RF Propagation in Mining Tunnels

Introduction

Due to inherent higher order basis functions, efficient parallelization on multi core CPUs and support for simulations on GPU platforms, WIPL-D software can be effectively used for radio frequency propagation problems. One such problem would be determining power transfer between transmitter and receiver antennas at radio frequency (RF) frequencies in under-ground tunnels of significant length (several hundreds of meters).

Problem Description

The simulation setup involves positioning two antennas (transmitter and receiver) inside a very long tunnel. Usually walls are made of concrete, where material properties are not specific. For the purpose of demonstration, antennas can be simple wire dipole antennas (low profile antenna with omnidirectional radiation pattern). Tunnel cross section can be considered as rectangular for the purpose of demonstration. To reduce EM simulation challenges, antennas are placed in the center of tunnel cross section so the problem becomes symmetrical.

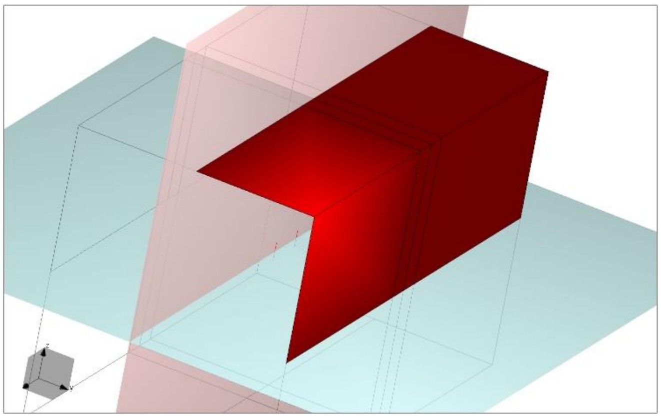

Figure 1. Tunnel walls and two dipole antennas

Tunnel height is 7.2 feet and width is 6 feet. Walls are defined as concrete where characteristics vary: Er between 4 and 7 and Sigma between 0.02 and 0.0002.

Simulations are carried out at 455 and 915 MHz. Dipole half-length is 0.215 feet and wire radius is 1.5 mm at 915 MHz, and half-length is 0.432 feet and wire radius is 3 mm at 455 MHz.

Simulations Results

Simulations include variety of tests performed to establish behavior of coupling between antennas based on tunnel characteristic and spacing between antennas. All simulations were performed as full wave electromagnetic (EM) runs without any approximate methods being included. Simulations are performed at lower operating frequency to speed up EM simulations and distance between antennas is usually swept between 100 and 300 feet.

The basic test was to determine influence of tunnel height for tunnel properties kept constant. It is important to notice that this parameter has the most significant impact to propagation between dipoles.

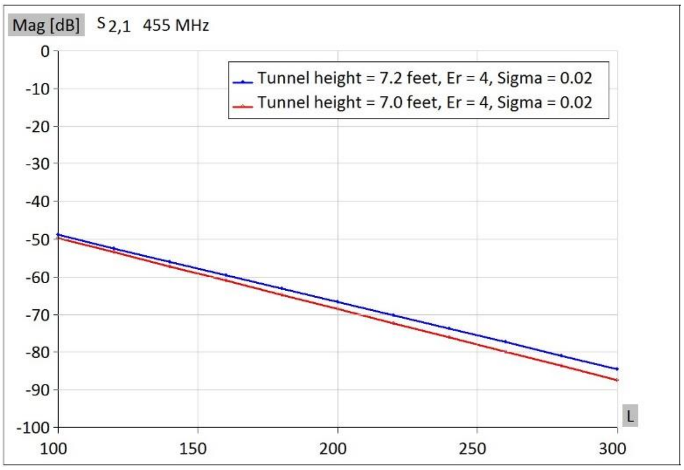

Figure 2. Influence of tunnel height

In addition to that, it is interesting to investigate how material properties of concrete influence the propagation model.

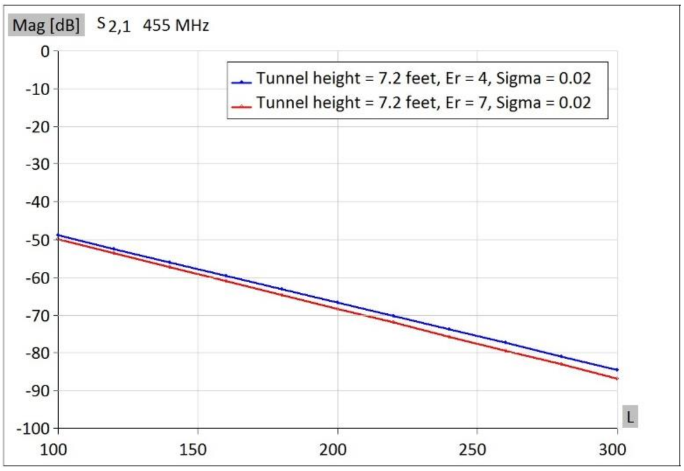

Figure 3. Influence of concrete Er

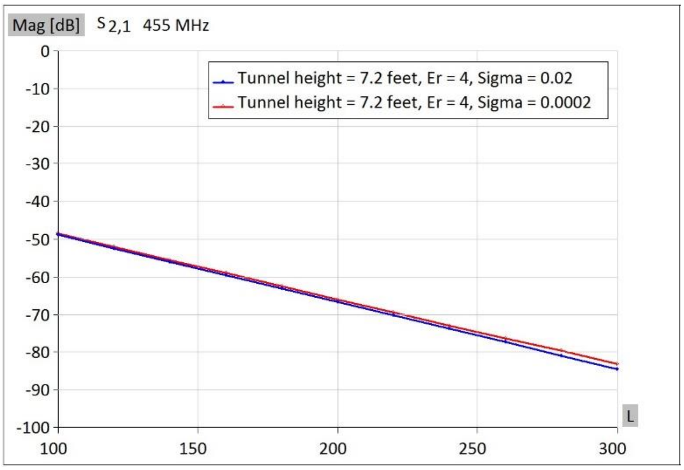

Figure 4. Influence of Sigma in concrete

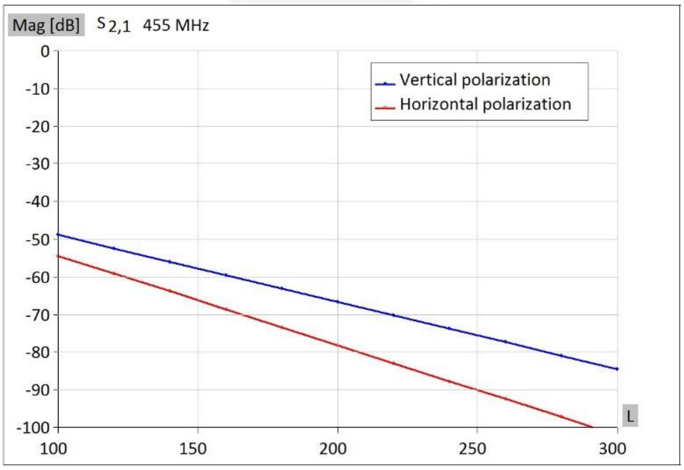

Figure 5. Propagation of different polarization

Since tunnel height and width are not identical (7.2 feet and 6 feet), simulations were carried out to illustrate how vertical and horizontal polarization propagate. All the results so far were presented for vertical polarization.

Next figure shows comparison of measured and simulated data, where the distance between antennas is spanned between 0 and 500 feet. Measurements were made in a tunnel with an arched roof and a 1 x 1 ft trench in one of the floor corners.

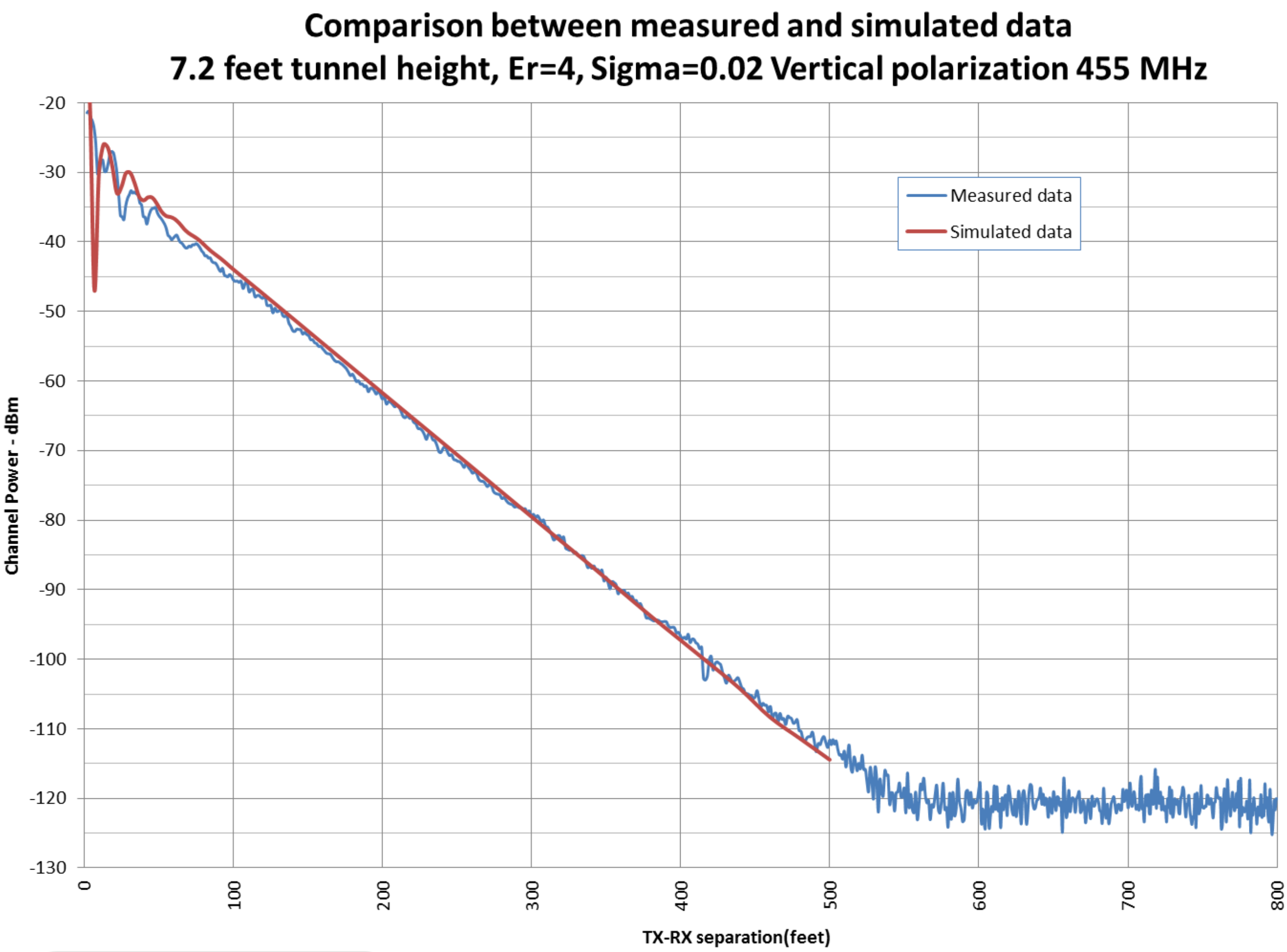

Figure 6. Comparison between measured and simulated data

EM Simulation Challenges

Since this is a typical problem for propagation models, where the electrical size of structures in measured in hundreds f wavelengths, it is a big challenge for EM simulation to solve this problem. At 455 MHz, 100 feet tunnel is 45 wavelengths long, which yields to 230 wavelengths for 500 feet tunnel.

At 455 MHz, the simulation can be carried out at standard desktop PC if it is empowered with inexpensive Nvidia GPU card such as GTX 1080. Simulation of 500 feet long tunnel at 455 MHz requires 69,000 unknowns and typically lasts 15-20 minutes per frequency point (assuming standard desktop with quad core CPU and the mentioned GPU card used for speed up of matrix inversion phase):

Intel® Core™ i7-7700 CPU @ 3.60 GHz with 64 GB RAM and NVIDIA GeForce GTX 1080 GPU

Further challenge is to run the same simulation at 915 MHz, which is equivalent to 4 times larger problem because number of unknowns scales as square of frequency. Therefore, simulation is performed by using GPU based platforms using 3-4 GPU cards:

Intel® Xeon® CPU E5-2650 v4 @ 2.20 GHz (2 processors) with 256 GB RAM and four GPU cards NVIDIA GeForce GTX 1080 Ti, 6 SATA HDDs configured in RAID-0.

The simulation time is 2-3 hours per frequency point. Comparison between the measured and the simulated data at this frequency is given below.

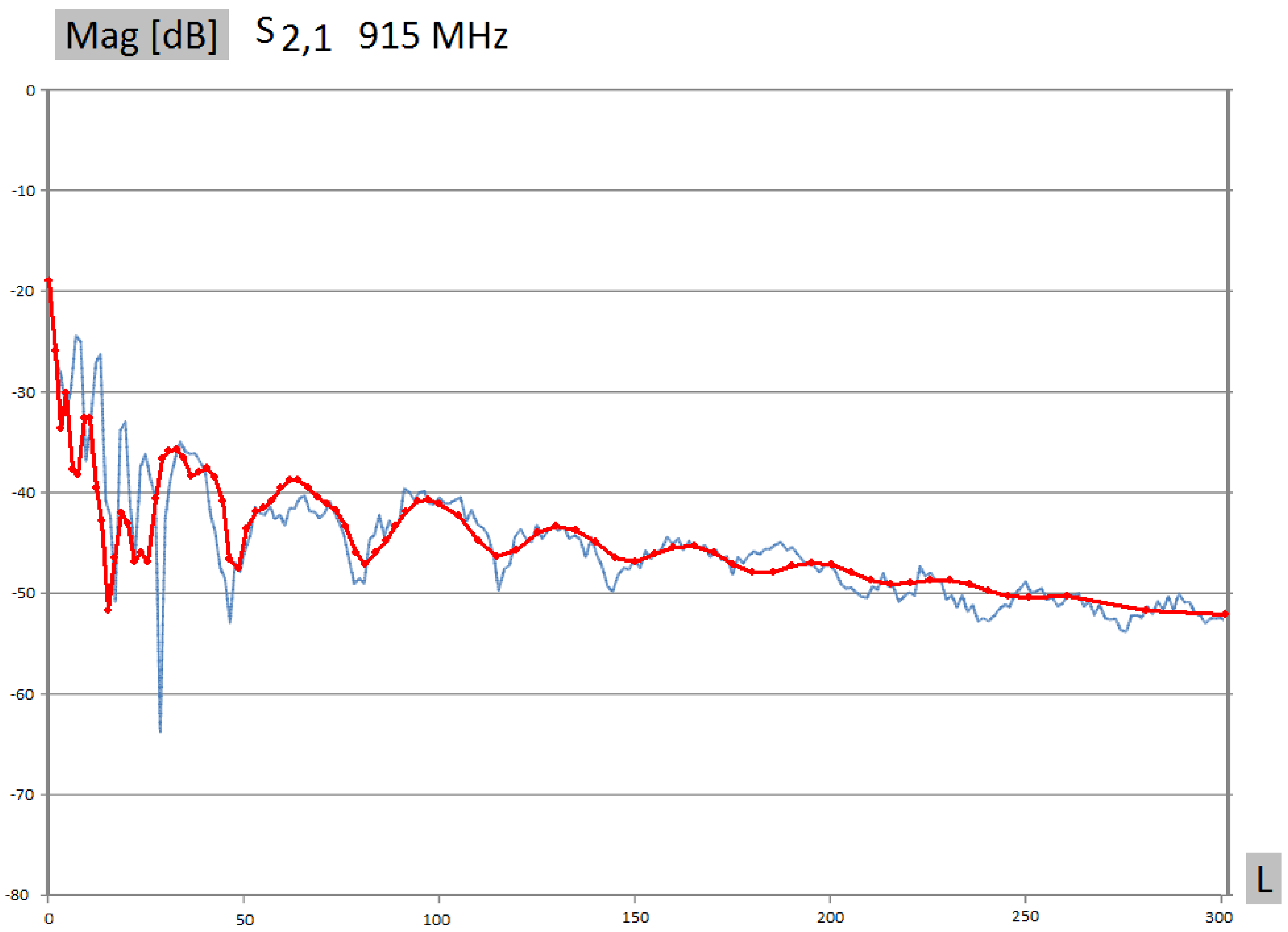

Figure 7. Comparison between measured and simulated data (blue curved is measured and red is simulated)