The study on Crosstalk of Single Wire and Twisted-Wire Pair

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***Abstract*- A method based on time-domain Baum-Liu-Tesche (BLT) equations of transmission line model is presented in this paper for solving the crosstalk problem between a single wire and a twisted-wire pair. The single wire and the twisted-wire pair (TWP) together are modeled as a set of uniform multi-conductor transmission lines with abrupt interchanges of wire positions at the end of each loop of the twisted-wire pair, each group of multi-conductor transmission lines is solved by using the finite-difference time-domain (FDTD) method, the nodes of the twisted pair are corrected by using twisted-wire pair two-line hybrid iterative method. Finally, the time-domain results are obtained. It is found that the simulation results obtained by using BLT equations proposed in this paper agree very well with the results of commercial simulation software, the method is verified to be corrected.**

***Key words*- Crosstalk, Twisted-wire pair, BLT Equations, FDTD**

I. INTRODUCTION

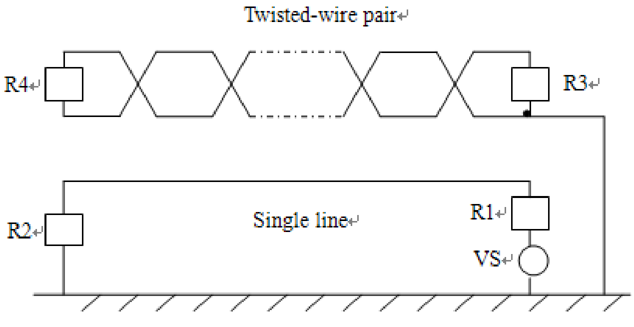
A twisted-wire pair (TWP) consists of two identical wires which are smoothly twisted together. Aside from the obvious advantage of holding the two wires together, the twist also tends to reduce inductive coupling because of its special structure, which was shown in [1]. TWP is widely concerned in many fields of electromagnetic compatibility. Study of crosstalk problem involving TWP is practically valuable.

The analysis of crosstalk involving TWP is complex because of the special structure of TWP, it can not be solved via using transmission line equations directly. Traditional research about TWP is generally expanded in the frequency domain, the time-domain terminal response can not be obtained effectively.
Investigation of crosstalk between single wire and TWP in specific frequency band is presented in [2]. Studies on TWP has generally concentrated on determining the magnetic field resulting from the excitation of an isolated twisted pair, which are shown in [3]-[5]. Study of the near end crosstalk in twisted pair cables is shown in [6].

A method based on time-domain Baum-Liu-Tesche (BLT) equations [7]-[9] of transmission line model is presented in this paper for solving crosstalk problem between a single wire and a TWP. The TWP is modeled as a cascade of loops consisting of uniform two-wire sections with abrupt interchanges of wire positions at the end of each loop. The single wire and the TWP together are modeled as a set of uniform multi-conductor transmission lines with a specific way of cascade at the end of each loop of twisted pair, each group of multi-conductor transmission lines is solved by using the finite-difference time-domain (FDTD) method, the nodes of the twisted pair are corrected using twisted pair two-line hybrid iterative method. Finally, the time-domain results are obtained. It is found that the simulation results obtained by using BLT equation proposed in this paper agree very well with the results of commercial simulation software, the method is verified to be corrected.

II. MODEL

The crosstalk configuration of a single wire and a twisted-wire pair is shown in Fig. 1. In Fig. 1(a), VS is the voltage source. The cross-sectional view is shown in Fig. 1(b). In Fig. 1, the single wire is designated as the generator wire, the TWP is designated as the receptor wire. The single wire and the twisted-wire pair (TWP) together are modeled as a set of uniform multi-conductor transmission lines with abrupt interchanges of wire positions at the end of each loop of twisted pair. Approximations about the twisted pair are shown as follow: (a) the twisting part is considered as uniform transmission line; (b) two twisted parts are approximately infinite small. One section of the TWP is shown in Fig. 2. The voltage control equation at the cascade can be written as:



(a)

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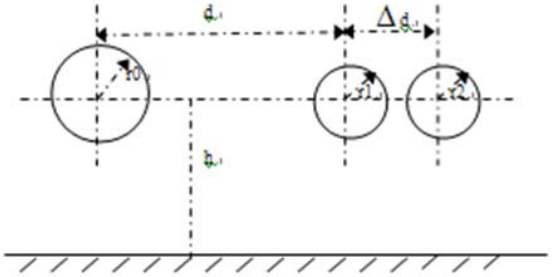
* Project supported by the Fundamental Research Funds for The Central Universities (Grant No.SWJTU12ZT08).



(b)

Figure 1. Single wire and TWP configuration. (a) A longitudinal view. (b) A cross-sectional view.

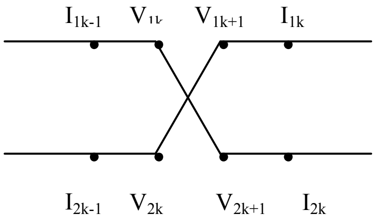


Figure 2. The twisted part of twisted-wire pair

$$\begin{bmatrix} V_{1k} \\ V_{2k} \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix} \begin{bmatrix} V_{1k+1} \\ V_{2k+1} \end{bmatrix} \tag{1}$$

The time-domain form of the First Telegraph Equation and Second Telegraph Equation obtained according to Maxwell's equations can be written as

$$\frac{\partial V(z,t)}{\partial z} + L(z)\frac{\partial I(z,t)}{\partial z} + R(z)I(z,t) = V_F(z,t) \tag{2a}$$

$$\frac{\partial I(z,t)}{\partial z} + C(z)\frac{\partial V(z,t)}{\partial z} + G(z)V(z,t) = I_F(z,t) \tag{2b}$$

In (2), $V_F(z,t)$、$I_F(z,t)$ are the column vector consisting of voltage source and current source of the single wire and TWP configuration separately. R、L、G、C are the cable per-unit-length distribution parameters matrix, which can be obtained through electromagnetic simulation. Equation (2) is discrete by using FDTD, the terminal responses of the multi-conductor transmission lines consisting of a single wire and a twisted-wire pair can be written as

$$V_k^{n+1} = (C\frac{\Delta z}{\Delta t} + \frac{G}{2}\Delta z)^{-1}((C\frac{\Delta z}{\Delta t} - \frac{G}{2}\Delta z)V_k^n - (I_k^{n+1/2} - I_{k-1}^{n+1/2})) \tag{3a}$$

$$I_k^{n+3/2} = (L\frac{\Delta z}{\Delta t} + \frac{R}{2}\Delta z)^{-1}((L\frac{\Delta z}{\Delta t} - \frac{R}{2}\Delta z)I_k^{n+1/2} - (V_{k+1}^{n+1} - V_k^{n+1})) \tag{3b}$$

Considered the terminal condition shown in Fig 1, the terminal response of the single wire and twisted-wire pair can be expressed as

$$V_1^{n+1} = (\frac{\Delta z}{\Delta t}R_S C + E)^{-1}[(\frac{\Delta z}{\Delta t}R_S C - E)V_1^n - 2R_S I_1^{n+1/2} + (V_S^{n+1} + V_S^n)] \tag{4a}$$

$$V_{NDZ+1}^{n+1} = (\frac{\Delta z}{\Delta t}R_L C + E)^{-1}[(\frac{\Delta z}{\Delta t}R_L C - E)V_{NDZ+1}^n + 2R_L I_{NDZ}^{n+1/2}] \tag{4b}$$

In (4), R_S and R_L are the beginning and end impedance matrix separately. Considered the iteration integrity of the nodes of the twisted part, the iteration equations of the nodes of the twisted part can be expressed as

$$V_{1k}^{n+1} = (C\frac{\Delta z}{\Delta t} + \frac{1}{2}G\Delta z)^{-1}((C\frac{\Delta z}{\Delta t} - \frac{G}{2}\Delta z)V_{1k}^n - (I_{2k}^{n+1/2} - I_{1k-1}^{n+1/2})) \tag{5a}$$

$$V_{2k}^{n+1} = (C\frac{\Delta z}{\Delta t} + \frac{1}{2}G\Delta z)^{-1}((C\frac{\Delta z}{\Delta t} - \frac{G}{2}\Delta z)V_{2k}^n - (I_{1k}^{n+1/2} - I_{2k-1}^{n+1/2})) \tag{5b}$$

III. NUMERICAL SIMULATION

A. *Example one*

The crosstalk configuration of a single wire and a straight-wire pair (SWP) is shown in Fig. 3, the single wire is designated as the generator wire, the SWP is designated as the receptor wire. In Fig. 3, $R1=0, R2=R3=R4=50\,\Omega$, the length of the single line and SWP are 1 m, $r_0=r_1=r_2=0.69$ mm, h=5 cm, d=5 cm, △d=1.75 mm. The waveform of the voltage source is shown in Fig. 4。The results are shown in Fig. 5-6.

Fig. 5-6 show two methods agree well with each other, which verifies the correctness of dealing with crosstalk problem of the single wire and SWP by using multi-conductor transmission line theory.

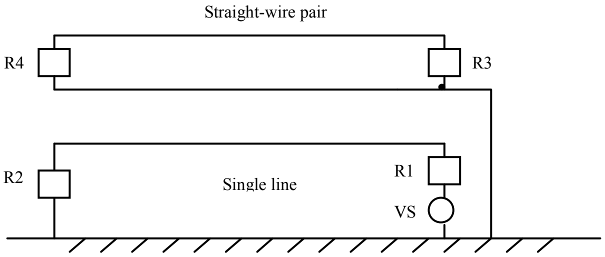


Figure 3. Single wire and SWP configuration.

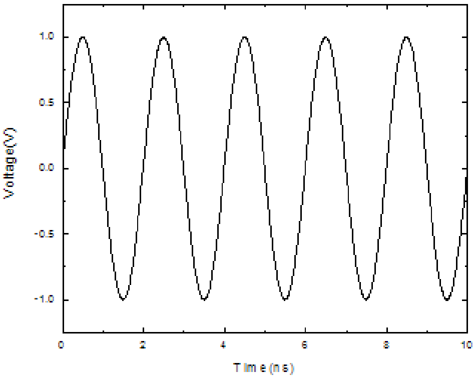


Figure 4. The waveform of voltage source

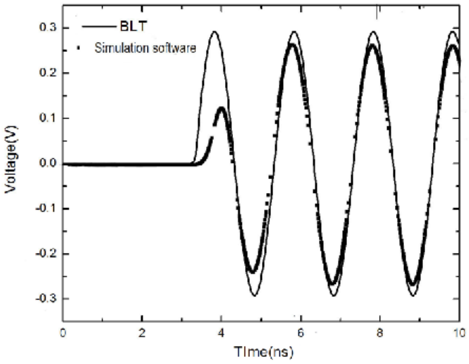


Figure 5. Results of the far end of the single wire.

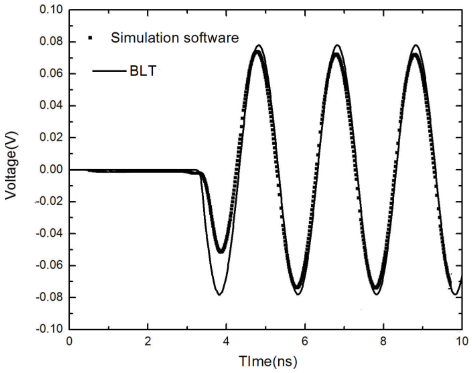


Figure 6. Results of the far end of the SWP.

B. *Example two*

The crosstalk configuration of a single wire and a twisted-wire pair (TWP) is shown in Fig. 1, the single wire is designated as the generator wire, the TWP is designated as the receptor wire. In Fig. 1 $R1=0, R2=R3=R4=50\ \Omega$, the length of the single line and TWP are 1 m, r_0=0.69 mm, r_1=r_2=0.564 mm, h=5 cm, d=5 cm, □d=1.25 mm, the length of each twisted loop is 2 cm. The waveform of the voltage source is shown in Fig. 7. The results are shown in Fig. 8-9.

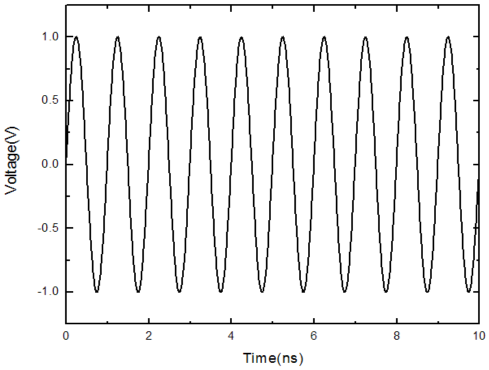


Figure 7. The waveform of voltage source

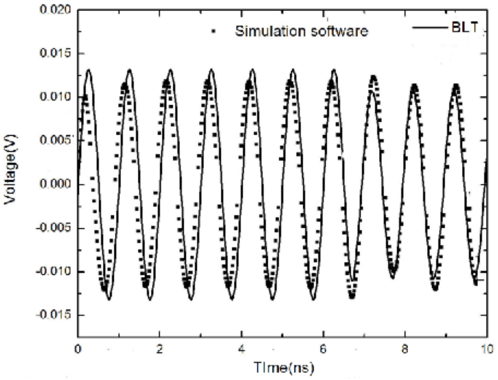


Figure 8. Results of the near end of the TWP

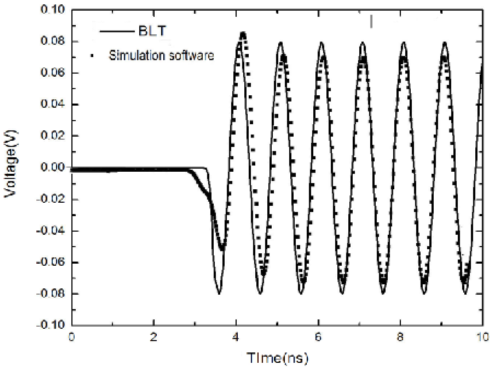


Figure 9. Results of the far end of the TWP

Fig. 8-9 show two methods agree well with each other, which verifies the correctness of dealing with crosstalk problem of the single wire and TWP by using BLT equations proposed in this paper. It is known that the crosstalk amplitude between a single wire and SWP has no matter with the frequency of voltage source, it is decided by the amplitude of voltage source. In Fig.6 and Fig.9, the response of SWP and TWP has the same level, although the distance of TWP is smaller, which shows the TWP can reduce inductive coupling.

IV. CONCLUSION

The terminal response of the single wire and twisted-wire pair can be obtained accurately by using the method based on time-domain BLT equation of transmission line model presented in this paper for solving crosstalk problem between a single wire and a TWP which can not be solved via using transmission line equations directly. The results match well with the results of commercial simulation software.

ACKNOWLEDGMENT

This work is supported by the Fundamental Research Funds for The Central Universities (Grant No. SWJTU12ZT08).

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