Additional 4 DOI: https://doi.org/10.5281/zenodo.23541753

Modern Vehicles as Occupied Electromagnetic Environments: Measuring What Reaches the Person in the Seat

Author: J. Joaquín Machado, EMR Researcher and EFEIA Founder & Director. **EFEIA Institute**, Miami, Florida, USA. info@efeia.org. **Evidence grades:** (a) peer-reviewed, standards body, court or regulatory record, or accredited laboratory report; (b) institutional report, agency guidance or press release, preprint, thesis or recognized seal; (c) manufacturer, advocacy or media source. **Disclosure:** the author is also NOXTAK's founder and CTO. NOXTAK develops SPIRO, the passive nanocomposite tested in the author's vehicle study cited here (Section 5), and received the 180 cases reported in Part 5.

Scope: exposure of drivers and passengers to low-frequency and radiofrequency fields in battery-electric, hybrid and modern combustion vehicles, including connected and automated platforms, while driving and charging. **RFI questions answered:** 4(k), 4(l), 4(m), 5(n), 5(o), 7, 8, 9, 10(f), 11(a), 11(b), 11(d), 11(e), 13(i), 16 and 17(a) to 17(c), each tagged in brackets where answered.

OUR PROPOSAL

EFEIA proposes a coordinated national research and standards program, led by HHS with DOT and NHTSA, the FCC and NIST and carried out with independent laboratories, that evaluates the modern vehicle as an occupied electromagnetic environment: every source, every seat and every realistic operating state, connected to what the occupant's body absorbs (National Plan, submitted with this summary).

In 24 months it would deliver a reproducible whole-cabin protocol from low frequencies to the highest installed radar band, an occupant dosimetry dataset that includes children, pregnant occupants and professional drivers, a consented symptom registry with a clinical pathway, and recommendations for a vehicle-specific regulatory framework.

Engineering measures and filtering technologies would be judged under the same independent, technology-neutral protocol.

1 SUMMARY OF THE ISSUE [Q13(i)]

Bottom line. U.S. drivers spend about an hour a day at the wheel [1], seated centimeters from power electronics, cables and a growing set of radio transmitters and radars. National campaigns in Europe find brief magnetic-field peaks, highest at the feet, that current methods can miss, and no U.S. rule requires anyone to assess what reaches the occupant from all sources together.

1. Two layers, one cabin. Traction currents, batteries, inverters, seat heaters and magnetized tires produce low-frequency magnetic fields [2,3]; cellular, Wi-Fi, Bluetooth, ultra-wideband keys, vehicle-to-everything (V2X) links and radars at 57-64 GHz (cabin) and 76-81 GHz (road) add radiofrequency (RF) and microwave fields [4,5,6]. Architecture matters more than fuel: the highest Swiss low-frequency peaks came from two electric cars and the diesel reference [2].

2. Low averages, brief high peaks. In the German federal campaign, the reference values of the 1999 EU Council Recommendation were exceeded locally or briefly in all vehicles but one, with the highest fields often in the front footwells; basic restrictions were never exceeded [7]. Swiss averages were up to 5% (low frequency) and about 10% (RF) of the limits, with low-frequency peaks up to about 50% [2].

3. Methods built for parts, not for the cabin. IEC 62764-1 covers 1 Hz to 100 kHz and excludes transmitting antennas [8]; UN Regulation No. 10 governs electromagnetic compatibility, not exposure [9]; FCC exposure rules, which provide for multiple sources, classify transmitters as mobile or portable devices and contain no vehicle-specific procedure [10]. Both campaigns state that their protocols could miss short peaks [2,7].

Compliance is not protection. A reference level met at one probe position does not characterize a child's seat or a ten-hour shift; an implant review warns that "compliance with ICNIRP does not suggest that the safety of patients with CIEDs is guaranteed" [11]. The RF limits rest on heating averaged over 6 or 30 minutes and the low-frequency limits on nerve stimulation [12,13]; neither addresses modulation, polarization, combined sources, or how close and how long people are exposed (Section 6).

2 WHY IT MATTERS [Q11, Q13(i)]

Time in the cabin is long and growing. Drivers averaged 60.4 minutes and 2.44 trips a day in 2024 [1], and about 22% of new light-duty vehicles sold in 2025 were hybrid, battery-electric or plug-in hybrid [14]. **[Q11(e)]** Professional drivers spend whole shifts inside: in 2025 there were 2,221,200 jobs for heavy and tractor-trailer truck drivers, 563,200 for bus drivers (396,800 in school buses) and 455,700 for taxi and shuttle drivers and chauffeurs [15].

[Q11(a)] Children ride where fields can be higher. In hybrid cars measured in Israel, fields were higher at the back seats, and at the back right seat 16% to 69% of measurements exceeded 0.2 µT [16]. Childhood leukemia is associated with time-averaged residential power-frequency fields above 0.3 to 0.4 µT, the basis of the IARC Group 2B classification [17,18,19]; whether this applies to the frequencies and durations of cabin exposure has not been studied. A 2026 review concludes that "magnetic field exposure during routine EV use should not be presumed harmless" and calls for "dedicated analysis of children as a vulnerable subgroup" [20]. Near the coils of a wireless-charging minibus, modeled ICNIRP basic restrictions "are exceeded up to 12% for an adult and up to 38% for a newborn", while they were "never exceeded within the vehicles" [21].

[Q11(d)] Implants. Studies of electric and hybrid cars and of high-power and 220 V charging found no interference in pacemaker and defibrillator patients under the conditions tested [22,23,24,25], but the field along a charging cable reached 116.5 µT [26], and the two wireless EV chargers tested caused no interference but were reported without field strengths [11].

People report symptoms. In a survey of electrohypersensitive people in Japan, 65% attributed health problems to other passengers' mobile phones on trains or buses and 12% could not use public transportation at all [27].

3 CURRENT LIMITATION OR GAP [Q5(o), Q8]

G1. No U.S. requirement to assess the occupant. EFEIA found no provision on electric or magnetic fields in the Federal Motor Vehicle Safety Standards; their electrical rules, FMVSS No. 305 and 305a, address electric shock [28]. FCC rules classify each transmitter as mobile (20 cm or more from the body) or portable and do not mention vehicles; the radar rules apply the exposure rules "as appropriate" [10,6,5]. FCC consumer guidance assumes antennas outside the cabin, where "the metal body of the vehicle can effectively shield occupants" [29]; V2X antennas, interior radar and digital-key anchors can now be mounted inside it [30,5,4].

G2. No whole-cabin method. IEC 62764-1 excludes transmitting antennas and the charging station [8]; China's GB/T 37130-2018, a recommended standard for 10 Hz to 400 kHz, excludes wireless charging [31]; Japan's JASO TP-13002 covers 10 Hz to 400 kHz in vehicles with traction batteries [32]. None covers on-board transmitters or combines low-frequency and RF exposure. The Swiss authors list the lack of limits for vehicle interiors and of a method to combine sources across the spectrum as unresolved: "One outstanding issue remains the insufficient EMF regulation for vehicle interiors" [2].

G3. Peaks are missed. The Swiss authors consider that, with the temporal and spatial gaps of their protocol, they probably did not capture all short peaks or the maximum field strengths, and that a strict worst case needs targeted measurements at higher temporal and spatial resolution [2]. BfS notes that current standards do not capture peaks shorter than 0.2 s and recommends that automotive procedures reliably capture short, spatially limited magnetic-field peaks and the combined action of several sources [33,7]. Slow sampling can underestimate maxima two to three times [34], and a 5 Hz spectral resolution "very likely" underestimates exposure [35].

G4. Today's radars have not been measured in the cabin. Interior radar for child-presence detection is authorized at 57-64 GHz, and road radar at 76-81 GHz with up to 50 dBm average EIRP [5,6]; EFEIA found no in-cabin measurement of either, and the in-vehicle RF surveys cited here stop at 6 GHz [2,36].

G5. Occupants are not represented. The V2X dosimetry study modeled one adult male driver [37]; in a car model, children's whole-body SAR was typically 1.1 to 1.3 times, and their limb SAR 2 to 3 times in several scenarios, that of adults [38]. EFEIA found no in-vehicle dosimetry for pregnant occupants.

G6. Phones inside a metal box. Standard channel models assign a car penetration loss of 9 dB on average and 20 dB with metallized windows [39], and phones raise uplink power to compensate for path loss (Section 4). EFEIA found no published measurement of handset output power in occupied passenger cabins on current LTE and 5G networks.

G7. No pathway for symptoms, and fields change over time. No registry records symptoms attributed to vehicles; motion sickness, which stronger regenerative braking increased in an on-road study [40], is one alternative cause to rule out. In shared electric cars monitored for two years, fields rose after component and

hub replacement [41]; no rule requires reassessment after repairs or software updates.

4 EXISTING EVIDENCE [Q4(k), Q7]

Table 1. Measured and modeled exposure in vehicles. Values as printed in each source, except the Tognola percentage (calculated) and the µT value for the EFEIA study (conversion).

Topic	Source (grade)	Result as reported
National campaign, Germany	BfS 2025 (b) [33,7,42]	14 car models (11 battery-electric, 2 hybrid, 1 combustion), test bench, track and traffic: 1999 EU reference values exceeded locally or briefly in all but one; ICNIRP 2010 levels less often; basic restrictions never; highest in front footwells, at switch-on and load changes. Charging: up to 219% of the reference value in the driver footwell for 2-5 s at the start (AC, 11 kW), 5.8% or less afterwards
National campaign, Switzerland	Eberhard 2023 (b) [2]	5 battery-electric cars and 1 diesel, DC-100 kHz and 90-6000 MHz: averages up to 5% of ICNIRP 2010 reference levels (low frequency) and up to about 10% of RF limits (maximum 12% on the Swiss NISV basis); low-frequency peaks up to about 50%, "hardly directly related to the electric drive"; RF typically up to 3 V/m, single values up to 7 V/m; wireless charging not investigated. The authors see no additional health risk from the electric drive and no need for a larger follow-up, and name interior regulation and connectivity as open issues
EU research	Vassilev 2015 (a); Trentadue 2020 (b) [43,35]	8 electrified and 3 conventional cars: up to 20% of ICNIRP 2010 reference levels near the battery and at the feet during start-up, under 2% at front-passenger head height, about 10% in conventional cars. Six models: weighted-peak results above 100% "in PHEVs and only in one EV", highest at the feet in acceleration and braking
U.S. utility research	Tell 2013 (a)† [44]	Geometric mean 0.095 µT in 7 electric cars and 0.051 µT in 4 gasoline cars, 40-1,000 Hz
Tires, all cars	Stankowski 2006 (a) [3]	Up to 100 µT at the tires; several µT at the feet and back seat, 10-200 Hz
Long-term monitoring	Yang 2019 (a) [41]	3 shared electric cars over 2 years: highest mean 1.57 µT (front seat, acceleration); fields rose after repairs
RF, V2X and Bluetooth	Schilling 2022 (a) [30]	With the antenna on the windscreen, V2X "generated the highest electric field strengths inside a car", on average about three times the other in-car devices, maximum 15.1% of the ICNIRP 1998 reference level; the roof antenna was strongly attenuated by the car body; the authors advise against transmitting antennas in the cabin
RF dosimetry	Tognola 2021 (a) [37]	Four external 5.9 GHz antennas at 30 W EIRP, worst case next to the driver's head: head SAR 1.58 W/kg (79% of the 2 W/kg ICNIRP 2020 limit), whole-body 8.33 mW/kg
Cardiac implants	Lennerz 2018, 2023; Tondato 2017; Wase 2023 (a) [22,23,24,25]	108 patients, 4 electric cars with charging; 130 patients, 561 high-power charging sessions with the cable over the device; 30 defibrillator patients in a hybrid; defibrillator patients beside a charging electric car, including at 220 V: no interference
EFEIA vehicle study	Machado 2025 (a)‡ [36]	Two Tesla Model Y (2021, 2022), "952 EMF data points" in Miami-Dade County, driving, idle and charging: ELF/LF electric field peaks during Supercharging, up to 113 V/m in the Supercharger zone; RF peaks at 2.4 and 5 GHz at the console, display and adjacent seats; magnetic flux density 0.21-0.62 mG at 14 points, peak 1.94 mG (0.194 µT); body voltage highest at the front seats during Supercharging and high-speed driving

† Funded by EPRI; EPRI and Southern California Edison authors (stated); not downgraded. ‡ The author's own study; relationship stated in the reference.

F1. Well established: fields peak near the floor and during transients. Magnetic fields are highest at the feet and front footwells and during start-up, acceleration, braking and load changes, and vary more with model and component than with fuel [43,7,2,35].

F2. Consistent: low averages; brief peaks that can exceed reference values. Averages are a few percent of reference levels everywhere; brief local peaks exceeded the 1999 EU reference values in all but one vehicle in Germany [7], exceeded 100% in some plug-in hybrids and one electric car in the JRC tests [35], and reached about 50% in Switzerland [2]; basic restrictions were not exceeded where assessed [7].

F3. Moderate: transmitters inside the cabin set in-cabin RF. On-board systems, especially antennas inside the cabin, gave the highest in-car fields [30]; modeled exposure approached the head limit only with high-power antennas next to the driver's head [37].

F4. Reassuring under tested conditions, limited elsewhere: cardiac implants. No interference in studies of 108, 130 and 30 patients and in one small study at 220 V [22,23,24,25]; wireless charging has been tested in two systems without reported field strengths [11], and EFEIA found no clinical tests for other implant types.

F5. Exploratory: EFEIA's vehicle study. Two vehicles in one city; body voltage is a coupling indicator, not tissue absorption, and the bioelectrography outcomes are not SAR or clinical endpoints [36,4]. After a passive nanocomposite was installed (Section 5), the paper reports a 61.95% reduction in the BioWell environmental activity index (entropy in the abstract; as printed), with all six 18-minute blocks inside the 25-100 unit "optimal" range [36]; GDV/Bio-Well is a method under active scientific validation.

5 WHAT EFEIA CAN CONTRIBUTE [Q4(k), Q4(l), Q10(f)]

EFEIA's author first called for a vehicle exposure protocol on the model of SAR testing for phones in 2020 [45].

Table 2. EFEIA datasets and actions.

Dataset or action	Gap	Contribution	Status
Tesla Model Y study	G3	Multi-state protocol (driving, idle, AC charging and Supercharging); seat and console mapping of ELF/LF electric and magnetic fields, RF 0.3-6 GHz, body voltage and environmental bioelectrography [36]	Published 2025
180 reported cases	G7	As of 21 October 2026, NOXTAK has received 180 cases of people who attribute symptoms or adverse experiences to electric-vehicle use and sought help, including filtering. An author-reported service count, not a prevalence estimate or adjudicated injuries [4]	Reported; consented registry planned
National plan	G1-G7	24-month program: scenario library, seat-resolved maps from 1 Hz to the highest radar band, occupant dosimetry atlas, symptom registry, cabin exposure dossier and change control [4]	Submitted with this summary
Architectural index	G5	An index of the electronic complexity of 22 electric cabins and an inferred ranking, offered to stratify sampling; not measured dose or risk [4]	Hypothesis; needs independent verification
Mitigation testing	G1	Engineering measures and filtering technologies, including the nanocomposite, tested under one protocol with sham controls and blinded analysis (Section 4) [4]	Proposed

[Q4(l)] Each EFEIA dataset will record instrument model and serial number, calibration certificate, probe and bandwidth, detector and sampling interval, vehicle model, configuration and software version, seat and probe position, operating state, route, network conditions and uncertainty.

6 ADDITIONAL RESEARCH NEEDED [Q5(o), Q8, Q16]

R1. Seat-resolved national campaign. A stratified fleet sample by propulsion, age and sensing and connectivity architecture, with repeat units, from 1 Hz to the highest installed radar band [4,7], and time-domain capture of peaks at higher temporal and spatial resolution, synchronized to vehicle telemetry [2,7]. **R2. Occupant dosimetry.** Induced internal electric fields at low frequency, SAR and absorbed power density at RF and millimeter waves, in adult, child, child-seat and pregnant models, validated with phantoms and interlaboratory comparison [38,37,12]. **[Q13(i)] R3. Interior radar and V2X** at 57-64 and 76-81 GHz, at operating duty cycles [5,6]. **R4. Phone and hotspot uplink power inside vehicles** on current LTE and 5G networks, by coverage and window type [39]. **[Q11(a)] R5. Children:** whether the childhood-leukemia association with time-averaged power-frequency fields is relevant to cabin exposure, and the cumulative exposure of children on daily routes [17,20]. **[Q11(b)] R6. Pregnancy:** maternal and fetal models at realistic seat geometries [4]. **[Q11(d)] R7. Implants:** wireless charging with field strengths reported, and neurostimulators, insulin pumps and hearing implants near chargers and interior transmitters [11]. **[Q11(e)] R8. Professional drivers:** full-shift personal exposure logging in trucks, buses and ride-hailing cars. **[Q4(m)] R9. Health:** a consented symptom registry with differential assessment (motion sickness, braking, noise, vibration, heat, display use), then preregistered, sham-controlled, double-blind provocation studies in real cabins below thermal thresholds, with heart-rate variability, sleep and attention endpoints [4,40]. **R10. Durability:** reassessment after repairs, component replacement and software updates [41].

7 PROPOSAL AND NEXT STEPS [Q5(n), Q9, Q17]

[Q17] P1. HHS, through OASH, convenes DOT and NHTSA, the FCC, NIST and NIOSH to authorize the 24-month national program in the National Plan [4], with an independent scientific steering process and independent laboratories. **[Q5(n)] P2.** NIST, with IEC Technical Committee 106 and SAE, develops a whole-cabin protocol that extends IEC 62764-1 to on-board transmitters and radars, captures peaks, combines sources across the spectrum and is validated by interlaboratory comparison [8]. **[Q17(b)] P3.** NIEHS funds the occupant dosimetry atlas and the health studies (R2, R5, R9). **[Q17(c)] P4.** CDC, with NIOSH, sets the case definition for the symptom registry and leads professional-driver surveillance (R8, R9). **[Q17(a)] P5.** FDA's Center for Devices and Radiological Health publishes interference distances by implant type for EV chargers, wireless charging and interior radar (R7). **[Q5(n)] P6.** The FCC states, in ET Docket 13-84, where comments are due 22 October 2026, how vehicle-integrated transmitters are assessed for occupants at actual seat distances and in combination [10,46]. **[Q9] P7.** Through the interagency review in P1, new models carry a cabin exposure dossier: an inventory of transmitters and antenna locations, the scenarios tested and seat-resolved results, reassessed after changes that alter exposure [4]. **P8.** Protection claims, including those for filtering technologies, are evaluated under the national framework of Section 4 (Exhibit 4A), with the nanocomposite tested as one candidate (Section 5).

Related: Sections 1 (instrumentation), 2 (urban monitoring), 3 (EHS and implants), 4 (shielding and consumer

products), 5 (the nanocomposite, with the relationship disclosed) and 6 (what the limits assume).

KEY REFERENCES

1. Hungund AP, Steinbach R. American Driving Survey: 2024. Research brief. Washington, DC: AAA Foundation for Traffic Safety; December 2025. pp. 3-4. https://aaafoundation.org/american-driving-survey-2024. (b, institutional report)

2. Eberhard J, Fröhlich J, Zahner M. Elektromagnetische Felder (EMF) in Elektrofahrzeugen. Schlussbericht. Bern: Bundesamt für Energie BFE; 31 March 2023. ARAMIS project 50465 (EMFEMOB). English summary p. 5; pp. 45, 59-60. https://www.aramis.admin.ch/Dokument.aspx?DocumentID=70257. (b, government-funded report; Forschungsstiftung Strom und Mobilkommunikation and Fields at Work GmbH)

3. Stankowski S, Kessi A, Bécheiraz O, Meier-Engel K, Meier M. Low frequency magnetic fields induced by car tire magnetization. Health Physics. 2006;90(2):148-153. doi:10.1097/01.hp.0000174526.10639.ff. (a)

4. Machado, J. J. (2026). *National plan for electromagnetic biocompatibility in modern vehicles: A proposal for whole-vehicle exposure assessment, occupant dosimetry and regulatory development* [Proposal]. Zenodo. https://doi.org/10.5281/zenodo.23541733 (b; Additional 4 · National Plan, submitted with this summary; EFEIA's own proposal, dated 21 October 2026; the author is NOXTAK's founder and CTO, and the 180 cases it reports were received by NOXTAK)

5. Federal Communications Commission. Amendment of Section 15.255 of the Commission's Rules. Report and Order, ET Docket No. 21-264, FCC 23-35. Released 19 May 2023. Federal Register. 2023;88:47384-47395. 47 CFR 15.255. (a, regulatory record)

6. Federal Communications Commission. Amendment of Parts 1, 2, 15, 90 and 95 of the Commission's Rules to Permit Radar Services in the 76-81 GHz Band. Report and Order, ET Docket No. 15-26, FCC 17-94. Released 14 July 2017. Federal Register. 2017;82:43865-43872. 47 CFR Part 95 Subpart M, §§ 95.3367 and 95.3385. (a, regulatory record)

7. Geschwentner D, Zang M. Magnetische Felder bei der Elektromobilität. UMID: Umwelt und Mensch Informationsdienst. 2025;(2):2-9. pp. 6-7. Summarizes BfS-RESFOR-243/25 (fields while driving, urn:nbn:de:0221-2025031250843) and BfS-RESFOR-252/25 (fields while charging, urn:nbn:de:0221-2025112157059). https://www.umweltbundesamt.de/system/files/medien/14946/publikationen/2026-06/umid%202502_Artikel%201%20DNK.pdf. (b, federal agency article; first author at the BfS Competence Centre for EMF)

8. International Electrotechnical Commission. IEC 62764-1:2022. Measurement procedures of magnetic field levels generated by electronic and electrical equipment in the automotive environment with respect to human exposure. Part 1: Low-frequency magnetic fields. Edition 1.0, 15 September 2022. (a, standard)

9. United Nations Economic Commission for Europe. UN Regulation No. 10. Uniform provisions concerning the approval of vehicles with regard to electromagnetic compatibility. 07 series of amendments, ECE/TRANS/WP.29/2024/90, adopted November 2024. (a, regulatory record)

10. 47 CFR 1.1307(b), 1.1310, 2.1091 and 2.1093. Radiofrequency radiation exposure limits and evaluation of mobile and portable devices. eCFR, read 21 October 2026. (a, regulatory record)

11. Driessen S, Napp A, Schmiedchen K, Kraus T, Stunder D. Electromagnetic interference in cardiac electronic implants caused by novel electrical appliances emitting electromagnetic fields in the intermediate frequency range: a systematic review. Europace. 2019;21(2):219-229. doi:10.1093/europace/euy155. (a; funded by the European Research Group on Environment and Health in the Transport Sector (EUGT), stated; not downgraded)

12. International Commission on Non-Ionizing Radiation Protection. Guidelines for limiting exposure to electromagnetic fields (100 kHz to 300 GHz). Health Physics. 2020;118(5):483-524. doi:10.1097/HP.0000000000001210. (a, standards body)

13. International Commission on Non-Ionizing Radiation Protection. Guidelines for limiting exposure to time-varying electric and magnetic fields (1 Hz to 100 kHz). Health Physics. 2010;99(6):818-836. doi:10.1097/HP.0b013e3181f06c86. (a, standards body)

14. Dwyer M. Electric vehicle sales fell as hybrid vehicle sales continued to rise in 2025. Today in Energy. U.S. Energy Information Administration; 9 February 2026. https://www.eia.gov/todayinenergy/detail.php?id=67144. Data from Omdia. (b, federal agency)

15. U.S. Bureau of Labor Statistics. Occupational Outlook Handbook: Heavy and tractor-trailer truck drivers; Bus drivers; Taxi drivers, shuttle drivers, and chauffeurs. 2025 employment. https://www.bls.gov/ooh/transportation-and-material-moving/. (b, federal agency)

16. Hareuveny R, Sudan M, Halgamuge MN, Yaffe Y, Tzabari Y, Namir D, Kheifets L. Characterization of extremely low frequency magnetic fields from diesel, gasoline and hybrid cars under controlled conditions. International Journal of Environmental Research and Public Health. 2015;12(2):1651-1666. doi:10.3390/ijerph120201651. (a; funded by the Israeli Ministry of National Infrastructures, Energy and Water Resources)

17. International Agency for Research on Cancer. Non-ionizing radiation, Part 1: static and extremely low-frequency (ELF) electric and magnetic fields. IARC Monographs Vol. 80. Lyon: IARC; 2002. pp. 332-338. (b, institutional report)

18. Ahlbom A, Day N, Feychting M, et al. A pooled analysis of magnetic fields and childhood leukaemia. British Journal of Cancer. 2000;83(5):692-698. doi:10.1054/bjoc.2000.1376. (a)

19. Greenland S, Sheppard AR, Kaune WT, Poole C, Kelsh MA. A pooled analysis of magnetic fields, wire codes, and childhood leukemia. Epidemiology. 2000;11(6):624-634. doi:10.1097/00001648-200011000-00003. (a; NIEHS-funded)

20. Tsai P-H, Chen X. From measurement to health: a synthesis of EMF exposure, biological evidence, and safety guidelines in electric vehicles. International Journal of Environmental Research and Public Health. 2026;23(10):1242. doi:10.3390/ijerph23101242. (a, review)

21. Liorni I, Bottauscio O, Guilizzoni R, et al. Assessment of exposure to electric vehicle inductive power transfer systems: experimental measurements and numerical dosimetry. Sustainability. 2020;12(11):4573. doi:10.3390/su12114573. (a; EMPIR project 16ENG08 MICEV)

22. Lennerz C, O'Connor M, Horlbeck L, et al. Electric cars and electromagnetic interference with cardiac implantable electronic devices: a cross-sectional evaluation. Annals of Internal Medicine. 2018;169(5):350-352. doi:10.7326/M17-2930. (a)

23. Lennerz C, Schaarschmidt C, Błażek P, et al. High-power chargers for electric vehicles: are they safe for patients with pacemakers and defibrillators? Europace. 2023;25(5):euad042. doi:10.1093/europace/euad042. (a)

24. Tondato F, Bazzell J, Schwartz L, et al. Safety and interaction of patients with implantable cardiac defibrillators driving a hybrid vehicle. International Journal of Cardiology. 2017;227:318-324. doi:10.1016/j.ijcard.2016.11.090. (a)

25. Wase A, Hussain UA, Ratajczak T, Aung TT, Ali O, Markert RJ. The impact of electromagnetic interference from charging all-electric vehicles on implantable cardioverter-defibrillator performance. Journal of Innovations in Cardiac Rhythm Management. 2023;14(10):5600-5604. doi:10.19102/icrm.2023.14102. (a)

26. Lennerz C, Horlbeck L, Weigand S, et al. Patients with pacemakers or defibrillators do not need to worry about e-cars: an observational study. Technology and Health Care. 2020;28(1):1-12. doi:10.3233/THC-191891. (a)

27. Kato Y, Johansson O. Reported functional impairments of electrohypersensitive Japanese: a questionnaire survey. Pathophysiology. 2012;19(2):95-100. doi:10.1016/j.pathophys.2012.02.002. (a)

28. 49 CFR Part 571, Federal Motor Vehicle Safety Standards, including Standard No. 305 (electric-powered vehicles: electrolyte spillage and electrical shock protection) and Standard No. 305a (electric powertrain integrity, mandatory from 1 September 2027 for vehicles of 4,536 kg GVWR or less and from 1 September 2028 for heavier vehicles). eCFR, read 21 October 2026. (a, regulatory record)

29. Federal Communications Commission. Human exposure to RF fields from vehicle-mounted antennas. Consumer guide, last updated or reviewed 15 October 2019; archived, no longer actively maintained. https://www.fcc.gov/consumers/guides/human-exposure-rf-fields-mobile-vehicle-mounted-antennas. (b, federal agency guidance)

30. Schilling L-M, Bornkessel C, Hein MA. Human RF electromagnetic exposure to V2X-communication. Advances in Radio Science. 2022;19:233-239. doi:10.5194/ars-19-233-2022. (a)

31. State Administration for Market Regulation, Standardization Administration of China. GB/T 37130-2018. Measurement methods for electromagnetic fields of vehicle with regard to human exposure. Issued 28 December 2018; in force 1 July 2019. (a, national standard)

32. Society of Automotive Engineers of Japan. JASO TP-13002. 自動車の人体ばく露に関る電磁界測定方法 (Measurement method of electromagnetic fields in vehicles with regard to human exposure; translation). Technical paper, March 2013. (b, pre-standard technical paper)

33. Bundesamt für Strahlenschutz. Press release 005/2025 on the e-mobility exposure project (Vorhaben 3620S82473; Seibersdorf Labor, femu at RWTH Aachen University Hospital and ADAC Technik Zentrum). 9 April 2025. https://www.bfs.de/SharedDocs/Pressemitteilungen/BfS/DE/2025/005.html. (b, national agency press release)

34. Gryz K, Karpowicz J, Zradziński P. Complex electromagnetic issues associated with the use of electric vehicles in urban transportation. Sensors. 2022;22(5):1719. doi:10.3390/s22051719. (a; Polish national programme on safety and working conditions)

35. Trentadue G, Zanni M, Martini G. Assessment of low frequency magnetic fields in electrified vehicles. JRC120312, EUR 30198 EN. Luxembourg: Publications Office of the European Union; 2020. doi:10.2760/056116. (b, European Commission Joint Research Centre report)

36. Machado JJ. Evaluation of EMF exposure in TESLA Model Y (2021/2022) and testing the efficiency of SPIRO technology: an environmental bioelectrography study. Journal of Applied Biotechnology and Bioengineering. 2025;12(4):131-143 (Crossref lists 131-142). doi:10.15406/jabb.2025.12.00395. (a; the author's own study; the author is NOXTAK's founder and CTO, and NOXTAK makes SPIRO, the nanocomposite tested)

37. Tognola G, Masini B, Gallucci S, et al. Numerical assessment of RF human exposure in smart mobility communications. IEEE Journal of Electromagnetics, RF and Microwaves in Medicine and Biology. 2021;5(2):100-107. doi:10.1109/JERM.2020.3009856. (a)

38. Harris L-R, Zhadobov M, Chahat N, Sauleau R. Electromagnetic dosimetry for adult and child models within a car: multi-exposure scenarios. International Journal of Microwave and Wireless Technologies. 2011;3(6):707-715. doi:10.1017/S1759078711001000. (a)

39. 3rd Generation Partnership Project. 3GPP TR 38.901 V19.5.0 (2026-09). Study on channel model for frequencies from 0.5 to 100 GHz (Release 19). Clause 7.4.3.2, car penetration loss. (a, standards)

40. Xie W, Wang Z, Jiang Y, Huang C, Wang J, He D. Exploring the effects of regenerative braking and the auditory cues for alleviating motion sickness in electric vehicles. International Journal of Human-Computer Interaction. 2025;41(24):15493-15505. doi:10.1080/10447318.2025.2499155. (a)

41. Yang L, Lu M, Lin J, et al. Long-term monitoring of extremely low frequency magnetic fields in electric vehicles. International Journal of Environmental Research and Public Health. 2019;16(19):3765. doi:10.3390/ijerph16193765. (a; China Academy of Information and Communications Technology authors)

42. Bundesamt für Gesundheit (Switzerland). Auto, Elektroauto, Hybridauto. Factsheet. 5 February 2026. Table 3, p. 7. https://www.bag.admin.ch/dam/de/sd-web/1QpYPc8-6-N6/Faktenblatt%20Auto.pdf. (b, national agency factsheet)

43. Vassilev A, Ferber A, Wehrmann C, Pinaud O, Schilling M, Ruddle AR. Magnetic field exposure assessment in electric vehicles. IEEE Transactions on Electromagnetic Compatibility. 2015;57(1):35-43. doi:10.1109/TEMC.2014.2359687. (a; EU FP7 project EM-SAFETY)

44. Tell RA, Sias G, Smith J, Sahl J, Kavet R. ELF magnetic fields in electric and gasoline-powered vehicles. Bioelectromagnetics. 2013;34(2):156-161. doi:10.1002/bem.21730. (a; funded by EPRI; EPRI and Southern California Edison authors, stated; not downgraded)

45. Machado J. Electromagnetic exposure in hybrid and electric vehicles (EV): how safe are you? NOXTAK; 12 November 2020. https://noxtak.com/electromagnetic-exposure-in-hybrid-and-electric-vehicles-ev-how-safe-are-you-2/. (c, the author's own position statement, published by NOXTAK)

46. Federal Communications Commission, Office of Engineering and Technology. FCC seeks comment on RF exposure issues subject to D.C. Circuit remand in Environmental Health Trust v. FCC. Public Notice DA 26-997, ET Docket No. 13-84, released 17 September 2026. Federal Register. 2026;91(182):60128-60131. (a, regulatory record)