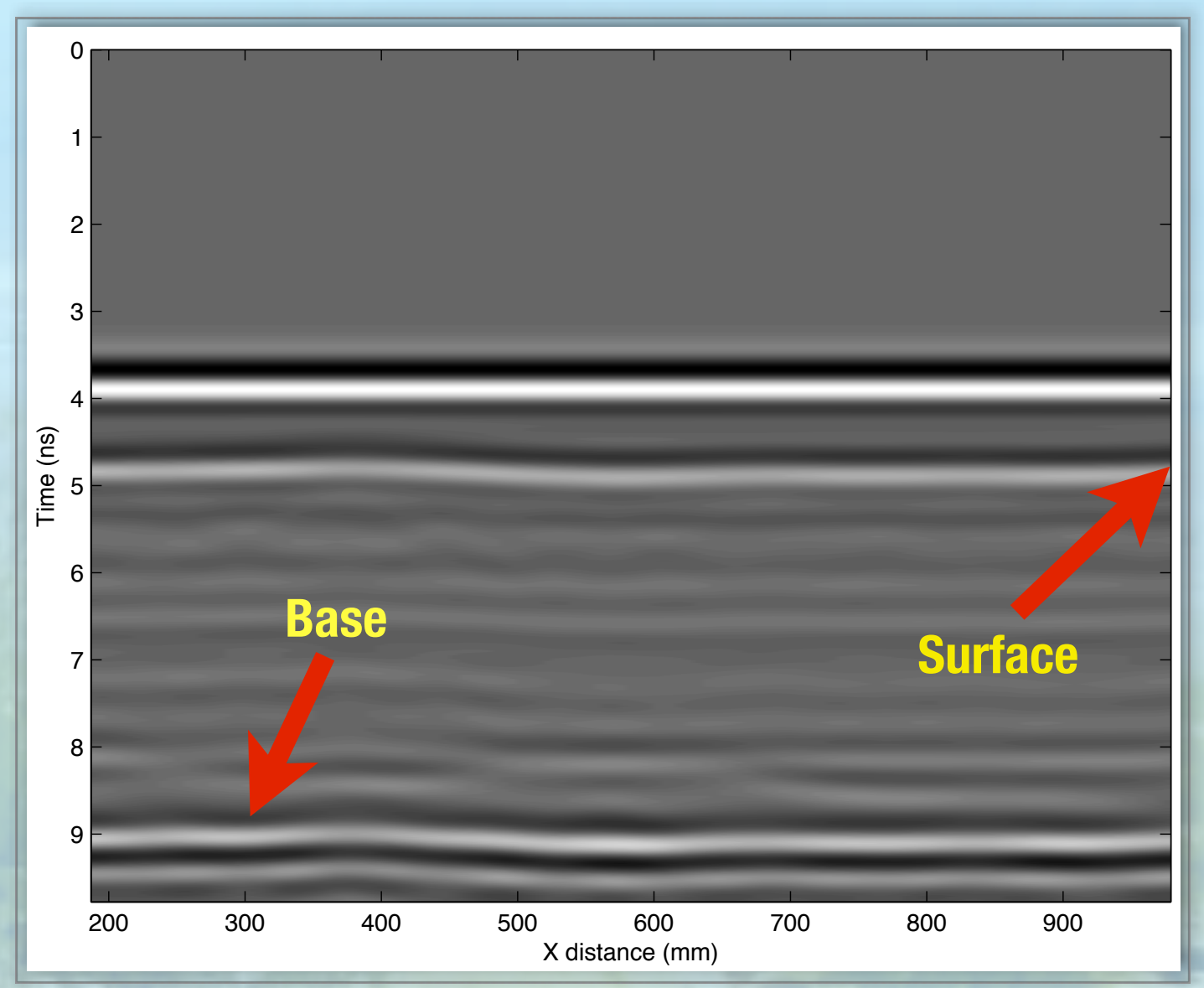
The surface is relative smooth with small variation as it is expected in old or highly used roads. Again fractals were used to incorporate the rough surface.

Three cracks which were created using random walks are implemented into the model. The cracks are filled with air and their width is 3 mm. One of them occurs in the first layer but does not reach the surface (its not visible), one of them occurs in the second layer and the third one occurs in both layers.

The dimensions of the model are 1300 x 300 x 600 (x,y,z). The discretization spatial step is 1 mm and the time step is 1.925 ps (Courant limit). The simulations run in parallel using the cluster computer provided by The University of Edinburgh [2].

In order to reduce the computational cost, we divide the domain in subdomains according to the position of the antenna unit. Its trace of the resulting B-scan is calculated in a different subdomain. With this, we assume that the scattering field which occurs outside of the subdomains is negligible compared with the scattering field inside the subdomains. This assumption was made based on the field patterns given previously.

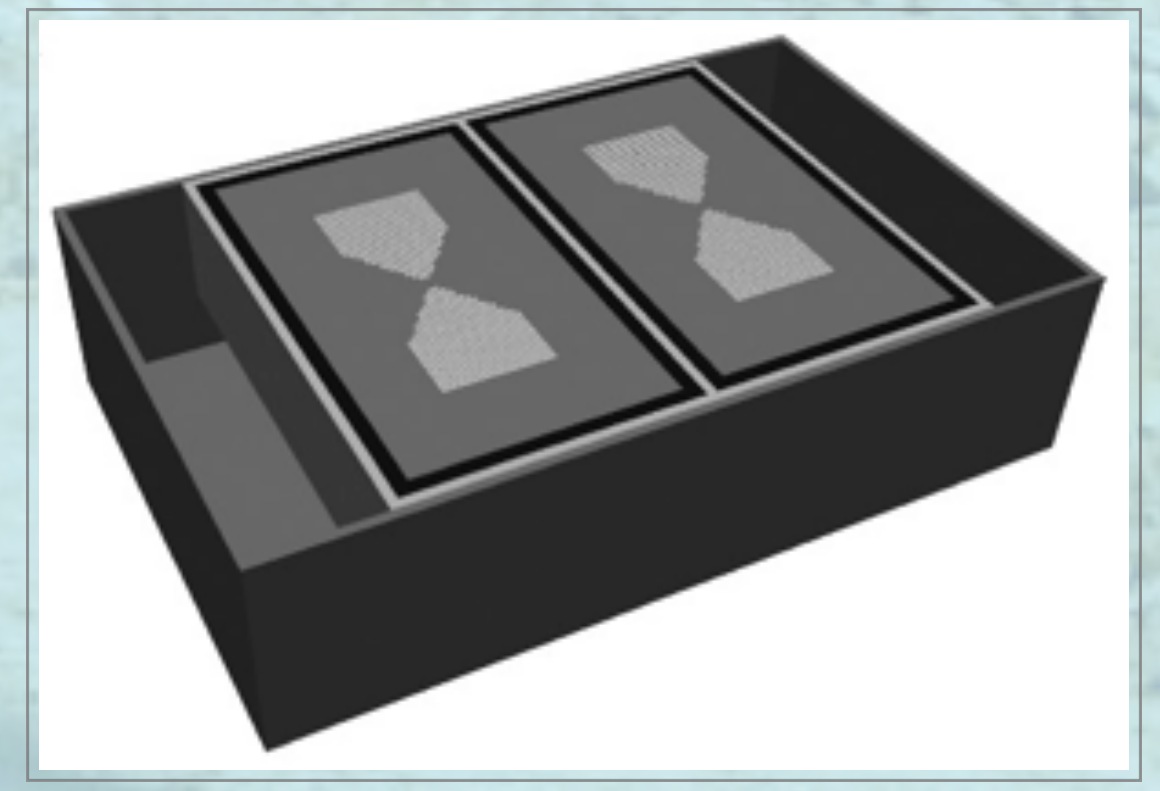




From the resulting B-scan (with a linear gain applied) it is evident that the proposed antenna obtains clear reflections from the base layer and that the cracks and the inhomogeneity's play negligible role to the resulting B-scan.

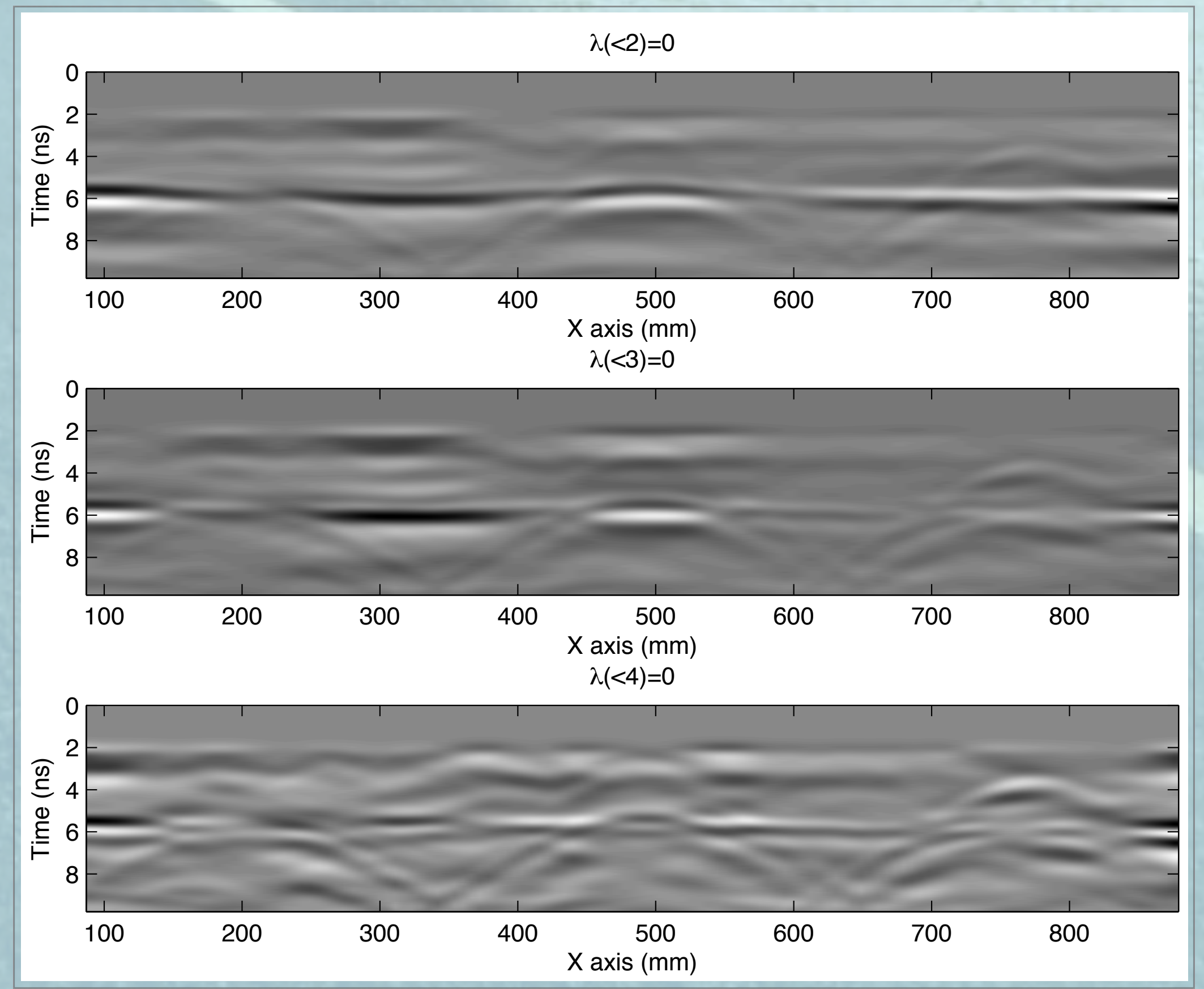
From the above we conclude that the suggested antenna can be used for pavement evaluation but it is not recommended to be used for crack detection.

Ground coupled antennas



In the same model with the one explained previously we use a commercial based bow-tie antenna with 1.6 GHz central frequency modeled by Warren and Giannopoulos 2011. This antenna is ground coupled antenna and it is placed 2 cm above the ground.

A singular value decomposition is applied to the data and 2, 3 and 4 dominant values are filtered out. From the resulting B-scans it is evident that ground coupled antennas are more attractive choices for detecting cracks.



References

[1] A. Giannopoulos, "Modeling Ground Penetrating Radar by GprMax", *Constructions and Buildings Materials,* vol.19, pp. 755-762, 2005

[2] http://www.ed.ac.uk/schools-departments/information-services/services/research-support/research-computing/ecdf/,16 April 2014

[3] C. Warren, A. Giannopoulos,"Creating FDTD models of commercial GPR antennas using Taguchis optimisation method, *Geophysics,* vol. 76, no. 37, 2011.