

Analysis of the radiation field distribution characteristics of the LTE-R leakage coaxial cable in the high-speed train

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Abstract—The LTE system based on the high-speed has become the representation of the world's most advanced mobile communications industry, and most of its indicators are not ripe. This paper analyzes the radiation field distribution characteristics of the LTE-R leakage coaxial cable in the high-speed train by analyzing the fundamentals of the cable and using the computer simulation analysis to propose feasible solutions.

Keywords—high-speed train; LTE-R; leakage coaxial cable; radiation field

I. INTRODUCTION

With the railway laying and putting to use of the recent Chinese intercity high-speed, there is rarely research of the personal mobile communication systems, so in order to ensure the high reliability and high safety of the high-speed railway mobile communication system that it's extremely necessary to research the LTE-R system structure of the train.

In this paper, based on the background of the high-speed railway wireless communication environment and combined with the all aspects of research and application status of leakage coaxial cable and LTE communication coverage, and the high demands of in-vehicle network users, I have a brief discussion of the radiation characteristics about the leakage coaxial cable of LTE system. I have initially built the theoretical analysis system in order to improve the efficiency and reliability of the wireless communication in the train, and provide necessary basis for erection of the cable.

A. The basic principles and calculation methods

The demands of the high-speed trains for wireless communication system is that the radio can evenly spread in the car. So even in the fast-moving car, it can make sure the reliability and validity of the received signal. Learned from the literature, we use the repeater (car transponder equipment) outside the train. The radio signal transmission loss of indoor closed environment is lower than the free-space propagation loss, so if we use

separate transmission equipment, it will help to improve the received signal power. Therefore, the repeater communicates with the users in the train by leaked cables. As shown in the figure 1, there is a plurality of openings in the leakage coaxial cable. Each opening is equivalent to an antenna, which can send and receive signal. The opening transmit electromagnetic radiation to the outside, and the electromagnetic radiation can also react to the leakage cable by the openings and transmit to the receiving end.

The users in the train can also communicate with the private network directly, but due to the influence of the Doppler frequency shift and the insertion loss, the received signal to noise ratio is poor. [1] The leakage cable in the carriage can help to improve the user's data rate, and take advantage of a closed environment channel conditions.

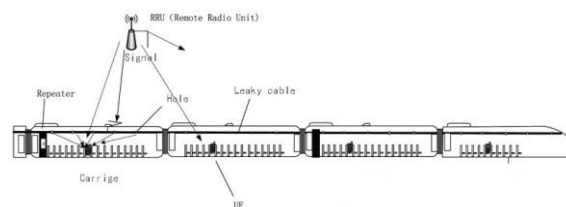


Figure 1. The train, repeater and the network base station

II. BASIC PRINCIPLES OF LEAKY COAXIAL CABLE

Leaky cable is structured into four layers: the inner conductor, dielectric outer conductor and jacket.

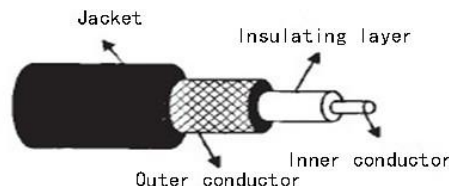


Figure 2. Cable basic structure

This work was supported by the "NSFC" (U1234205), the "SRFDP" (20120009110005), the "National Science and Technology Major Project" (2011ZX03001-007-01), and the "Basic scientific research business expenses" (2012JBM021)

978-1-4673-6079-1/13/\$31.00 ©2013 IEEE

Leakage principle: The purpose of RF coaxial cables is transmitting the signal energy from one side to the other side, and expects to have the greatest horizontal shielding so that the signal can not penetrate the cable to avoid transmission of RF signal energy loss.[2] To reduce the leakage horizontal cable shielding, we make out some slots so that the electromagnetic energy can be radiated to the outside of the cable.

A. The frequency band of leak coaxial cable

The frequency range of leak coaxial cable means that it's status is single-mode and other modes is in a non-radiation state. According to the radiation theory of space harmonic, [3]the leak coaxial cable which has periodic grooves in the outer surface of the structure can make infinite number of space harmonics, can satisfy the boundary conditions. Most space harmonics only can exist in the form of the surface wave, and it can produce radiation only when $m \leq -1$. The frequency range is :

$$-\frac{c}{1+\sqrt{\epsilon_r}} \cdot \frac{m}{p} < f < -\frac{c}{\sqrt{\epsilon_r}-1} \cdot \frac{m}{p} \quad (1)$$

Where C is the speed of light, ϵ_r is the equivalent relative dielectric constant, P is the length of the period of grooves.

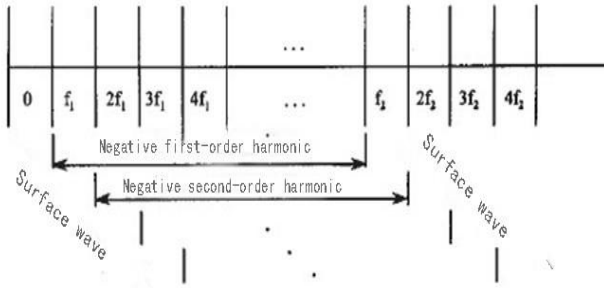


Figure 3. the harmonic radiation band

If the work frequency of LTE-R is 2400MHz,so we need to meet the condition that

$$2400 \times 10^6 < f_1 = \frac{c}{1+\sqrt{\epsilon_r}}, \text{ put the}$$

$c = 3 \times 10^8$, $\epsilon_r = 1.25$, into the terms, $p < 58.9\text{mm}$, it means that the grooving cycle must be less than 58.9mm, it can be used to transmit signals by radiation wave.

B. The calculation of the radiation field in the train

Because electromagnetic energy is radiated or coupled out through the leaky cable outer conductor, so the space field around the leaky cable is composed by many of the electromagnetic field emitted from the radiation..[4]

The high-speed railway train is the type of CRH, for example, the measurement of CRH-type train: the intermediate car length is 25m, total length is 201.4m, width is 3.38m, height is 3.7m. If we want lay the leaky cable in the train, that might be equivalent to we lay the cable in a $25\text{m} \times 3.38\text{m} \times 3.7\text{m}$ room that the walls are good conductive properties.

Since the vertical slotted leaky coaxial cable only have the forward radiation, and the tilt slotted leaky coaxial cable have the Omni directional radiation, at the same time the leaky coaxial cable can only be installed in the top of the car, so we use the vertical slotted ways to make the direction of the radiation field more efficiency.[5]

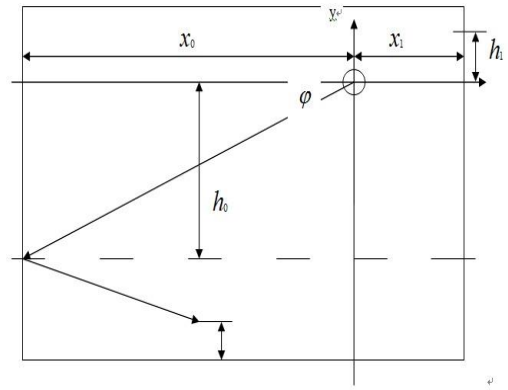


Figure 4. The flat view

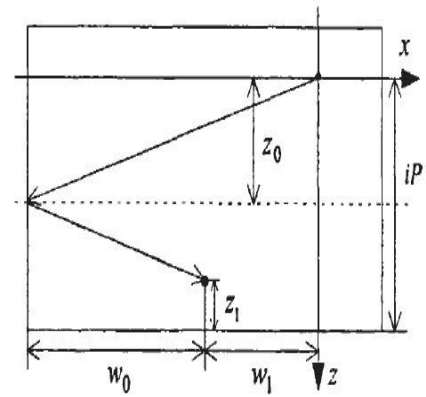


Figure 5. The top view

Free space radiation field:

$$E_y = V(\theta_i, \phi_i) \frac{e^{-jk_0(r_i+r_{il})-j\beta ip}}{r_i+r_{il}} \sin \theta_i \cos \phi_i \Gamma_h \quad (2)$$

In the formula,

$$\beta = k_0 \sqrt{\epsilon_r}, \quad \theta_i = \arctan\left(\frac{\sqrt{x_0^2 + h_0^2}}{z_0}\right),$$

$$\varphi_i = \arccos\left(\frac{x_0}{\sqrt{x_0^2 + h_0^2}}\right), r_i = \sqrt{x_0^2 + h_0^2 + z_0^2},$$

$$r_{il} = \sqrt{w_0^2 + (h - h_0)^2 + (iP - z_0)^2},$$

$$\Gamma_h = \frac{\sin \gamma - \sqrt{\varepsilon - \cos^2 \gamma}}{\sin \gamma + \sqrt{\varepsilon - \cos^2 \gamma}},$$

$$\gamma = \arctan\left(\frac{x_0}{\sqrt{z_0^2 + h_0^2}}\right)$$

ε is the relative permittivity, Γ_h is the horizontally polarized wave reflection coefficient.

III. HFSS SIMULATION

In the calculation, according to the actual situation, the size of the carriage is 25m×3.38m×3.7m, the walls of the carriage are good conductor. The leakage cable hang on the roof, the characteristic impedance is 50, the inner conductor radius is 9mm, and the outer conductor radius is 22.8mm, the dielectric constant of stratum medium is 1.25, based on the single vertical conditions discussed above ,the slit period is 0.05mm.[6]

At first in the free space, we discuss the spatial field distribution of leaky coaxial cable by HFSS simulation, as it shown in the figure, the electric field emitted through the gap radially, which verify LCX radiation field performance.

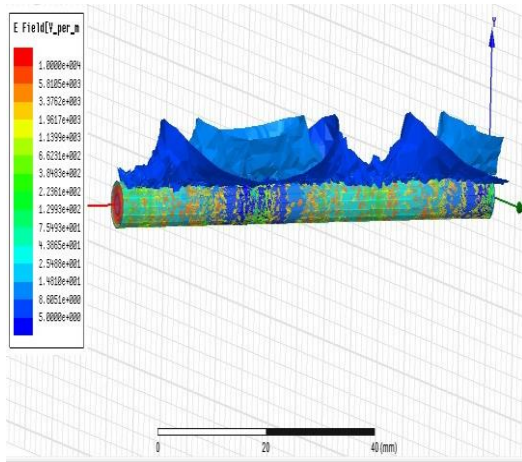


Figure 6. Simulation1

Installed inside the carriage simulation:

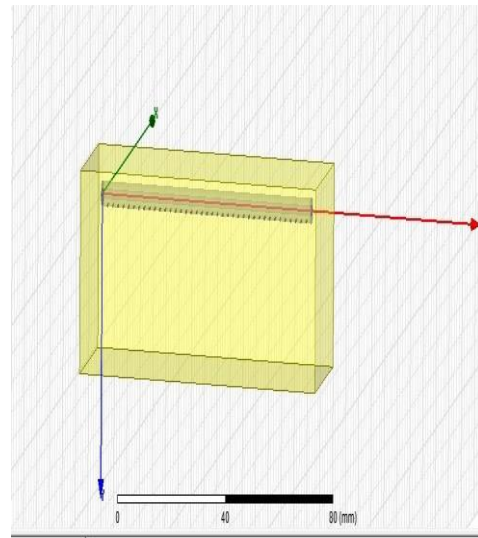


Figure 7. model 1

IV. ANALYSIS OF SIMULATION RESULTS

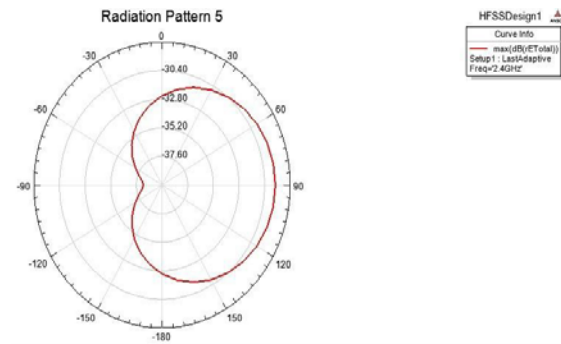


Figure 8. radiation pattern

The picture shows that E-plane radiation patterns, it has the same direction as the literature. As we see, the LCX has the smooth coverage in the train.

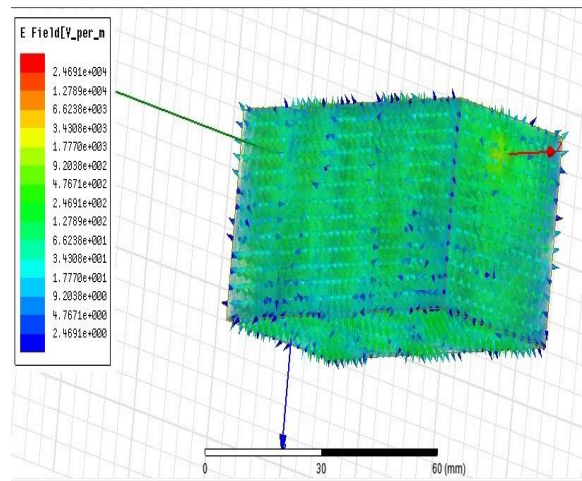


Figure 9. The E field of LCX

The picture shows that the electric field distribution and the electric field distribution vector in the carriage.

From the figure, the cable solution within the external space (the carriage is regarded as a good conductor compartment), the leakage of electromagnetic energy with the internal surface of the cable transmission waveform are up and down synchronously, and it can meet the car signal reception.[7] Depending on the different frequencies of LTE ,[8]the field distribution inside are also different and the slot on the lcx is different in order to meet different signal coverage. In summary, the leaky coaxial cable in the high-speed train are feasible.

V. CONCLUSION

The paper established a leakage cable model in the train by Ansoft HFSS, and its field characteristics are simulated comparison with the existing literature in order to verify the high-speed rail train feasibility of erecting leaky coaxial cable. With the development of communication technology, people have more demand for the high-quality information exchange day by day. The application of leakage cable will be more widely used. So it's necessary to select the appropriate cables and network system for different services and other special scenes. [9]The further research of leakage cable is needed to play the unique feature of being both transmission line and antenna.

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