Evaluate the shielding effectiveness of driver’s cab for metro and its influence on electromagnetic exposure safety

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Abstract. In order to study the shielding effectiveness of metro driver cab and its impact on the safety of driver high frequency electromagnetic exposure, this paper constructs the high frequency electromagnetic environment model of metro cab under the radiation of external and internal exposure sources, its shielding effect is simulated correspond, and the safety of high frequency electromagnetic exposure of metro driver is analysed. The simulation results show that the under digital trunked system antenna (external exposure source) radiation, the peak value of electric field strength inside the metro cab without aluminium alloy body is 1.7214 V/m, which 322 times higher than that of aluminium alloy cab; under the communication based train control system antenna (internal exposure source) radiation, the peak value of electric field strength inside the aluminium alloy material metro cab is 3.1625 × 10⁻¹ V/m, which 26 times higher than that of without aluminium alloy body. The compared results reveal that the shielding effect of metro cab on the external exposure source is significantly greater than the internal exposure source. Although the radiation dose absorbed by the metro driver varies by 4 to 125 times in different situation, still lower than the international occupational electromagnetic exposure limit, which indicate that the shielding effect of metro cab in the above situation will not cause health hazards to the driver.

1. Introduction
It is estimated that the total mileage of the subway will increase to 7,000 kilometers and spread over 40 cities by 2022. With the establishment of the intelligent subway system, more and more electronic communication equipment would be put into the metro construction and operation, lead metro electromagnetic environment to be more and more complicated. The high frequency electromagnetic exposure sources mainly concentrate in the metro cab, its electromagnetic compatibility not only influence the effective communication of the subway, but also relate to the safety of subway driver. Therefore, it is a practical issue to study the shielding effect of metro driver cab and its impact on the high frequency electromagnetic exposure safety of driver.

The previous studies of shielding effectiveness of vehicle mainly focused on the influence by external cable and the contact network [1-2], and analyzed the electromagnetic compatibility between different devices or systems [3-5]. In 2012, the world health organization had defined electromagnetic waves as possible carcinogens, which generated the nationwide concern. The electromagnetic exposure safety of staff and passengers in vehicles has become a research hotspot [6-8]. However, there have been few studies of the shielding effectiveness on the metro. In order to clarify shielding effectiveness of metro driver cab, its high frequency electromagnetic environment under the radiation of internal and external electromagnetic exposure sources were modeled at first. Secondly, the
shielding effect of the cab with or without aluminium alloy body was simulated, and the high frequency electromagnetic exposure level in driver's human model was analyzed quantitatively. Lastly, we compared simulation results with the occupational electromagnetic exposure limit, which established by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) [9], the exposure safety of cab and its influence on the health of driver was evaluated.

2. Analog model and method

2.1. High frequency exposure sources
The high frequency exposure sources of cab are mainly composed of the Terrestrial Trunked Radio (TETRA) system antenna and the Communication Based Train Control (CBTC) System antenna. The TETRA system antenna is installed outside of cab as the external electromagnetic exposure source. We have proposed the TETRA system antenna based on 6-layer disc yagi_uda structure with centre frequency 835 MHz, its radiation performance has been verified in published paper [10]. The CBTC system antenna adopts dual-antenna structure, and it is installed inside of the subway driver cab as the internal electromagnetic exposure source. We have proposed the CBTC system antenna based on 7-units yagi_uda structure with centre frequency 2450 MHz, its radiation performance has been verified in published paper [11].

2.2. The human model of metro driver
The head and the trunk consists the human model of metro driver. The head model has scalp, skull and brain, which based on the internationally accepted 3-layer head model [12]. According to the 4-order Cole-Cole equation [13], the relative dielectric constant ($\varepsilon_r$), conductivity ($\sigma$) and density ($\rho$) of different human tissues at 835 MHz and 2450 MHz are calculated respectively, as shown in table 1. The dielectric parameter and density of brain tissue is the average of white matter and grey matter. The dielectric parameter and density of trunk tissue is the average of the skin, blood, muscle and bone.

| Table 1. Dielectric properties and tissue density of human model. |
|---------------------|--------|--------|--------|--------|--------|--------|
| frequency          | dielectric properties | scalp  | skull  | white matter | grey matter | muscle | blood |
| 835 MHz            | $\varepsilon_r$       | 46.355 | 12.517 | 39.116   | 53.056   | 55.192 | 61.575 |
|                    | $\sigma$ (S/m)        | 0.821  | 0.136  | 0.5711   | 0.915    | 0.921  | 1.510  |
| 2450 MHz           | $\varepsilon_r$       | 42.853 | 11.381 | 36.16    | 48.911   | 52.729 | 58.264 |
|                    | $\sigma$ (S/m$^2$)    | 1.592  | 0.394  | 1.215    | 1.808    | 1.739  | 2.545  |
|                    | $\rho$ (kg/m$^3$)     | 1100   | 1850   | 1030     | 1030     | 1040   | 1058   |

2.3. Model of metro driver cab
The model of metro driver cabis consistent with the actual subway, with thickness of 10 mm. The material of cab body set as aluminium alloy (AI alloy), which relative dielectric constant of 1 and conductivity of 3.3×10$^7$ S/m. All the windows set as glass, which relative dielectric constant of 5.5 and the conductivity is approximately zero. The medium in the cab set as air, the relative dielectric constant of 1.0006, and the conductivity is approximately zero. The metro cab model radiated by TETRA and CBTC system antennas is depicted in figure 1.
3. Numerical simulation

This study adopts finite element method to simulate electric field intensity (\(E\)) inside and outside the cab, and the average specific absorption rate (\(\text{SAR}_{10g}\)), induced electric field intensity (|\(E|\)), induced magnetic field intensity (|\(H|\)) of driver.

3.1. Shielding effect of cab on the external exposure source and its influence on driver

The material of cab set as AI alloy, all the windows set as glass, the feed set as the excitation port, and the absorption boundary set as 50 mm from the cab. The variation of \(E\) inside and outside the AI alloy cab is shown in figure 2.

![Figure 2. The distribution of \(E\) inside and outside the AI alloy cab (TETRA).](image)

It is seen from figure 2 that the peak value of \(E\) is 4.6892 \(\times 10^3\) V/m, mainly locates near the antenna feed. After the electromagnetic wave entered into the AI alloy cab, the intensity of \(E\) rapidly attenuates below 0.19 V/m, it demonstrates that the AI alloy cab has obvious shielding effect on the external exposure source. The distribution of \(E\) in the cab varies from 0.007 to 0.11 V/m in the AI alloy cab, which was basically consistent with the field measurement result of 0.006~0.109 V/m. The intensity of |\(E|\) formed in the human body model is small.

The materials of cab and all windows are replaced by air, the variation of \(E\) inside and outside the cab without AI alloy body is shown in figure 3.

It is seen from figure 3 that the peak value of \(E\) is 3.9085 \(\times 10^3\) V/m. There is no obvious attenuation after electromagnetic wave entered into the cab. The distribution of \(E\) in the cab varies from 0.002 to
35.99 V/m. The intensity of $|E|$ formed in the human body model is stronger than that of figure 2.

![Image](image_url)

Figure 3. The distribution of $E$ inside and outside the cab without AI alloy (TETRA).

In different situation, the peaks values of SAR$_{10g}$, $|E|$ and $|H|$ in 835 MHz human tissues of driver, and the corresponding ICNIRP standard are shown in table 2.

| ICNIRP         | Skull            | Brain           | Scalp            | Trunk           |
|---------------|------------------|-----------------|------------------|-----------------|
| AI alloy      | SAR$_{10g}$ (W/kg) | 0.4             | 2.7126x10$^{-8}$ | 1.3552x10$^{-7}$ | 2.1150x10$^{-7}$ | 3.7186x10$^{-7}$ |
|               | $|E|$ (V/m)       | 86.67           | 6.5775x10$^{-2}$ | 2.8220x10$^{-2}$ | 4.9606x10$^{-2}$ | 4.6580x10$^{-1}$ |
|               | $|H|$ (A/m$^{-1}$) | 0.23            | 4.0603x10$^{-4}$ | 5.6317x10$^{-4}$ | 4.3231x10$^{-4}$ | 7.8213x10$^{-4}$ |

From table 2, it can be seen that the peak values of SAR$_{10g}$, $|E|$ and $|H|$ of the skin in the cab without AI alloy are 26, 4 and 5 times more than that of the AI alloy cab respectively, and SAR$_{10g}$, $|E|$ and $|H|$ of the skin in the cab without AI alloy are 125, 11 and 9 times more than that of the AI alloy cab respectively, and SAR$_{10g}$, $|E|$ and $|H|$ of the scalp in the cab without AI alloy are 91, 10 and 9 times more than that of the AI alloy cab respectively.

The results indicate that the peak values of SAR$_{10g}$, $|E|$ and $|H|$ of driver’s human tissues in AI alloy cab are lower than that of the cab without AI alloy. All exposure level in driver is lower than the occupational exposure limit.

3.2. Shielding effect of cab on the internal exposure source and its influence on driver

The variation of $E$ inside and outside the AI alloy cab is shown in figure 4.

It is seen from figure 4 that the peak value of $E$ is 0.12 V/m, mainly locates near the antenna feed, the intensity of $E$ attenuates below 0.03 V/m after the electromagnetic wave through the AI alloy subway to absorbing boundary. It demonstrates that the AI alloy cab has shielding effect on the interior exposure source. On the contrary to external exposure source, the intensity of $E$ is increased due to reflection or resonance of the metal cab, and there is a significant electromagnetic wave emitted out from the window. The distribution of $E$ inside the AI alloy cab varies from 0.017 to 0.126 V/m, which was basically consistent with the field measurement result of 0.0016–0.127 V/m. The intensity of the $|E|$ entering the human body model is small.
The distribution of $E$ inside and outside the AI alloy cab (CBTC) is shown in Figure 4. The variation of $E$ inside and outside the cab without AI alloy body is shown in figure 5.

![Figure 4: Distribution of $E$ inside and outside the AI alloy cab (CBTC).](image)

![Figure 5: Distribution of $E$ inside and outside the cab without AI alloy (CBTC).](image)

It is seen from figure 5 that the peak value of $E$ is 0.058 V/m. The intensity of $E$ has a uniform trend inside and outside of the cab without AI alloy, and it is stronger with closer the radiation source. The distribution of $E$ in the cab without AI alloy varies from 0.007 to 0.05 V/m. The intensity of $|E|$ formed in the human body model is small.

| Table 3. The peak values of SAR$_{10g}$, $|E|$, and $|H|$ in 2450 MHz human tissues. |
|-------------------------------|-----------------|-----------------|-----------------|-----------------|
| AI alloy                      | ICNIRP          | Skull           | Brain           | Scalp           |
| SAR$_{10g}$ (W/kg$^{-1}$)     | 0.4             | 3.7204x10$^{-8}$| 1.0153x10$^{-7}$| 2.3609x10$^{-7}$| 3.9184x10$^{-7}$|
| $|E|$ (V/m$^{-1}$)             | 137             | 2.4566x10$^{-2}$| 1.8337x10$^{-2}$| 2.4600x10$^{-2}$| 3.1625x10$^{-1}$|
| $|H|$ (A/m$^{-1}$)             | 0.36            | 2.6647x10$^{-4}$| 4.0903x10$^{-4}$| 5.3062x10$^{-4}$| 7.2466x10$^{-4}$|
| Without AI alloy              | SAR$_{10g}$ (W/kg$^{-1}$) | 0.4 | 1.5636x10$^{-9}$ | 4.6141x10$^{-9}$ | 1.0005x10$^{-8}$ | 1.5053x10$^{-8}$ |
| $|E|$ (V/m$^{-1}$)             | 137             | 5.8427x10$^{-3}$| 4.4576x10$^{-3}$| 6.6924x10$^{-3}$| 3.4243x10$^{-2}$|
| $|H|$ (A/m$^{-1}$)             | 0.36            | 5.7263x10$^{-5}$| 8.4430x10$^{-5}$| 1.0790x10$^{-4}$| 1.8720x10$^{-4}$|
In different situation, the peak values of SAR$_{10g}$ |$E$|, |$H$| in 2450 MHz human tissues of driver and the corresponding ICNIRP standard are shown in table 3.

From table 3, it can be seen that the peak values of SAR$_{10g}$ |$E$| and |$H$| of the trunk in the AI alloy cab are 26, 9 and 4 times more than that of the cab without AI alloy respectively, and the peak values of SAR$_{10g}$ |$E$| and |$H$| of the brain in the AI alloy cab are 22, 4 and 5 times more than that of the cab without AI alloy respectively, and the peak values of SAR$_{10g}$ |$E$| and |$H$| of the skull in the AI alloy subway are 24, 4 and 5 times more than that of the cab without AI alloy respectively, and the peak values of SAR$_{10g}$, |$E$| and |$H$| of the scalp in the AI alloy cab are 24, 4 and 5 times more than that of the cab without AI alloy respectively.

The results indicate that the peak values of SAR$_{10g}$ |$E$| and |$H$| of driver’s human tissues in the AI alloy cab are higher than that of the cab without AI alloy. All exposure level in the driver is lower than the occupational exposure limit.

4. Numerical simulation

This study simulated the shielding effect of metro cab for metro on different exposure resources and its impact on the driver. We had the followed conclusions:

- Under the TETRA system antenna radiation, the peak value of |$E$| in the cab without AI alloy was 322 times more than that of the AI alloy cab, it demonstrated that the AI alloy cab had good performance on shielding effectiveness against the external exposure source, because the high conductivity material would form strong induced electric current to reduce the external electromagnetic field penetrate. The variation of SAR$_{10g}$ in driver’s tissues was 26 to 125 times, the variation of |$E$| was 4 to 11 times, and the variation of |$H$| was 5 to 9 times, it indicated that the shielding effect on exterior exposure resource of cab could reduce the exposure level of driver.

- Under the CBTC system antenna radiation, the peak value of |$E$| in the AI alloy cab was twice times more than that of the cab without AI alloy, it demonstrated that the internal exposure source would enhance the field strength of metro cab, because the high frequency electromagnetic wave would form multi reflection and reinforce resonance phenomenon. The variation of SAR$_{10g}$ in driver’s tissues was 24 to 26 times, the variation of |$E$| was 4 to 9 times, and the variation of |$H$| was 4 to 5 times, it indicated that the shielding effect on interior exposure resource of cab could increase the exposure level of driver.

- In different conditions mentioned above, the SAR$_{10g}$ |$E$| and |$H$| in different tissues of driver were 41802, 50 and 59 times lower than that of occupational exposure limit of ICNIRP standard.

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