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Application of Automobile Antenna Simulation in Experimental Teaching based on CST

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Abstract

In this paper, it is proposed to construct electromagnetic compatibility of vehicle antenna in experimental teaching. Three types of vehicle antenna models are adopted, and full-wave electromagnetic simulation software CST is adopted to better show the outstanding significance of electromagnetic simulation software to assist experimental teaching, so as to better understand the application of vehicle antenna simulation in experimental teaching.

Keywords

Electromagnetic Compatibility; CST; Vehicle Antenna; Experimental Teaching.

1. Introduction

With the development of science and technology, the integration of electronic equipment in automobiles has become higher and higher, resulting in the electromagnetic environment inside the vehicle has become very complicated. When various antennas on the vehicle are affected by the complex electromagnetic environment, they also affect the electromagnetic environment. The coupling between antenna and antenna, antenna and vehicle body or cable may lead to the deterioration of antenna performance, and seriously affect the work of the whole communication system. The purpose of this paper is to study the electromagnetic compatibility performance of the antenna on the vehicle and evaluate the radiation effect of the antenna on the vehicle based on the antenna orientation diagram [1]-[5].

Electromagnetic compatibility(EMC) is defined as "equipment (system or subsystem) together in their common electromagnetic environment to perform their respective functions of any other equipment is not common to its electromagnetic environment produce electromagnetic interference of a state of coexistence of unsustainable, This includes two aspects: on the one hand, the equipment (system, subsystem) will not be subjected to the electromagnetic emission of other equipment (system, subsystem) in the same electromagnetic environment and lead to the disallowed degradation, that is, it has a certain degree of immunity to the outside world; On the other hand, it will not cause other devices in the same electromagnetic environment to be subjected to the electromagnetic emission of the impermissible degradation, that is, the electromagnetic interference to the outside world is within a certain range. "Electromagnetic compatibility (EMC) of antennas means that "antennas or antenna systems in a common electromagnetic environment can maintain their own performance without degrading the performance of other antennas, that is, antennas on a certain device will not be affected by other devices in the same electromagnetic environment, such as antenna carrier, layout, adjacent scatterers and other antennas, resulting in degraded performance. On the other hand, it will not degrade the performance of other antennas in the same electromagnetic environment."[6]-[9].

2. Electromagnetic Compatibility Parameters of Antennas

The electrical parameters of antennas (Basic Antenna Parameters) refer to the parameters that describe the operating characteristics of antennas.Electrical parameters are also known as electrical indicators.The electrical parameters of an antenna generally include: directional pattern, antenna efficiency or gain, antenna polarization mode, effective length, frequency band width, input impedance and radiation impedance, etc. This paper aims at the application of teaching experiments, and mainly considers the following electrical parameters of the antenna.The antenna input impedance is the ratio of voltage to current at the antenna input.The formula of input impedance is where.

$$Z_{\text{in}} = \frac{2P_{\text{in}}}{I_{\text{in}}^2} = \frac{U_{\text{in}}}{I_{\text{in}}} = R_{\text{in}} + \text{j}X_{\text{in}} \tag{1}$$

P_{in} is the input power of the antenna, U_{in} and I_{in} is the voltage and current at the input end of the antenna respectively, R_{in} and X_{in} is the input resistance and input reactance of the antenna respectively.

The antenna is connected to the receiver or transmitter through the feeder. However, after the incident wave transmitted from the transmitter passes through the antenna, the incident wave will not all be emitted, and a part of the electromagnetic wave is reflected back, which is called reflected wave.Therefore, there will be both incident wave and reflected wave in the antenna feeders, but they will be superimposed in the circuit with different components.The reflection coefficient T is used to represent the impedance matching degree between the antenna and the feeder, and the formula is

$$\Gamma = \frac{Z_{\text{in}} - Z_0}{Z_{\text{in}} + Z_0} \tag{2}$$

We hope that the best case is $\Gamma = 0$ when $Z_0 = 1$, which means that the incident wave emitted by the transmitter is all sent to the outside through the antenna, and no reflection occurs, and the efficiency of the antenna is 100%.When $Z_0 = 0$ and $\Gamma = 1$ means that the incident wave emitted from the transmitter is fully reflected and the antenna has a radiation efficiency of 0%.However, this is one of the rare cases that usually doesn't happen.

3. Modeling and Simulation of Vehicle Antenna

3.1. Vehicle Equivalent Type I antenna - Whip Antenna

Whip antenna has the advantages of simple structure, stable performance, convenient use, easy to install and maintain on the platform, good omnidirectional and can communicate in motion. A series of advantages make it one of the most commonly used antenna types on vehicles. The antenna is placed on different carriers and different positions of vehicles, and the overly fine feeder model brings great inconvenience to the setting of model parameters. Therefore, we use a simple discrete port model to replace the complex coaxial line model here. In fact, the discrete port is a current source with internal resistance, which is added to the gap between the antenna bottom and the carrier surface. The excitation signal is Gaussian pulse signal.

$$E_{\text{i}} = \exp\left(-\frac{4\pi(t - t_0)^2}{\tau^2}\right) \tag{3}$$

Where, t_0 is the time for the Gaussian pulse to reach the maximum value, and τ is the pulse width. In order to ensure that the Gaussian pulse is approximately zero when t=0, $\left(\frac{2\sqrt{\pi}\text{t}_0}{\tau}\right)^2$ is

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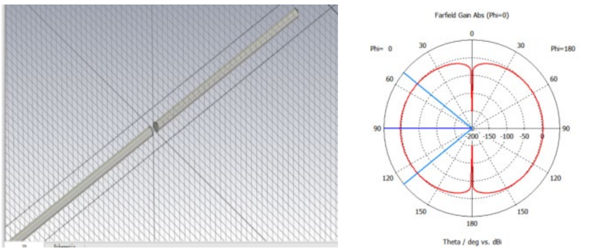
required to approach infinity. In actual calculation, $\left(\frac{2\sqrt{\pi t_0}}{\tau}\right)^2 \geq 10$ can meet the demand.The time domain form of Gaussian pulse is:

$$G(\mathrm{f}) = \exp\left(-\pi t^2 \mathrm{f}^2 / 4\right) \tag{4}$$

The bandwidth of the Gaussian pulse is usually $\mathrm{f} = 2/\tau$, and the spectrum is equal to 4.3% of the maximum value.Is 45.6% of the maximum value at $\mathrm{f} = 1/\tau$ and approximately 10% of the maximum value at $\mathrm{f} = 1.7/\tau$.

The simulation model and simulation results are shown in the figure below



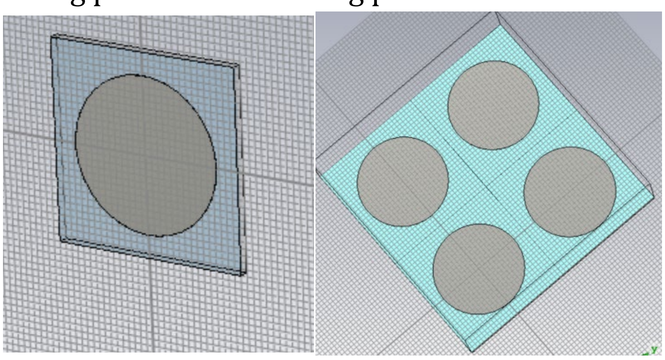
(a) Simulation model (b) Direction diagram

Fig 1. Discrete port feed simulation model and direction diagram

From the above analysis, it can be seen that the antenna has excellent performance in various aspects, and the antenna has good omnidirectional radiation characteristics, which can achieve omnidirectional uniform radiation in the full frequency band of the horizontal direction. The antenna can be used in the subsequent analysis and research of commercial vehicle antenna effect.

3.2. Vehicle Equivalent Type II Antenna - Array Antenna

The main functions of the second type of antenna include short-range protection radar, environmental awareness radar, electronic interference, etc. The second type of antenna is realized by distributed UWB active array antenna. Based on the detection antenna aperture of the future active protection system, it expands the functions of interference, passive precise orientation and environment awareness. The antenna is mounted on the top of the vehicle and is divided into a transmitting part and a receiving part.



(a)Part of launch (b) Part of receiving

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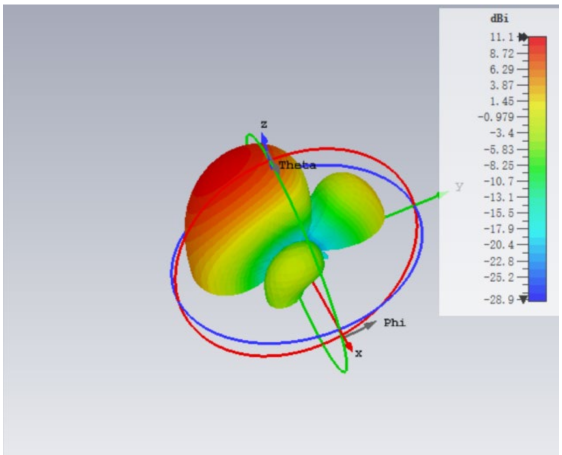
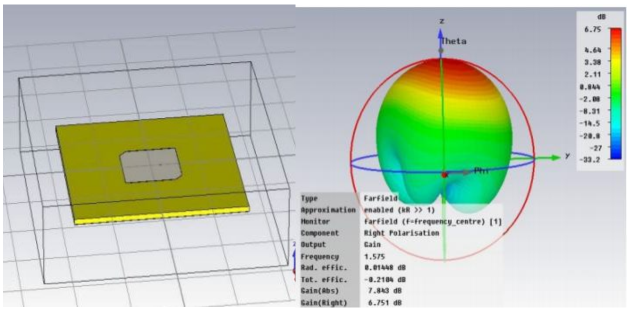


(c) Direction diagram

Fig 2. Simulation model of transmitting and receiving part of array antenna and direction diagram

3.3. The Third Type of Vehicle-mounted Equivalent Antenna - Patch Antenna

The third type of antenna is the GPS navigation antenna, which only receives but does not transmit. The patch antenna model is established for equivalence and the antenna layout is analyzed. The simulation model of the specific patch antenna is shown in the figure below:



(a)Simulation model (b) Direction diagram

Fig 3. Partial simulation model and direction diagram of array antenna emission

The maximum gain direction and maximum gain of the main lobe can be obtained by the far-field pattern of the antenna.

Through the simulation model and simulation results in this part, it is confirmed that the vehicle-mounted equivalent type I antenna - whip antenna, vehicle-mounted equivalent type II antenna - array antenna and vehicle-mounted equivalent type III antenna - patch antenna can provide model support for the influence of the vehicle body on the performance of each antenna in this paper, so it can meet the application of the automobile antenna simulation in experimental teaching.

4. Coupling Simulation between Vehicle Body and Various Antennas

4.1. Coupling Degree of Vehicle Antenna

The working frequency band of vehicle antenna has a large span, and the output power of each transmitter is not the same, which makes the electromagnetic environment of vehicle complicated, resulting in the distortion of antenna radiation characteristics and the change of antenna electrical parameters. Electromagnetic coupling between antennas, accidental

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coupling through the body surface to the antenna, and coupling through the interior wires are many of the causes of interference [10][11].

The coupling between antennas is one of the important ways to spread electromagnetic interference between electronic devices, that is, one antenna receives the electromagnetic wave emitted by another antenna, thus affecting the normal operation of the receiving antenna, and even causing irreversible damage to the antenna or other equipment in serious cases, resulting in more serious consequences. Coupling degree is usually used to quantitatively represent the degree of coupling. Antenna coupling degree is defined as the ratio of the transmitted power of one antenna to the received power of another antenna, namely:

$$c = 10\log\left(\frac{p_{out}}{p_{in}}\right)(dB) \tag{5}$$

$$\frac{p_{out}}{p_{in}} = c\left(1-|\Gamma|^2\right) \tag{6}$$

Where, p_{in} represents the net input power of transmitting antenna, and p_{out} represents the net output power of receiving antenna. Γ is the reflection coefficient at the transmitting antenna end.

In the process of antenna simulation, since each antenna has a port as the excitation, according to the field path conversion principle and microwave network theory, we can equivalent the antenna system composed of two antennas to a two-port network. The excitation port of each antenna is regarded as a network port, and the antenna feeder is equivalent to the transmission line of the network port. The S-parameter of the two-port network can be obtained by using the simulation software. In other words, the S-parameter matrix of the two-port network can be obtained by using the scattering matrix method, so as to obtain the coupling coefficient.

Where, a1 and a2 are incident waves and b1 and b2 are scattered waves, then the S-scattering parameter of this two-port network is:

$$b_1 = S_{11}a_1 + S_{12}a_2 \tag{7}$$

$$b_2 = S_{21}a_1 + S_{22}a_2 \tag{8}$$

The matrix form is:

$$b = Sa; \begin{pmatrix} b_1 \\ b_2 \end{pmatrix} = \begin{pmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{pmatrix}\begin{pmatrix} a_1 \\ a_2 \end{pmatrix} \tag{9}$$

Where, $S_{11} = \left.\frac{b_1}{a_1}\right|_{a_2=0}$ is the reflection coefficient of port 1 when port 2 matches. $S_{21} = \left.\frac{b_2}{a_1}\right|_{a_2=0}$ is the transmission coefficient from port 1 to port 2 when port 2 matches. $S_{12} = \left.\frac{b_1}{a_2}\right|_{a_1=0}$ represents the transmission coefficient from port 2 to port 1 when port 1 matches. $S_{22} = \left.\frac{b_2}{a_2}\right|_{a_1=0}$ represents the reflection coefficient of port 2 when port 1 matches.

The formula of coupling degree L(dB) between antennas can be obtained from the S-matrix:

$$L(\omega) = 20\lg|S_{ij}| \tag{10}$$

Through the above analysis and research on the coupling degree of vehicle antenna, we will mainly study the simulation of the coupling between the vehicle body and each antenna.

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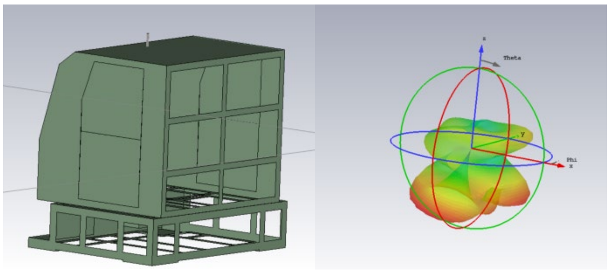
4.2. Simulation of Coupling between Vehicle Body and Antenna

4.2.1. Simulation of Coupling between Vehicle Body and the First Type Antenna

The first type antenna is installed in the corresponding position of the vehicle body. Through simulation analysis, the simulation model diagram of coupling between vehicle body and the first type antenna and the corresponding simulation result diagram are given below.

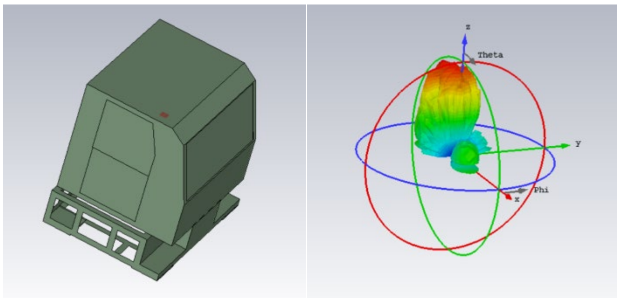


(a)Simulation model (b) Direction diagram

Fig 4. Vehicle equivalent Type I antenna and vehicle simulation model and direction diagram

4.2.2. Simulation of Coupling between Vehicle Body and the Second Type of Antenna

Due to the small wavelength of the second type of antenna, the vehicle belongs to the object of electric large size. When calculating the far field direction diagram of the antenna after loading, the high frequency algorithm is used, and the bouncing ray method is used. The excessively large and complex vehicle body leads to a large number of rays, which greatly increases the amount of computer computation and operation time. In addition, the simplification of the car body does not have much impact on the calculation results, so we use the car model for simulation. Through the simulation analysis, the following is the simulation model diagram of the coupling between the car body and the second type of antenna and the corresponding simulation result diagram.



(a)Simulation model (b) Direction diagram

Fig 5. Vehicle equivalent Type II antenna and vehicle simulation model and direction diagram

4.2.3. Simulation of Coupling between Vehicle Body and the Third Type of Antenna

The Type 3 antenna is installed in the corresponding position of the vehicle body. Through simulation analysis, the simulation model diagram of coupling between vehicle body and Type 3 antenna and the corresponding simulation result diagram are given below.

By observing the simulation results of the first type of antenna on the car body, it can be seen that the antenna direction pattern has changed greatly, and the car body has a great influence on the antenna directivity. By observing the simulation results of the second type of antenna on the car body, it can be seen that the direction pattern is mainly manifested in small sidelobe, sharp antenna far field direction pattern, and slightly larger gain in the main radiation direction. Similar to the second type of antenna, the simulation was carried out after simplifying the car body model. It can be seen from the results that the direction pattern of the simulation between

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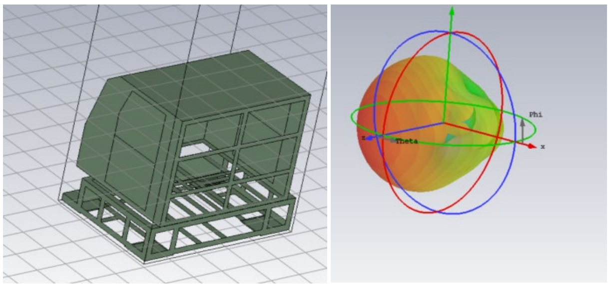
the car body and the third type of antenna is that the sidelobe decreases to a certain extent, the main lobe gain increases to a certain extent, and the direction pattern becomes sharp.



(a)Simulation model (b) Direction diagram

Fig 6. Vehicle equivalent Type Ⅲ antenna and vehicle simulation model and direction diagram

5. Conclusion

Starting from the vehicle antenna effect, the CST electromagnetic simulation software is used to complete the establishment of three equivalent models of vehicle antenna according to the relevant electromagnetic compatibility theory, and the electromagnetic characteristics of whip antenna, array antenna and patch antenna are analyzed, and then combined with the actual vehicle model, The electromagnetic characteristics of the antenna when it is installed on the carrier are analyzed in detail, and the coupling effect between the directional pattern and the antenna is analyzed. The significance of automobile antenna simulation using electromagnetic simulation software CST in experimental teaching is more clearly understood.

Acknowledgments

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References

[1] Dudek M, Nasr I , Bozsik G , et al. System Analysis of a Phased-Array Radar Applying Adaptive Beam-Control for Future Automotive Safety Applications[J]. Vehicular Technology, IEEE Transactions on, 2015, 64(1):34-47.

[2] Kim J , Kwon S C , Choi G . Performance of Video Streaming in Infrastructure-to-Vehicle Telematic Platforms With 60-GHz Radiation and IEEE 802.11ad Baseband[J]. IEEE Transactions on Vehicular Technology, 2016:10111-10115.

[3] Tirkas P A, Balanis C A . Finite-difference time-domain method for antenna radiation[J]. IEEE Transactions on Antennas & Propagation, 1992, 40(3): P.334-340.

[4] Luebbers R , Chen L . FDTD calculation of radiation patterns, impedance, and gain for a monopole antenna on a conducting box[J]. IEEE Trans Antennas Propag, 1992, 40(12):1577-1583.

[5] Foreman, T. L . Antenna coupling model for radar electromagnetic compatibility analysis[J]. IEEE Transactions on Electromagnetic Compatibility, 2002, 31(1):85-87.

[6] Rostamzadeh C , Deroy P , Barchanski A , et al. Investigation of electromagnetic field coupling from DC-DC buck converters to automobile AM/FM antennas[C]// IEEE International Symposium on Electromagnetic Compatibility. IEEE, 2016.

[7] Sunmin, Gwon, Hyungu, et al. A Study on Electromagnetic Interference of Electric Vehicles with Variations of Charging Device Inlet Location[J]. Transaction of the Korean Society of Automotive Engineers, 2016, 24(6):694-701.

ISSN: 2710-0170

[8] K, El, Khamlichi, et al. An Efficient Model of the Electromagnetic Field Radiated from Different PLC Configurations[J]. International Journal on Communications Antenna & Propagation Irceap, 2016.

[9] Ott, Henry W. Electromagnetic Compatibility Engineering (Ott/Electromagnetic Compatibility) || Electromagnetic Compatibility[J]. wiley & sons, 2009, 10.1002/9780470508510:1-43.

[10] Yu J H, Ma X L, Zheng Y L. Simulation and Research on Electromagnetic Character and Coupling Degree of Vehicle Antennas[J]. Journal of System Simulation, 2008.

[11] Wu H, Hao Y, Tan X, et al. Simulation and Analysis on Electromagnetic Character and Coupling Degree of Vehicle Antennas[J]. Electronic Test, 2013.