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Smart Mobility Communication and Human Exposure to RF Fields: a Numerical Dosimetry Approach

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Objectives

- Assess with numerical dosimetry in-vehicle exposure to RF fields generated in a realistic vehicle-to-vehicle (V2V) communication scenario.

- In particular, model a realistic the exposure scenario using:

  - ✓ realistic (for shape, dimension and materials) 3D model of a car;
  - ✓ multiple V2V antennas that are operated at the typical V2V frequency;
  - ✓ and a realistic human model of a people (driver) inside the car.

Background

- It is expected that there will be more than 72 million connected vehicles million by the end of 2023.
- Connected vehicle services will lead to enhanced road safety, travel efficiency, and productivity.
- Vehicular communication include communication services with other cars (V2V) and road infrastructure (V2I), with pedestrian (V2P), with the network (V2N), or in general with everything, including IoT devices (V2X).
- Two are the main wireless access technologies for vehicular communications: IEEE 802.11p in the U.S., ITS-G5 in Europe, and Cellular-V2X (C-V2X), all working at 5.9 GHz.

The research gap

- To the best of the authors' knowledge, none of previous studies estimated human exposure to RF generated in V2V communication and specifically at 5.9 GHz.
- Previous studies assessed RF exposure in cars at 'traditional' mobile/wireless technologies (e.g., GSM, UMTS, ZigBee, WiMax, and Bluetooth) that operate at frequencies lower than in V2V.
- The V2V exposure scenario has peculiar characteristics for what concerns the environment (car and its metallic parts that shield the field + people inside the car) and frequencies (5.9 GHz).
- As such, it is not possible to infer the dose of exposure from a simple post-processing of results from previous studies.

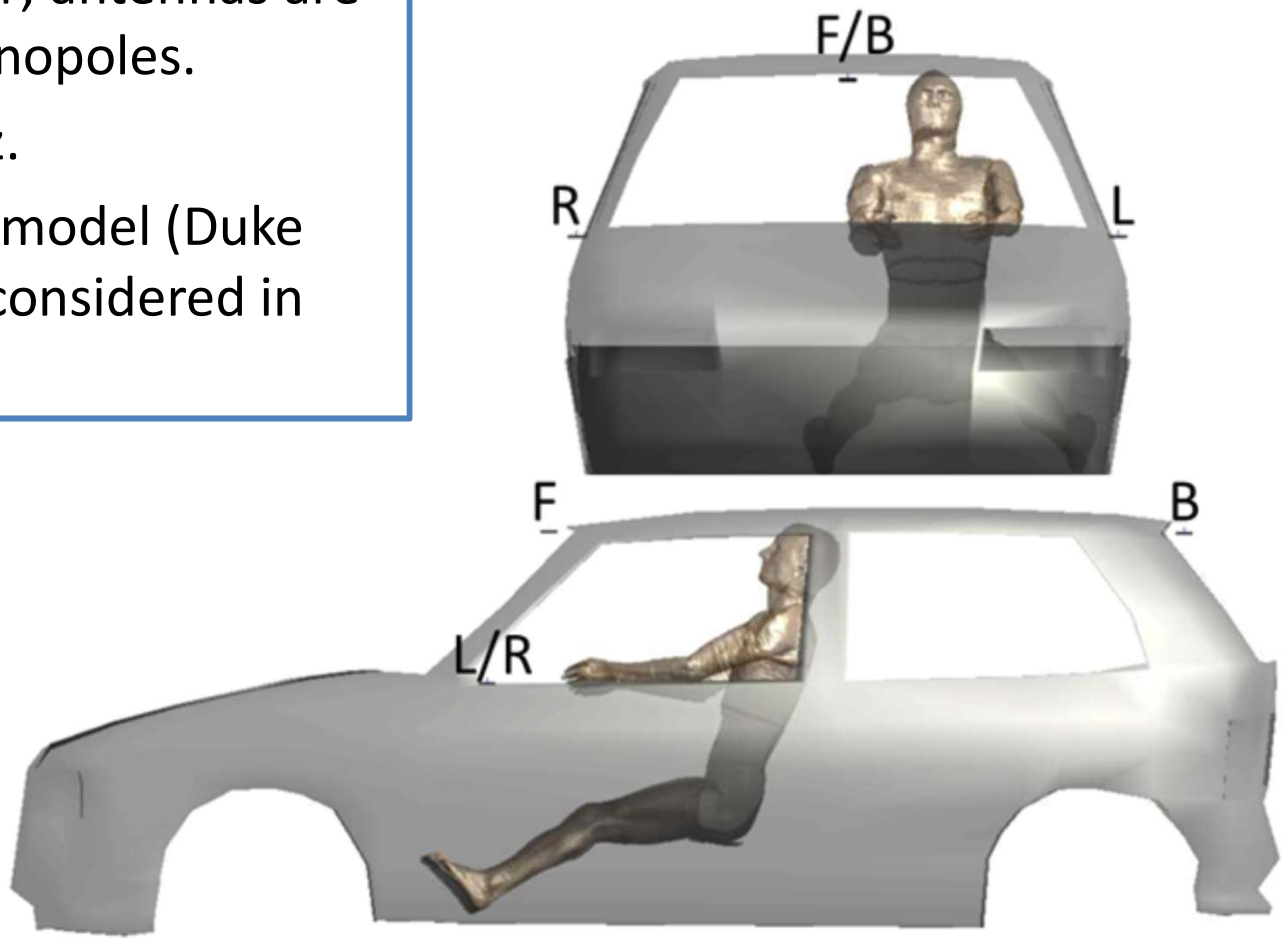
The modelled V2V exposure scenario

Car: 3D realistic model made of PEC (car body) and glass (six windows).

RF sources: 4 V2V antennas at the left/right and front/back sides of the car; antennas are modeled as quarter-wave monopoles.

Operating frequency: 5.9 GHz.

Human phantom: adult male model (Duke ViP family); all model tissues considered in the assessment of exposure.



Exposure simulation

- **EMF calculation:** finite-difference time-domain (FDTD) method using the simulation platform SIM4life (ZMT Zurich Med Tech AG, Zurich, Switzerland).
- **Computational domain:** it included the car model + the 4 antennas + the human phantom.
- **Discretization and boundaries:** non-uniform grid of 2 mm maximum step (total number of about 10^9 cells); boundaries were modelled as Perfectly Matching Layer (PML).

Further details on the simulation procedure:

Tognola G. et al., "Numerical Assessment of RF Human Exposure in Smart Mobility Communications," *IEEE J Electrom, RF and Microwaves in Med and Biology*, 2020 Early Access, doi: 10.1109/JERM.2020.3009856.

Exposure assessment and analysis

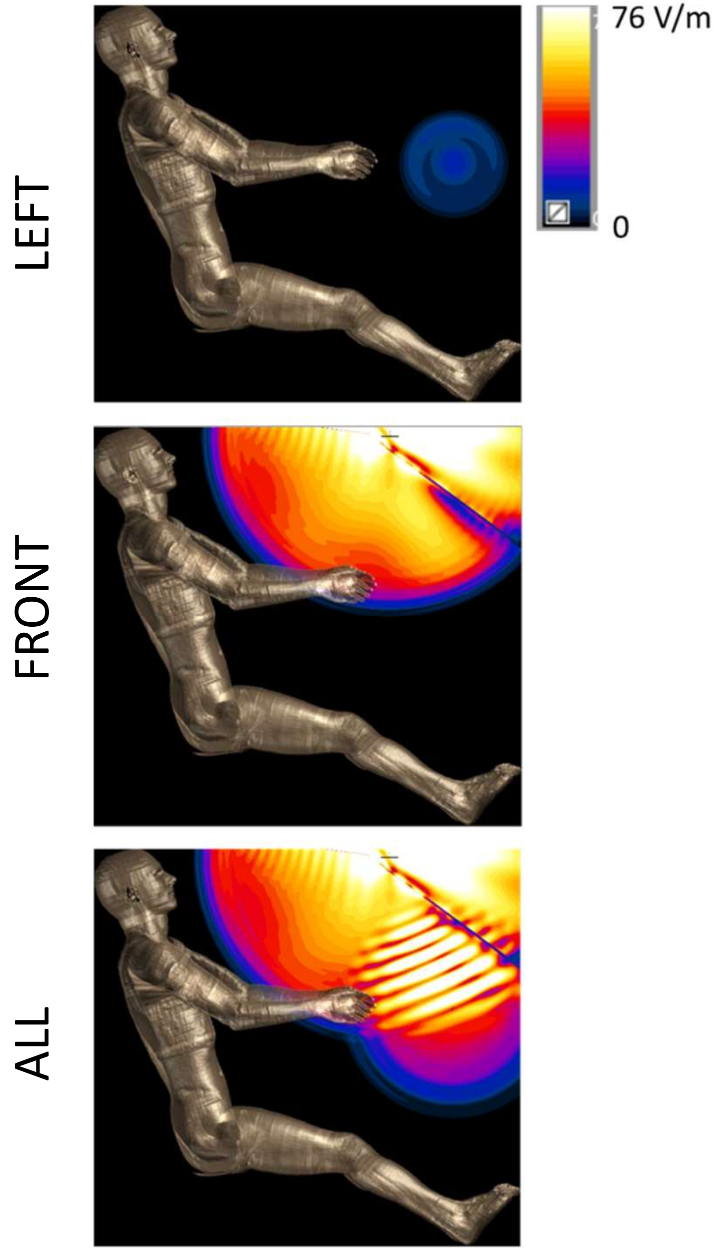
- **Variables extracted:** E field (V/m) and Specific Absorption Rate (SAR).
- **SAR calculation:**
    - whole body SAR;
    - local SAR averaged over 10 g of in the
        - limbs;
        - head;
        - torso;
        - and all tissues of Duke.

Results – Distribution of electric field

E field of single antenna and all antennas together measured on the sagittal plane at the midline of Duke.

Worth noting:

- The electric field decreased very quickly with the distance from the source and was negligible at distances greater than 50 cm.
- Only antennas closer to the phantom, i.e., left and front antennas, generated a significant field.
- Right and back antennas' field (not displayed) was negligible.
- Exposure to all antennas generated a greater spread of the distribution and a marginal increase of the magnitude of the field.



Results – SAR

SAR in the whole body and in body regions during exposure to all antennas simultaneously.

SAR (mW/kg)	Peak local SAR 10g (mW/kg)					
Whole body	head	torso	L arm	R arm	L leg	R leg
0.78	$\ll 10^{-8}$	$\ll 10^{-8}$	267	249	32	$\ll 10^{-8}$

Worth noting:

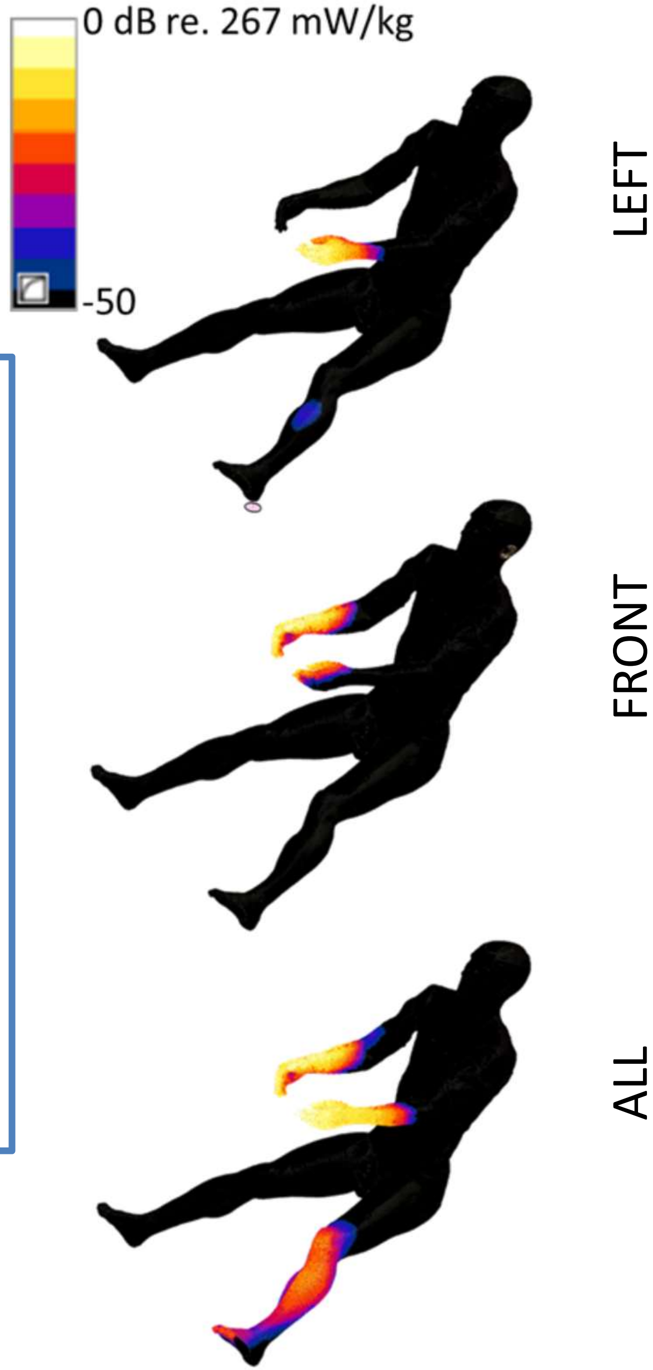
- ➢ Both whole body and peak local SAR were well below the ICNIRP and IEEE limits for the general public in the 100 kHz-6 GHz band:
  - 0.08 W/kg for whole body exposure and;
  - 4 W/kg for local exposure at the limbs.
- ➢ SAR in the head and torso was negligible (direct consequence of the greater distance of head and torso from the antennas).
- ➢ Peak SAR (see the table above) was always observed in the skin.

Results – SAR

Evaluation of SAR in the different tissues, in particular on the skin, induced by single antennas and all antennas together.

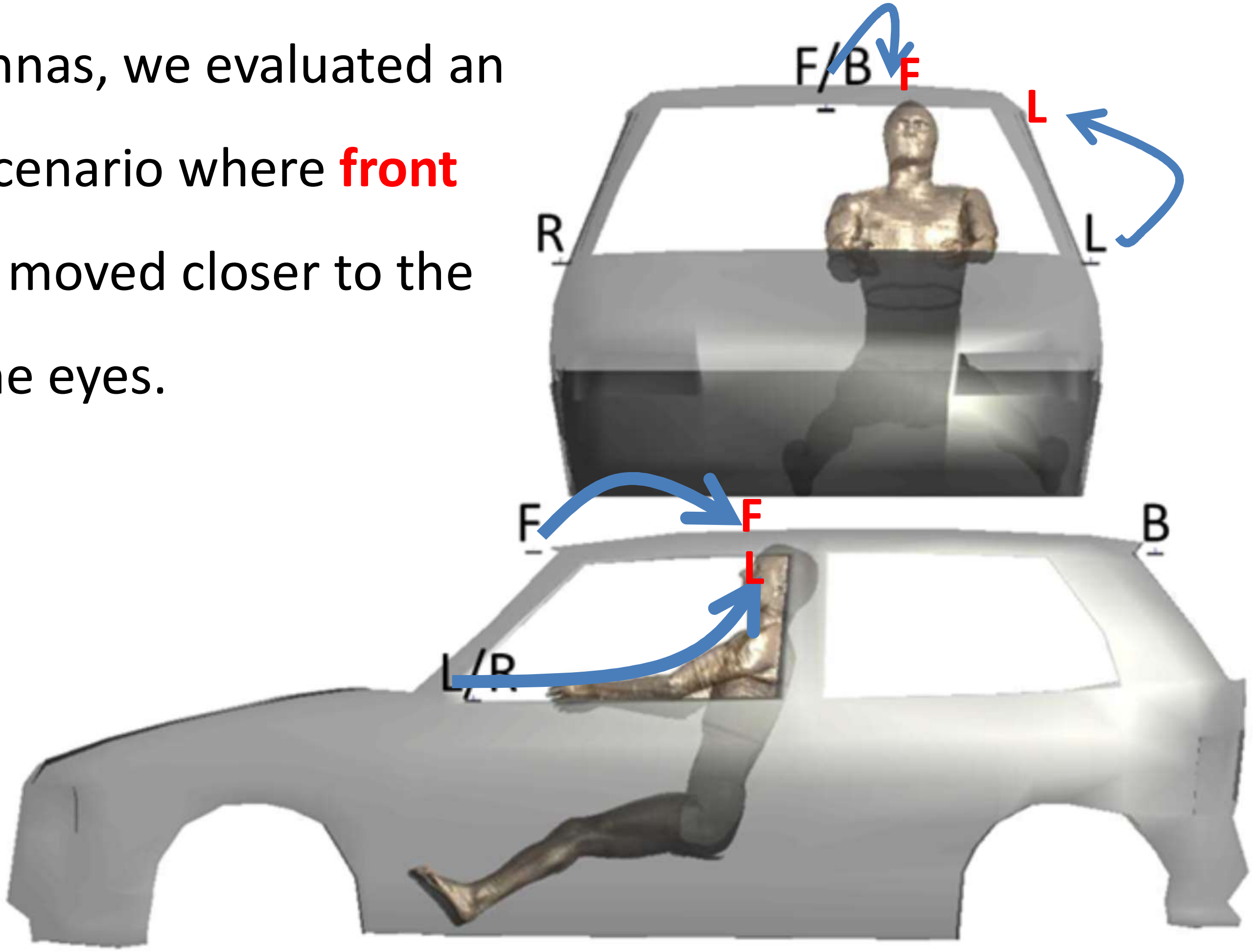
Worth noting:

- Significant SAR values were observed only in the most superficial tissues of the body, i.e., in the skin and very marginally in the subcutaneous adipose tissue.
- Similarly to the electric field, SAR was localized only in the body regions closest to the antennas (i.e., the limbs).
- In these latter regions, SAR spreads over quite narrow areas.



Results – worst-case exposure scenario

Since exposure decreased rapidly with the distance from the antennas, we evaluated an additional worst-case scenario where **front** and **left** antennas were moved closer to the head, in particular to the eyes.



Results – worst-case exposure scenario

Evaluation of SAR in the whole body and in body regions in the worst-case scenario (and all antennas together).

SAR(*) (mW/kg)	Peak local SAR 10g(*) (mW/kg)					
Whole body	head	torso	L arm	R arm	L leg	R leg
8.33	1581	227	761	62	7	$<<10^{-8}$

(*) Tognola G. et al., "Numerical Assessment of RF Human Exposure in Smart Mobility Communications," IEEE J Electrom, RF and Microwaves in Med and Biology, 2020 Early Access, doi: 10.1109/JERM.2020.3009856.

Worth noting:

- SAR in the head and torso was now significant due to contributions of front and left antennas moved closer to the head.
- Again, both whole body and peak local SAR were well below the ICNIRP and IEEE limits for the general public in the 100 kHz-6 GHz band:
  - 0.08 W/kg for whole body exposure and;
  - 4 W/kg for local exposure at the limbs.
- Again, peak SAR was always observed in the skin. Additional tissues with relevant SAR were: eyes, CSF, brain, blood, and skull.

Conclusions

- The electric field generated by antennas operated at 5.9 GHz rapidly decreased with the distance from the source, much more than that observed with ‘traditional’ mobile/wireless technologies (e.g., GSM, UMTS, ZigBee, WiMax, and Bluetooth).
- The electric field was significant only in the regions closer to the antennas.
- The head and torso were characterized by significant SAR only in the worst case scenario.
- Whole body and local SAR were well below the ICNIRP and IEEE limits of exposure for the general public in the 100 kHz-6 GHz band.
- The highest SAR was in the skin.
- The effect of simultaneous exposure to all four antennas was a (marginal) increase in the average value of SAR and an evident increase in the spread of SAR over the skin.