Research on lightning numerical simulation of wheeled armored vehicle with the enclosure and cables.

Liu Yi¹, Zhang Bin¹, Si Zhiqiang²
¹ Bengbu Campus of Armored Military Academy, Bengbu 233000, China
² The Third Integrated Training Base of Army, Guangzhou 510000, China
1035213546@qq.com

Abstract. In order to further improve the all-weather combat capability of army armored equipment, the paper adopts the compact model of the CST MICROWAVE STUDIO. The CST MICROWAVE STUDIO is based on the numerical simulation technology of transmission line matrix algorithm and the paper has a study on the full-scale lightning strike numerical modeling and simulation. The induced electric field of the enclosures and the induced current of cables are analyzed. The simulation results showed that the method could effectively simulate the lightning response of armored vehicles, the electric field inside different enclosures and the lightning strike response of different cables are compared. It can provide reference for lightning protection design of armored vehicles and has a certain engineering application value.

1. Introduction
Lightning is generated by discharging in the air or clouds, including three types of lightning: cloud to ground lightning between clouds and the earth, cloud to cloud lightning between different clouds and cloud to cloud lightning within the same cloud layer. Especially in thunderstorm, cumulonimbus accumulates a lot of charges. Generally, positive charges accumulate at the top of cumulonimbus, while negative charges and a few positive charges accumulate at the bottom. Charge in clouds can change the electric field in the atmosphere, and the effect of induced electric field can cause other metal objects to accumulate charges with opposite polarity. When the charges on other objects accumulate to a certain extent, air will be broken down and a lightning channel will be formed between clouds and metal objects, which is called cloud to ground lightning, so it can be seen that armored combat vehicles may also suffer lightning strike.

The existing research on lightning protection of whole level mainly focuses on aircraft, America, Europe and other countries have promulgated many standards and regulations for trial voyage[1-4]. Chen Xiaoning et al[5] made a numerical simulation study on the lightning strike attachment area of a helicopter, the lightning strike attachment area of a helicopter was divided by CST simulation software electrostatic studio. Huang Liyang et al[6] studied the indirect lightning effect of a helicopter, analyzed and studied the electromagnetic field distribution inside and outside the airframe and the coupling effect of airborne cables. Guo Fei et al[7] carried out numerical simulation analysis on indirect lightning strike effect of a certain airliner, studied the coupling of lightning electromagnetic through holes and slots, the distribution of electromagnetic field inside and outside the airframe and the coupling law of airborne cables. Gao Cheng et al[8] studied the lightning attachment point of composite aircraft, the results showed that composite structure reduced the probability of lightning strike. Nie Ru
and Marc Meyer\textsuperscript{[9-10]} studied the intensity and distribution of lighting electromagnetic at different positions of fuselage. At present there is no research result on lightning strike of armored vehicles, in the absence of a large number of measured data, it has a great significance to carry out full scale lightning strike simulation research on armored vehicles.

CST MICROSTRIPES Studio based on the Transmission Line Matrix Method(TLM) is a software specializing in system level EMC simulation\textsuperscript{[11]}. Its unique compact model can accurately simulate holes, seams, metal shielding meshes and other structures without meshing. The lightning current waveform specified in SAE-ARP5412 was used to simulate the lightning of full-scale armored vehicles. the distribution of surface current and the electromagnetic field distribution inside and outside the vehicle were analyzed.

2. Principle of numerical simulation

Transmission Line Matrix Method (TLM) was first proposed by Johns P B and Beurle R L based on Huygens principle, through gradual improvement to become a method of electromagnetic wave propagation and dispersion characteristics \textsuperscript{[12-14]}. When TLM algorithm is used to solve the electromagnetic field of dielectric, the dielectric properties are replaced by TLM matrix, which is composed with many nodes, each node has a different physical properties of dielectric, the transmission line is responsible for energy storage and redistribution. By iterated operation, the field distribution in the computational region can be solved, and the time domain results can be transformed into the frequency domain results in a certain frequency domain by Fourier transform.

The two-dimensional TLM algorithm is composed of parallel transmission line grids, pulse from four branches with the same characteristic impedance coming into one node, then come into the adjacent nodes by scattering, the formula is deduced as follows\textsuperscript{[15]}:

\begin{align*}
    S \bullet V_{k+1} &= C \bullet V_k \\
    V^t_{k+1} &= S \bullet V^i_k \\
    V^r_k &= C \bullet V^t_{k+1}
\end{align*}

In the formula, $V^i_k$ is the incident pulse voltage vector of each node at $k$ time, $V^r_k$ is the reflected pulse voltage vector of each node at $k$ time, $S$ is the impulse scattering matrix, $C$ is the connection matrix of network topology, $k$ is the discrete time interval of scattering.

The three-dimensional TLM algorithm consists of three parallel nodes and three series nodes in three coordinate axes, the voltage on three parallel nodes are the electric field component, the current on three series nodes represent the magnetic field component, the scattering process and inhomogeneous field are the same as two-dimensional TLM algorithm.

3. Construction of the simulation environment

3.1 Source excitation

Referring to the waveforms and methods of SAE 5412 and SAE 5416, which define the aircraft lightning indirect effect test, the lightning attachment points are usually located in the protruding parts of the body, such as turrets, guns, deck protruding parts and so on. The lightning current is a double exponential waveform, the waveform function is shown in formula 3 and the waveform diagram is shown in figure 1.

\[ I(t) = I_0(e^{-\alpha t} - e^{-\beta t}) \]

In the formula, $I_0$ is 218810A, $\alpha$ is 11354s\textsuperscript{-1}, $\beta$ is 647265s\textsuperscript{-1}, the duration of lightning current is set to 100 $\mu$s, which is the same as the simulation time.

The injection mode of lightning current in the simulation is shown in figure 2, the lightning current is injected into the gun of the body and released through the rear deck of the body. In the simulation process, two slender ideal conductors are used to simulate the process the lightning current injection and discharge.
3.2 Creation of enclosures and cables
As shown in figure 3, in order to simulate different enclosures inside the vehicle, four enclosures are created by using the enclosure creation tool provided by MICROSTRIPIES Studio. According to the order from left to right, from front to back, number 1, 2, 3, 4 enclosure is sequentially numbered, enclosure 1 and enclosure 2 are connected by single line and a RG58 coaxial line, enclosure 3 and enclosure 4 are also connected by a single line and a RG58 coaxial line, the left side is the coaxial line and the right side is the single line.

![Figure 1. Waveform of lightning current](image1)

![Figure 2. Lightning current injection method](image2)

![Figure 3. The creation map of enclosure and cable](image3)
3.3 Simulation settings
The full-scale model of an armored vehicle is used in the simulation, its length, width and height are 5450mm, 2174mm and 2340mm, the vehicle is made of steel and its thickness is 10mm. The enclosure is a cube with a side length of 150mm, which is made of aluminium alloy and its thickness is 1mm. In order to accurately simulate the electromagnetic field of lightning coupling into the vehicle through holes and slots, all the glass of the vehicle are equipped with a 20-grid metal screen, the mesh size is 1.223mm width, 0.001mm depth and 0.927 in coverage. In order to accurately simulate the electromagnetic intensity inside the enclosure, ventilation holes are set on the enclosure, which has a width of 5mm, depth of 1mm and a coverage rate is 0.7.

The simulation frequency is 30MHz, and the simulation time is the same as the time of the lightning current waveform, the discretization model of armored vehicle is obtained by meshing, the maximum mesh size is 363mm, the minimum mesh size is 50mm, the number of meshes is 323.51k, the time step is 1200000.

The boundary conditions are all expanded by 30%, armored vehicles travel on the ground, which is different from the lightning process of aircraft, therefore, the direction pointing to the ground should be set as electric wall and the other directions should be set as absorbing boundary. In order to eliminate the effect of electrostatic field caused by charge accumulation, the two ideal conductor extensions, which simulate the injection and discharge of lighting current are all in contact with the absorbing boundary, thus forming a current loop to eliminate the charging effect.

TLM algorithm can calculate the electromagnetic field strength at any point at one time, therefore, the lightning shock response of armored vehicles can be obtained by adding electric field and magnetic field probes inside and outside the vehicles through iterative calculation.

4. Analysis of simulation results

4.1 The induced electric of different enclosures
Taking the induced electric field at the center position of four different enclosures into consideration, the induced electric field of the number 1 enclosure is shown in figure 4, the induced electric field inside the enclosure also presents a double exponential waveform trend, with the peak value of the induced electric field is 0.731 kV/m.
Table 1 lists the peak value of the induced electric field at the center of different enclosures, table 1 shows that the maximum peak value of the induced electric field inside the enclosure is 0.997 kV/m in enclosure 4, which is nearly 40% lower than the peak value of the induced electric field in front of the cabin, this shows that the enclosure has a better shielding effect. However, due to the existence of ventilation holes on the enclosure, the electromagnetic peak value inside the enclosure still nearly 1 kV/m.

| Position | Enclosure 1 | Enclosure 2 | Enclosure 3 | Enclosure 4 |
|----------|-------------|-------------|-------------|-------------|
| Peak value (kV/m) | 0.731 | 0.916 | 0.903 | 0.997 |

4.2 Coupled response of cables
Wire x-y is defined to represent the connection cable between enclosure x and enclosure y, taking the single wire between enclosure 1 and enclosure 1-2, the outer conductor of coaxial line between enclosure 1 and enclosure 2 Cable 1-2, inner conductor of coaxial line of enclosure 1 and enclosure 2 Inside cable 1-2 into consideration, the induced current waveform is shown in figure 5.

![Figure 5. Induced current of different cables](image)

The peak value of induced current of Single wire 1-2, Cable 1-2 and Inside cable 1-2 are 334mA, 251mA and 1.16mA, the induced current of outer conductor of coaxial line is 75.1% of that of single line, the induced current of inner conductor of coaxial line is 0.34% of that of single line. This shows that the lightning response of coaxial line is smaller than that of single line, and has a better shielding effect than single line.

5. Conclusion
Using the CST MICROSTRIPES Studio, the electromagnetic field inside and outside the vehicle can be simulated accurately, this method is simple, convenient, economical and efficient, without the support of large number of test data, numerical simulation can provide reference for lightning protection design of armored vehicles. The enclosure can provide a better shielding effect for lightning electromagnetic pulse protection, the existence of radiation holes reduce the shielding effect to a certain extent, therefore, it is necessary to optimize the design of radiation holes on the enclosure. The shielding effect of coaxial line is better than that of single line, so the armored vehicle should use less...
single line and use the harness line as far as possible to ensure the protection of lightning electromagnetic pulse.

References
[1] SAE. ARP5412. *Aircraft Lightning Environment and Related Test Waveforms*. Warrendale, PA: Society of Automotive Engineers, 2005.
[2] SAE. ARP5414. *Aircraft Lightning Zoning*. Warrendale, PA: Society of Automotive Engineers, 2005.
[3] SAE. ARP5416. *Aircraft Lightning Test Methods*. Warrendale, PA: Society of Automotive Engineers, 2005.
[4] USOD. MIL-STD-464, *Electromagnetic Environment Effects Requirements for System*. U.S.A: United States Department of Defense, 1997.
[5] CHEN Xiaoning, HUANG Liyang, GUO Fei, et al. *Numerical Simulation of Lightning Initial Attachment Zones on helicopter*. Chinese Journal of Radio Science, 2015, 30(5): pp 910-916.
[6] HUANG Liyang, CHEN Xiaoning, GUO Fei, et al. *Numerical Simulation of Lightning Indirect Effects on Helicopter*. High Power Laser and Particle Beams, 2015, 27(8): 083205 pp 1-5.
[7] GUO Fei, ZHOU Bihua, GAO Cheng. *Analysis for Lightning Indirect Effects of the Aircraft by Numerical Simulation*. Chinese Journal of Radio Science, 2012, 27(6): pp 1129-1133.
[8] GAO Cheng, SONG Shuang, SHI Zhenhua, et al. *Impact of Composite Structure of Aircraft on Lightning Attachment Points*. Journal of PLA University of Science and Technology, 2013, 14(2): pp 227-230.
[9] NIE Ru. *Numerical Simulation and Transient Analysis of Lightning Strike Aircraft Base on CST Simulation Software*. Insulators and Surge Arresters, 2018, (1): pp 126-130.
[10] MEYER M, FLOURENS F, ROUQUETTE Ja, et al. *Modeling of Lightning Indirect Effects in CFRP Aircraft*. EMC Europe, Hamburg, September 8-12, 2008: pp 1-5.
[11] CST *MICROSTRIPESM-Workflow and Solver Overview*. CST Computer Simulation Technology AG, 2012.
[12] HOEFER W J R. *The Transmission-line Matrix Method Theory and Applications*. IEEE Trans on Microwave Theory and Techniques, 1985, 33(10): pp 882-893.
[13] GIAMPAOLO T, WOLFGANG J R, HOEFER W J R. *Simple Equivalent Circuit Modeling of Small Apertures in Transmission Line Matrix(TLM) Method*. Microwave Symposium Digest, IEEE MTT-S International, Baltimore, June 7-12, 1998: pp 901-904.
[14] AKHTARZAD S, JOHNS P B. *Solution of Maxwell's Equations in Three Space Dimensions and Time By The TLM Method of Analysis*. Proceedings of the Institution of Electrical Engineers, 1975, 122(12): pp 1344-1348.
[15] ZHANG H, WANG Q K, XU Q W. *Transmission Line Matrix Method and Its Applications*. Telecommunication Engineering, 2002, 3(5): pp 59-65.