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Personal Safety in Electromagnetic Environment of Electric Vehicle

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Abstract

With the extensive application of automotive electrical and electronic equipment, issues of electromagnetic radiation and electromagnetic compatibility have become increasingly prominent, human body in complex automotive electromagnetic environment is bound to be some damage of electromagnetic radiation. This paper established a relatively sophisticated car simulation model,through electromagnetic characteristics of antenna model, we got automotive electric field distribution and simulation results of human body SAR value, so conclusion can be drawn that automotive electromagnetic environment is relatively safe to passengers.

Keywords*: Automotive electromagnetic compatibility;electromagnetic radiation; antenna model; electromagnetic environment*

1. Introduction

In recent years with the large number of electrical and electronic equipment used in automotive, making car electromagnetic environment complicated and exacerbated, thus the impact of electromagnetic radiation on human security received increasingly widespread domestic and international attention. Passengers exposed to car electromagnetic environment, will be affected by electromagnetic radiation of interior interference sources, and the hazard to personal safety in electric vehicles is particularly serious which has more electrical and electronic equipment. Therefore the personal safety in electric cars becomes extremely important.

The main interference source of electromagnetic radiation inside electric vehicles included car antennas, wiring harness, DC-DC converters, motors, *etc.* [1-3]. Electromagnetic wave frequency generated by automotive electrical is generally between 0.15-1000MHz, which overlap the frequencies of common radio communications, radio and television [4-6]. At present domestic and foreign auto industry has developed a relevant EMC testing standards to regulate automotive design of EMC requirements, but still has no automotive electromagnetic radiation standard to interior human health [5-8].

The weak electromagnetic fields of body's organs and tissues are stable and orderly, once subjected to external electromagnetic interference, broking the equilibrium of weak electromagnetic fields, then body suffers damage [9]. Automotive electromagnetic field is bound to affect the interior electromagnetic field of human body, so the electromagnetic radiation detriment of human body is is inevitable.

This paper conducted car model and mesh of vehicle,through simulation analysis of car antenna, obtained curves of S11 parameters, far-field distribution, electric and magnetic field strength. Then calculated the distribution of body SAR values numerical calculation method. Compared to body magnetic field distribution, and reference to electromagnetic radiation and electromagnetic interference standards, we come to personal safety findings inside car.

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(1) Replace the overdutied circuit breaker if it is an old breaker or there are other maintenance problems.

(2) Swap breakers within the substations if they have different interrupting capability and swapping possible.

(3) Change the system configuration by opening tie breakers, lines or transformers.

(4) Apply current limiting devices in the substations if there are several overdutied breakers in the substations.

2. Automotive Electromagnetic Simulation Analysis

2.1. Numerical Methods

Method of Moments (MoM) is an effective numerical methods to solve electromagnetic boundary value problems. EMC Studio software can accurately analyze EMC problems, such as carriers, cable harness and interconnect systems, electronic equipment, antennas, internal and external electromagnetic environment issues. EMC Studio integrated using the method of moments (MoM), equivalent source (MAS), the transmission line (MTL), network analysis (SPICE), physical optics ((PO) and other methods to accurately analyze EMC issues of complex systems such as vehicles, aircraft, ships, computer systems and interior equipment with cables.

Finite Difference Time Domain (FDTD) method is a direct time-domain method to solve electromagnetic problem, which is one of the most widely used numerical algorithm on computational electromagnetics and has great development prospects. XFDTD is an software to solve three-dimensional electromagnetic problems based on finite difference time domain numerical algorithm, which can be used to simulation analysison bio-electromagnetics, mainly used to calculated body SAR values[10-13].

2.2. Vehicle Modeling and Meshing

First need pretreatment for three-dimensional model of car body. The accuracy of numerical simulation on automotive EMC problems depends on: original testing parameters of solid models such as metal body, connecting cables, electronic control unit and electronic components and antenna. General complex three-dimensional body model is mainly for mechanical performance analysis, therefore contains a large number of local details. For electromagnetic field simulation, many of local structure details are unimportant, and will bring a huge number of meshes. Therefore, the imported three-dimensional model can not be directly used for EMC analysis, it needs simplified methods, which are:

(1) Remove some small and unimportant parts;

(2) Remove the intersection and overlap area.

After simplified three-dimensional solid model of body, three-dimensional solid model can be directly imported into EMC analysis software. The software will automatically equivalent import solid geometry model for different surface units. Once body solid model divided, the software will automatically mesh or user-defined, as shown in Figure 1.

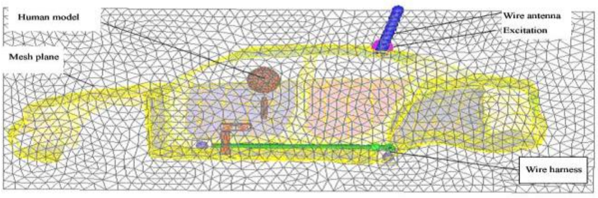

Figure 1. Car Solid Geometry and Meshs

In Figure 1, the size of radiation plate is 2.5 × 5.5, meshs of 0.25m, automotive wiring harness, antenna, human body, *etc.* is including in *XZ* plane. Taking into account the radiation of electric car rear panels and front motor, established Cartesian coordinate system in accordance with spatial position, people sitting in cab position, automotive wiring harness at bottom, and motor is disposed in front cabin.

Field strength at feeding point is

$$E_x(i, j, k) = \frac{V(t)}{\Delta x} \tag{1}$$

Where $V(t)$ represents excitation voltage, Δx is step size in x direction, i,j,k coordinate along x,y,z direction.

Excitation source set as sine wave, center frequency of 80-120MHz, steps of 5MHz, antenna placed along Z-axis direction, and feed is 50Ω . Simulated distribution contours of electric field and magnetic field are shown in Figure 2 and Figure 3.

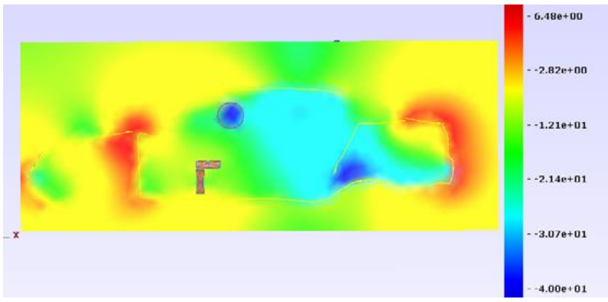

Figure 2. Electric Field Radiation Cloud of Body in Car

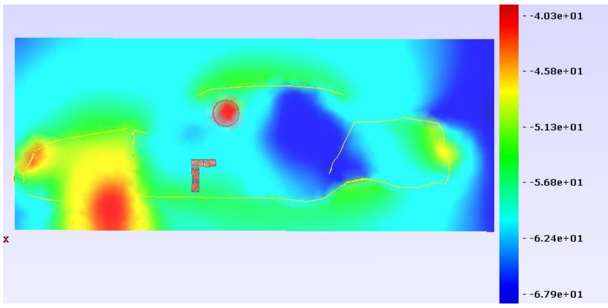

Figure 3. Magnetic Field Radiation Cloud of Body in Car

As can be seen from the electric field distribution, the front and rear of the vehicle body in a large amount of electromagnetic radiation, in front and rear of vehicle body has larger amount of electromagnetic radiation, at trunk position radiation becomes smaller, which is mainly due to electrical equipment such as motor and battery plate disposed in the front and rear, generate larger current, thus has a larger electric field radiation.While in Figure 3, front cabin having current loop effect generate larger radiation, instead, the back get smaller amount. Automotive surface by virtue of metallic conductors, get more radiation, in interior space electromagnetic field is relatively small, close to electromagnetic field value in air space.

2.3. Simulation Analysis of Antenna Problems

Studies of antenna, is to research on electromagnetic field distribution generated by the antenna, as well as antenna characteristics determined by its distribution. The substance of antenna problem is to solve Maxwell equations satisfied specific boundary conditions. Strict solve antenna problems are very complex and difficult, therefore, it often idealized conditions to deal with specific antenna problems, taking approximation method to obtain desired result.

Antenna length is 0.75m, frequency range is 80-120MHz, Figure 4 shows simulation results.

2.4. S11 Parameter (dB)

By transmission line theory, when transmission line discussed above is treated as the i-th transmission system connected to a microwave network, there exists incident and reflected waves in this transmission system. Relations between normalized incident and reflected waves can be expressed as $u_1^- = \Gamma_i u_1^+ = S_{ii} u_i^+$. Then considered two-port network, normalized reflected wave represented with normalized incident wave of each port reference plane, can be written as:

$$\left.\begin{aligned} u_1^- &= S_{11} u_1^+ + S_{12} u_2^+ \\ u_2^- &= S_{21} u_1^+ + S_{22} u_2^+ \end{aligned}\right\} \tag{2}$$

Compared with matrix form:

$$\begin{bmatrix} u_1^- \\ u_2^- \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \begin{bmatrix} u_1^+ \\ u_2^+ \end{bmatrix} \tag{3}$$

Where $[u^-]$,$[u^+]$ are column matrix of normalizing reflected wave and incident wave; $[s] = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix}$ scattering matrix; S_{11},S_{12},S_{21},S_{22} scattering parameter.

S_{11} Scattering parameter in equation (1) is defined as follows:

$$S_{11} = \left.\frac{u_1^-}{u_1^+}\right|_{u_2^+ = 0} = \Gamma_1 \tag{4}$$

S_{11} represented reflection coefficient at T_1, when two-port network T_2 connected to matched load. If T_1 as signal input port, T_2 output port, then S_{11} represented return loss, that is how much energy is reflected back to source (T_1) [6], the smaller the better, the value is generally recommend $S_{11}<0.1$, namely -20dB. As can be seen from Figure 4, S_{11} parameter of vehicle antenna is maximum -1.7dB, far less than -20dB.

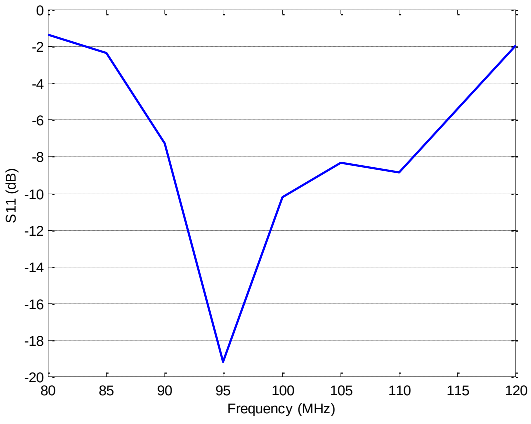

Figure 4. S_{11} Parameter of Car Antenna

The probe is located in cab seat position. Electric and magnetic fields distribution results of probe at set point can be drawn by simulation. Figure 5-6 is a simulation curves of the electric field and magnetic field strength.. As can be seen from the Figure 5-6, with increasing frequency, electric and magnetic fields showed a fluctuating trend, the overall trend is increase first then decrease after. At band 290-310MHz electric field strength reaches maximum, up to 0.56V/m. 300-310MHz magnetic field strength reaches maximum of 7.8×10^{-4}A / m.

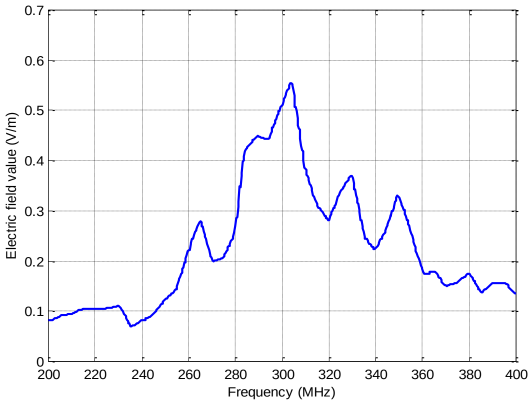

Figure 5. Electric Field Values of Car Antenna

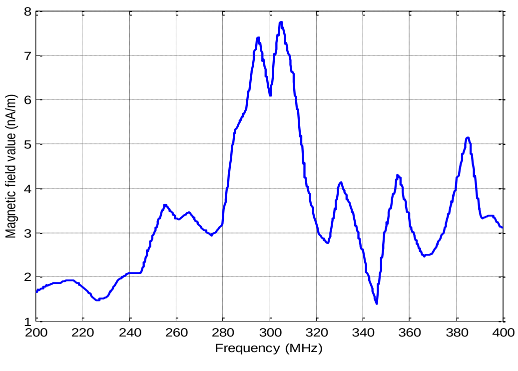

Figure 6. Magnetic Field Values of Car Antenna

3. Human Electromagnetic Simulation

3.1. SAR Analysis

Specific Absorption Rate (SAR) is used to characterize the physical quantity of radio frequency energy absorbed by body. SAR is defined as electromagnetic energy(*dw*) absorbed by per unit mass(*dm* or *pdv*) human tissue in per unit time(*dt*), in units of *mW/g*.

SAR can be calculated as follows:

$$SAR = \frac{d}{dt}\left[\frac{dw}{dm}\right] = \frac{d}{dt}\left[\frac{dw}{\rho dV}\right] \tag{5}$$

For ease of calculation, SAR can also be calculated using following formula:

$$SAR = \frac{\sigma |E|^2}{\rho} \tag{6}$$

Where E represents electric field (*V/m*); σ is conductivity of human tissue (*S/m*); ρ to density of human tissue(*kg/m*^{3}).

Human model is defined as conductor, given in two parts: head and torso. Human electrical parameters is shown in following table 1, defined respectively relative dielectric constant and conductivity of human head and torso.

Table 1. Electrical Parameters of Human Body

Parts of Human body	Dielectric Constant ε_r	Conductivit σ S/m	Mass Density ρ kg/m^3
Head	50	1	1000
Torso	55.9	0.97	1050
Atmosphere	1.0	0	1.0

3.2. SAR Analysis at Different Locations Inside Vehicle

Occupants living in vehicle will inevitably be affected radiation by car electromagnetic environment, while in the car at different spatial locations, the value of radiation amount received is different. When considering space inside car as a radiation field, considered human body of model with different dielectric constant, then irradiation of body can be obtained. In the automobile, different position of seat, different mass human body (adults and children) have different effects to electromagnetic radiation. Consider the following cars in the adult mainly electromagnetic radiation received by the size. When considering interference sources of vehicle antenna, body SAR value is examined at four different locations in car. Provided roof antenna at the rear of vehicle, simulating SAR values of human body in car received electromagnetic radiation, location map is shown in Figure 7.

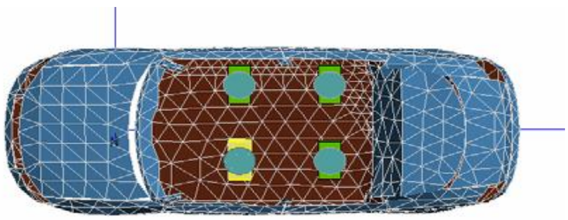

Figure 7. Schematic of Human Body at Different Locations Inside Vehicle

And body SAR distribution curves at different four seat are shown in Figure 8.

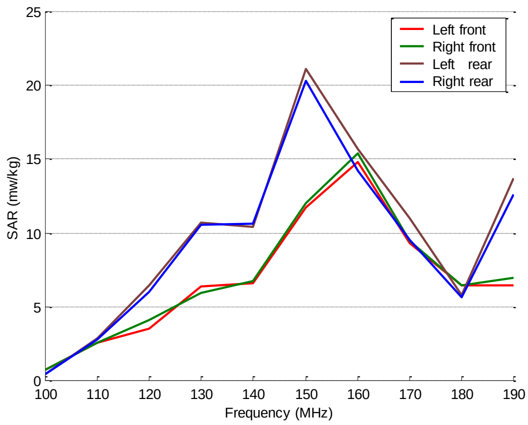

Figure 8. Body Sar Values of Different Seating Position

As can be seen from the Figure 8, at the rear left and rear right seat human body received larger electromagnetic radiation, the reason is antenna at rear of vehicle; while SAR values of left front and right front seat are almost identical, This is mainly due to the electrical equipment inside vehicle is spatial symmetrical around. The average SAR of human body is $1.01\times10^{-3} W / kg$, not exceed the national standard limits: within 24 hours, average SAR of whole-body in any continuous six minutes should be less than 0.02*W/kg* [14-15]. Therefore, the electromagnetic radiation to body inside vehicle is relatively safe. It can be concluded that the value of electromagnetic radiation is related to the distance from radiation source, SAR is the farther from radiation source the smaller, the closer the greater.

3.3. SAR Analysis at Different Locations Inside Vehicle with Sunroof

To increase lighting and adjust interior temperature and air quality, increasing occupants comfort and driving safety, car will be provided sunroof. sunroof will have some impact on electromagnetic environmentin car. Therefore, we contrast electromagnetic absorption changes with sunroof open or not open.

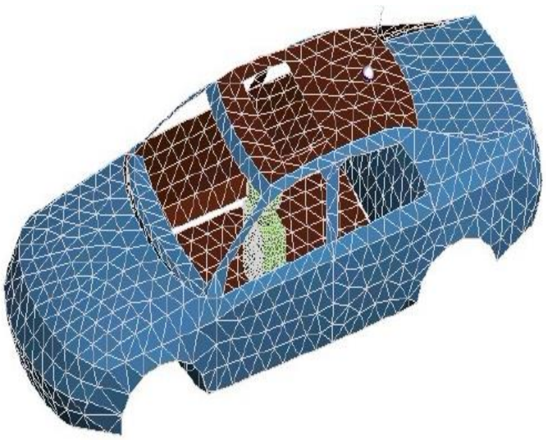

Figure 9. Schematic of Human Body Inside Car with Open Sunroof

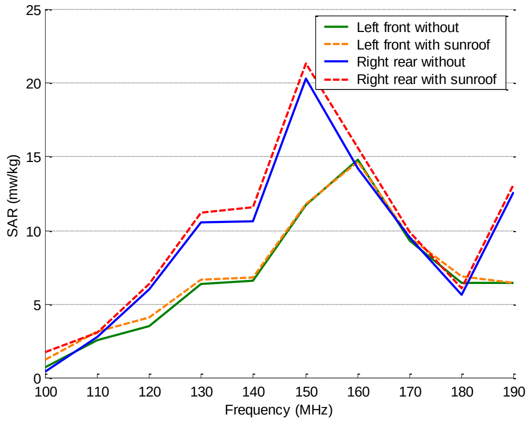

Figure 10. Comparation of Body Sar Values with to without Sunroof

Comparison can be seen from Figure 10 with sunroof open or not, Electromagnetic radiation absorption is slightly smaller with sunroof, mainly due to electromagnetic waves can radiate out from sunroof, therefore body SAR is relatively smaller. Body SAR value both reached maximum 0.015*W/kg* at 150MHz with sunroof or not.

3.4. SAR Analysis of Child Body at Different Locations Inside Vehicle

Children and adults have different volumes, with same density, the of mass is also different. Assuming automobile antennas as interference source, we examine body SAR distribution when child seitting in car of left front, right front, left rear, and right, considering at different positions the radiation absorption be different. SAR value distribution of child body at different seat is shown in Figure 11.

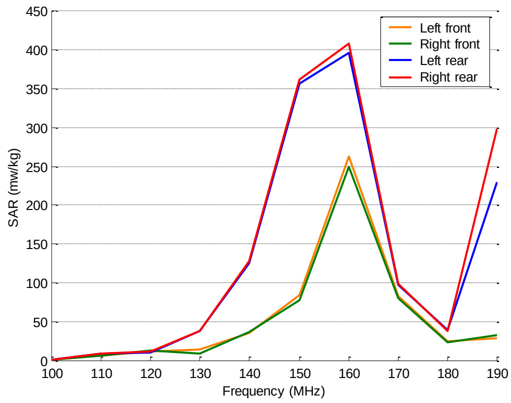

Figure 11. SAR Values of Child Body at Different Seating Position

3.5. SAR Calculation of Human Tissue with DC-DC Considered

The following add a DC-DC converter based on car antenna model, to compare human body SAR value of adults and children in car,as shown in Figure12-14.

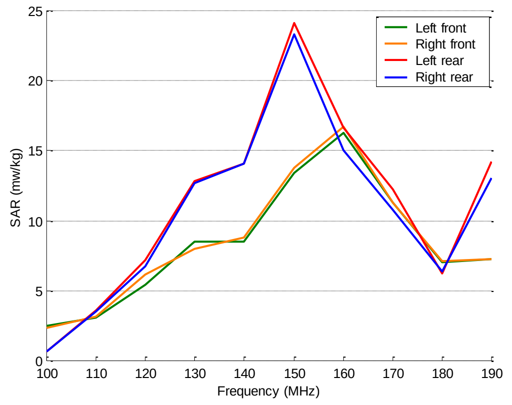

Figure 12. Adult SAR Values Considering Two Interference Sources of Antenna and DC-DC Converters

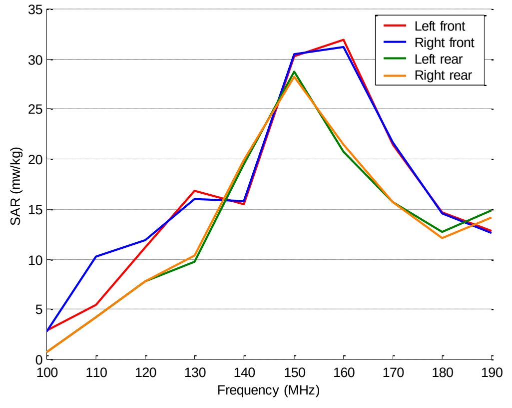

Figure 13. Child SAR Values Considering Two Interference Sources of Antenna and DC-DC Converters

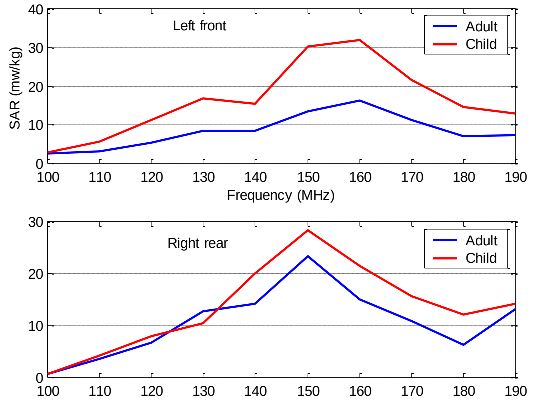

Figure 14. Body SAR Comparison of Adult and Child

As can be seen from Figure 14, childen electromagnetic radiation absorption is greater than adults, because smaller volume of childen, after receiving electromagnetic radiation, SAR is greater than adults. SAR presents first increase and then decrease trend, at frequency 160MHz, childen SAR reaches maximum value of 0.032*W/kg*.

To examine different effects of interference sources on human body, we established various interference sources combinations in FEKO software, SAR is substituted into calculation, obtained its contribution to electromagnetic radiation environment in car.

Among them: A-- Wire harness; B--DC/DC converter; C-- motors.

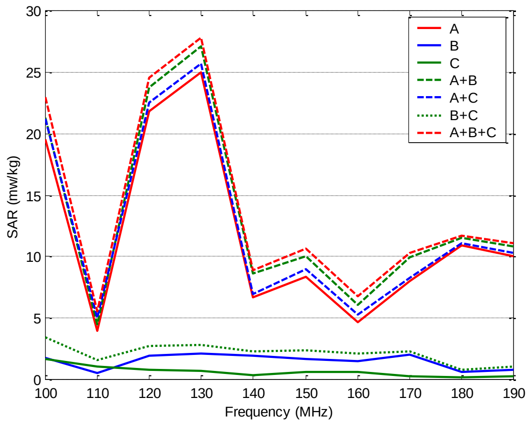

Figure 15. Body SAR Comparison of Different Interference Sources

Analysis From Figure 15, although different radiation frequency of wire harness and motor, the differences between body absorption of electromagnetic radiation is not obvious, wire harness is the prominent interference sources ,and the total amount of radiation is is less than 0.03*W/kg*.

4. Conclusion

This paper established a car model , made simulation analysis on car antennas, simulated electromagnetic radiation effects on human body of different positions in vehicle, calculated body SAR (W/kg) value in different seat position when sunroof opening or not, and electromagnetic radiation of different mass body(adults and children), the results show that:

(1) The closer to radiation source(antenna), the greater body SAR value.

(2)When sunroof opening due to electromagnetic radiation leak out of sunroof, body SAR value has decreased significantly.

(3)Due to the small size and density of childen, body SAR value is larger than adults'.

(4)After considering multiple radiation sources(eg. add DC-DC), body's SAR will increase, but compared to body simulation results, car antenna radiation will not cause very strong biological electromagnetic effects on human body, it is in line with personal safety requirements.

Future research should be dedicated to personal safety of automotive environment, exploring interdisciplinary applications of bioelectromagnetics and automotive fields. By improving structure, taking some electromagnetic protective measures, developing new electromagnetic compatibility regulations, electric vehicles will reduce electromagnetic radiation in the end.

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