

Wave Propagation Modeling Inside Vehicles by Using a Ray Tracing Approach

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Abstract-With the growing demand for sensors and actors in the automotive technology, a wireless concept for the data exchange between different system components inside a vehicle becomes interesting. In order to describe and thus assess the mobile radio channel in the vehicle, simulations are required. For low frequencies, full wave simulations using the Method of Moments are well suited. For higher frequencies, these models get inadequate concerning the computational effort. This paper discusses the demands for models that can describe the radio channel inside vehicles at high frequencies and presents an appropriate ray tracing approach. The results of a measurement campaign are used to validate the proposed ray optical model.

I. INTRODUCTION

After the great success of wireless communications used in land mobile radio systems, the wireless communications inside vehicles becomes more and more interesting.

On one hand, possible applications could be in the area of wireless multimedia devices such as video terminals. On the other hand, the steadily increasing number of sensors and actors in the area of the mechanics in modern vehicles causes growing cabling and connecting costs that could be minimized by using wireless concepts. Of course, this could not be used for safety critical sensors and actors that could affect the safe function of the vehicle (e.g. brake or steering system).

In the automotive sector, simulations by using full wave approaches (e.g. by using the Method of Moments) have been established [6,7,8] to e.g. optimize antenna positions in the vehicle under consideration of EMC problems and electromagnetic field exposure of the user [13].

The frequency range that will be available and suitable for wireless links in vehicles will be very high and might go up to the range of the 24 GHz ISM band. At those frequencies, an approach with full wave methods is not possible anymore due to the computational effort that would be required.

However, with increasing frequency ray optical approaches become valid, if the dimensions of the shadowing objects are much larger than the wavelength [1,3,9].

A comparison between the measurements and the ray optical simulation results as well as the full wave simulation results will show that even at low frequencies the ray optical models are suitable to describe the propagation channel with high accuracy.

II. DESCRIPTION OF THE APPROACH

Ray optical propagation models are well known in the domain of urban and indoor radio network planning [5]. In the last several years, these models have become more and more important as high accuracy predictions were needed [4,11]. Therefore, a Ray Tracing model for indoor scenarios was used as a basis for the described approach.

As the indoor propagation model allows the vector-oriented definition of an arbitrary number of objects with different materials, a vehicle can be modeled very well (see figure 1). Materials with multiple layers can be considered due to the ability to compute transmission attenuations.

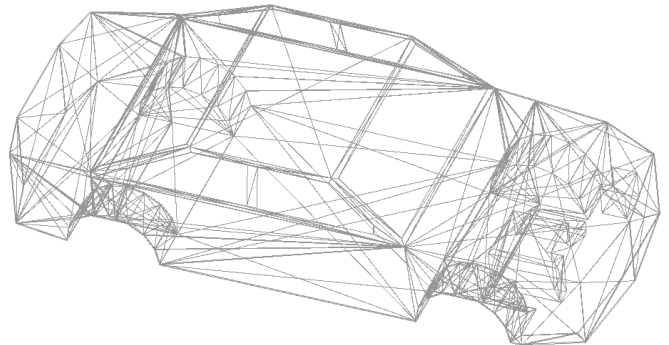


Fig. 1: Vector oriented database of a vehicle

The consideration of interactions that the ray paths encounter is done with the Geometrical and Uniform Theory of Diffraction (GTD/UTD) for diffractions and with the Fresnel coefficients for reflections and transmissions. Due to the objects that are found in a vehicle, the consideration of diffractions is much less important than the consideration of reflections and transmissions.

In urban and indoor environments, the databases that describe the buildings or walls are usually rather inaccurate. The phase of the signal contributions of different propagation paths is not considered for these environments, as the geometrical inaccuracies might be in the range of several wavelengths. Therefore, the network planning tools do not consider the phase at the superposition of different contributions, but perform an accumulation of the power [11,12].

In the situation of partly enclosed spaces in vehicles, usually very accurate CAD data are available from the construction of the vehicle. This makes it possible to compute the individual ray path contributions under consideration of the phase. This is very

important, as a large number of interactions must be taken into account due to the low reflection and diffraction losses of the materials utilized in vehicles [2]. For this purpose, the indoor propagation model is extended to consider the phase of the signals at their superposition.

III. SIMULATION RESULTS

Figure 2 shows two simulations in the same scenario. A transmitter power of -10 dBm was used. The left part of figure 2 shows the simulation with power accumulation, i.e. the contributions of the individual rays are accumulated, resulting in a predicted mean power value. This method is well-known from indoor and urban radio network planning (see section I.). The right part of figure 2 shows the same scenario with the contribution of the rays being superposed with consideration of the phase (the phase being gained from the different path lengths and the reflection coefficients).

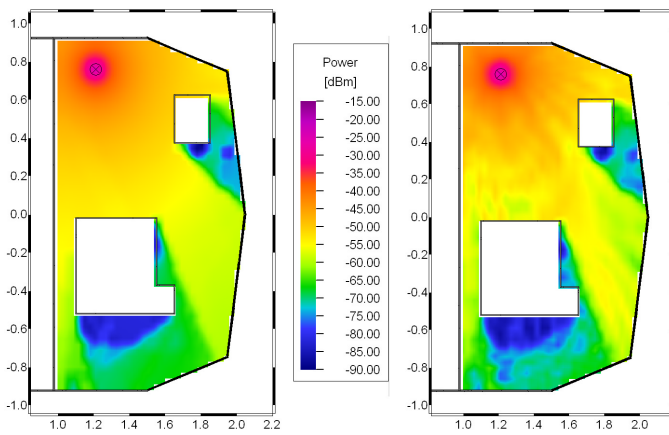


Fig. 2: Simulations with power accumulation vs. phase consideration

The comparison in figure 2 shows the interference effects caused by the phase consideration.

The ray optical model also allows to analyze the individual propagation rays and thus to explain the effects that occur in the engine compartment propagation scenario.

Figure 3 shows the display of propagation paths computed with the ray optical model. In the left figure (#1), a situation behind an obstacle is shown, in the right figure (#2), there is line of sight between the transmitting antenna and the reception point. The simulations are done with only 2 reflections to keep the ray display concise. With 3 and more reflections, of course much more propagation paths are computed.

Ray optical modeling also allows to determine the impulse response of the mobile radio channel and therefore the computation of the delay spread. The exact knowledge of the channel characteristics is important to assess different modulation schemes with regard to their suitability for the data transmission in vehicles.

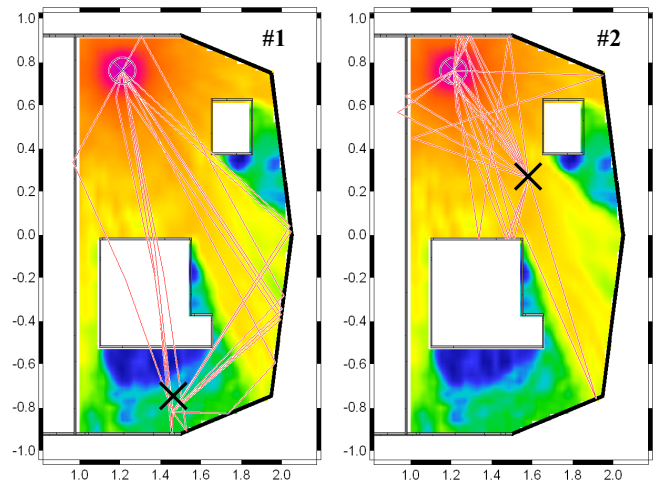


Fig. 3: Display of propagation rays

Figure 4 and 5 show two examples of the computed impulse response for the same situations as shown in figure 3.

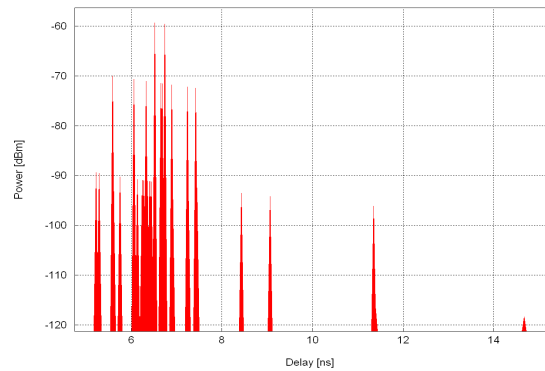


Fig. 4: Impulse response for situation #1

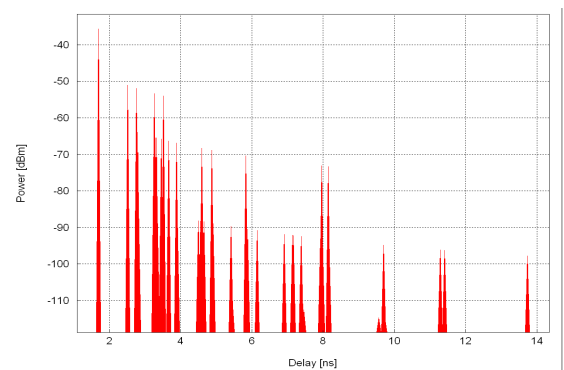


Fig. 5: Impulse response for situation #2

The predicted impulse response using this method shows a good agreement with measurements [4].

The propagation ray data can also be used to evaluate the direction of arrival (DOA) as well as to compute the angular spread. This information is helpful e.g. for the optimization of antennas used for the application in vehicles.

IV. VALIDATION WITH MEASUREMENTS

The measurements allow a comparison of the performance of the full wave and the ray optical approach and help to determine the frequency range where each of the approaches will be most suitable.

For this purpose, a model of a simplified engine compartment was manufactured, serving as environment for the measurement campaign [10]. A shortened $\lambda/4$ monopole was used both as transmitting and receiving antenna.

Figure 6 shows the sectional views of the model (top view at the left, side view at the right). The model consists of a partly enclosed space (i.e. the part heading to the ground is, like usually in cars, open) with only two objects in the engine compartment: the engine (large block) and the battery (small block, dashed in the right sectional view). This simple model has the advantage that the objects can be considered very precisely in the simulations due to their simple geometry, allowing an evaluation of the simulation methods which is independent of influences that occur due to approximations that would have to be made if the simulations had been done based on a real engine compartment with much more complex objects.

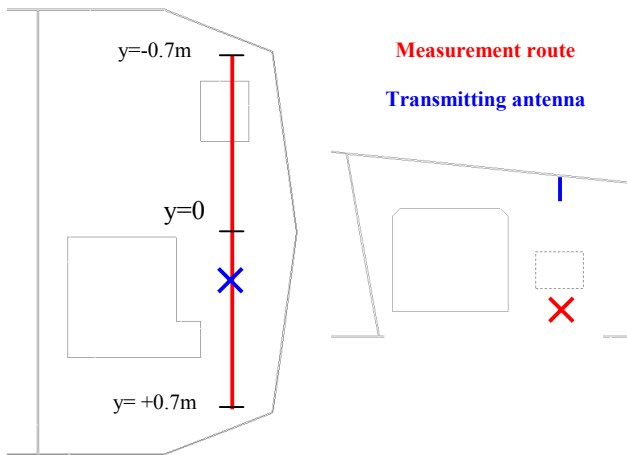


Fig. 6: Model of the engine compartment

The measurements were conducted at 866 MHz and 5.8 GHz, full wave simulations were done at 866 MHz only.

Figure 6 also shows the line where the measurements and the comparison with the simulations were conducted as well as the transmitting antenna position.

A. Number of Reflections versus Accuracy

The number of considered reflections has an important impact on the accuracy of the ray optical simulations. However, the maximum number of reflections that can be taken into account is limited by the required computational effort.

Figure 7 and 8 show the influence of the number of reflections on the accuracy at both mentioned frequencies. The statistical evaluation can be found in table 1.

TABLE 1
DIFFERENCE BETWEEN SIMULATION AND MEASUREMENTS
DEPENDING ON THE NUMBER OF REFLECTIONS

Scenario	Mean Value	Standard Deviation
866 MHz / 3 reflections	-2.3	4.7
866 MHz / 4 reflections	-0.7	4.2
5.8 GHz / 3 reflections	-2.0	5.8
5.8 GHz / 4 reflections	-0.6	5.4

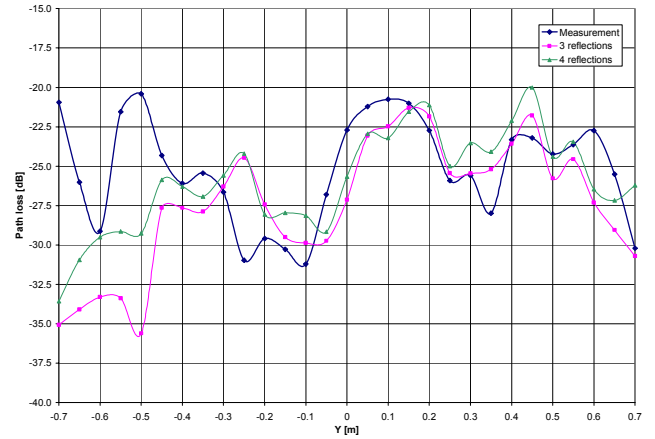


Fig. 7: Simulations and measurements at 866 MHz

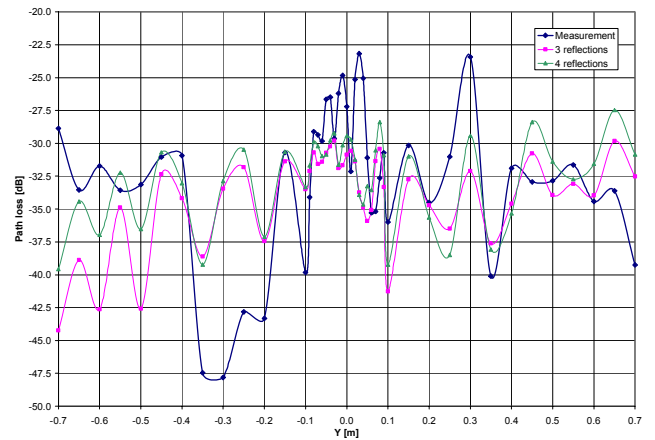


Fig. 8: Simulations and measurements at 5.8 GHz

The results show the improvement of the accuracy with a growing number of considered reflections at both frequencies.

As the change especially in the standard deviation is minor, the consideration of noticeably more reflections does not appear to be required.

As the achieved accuracy is in the range of the full wave simulations even at the low frequency of 866 MHz (where the ray optical models are at the limit of their validity due to the small objects in comparison to the wave length), the proposed model is very well suited to describe the scenario.

Concerning the computational effort, the ray optical approach is much less demanding when considering up to 4 reflections (see table 2).

TABLE 2
COMPUTATIONAL REQUIREMENTS
OF RAY OPTICAL VS. FULL WAVE SIMULATIONS

Scenario	Computation Time	Memory Requirements
866 MHz Full Wave Simulation with Method of Moments	23 hours ¹	1400 MB
866 MHz Ray Optical Simulation (4 reflections)	6 hours	20 MB

The full wave simulations are much more sensitive to inaccuracies in the description of the geometry of the scenario. This effect will have to be dealt with in further investigations.

B. Influence of the Phase Consideration

To show the necessity of the phase consideration, a comparison is made to a ray optical simulation with power accumulation. The results are shown in the figures 9 and 10, the corresponding statistical values are shown in table 3.

TABLE 3
DIFFERENCE BETWEEN SIMULATION AND MEASUREMENTS
WITH POWER ACCUMULATION VS. PHASE CONSIDERATION

Scenario	Mean Value	Standard Deviation
866 MHz / Power Accumulation	-3.6	4.5
866 MHz / Phase Consideration	-0.7	4.2
5.8 GHz / Power Accumulation	-2.6	5.8
5.8 GHz / Phase Consideration	-0.6	5.4

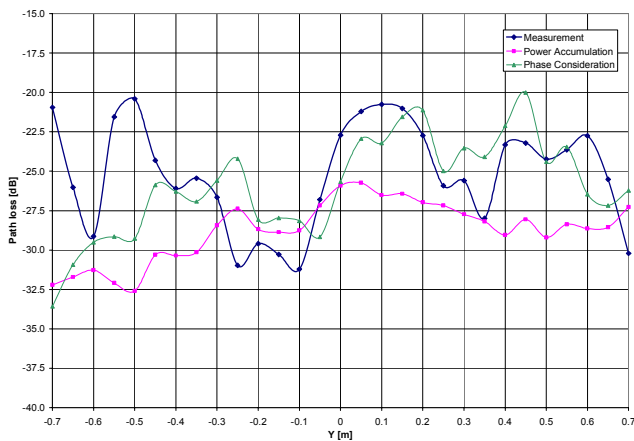


Fig. 9: Simulations and measurements at 866 MHz

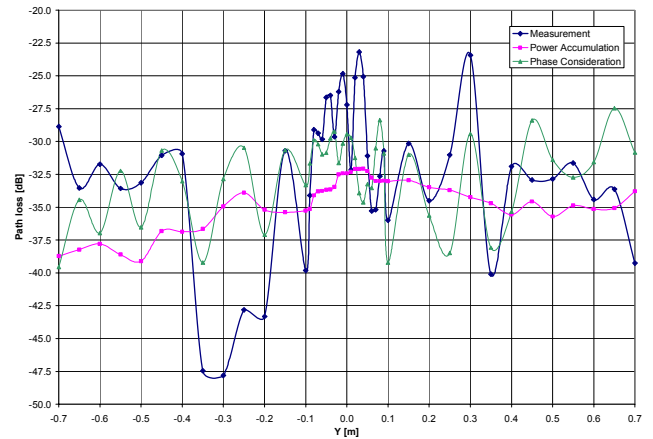


Fig. 10: Simulations and measurements at 5.8 GHz

Especially the much smaller mean values in the case of phase consideration as well as the better prediction of shadowing effects (see figures 9 and 10) show the necessity of the phase consideration. On the other hand, there is not much improvement in the standard deviation, which can be explained by the averaging properties of the power accumulation method.

C. Comparison to Full Wave results

Figure 11 shows the measurements in comparison to both the results of the full wave simulation (using the Method of Moments) and the ray optical simulation. The statistical evaluation is shown in table 4.

To achieve the high accuracy of the full wave simulation, beside the transmitting antenna the receiving antenna had to be considered in the simulation. In the ray optical simulation, an omni-directional receiving antenna was assumed.

Taking this into account, the ray optical model is a promising approach to describe the wave propagation scenario in vehicles.

TABLE 4
COMPARISON OF MEASUREMENTS
TO RAY OPTICAL VS. FULL WAVE SIMULATIONS

Scenario	Mean Value	Standard Deviation
866 MHz Full Wave Simulation with Method of Moments	-0.4	3.3
866 MHz Ray Optical Simulation (4 reflections)	-0.7	4.2

¹ As the receiving antenna had to be taken into account, for each of the 29 measurement points a separate simulation had to be computed. This might be avoidable in the future. A single simulation lasts 48 minutes.

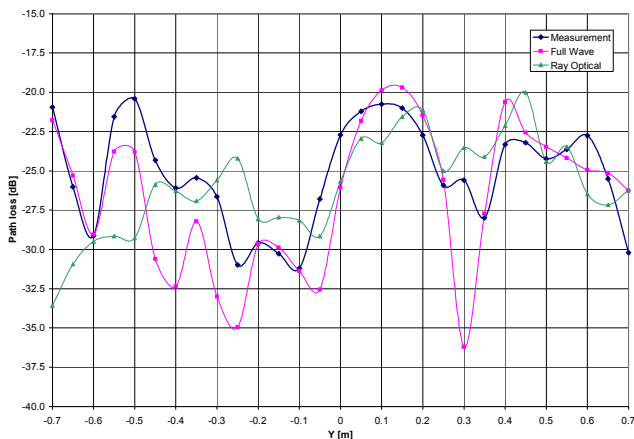


Fig. 11: Simulations and measurements at 866 MHz

V. CONCLUSIONS

In this paper, the demands for modeling the radio channel in partly enclosed spaces like found in vehicles are presented. A ray tracing approach for the propagation modeling in such a scenario is described.

The accuracy even at low frequencies is in the range of full wave simulation results. The ray optical model is less demanding in terms of computational power and is less sensitive to inaccuracies in the geometrical description of the scenario.

The future work will aim at the modeling of real engine compartments that naturally contain a lot of objects. These objects are especially hard to model for full wave simulations, so an advantage in the usage of ray optical models is also expected in that respect.

A further aspect is the investigation of the effect of considering more reflections. To achieve this, there is a demand for acceleration techniques in the used ray optical model in order to cope with the computational effort.

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