The analysis of TLM with high frequency coupling in PCB design

ZHAO Lian-qing[1], LV Zheng-quan[2]

School of Electric and Electronic engineering , North China Electric Power University, Beijing 102206

1. zhaolianqing@163.com ,2.lvzhengq@163.com

Abstract: With the help of the basic theory of transmission lines, two lines' high-frequency interference coupling of the mathematical model is used to calculate the quantitative analysis of the transmission lines of high-frequency interference. At the same time, the common parameters of the parallel wires on PCB are set for the simulation and authentication under the Matlab and Ansoft tools respectively. This method for quantitative analysis of high-frequency coupling provides a reliable mathematical model. In the PCB circuit board designing, this model can be referred to reduce the coupling of high frequency interference.

Key words: EMC(electromagnetic compatibility);TLM(transmission lines model);PCB(printed circuit board)

1 Introduction

With the development of new technologies, the rate of PCB alignment increasing, PCB circuit transmission line effects become normal constraints of work. PCB has become the transmission line alignment. Transmission line is a fit in two or more effective end-to-end transmission of power or signal transmission system. In a multi- transmission lines of PCB system, the coupling between transmission lines (including perceptual coupling and capacitive coupling), would have two harmful effects: First, it changes the bus crosstalk by the crosstalk characteristics of the transmission line. Second, the cross-talk produces the noise to the other transmission line. In this case, a mathematical model to analyze the parallel transmission lines in high-frequency crosstalk cases is presented, including two parallel transmission lines to simplify the circuit model. The analysis of the relationship of two parallel lines' distance, the length of two parallel lines, the distance from the source and the transmission signal frequency with the voltage gain are made based on this mathematical model. In order to solve the problem of high-frequency cross-talk problem, a reliable mathematical model and solution are presented .Specifically we will introduce the model built following.

2 Model

Figure 1 shows the two-transmission line under normal circumstances. One of which we call a drive signal transmission line, another line is the interference line. when we load a drive signal on the drive signal line, because of the high-frequency parasitic capacitance and parasitic inductance's effects , perturbed line will have a sensor voltage and induced current, which in the specific design of the PCB should be minimized strongly [1].
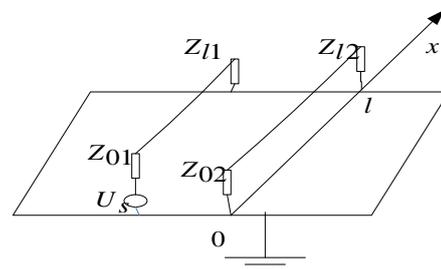

Figure 1 Two-wire transmission line model in PCB design

We cut a small section of the line for analysis. The establishment of a finite element model is shown in Figure 2;
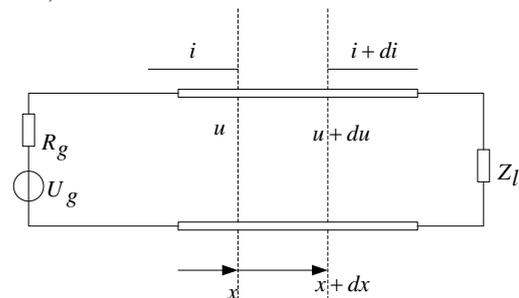

Figure 2 Finite element model for two-wire

Equivalent to a small section of the wire for the inductors and capacitors, and resistors form is shown as figure 3:
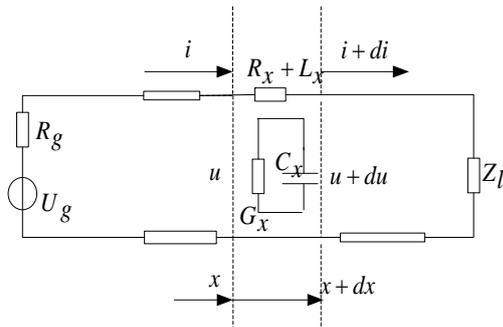
Figure 3 Equivalent circuit model of two wire

Selecting the two corresponding points on the wire, the reference voltage and current, the circuit is shown as figure 4 [2]:
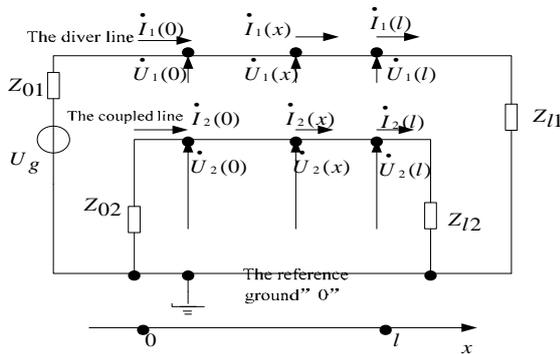

Figure 4   Equivalent circuit of voltage and current relations

In accordance with the relationship between voltage and current of the circuit, we obtain the following identity equation:

$$\begin{cases} \dfrac{du_1(x)}{dx} = -j\omega[L_1 I_1(x) + L_{12} I_2(x)] \\[2mm] \dfrac{du_2(x)}{dx} = -j\omega[L_{12} I_1(x) + L_2 I_2(x)] \\[2mm] \dfrac{dI_1(x)}{dx} = -j\omega[(C_1 + C_{12})U_1(x) - C_{12} U_2(x)] \\[2mm] \dfrac{dI_2(x)}{dx} = -j\omega[-C_{12} U_1(x) + (C_2 + C_{12})U_2(x)] \end{cases} \quad (1)$$

From this, we can make the following equations:

$$Y_{(x)} = \begin{bmatrix} U_{1x} \\ U_{2x} \\ I_{1x} \\ I_{2x} \end{bmatrix} \quad (2)$$

$$A = \begin{bmatrix} 0 & 0 & L_1 & L_{12} \\ 0 & 0 & L_{12} & L_2 \\ C_1 & -C_{12} & 0 & 0 \\ -C_{12} & C_2+C_{12} & 0 & 0 \end{bmatrix} \quad (3)$$

From this we get the matrix equation:

$$\dot{Y}(x) = -j\omega A Y(x) \quad (4)$$

Of which:

$$L = 0.2[\ln(\tfrac{2h+t}{w+t}) - (2h+t)\times10^{-3} + 0.2235\times10^{-3}(w+t) + 1.5] \,(\mu H) \quad (5)$$

$$L_{12} = 0.002[l \bullet \ln(\frac{\sqrt{l^2+d_0{}^2}+l}{d_0}) - \sqrt{l^2+d_0{}^2} + d_0] \,(\mu H) \quad (6)$$

$$C = \frac{\omega \cdot l \cdot \varepsilon_0 \cdot \varepsilon_r}{d} \,(pF) \quad (7)$$

In these equations：

h: the printed conductors and base-level inter-media thickness;

w : width of line;

t : thickness of line;

d_0: interval between two parallel lines;

l : The length of wire;

ε_0 : Dielectric constant of air;

ε_r: Relative dielectric constant;

ω : Signal frequency;

d : The distance between lines (in this article three variables d_1, d_2, d_3 were expressed as a drive line and to partitions, drive line and the disturbed line, as well as land lines and disturbed intervals).

When equations (1), (2), (3) are taken into the matrix equation and the initial matrix is $[U_0 \quad U_1 \quad I_0 \quad I_1]$, finally calculated by the Matlab solution $Y_{(x)}$ is as (2) and the matrix elements are shown in (8)-(11)

$$U_{1x} = conj(U_0) + conj(U_1) + K_1 conj(I_0) + K_2 conj(I_1) \quad (8)$$
$$U_{2x} = conj(U_0) + conj(U_1) + K_2 conj(I_0) + K_1 conj(I_1) \quad (9)$$
$$I_{1x} = K_3 conj(U_0) + K_4 conj(U_1) + conj(I_0) + conj(I_1) \quad (10)$$
$$I_{2x} = K_4 conj(U_0) + K_3 conj(U_1) + conj(I_0) + conj(I_1) \quad (11)$$

In the equations(8),(9),(10),(11):

the function $conj(x)$ is solving the conjugate complex number of x.

$K_1 =$

$e^{-0.2\times10^{-6}i\omega x(x\log((2h+t)/(w+t)) - 0.002h - 7.77\times10^{-4}t + 2.24\times10^{-4}w + 1.5)}$

$K_2 =$

$e^{-i\omega(0.2\times10^{-6}x\log(((x^2+d^2)^{0.5}+x)/d) - 0.2\times10^{-6}(x^2+d^2)^{0.5} + 0.2\times10^{-6}d))}$

$K_3 = e^{(-i\omega(tx\varepsilon_0\varepsilon_r/d1 + tx\varepsilon_0\varepsilon_r/d))}$

$K_4 = e^{(i\omega tx\varepsilon_0\varepsilon_r/d)}$

In the circuit：

$$\begin{cases} U_0 = U_g - Z_{01} I_0 \\ U_1 = -Z_{02} I_1 \end{cases} \quad (12)$$

$$\begin{cases} U_1(l) = -Z_{l1} I_1(l) \\ U_2(l) = -Z_{l2} I_2(l) \end{cases} \qquad \textbf{(13)}$$

These are the mathematical models we have established. The following specific analysis will be carried out.

3 Model Validation

After the establishment of the model we have used Matlab and Ansoft to verify analysis

3.1 Matlab Simulation

First of all, the equations **(1) (2) (3)** we select design parameters of a typical PCB. For two wire spacing, frequency, and source analysis of the distance will be pointed out that the disturbance of these parameters on-line by the impact of voltage gain. We set the parameters as follows in the line width for $0.1\,\mathrm{mm}$, the thickness of lines $25\,\mu\mathrm{m}$, PCB dielectric substrate thickness of $7\,\mathrm{mm}$. PCB material is FR-4, the relative dielectric constant of 4.4.

In the frequency 10GHz, line length $0.01\,\mathrm{m}$ conditions: We have to drive the lane line and the distance between perturbed and coupling analysis of voltage gain of Matlab. As figure 5 shown:
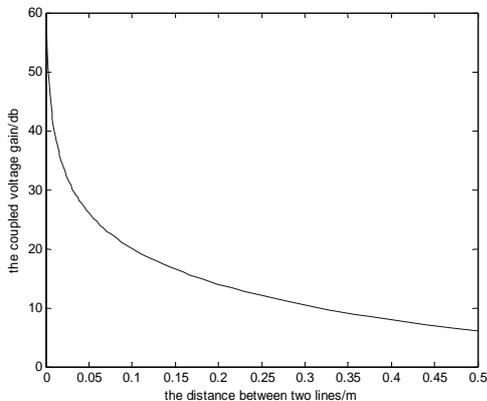

Figure 5 Coupling voltage and two lines from the relationship between

From Figure 5 , the interference with the lines and drive line coupling interval increased voltage gain is on the decline, especially in the range of $0.1\,\mathrm{m}$, a greater impact. Therefore, in the design of PCB parallel transmission lines, we should make every effort to increase the interval between the two.

When the line length is $0.01\,\mathrm{m}$ and the two lines at intervals of $0.01\,\mathrm{m}$,we use Matlab for frequency response analysis and obtain the figure 6 as follows:
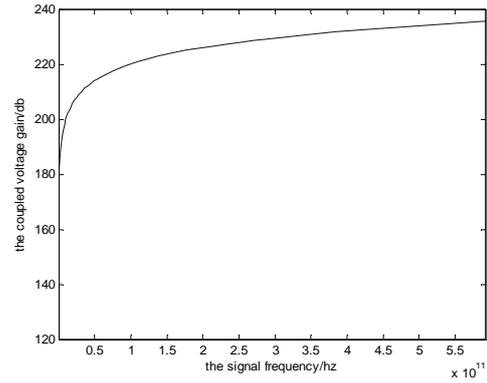

Figure 6 Relationship of signal frequency and voltage gain

Analysis of the figure 6,we can be conclude that when the frequency is increasing the voltage gain is increasing, but the variation becomes very flat after 5GHz .

When the line length of $0.01\,\mathrm{m}$, a frequency 100MHz, our analysis points to the relationship of the distance from the source and the voltage gain, as shown in figure 7.
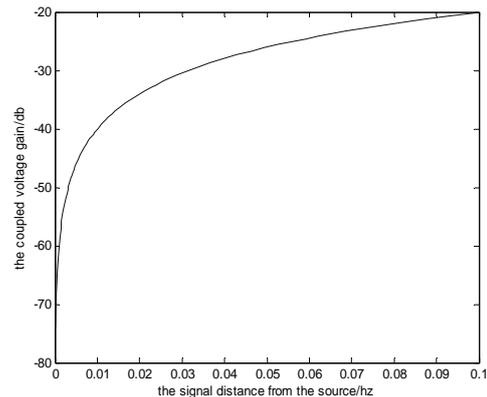

Figure 7 Relationship between distance from the origin and voltage gain

From figure 7,   the magnitude of crosstalk in parallel with the transmission line length increases, that is parallel to the longer length, the greater the crosstalk. However, when parallel to the length of a certain length, the crosstalk does not increase the rate. In the figure 7 in the very $0.04\,\mathrm{m}$ after the gentle slope, we can illustrate this point. Because the transmission line does not interfere with the energy of all the interference coupled into transmission lines, transmission lines and the interference of electromagnetic fields generated by induced current in turn, coupled to the drive online. Therefore, when we are in the design of PCB, we should minimize the length of parallel lines and the adjacent layers of signal lines should be vertical alignment to avoid parallel.

3.2 Ansoft HFSS simulation analysis to verify

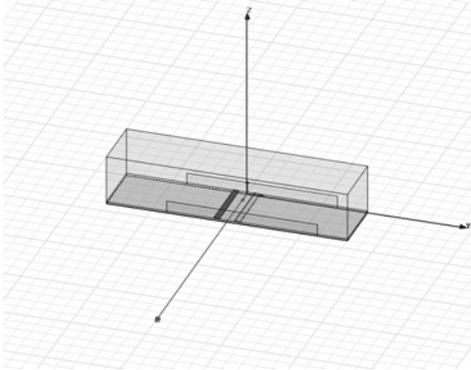First of all, we establish a system model using Ansoft as shown in figure 8 [3]:

Figure 8 Ansoft Design Model

In view of the above model, the choice of parameters and the parameters used in Matlab simulation are the same. The attenuation of the relationship between parameters and frequency as follows:
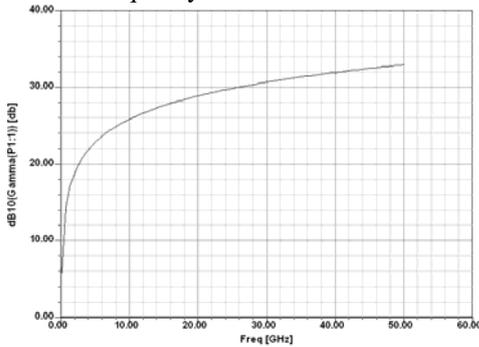

Figure 9 Relationship of signal attenuation parameters and frequency

From figure 9 when the frequency of voltage attenuation increases to a certain frequency，the voltage gain increases flatly , and this is the same with the Matlab simulation results.

4 Conclusion

Based on the transmission line model and the distribution parameters derived circuit equation, a mathematical model is carried out .we used Matlab and Ansoft simulation analysis on the design of PCB parallel wires' electromagnetic problem. At the same time, this model can also be extended to analyze more transmission lines' high-frequency interference problem.

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References

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