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# Characteristic of Electromagnetic Noise Based on the Theory of Multiconductor Communication Line

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## Abstract

Electromagnetic noise has serious influence on the performance of electrical system. In addition, while multiconductor cable harnesses play an important role in transmitting electromagnetic energy or signal between devices of electrical system, they are also the major path to transmit electromagnetic noise. Crosstalk, as typical electromagnetic noise within multi-conductor cable harnesses, is an important factor which affects the efficiency of transmission. In this paper, the n+1 transmission lines (n=2, n>2) are taken as the object of research. Based on the theory of Multi-conductor Transmission Line (MTL), the transmission of electromagnetic noise in transmission line is studied, including noise of generating line (called G-line) and line receiving interference (called R-line), the latter called crosstalk. Transfer functions of electromagnetic noise of G-line and R-line are simulated using FEKO (FEldberechnung bei Korpern mit beliebiger Oberflache). Two transfer functions are obtained to investigate the severity of noise of G-line and R-line. The characteristics of the parameters are also studied. Simulation results indicate that transfer functions have tight relationship with the electrical length. When the electrical length is small, voltage loss of interference line along the transmission line is relatively small, so is the far-end crosstalk; however, when the electrical length is large, voltage loss and the far-end crosstalk is larger, and resonances at high frequency.

**Keywords:** Electromagnetic noise; FEKO; electrical length;

## Introduction

With the increasing development and high frequency of electrical and electronic equipment, as the important component of various equipment connections, the immunity to electromagnetic noise of cables is extremely essential for the stable operation of electrical system [1-3]. Generally, electromagnetic noise can be divided into electromagnetic noise on G-line and new electromagnetic noise on R-line coupled by the electromagnetic noise of G-line, the latter is called crosstalk [4-6]. Because of the serious influence of the far-end electromagnetic noise on the device, we focus on the electromagnetic noise of the far-end multi-conductor cables [7-10]. This paper studies the G-line and R-line electromagnetic noise transfer condition in different situations based on MTL theory.

## The Model of Electromagnetic Noise (N+1) Transmission Line

For (n + 1) transmission line systems, "n" refers to wires that transmit electromagnetic energy; "1" refers to a ground reference line, such as the case in a multi-electric aircraft, the body of an electric car, etc. The model of (n+1) transmission lines is shown in Figure 1. The near-end and far-end voltage of G-line are, respectively, $\hat{U}_G(0)$ and $\hat{U}_G(l)$. K can be called the " transfer coefficient of G-line voltage ", which means that the closer the value is to 1.0, the smaller the voltage transfer loss; $\hat{U}_G(0)$and $\hat{U}_G(l)$can be derived by FEKO, then the amplitude of K can be obtained.

$$K = \frac{\hat{U}_G(l)}{\hat{U}_G(0)} \tag{1}$$

$\overline{H}_{FE}(\omega)$ is the ratio of $\hat{U}_R(l)$ to $\hat{U}_G(0)$ which is called "characteristic of far-end crosstalk".

$$H_{FE}(\omega) = \frac{\hat{U}_R(l)}{\hat{U}_G(0)} \quad (2)$$

The far-end voltage of R-line $\hat{U}_R(l)$ and the near-end voltage of G-line $\hat{U}_G(0)$ can be derived by FEKO, so that the amplitude of the $H_{FE}$ can be obtained.

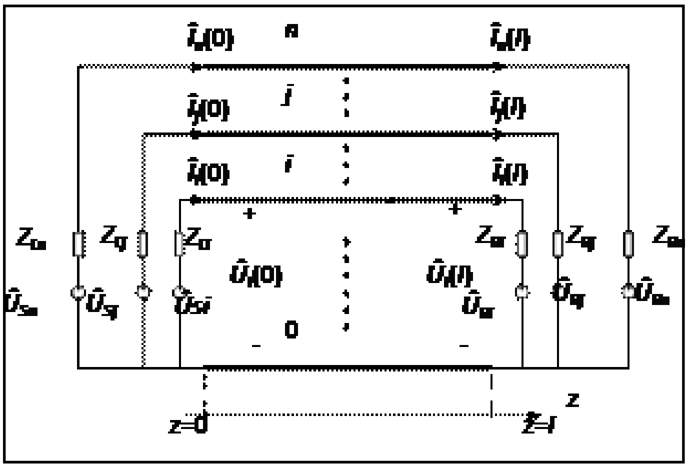


**Figure 1:** (n+1) conductor transmission model

In fact, $K$ and $H_{FE}$ are functions of length $l$ of transmission lines and frequency $f$, for the reason that introduces the $L_e$ which is the ratio of $l$ to wavelength λ.

$$K = K(f, l) \quad (3)$$

$$H_{FE} = H_{FE}(f, l) \quad (4)$$

$$L_e = l / \lambda \quad (5)$$

This comprehensive parameter makes (3) and (4) become

$$K = K(L_e) \quad (6)$$

$$H_{FE} = H_{FE}(L_e) \quad (7)$$

Based on this, the changes of $K$ and $H_{FE}$ with $L_e$ are studied.

For case where the electrical length, $L_e$, is small, the line can be represented by lumped parameters (inductance, capacitance, resistance). As $L_e$ increases, lumped parameter representation is no longer valid, and distributed parameter model must be used. For large $L_e$, one convenient representation is with the ABCD parameters, which A, B, C, and D are hyperbolic function of the propagation constant $\gamma = \alpha + \beta$, derived from the line physical parameters (resistance, capacitance, inductance and conductance). This article chooses to use FEKO simulation software to replace these traditional numerical calculation methods.

## Electromagnetic noise characteristics at the far-end of (2+1) transmission line

For the frequency range of (0.1~300) MHz, that is, the electrical dimension $L_e$ is in the range of (0.0005~1.5) m, the (2+1) conductor transmission line simulation is performed in FEKO.

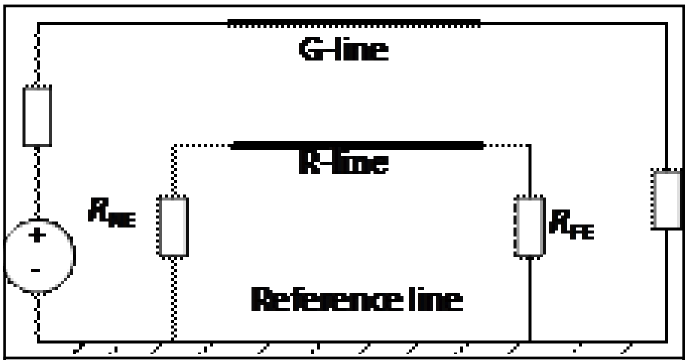


**Figure 2:** (2+1) conductor transmission model

In Figure 2, the length of the transmission line is l, the source on the interference line is composed of the noise source of G-line $\overline{U}_S$ and the source resistance $R_S$. $R_L$ is the far-end load of the interference line, and $R_{NE}$ and $R_{FE}$ represent the near-end load and far-end load on the R-line, respectively. The cable structure in this section is shown in Table 1.

Figure 3 shows that, when the electrical length, $L_e = l/\lambda$, is small, the loss of voltage is almost ignorable. As $f$ increases (i.e., $\lambda$ decreases) or $l$ increases, $L_e$ increases, and the effects of distributed line parameters must be considered. Moreover, the number of resonance points increases, and the voltage amplitudes at the near and far ends of the lines are no longer approximately equal, which leads to significant variations of $|K|$.

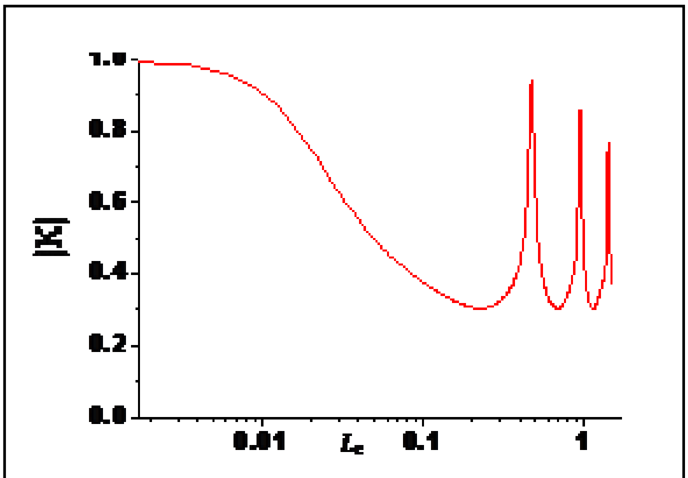


**Figure 3:** Interference line voltage transfer coefficient K of (2+1) transmission line

As shown in Figure 4 when the electrical length is small, $|H_{FE}|$ is small, that is, the far-end crosstalk voltage is small at low frequency.

As $f$ increases (i.e., $\lambda$ decreases) or $l$ increases, $L_e$ increases, and the effects of distributed line parameters must be considered., $|H_{FE}|$ increases and when it rises to a certain level, it begins to fall which is caused by resonance point.

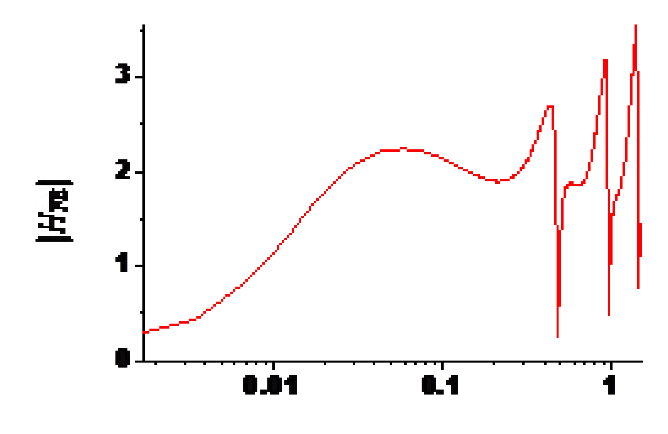


**Figure 4:** The far-end crosstalk transfer function HFE of the (2+1) transmission line

## Electromagnetic Noise Characteristics of Multi-layer Conductor Transmission Lines

For the ($n$+1, $n$>2) conductor system, the corresponding inductive-capacitive coupling model is too complicated compared to the (2+1) transmission line. This article takes $n$=7 and 19 as examples to research, where $n$=7 is a two-layer transmission line model, and $n$ = 19 is a multi-layer (actually three-layer) transmission line model.

The cables simulated in this section are shown in Figure 5. No.1 conductor is the G-line, and No. (2 ~ 7) conductors are the R-line. The blue circles surround the orange and red circles, represent the wire insulation.

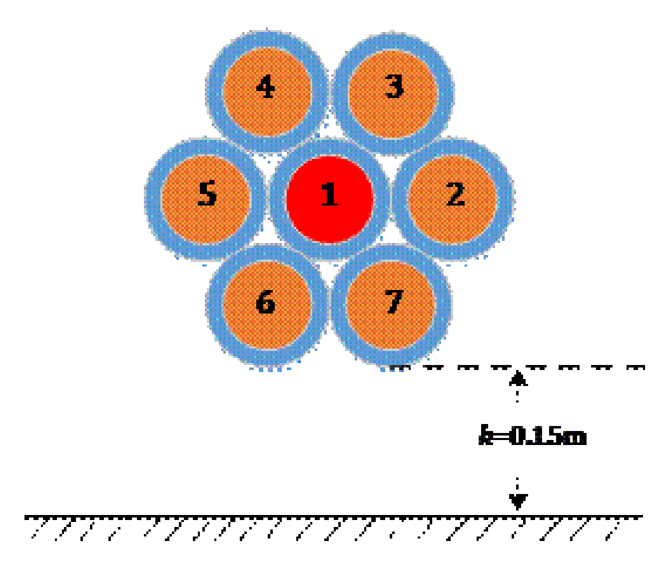


**Figure 5:** (7+1) conductor transmission lines

The cable structure in this section is shown in Table 2.

The simulation results show (Figure 6) that the far-end crosstalk voltages of No. (2~7) conductors are almost equal, so No.1 conductor is taken as the research object to study the features of $K$, and No.2 conductor is taken as the research object to study the features of $H_{FE}$.

As shown in Figure7, when the electrical length is small, the loss of voltage is almost ignorable. As $f$ increases (i.e., $\lambda$ decreases) or $l$ increases, $L_e$ increases, and the effects of distributed line parameters must be considered. Moreover, the number of resonance points increases, and the voltage amplitudes at the near and far ends of the lines are no longer approximately equal, which leads to significant variations of $|K|$. Compared with Figure 3, the amplitude of $|K|$ oscillates violently at high frequency.

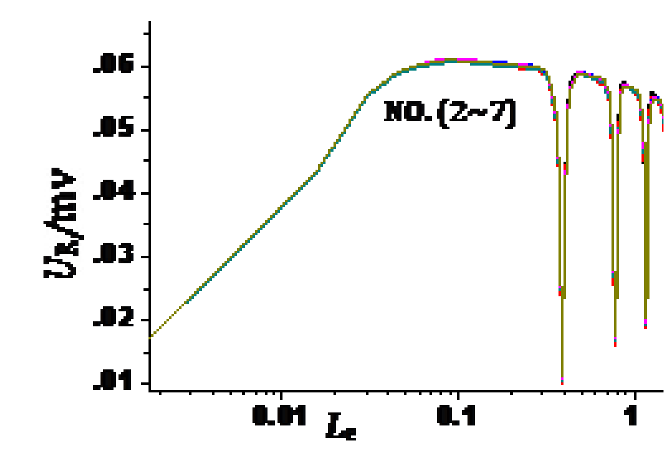


**Figure 6:** Far end crosstalk voltages of NO. (2~7) conductors

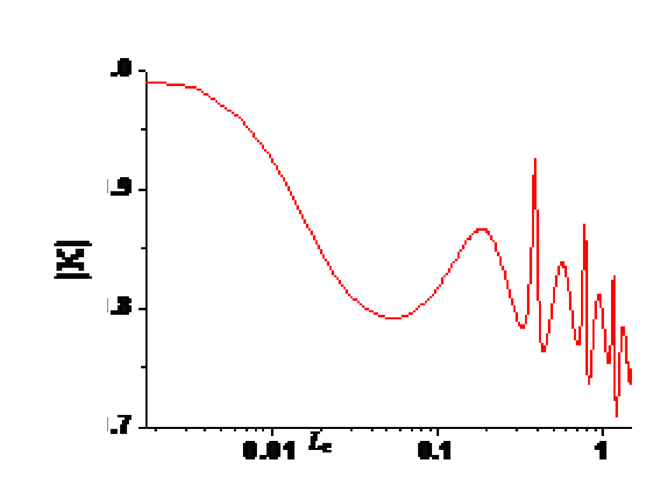


**Figure 7:** Interference line voltage transfer coefficient K of (7+1) transmission line

As shown in Figure 8, the features of $|H_{FE}|$ are similar to Figure 4, but resonance is more serious. The magnitude of $|H_{FE}|$ in Figure

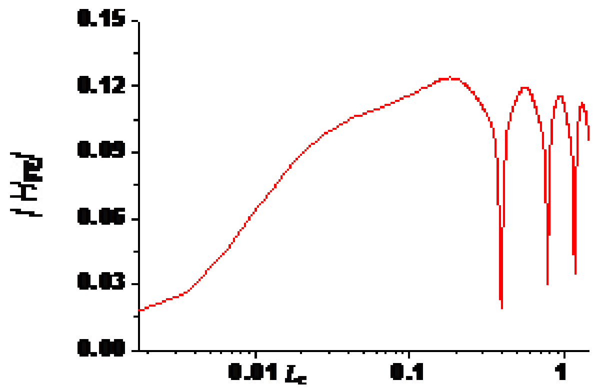


**Figure 8:** Far end crosstalk transfer function HFE of the (7+1) transmission line

**Table 1:** Parameters of (2+1) conductor transmission line

| Parameter | Value |
|---|---|
| Number of transmission lines *n* | 2 |
| Conductor diameter *D*/mm | 2.0 |
| Thickness of insulation layer *t*/mm | 0.5 |
| Ground height *h*/m | 0.15 |
| Length of transmission line *l*/m | 1.5 |
| Distance between conductors *d*/mm | 5.0 |

**Table 2:** Parameters of (7+1) conductor transmission line

| Parameter | Value |
|---|---|
| Number of transmission lines *n* | 7 |
| Conductor diameter *D*/mm | 2.0 |
| Thickness of insulation layer *t*/mm | 0.5 |
| Ground height *h*/m | 0.15 |
| Length of transmission line *l*/m | 1.0 |
| centre-to-centre distance/mm | 3.0 |

**Table 3:** Parameters of (19+1) conductor transmission line

| Parameter | Value |
|---|---|
| Number of transmission lines *n* | 19 |
| Conductor diameter *D*/mm | 2.0 |
| Thickness of insulation layer *t*/mm | 0.5 |
| Ground height *h*/m | 0.15 |
| Length of transmission line *l*/m | 1.0 |
| centre-to-centre distance/mm | 3.0 |

8 is smaller than Figure 4 in that the length of transmission line is smaller.

For the 3-layer transmission line, the simulation analysis is performed in the frequency range of (0.1~200) MHz, that is, $L_e$ is in the range of (0.0005~1) m. The (19+1) conductor transmission line is shown in Figure 9, the conductor No. 1 is the G-line, and the No. (2~9) conductors are the R-line.

The cable structure in this section is shown in Table 3.

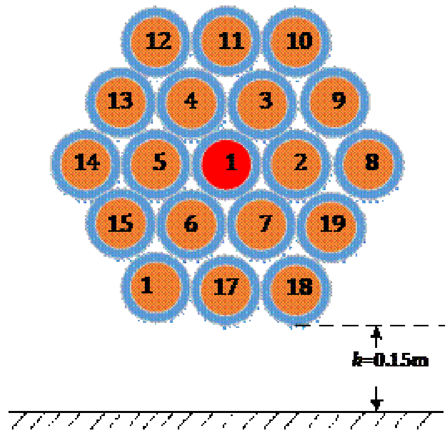


**Figure 9:** (19+1) conductor transmission lines

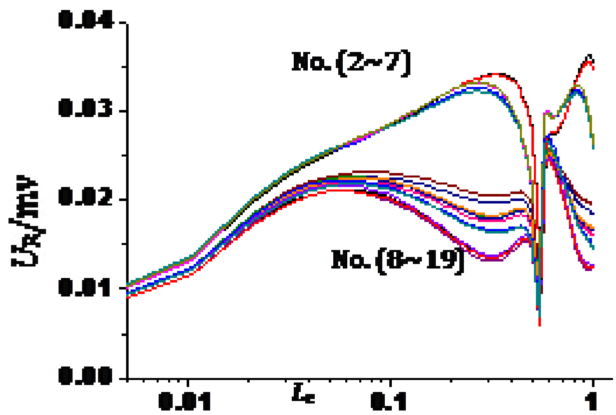


**Figure 10:** Far end crosstalk voltages of NO. (2~19) conductors

The simulation results show (Figure10) that the crosstalk voltages at the far end of No. (2~7) conductors in the middle layer are almost equal, and the crosstalk voltages of No. (8~19) conductors also has the same characteristics. Therefore, No.1 conductor is taken as the research object to study the features of *K*, and No.2 and No.8 conductors are the research object to study the features of $H_{FE}$, which are called $H_{FE2}$ and $H_{FE8}$, respectively.

As shown in Figure 11, when the electrical length is small, the loss of voltage is almost ignorable. As *f* increases (i.e., *λ* decreases) or *l* increases, $L_e$ increases, the amplitude of |*K*| oscillates at high frequencies, which overall shows a downward trend.

As shown in Figure 12, when the electrical length is small, $|H_{FE2}|$ and $|H_{FE8}|$ are small, that is, the far-end crosstalk voltage is small at low frequency; as the electrical length increases, $|H_{FE2}|$ and $|H_{FE8}|$ increase. When it rises to a certain level, it starts to fall because of the resonance point. In addition, in the entire frequency band $|H_{FE2}|$ is slightly higher than $|H_{FE2}|$. It can be seen that as the distance between the G-line and the R-line increases, the crosstalk voltage decreases.

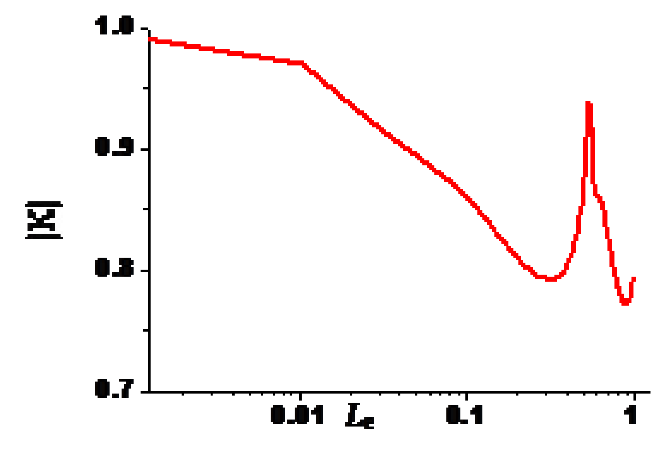


**Figure 11:** Interference line voltage transfer coefficient of (7+1) transmission line

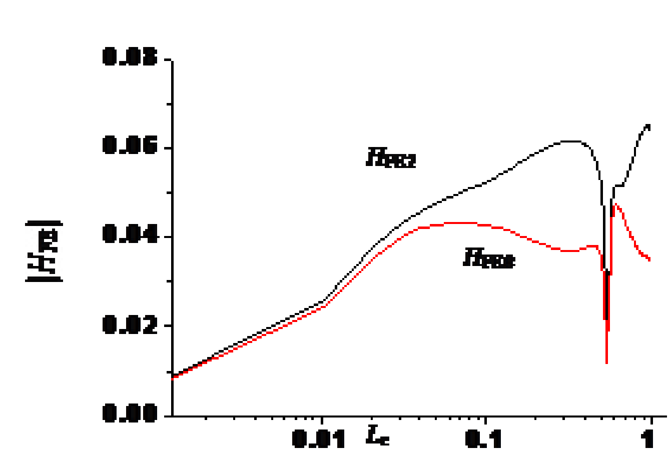


**Figure 12:** Far end crosstalk transfer function HFE of the (19+1) transmission line

## Conclusion

1. When electrical length is small, $|K|$ is close to 1, which indicates that the voltage loss of the G-line is small at low frequency; $|H_{FE}|$ is close to 0, which indicates that the far-end crosstalk voltage is small at low frequency.

2. As $f$ increases (i.e., $\lambda$ decreases) or $l$ increases, $L_e$ increases, and the effects of distributed line parameters must be considered, and $|K|$ shows a downward trend, indicating that the voltage on the G-line is losing along the transmission line; $|H_{FE}|$ begins to increase, indicating that the far-end crosstalk voltage has a positive correlation with the electrical length. And the resonance points appear when the electrical length is large.

3. The comparison of $H_{FE2}$ and $H_{FE8}$ shows that when the R-line is evenly distributed and the distance from the G-line is equal, the far-end crosstalk voltage is almost equal; when the G-line is set at the center of the harness, the closer the R-line is to the G-line, the more serious the crosstalk is.

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