TLM Simulation of Human Exposure to 400 MHz Electromagnetic Fields Inside a Car

Transmitters used in vehicle environments present potential threats to the health and safety of vehicle users, in terms of both human exposure to electromagnetic fields and vehicle EMC (electromagnetic compatibility). The recently revised automotive EMC directive (2004/104/EC) now requires vehicle manufacturers to identify acceptable frequencies, powers and antenna installations that can be used on vehicles without compromising their EMC performance. However, there is also a need to establish that the electromagnetic field distributions resulting from on-board transmissions, including both vehicle-mounted antennas and personal mobile systems, do not compromise the health and safety of vehicle users. Limits for human exposure to electromagnetic fields have been proposed by the EU for both general public (recommendation 1999/519/EC) and occupational (directive 2004/40/EC) exposures, based on guidance provided by the International Commission for Non-Ionising Radiation Protection (ICNIRP).

Benefits of simulation and TLM

Simulation methods offer computed field distributions with very fine spatial resolution without the practical difficulties of probe-positioning or the need for physical hardware or specialised test facilities. Calculation of SAR in every dielectric cell is also possible when needed, for any required combination of dielectric properties possible in the models. This avoids the need for the fluid-filled “phantoms” that would be required in measurements, allowing multiple occupancy effects to be investigated much more easily. Perhaps the most significant benefit of simulation, however, is that the cost of implementing mitigation measures is generally much lower if potential issues can be identified in the early stages of design and development.

Particular advantages of the transmission line matrix (TLM) method in this type of application include relatively frugal memory requirements (based on model volume rather than number of surfaces) and memory-saving capabilities such as sub-cell thin wire models and graded meshing. Bulk dielectrics are easily integrated into TLM models, and time-domain TLM is inherently stable because it derives from a “physical” model of space (as a network of interconnected transmission lines). An important practical advantage is that model building for complex structures is also relatively easy, since surface mesh quality is irrelevant when used for generating the TLM hexahedral mesh. The models and results presented in this document are from CST MICROSTRIPES™.

Human exposure issues

Standards specify limits for “basic restrictions”, which are described in terms of limb currents for low frequency (up to 10 MHz) and specific absorption rate (SAR) for high frequencies (from 100 kHz to 10 GHz). As these parameters are not easy to determine, the use of “reference levels” is permitted assessing for uniform, non-localized exposures. The reference levels are described in terms of more readily determined quantities, including electric and magnetic field strengths, as well as power density. Compliance with the reference levels should ensure compliance with the basic restrictions. Exposures exceeding the reference levels may still not breach basic restrictions, but further investigation is required in order to establish this. The use of reference levels is not considered to be appropriate for localized (i.e. on-body) sources. Due to cavity resonances, however, in-vehicle field exposure will be non-uniform when it results from non-localized sources.

Model construction

The vehicle model used for human exposure investigations is based on major metallic components of the car, including the main structure (body shell, doors, hood and trunk lid), significant cabin components (seat frames and steering gear) and other items such as the rear window heater and source antenna (e.g., roof-mounted monopole). For simulation of TETRA transmissions around 400 MHz, the meshing strategy employs 8.3 mm cubic cells over the vehicle interior, a 2.5 cm maximum cell dimension over the vehicle structure, and a 5 cm maximum in the region exterior to the vehicle. The output data collected includes space domain fields and SAR over a block containing the interior of the passenger compartment, as well as the antenna base current and voltage.
The human simulants used for SAR calculation are based on a homogeneous lossy dielectric body of human shape. A model of the surface geometry of the MIRA human model can then be modified using CAD tools in order to create suitable human models for different vehicles and/or seating positions. The surfaces of the human simulants are formed into bodies for volume meshing, which is then used to generate hexahedral mesh for the human simulants.

The mesh fragments representing the human simulants can then be imported into the TLM vehicle model in order to build the occupied vehicle model.

The impact of a driver on the internal field distribution is illustrated by the field plots shown below, for a vertical plane through the steering column of the car:

The electric field levels are generally lower with the driver present than for the empty vehicle.

However, local field enhancements may also occur in some localised regions (e.g. under rear seat back in this view).
In this investigation, the objectives were to assess the possible impact of different occupancy configurations on SAR levels, and to evaluate how the empty vehicle fields at power levels associated with the SAR limits in the occupied vehicle simulations relate to the field reference levels. This required 8 occupied vehicle simulations (for a driver and up to 3 passengers) and one empty vehicle simulation per antenna configuration investigated.

Post-processing and analysis

The process employed in order to evaluate the results was as follows.

1. Extract 10 g SAR datasets for each individual under each occupancy configuration;
   - normalize SAR data to 1 W radiated power;
   - determine maximum SAR and whole-body average SAR;
   - estimate power levels needed to reach SAR limits.
2. Extract empty vehicle internal electric and magnetic field datasets:
   - normalize RMS field data to 1 W radiated power;
   - determine average field over interior of passenger compartment;
   - estimate average field at lowest SAR limit power level (lowest over all occupancy configurations).

It was found that the average SAR limits were reached at lower power levels than the maximum SAR limits, and the highest average SAR was found with a single passenger behind driver, in the rear passenger. The mean SAR limits were reached at power levels associated with average fields over the interior of the empty vehicle at 260% of reference levels for ICNIRP general public exposure. This factor compares with a value of 225% reported for uniform plane-wave exposure of an inhomogeneous (anatomically detailed) standing human simulant in free space at 400 MHz [A.F. McKinlay et al, “Review of the Scientific Evidence for Limiting Exposure to Electromagnetic fields (0–300 GHz)”, Documents of the NRPB, Vol. 15, No. 3, 2004, pp. 143–145].

Conclusion

Comparing average empty vehicle fields with existing field reference levels at 400 MHz gives a similar level of protection to that obtained under plane wave illumination in free space, suggesting the in-vehicle electromagnetic field exposure assessment process indicated below.