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Research on Reflection of CAN Signal in Transmission Line*

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***Abstract* - This paper researches the way that physical layer of CAN bus affects the signal transmission. The analysis is based on the physical model of twisted-pair wire. According to this model, the effect of different wire physical parameters is discussed. Besides that, it reasons the cause of signal reflection, and brings method to solve the problems of signal transmission of CAN signal. In this way, references could be provided for the design of CAN system.**

Index Terms* - *CAN Bus; Vehicle Control system; signal reflection; physical layer; twisted-pair line

I. INTRODUCTION

CAN (Controller Area Network) has been widely applied in the fields of automotive engineering, automation control, aerospace and aviation, navigation, process engineering, spinning mechanics, agriculture mechanics and robots, etc, because of the excellent reliability, real-time and flexibility, it. With the development of CAN application, high-speed and long-distance application is now popularizing, based time triggered BUS is more and more. The integrality and real-time of BUS signal are very important. Consequently, the effect of transmitted medium is becoming more and more important. This paper states the research results of the signal reflection in the physical layer of the CAN bus, further more, analyzes the common problems in the engineering.

II. MATHEMATICAL ANALYSIS OF THE REFLECTION

A. The AC model of the twisted-pair line

The twisted-pair line is the communication medium of the CAN bus, its mathematical model when AC signals are transmitted is shown in Fig. 1.

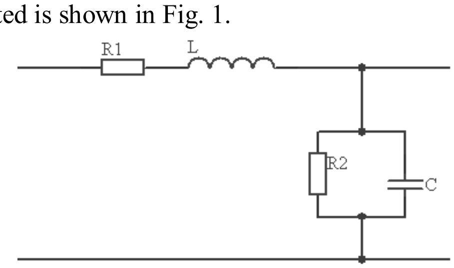

Fig.1. mathematical mode of the twisted-pair line

In Fig.1, R1 is the distributed resistance of the wire circuit, and L is the distributed inductance of the wire circuit, C is the capacitance, and R2 is the insulation resistance between the two wires. Because the signal in the bus is carried out by means of difference voltage, one of the two wires can be considered to be the "ground", while the other is the medium of the signal transfer.

B. Mathematical analysis of signal reflection in twisted-pair line

Twisted-pair line of certain length can be considered to be consisted of numberless lines which are unlimited short, each of which can be thought to be a circuit with concentrated parameters. The equivalent circuit of twisted-pair line is shown in Fig. 2.

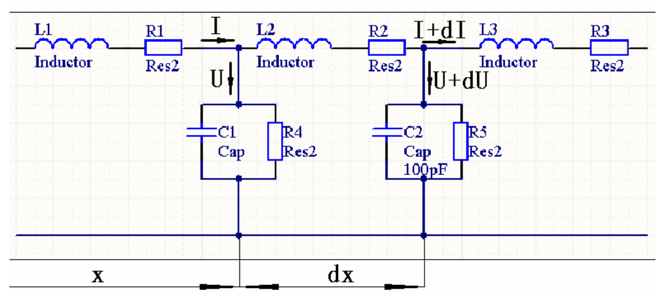

Fig.2. Model of twisted-pair line

While the electric voltage and current is sinusoidal wave, differential Equations can be obtained according to Kirchhoff's law:

$$\begin{cases} -\dfrac{dU}{dx} = (R + j\omega L)I \\ -\dfrac{dI}{dx} = (G + j\omega C)U \end{cases} \tag{1}$$

R in equations (1) is the effective resistance of the unit length cable circuit, and the unit is ohm/km. L is the inductance of the unit length cable circuit, and the unit is H/km. C is the capacitance of the unit length cable circuit, and the unit is F/km. G is the insulation conductance of the unit length cable circuit, and the unit is S/km. dx is the length of unlimited short cable.

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The differential in the left part of the equations (1) is negative, shows the voltage and current decline while x increase. If differential calculus is exerted to the equations (1), then substitute the left part of the equations (1) for it, we can get (2) as follows:

$$\begin{cases} \dfrac{d^2U}{dx^2} = (R+j\omega L)(G+j\omega C)U \\ \dfrac{d^2I}{dx^2} = (G+j\omega C)(R+j\omega L)I \end{cases} \quad (2)$$

Suppose that $\gamma = \sqrt{(R+j\omega L)(G+j\omega C)}$, then (2) can be rewritten as:

$$\begin{cases} \dfrac{d^2U}{dx^2} - \gamma^2 U = 0 \\ \dfrac{d^2I}{dx^2} - \gamma^2 I = 0 \end{cases} \quad (3)$$

The general solution of U in (3) is

$$U = A_1 e^{-yx} + A_2 e^{yx} \quad (4)$$

According to the first equation of (1), we can get:

$$I = \frac{1}{R+j\omega L}\frac{dU}{dx} = \frac{\gamma}{R+j\omega L}(A_1 e^{-\gamma x} + A_2 e^{\gamma x}) \quad (5)$$

Let $Z_C = \dfrac{\gamma}{R+j\omega L} = \sqrt{\dfrac{R+j\omega L}{G+j\omega C}}$, then there is:

$$I = \frac{1}{Z_C}(A_1 e^{-\gamma x} - A_2 e^{\gamma x}) \quad (6)$$

Substitute the boundary condition, integral constant A_1 and A_2 can be obtained. If the voltage and current at the beginning of the cable are U_0 and I_0, and substitute $x = 0$ into (4) and (6), there is

$$\begin{cases} U_0 = A_1 + A_2 \\ I_0 = \dfrac{1}{Z_C}(A_1 - A_2) \end{cases} \quad (7)$$

By solving it we can get the solutions of:

$$\begin{cases} A_1 = \dfrac{U_0 + I_0 Z_C}{2} \\ A_2 = \dfrac{U_0 - I_0 Z_C}{2} \end{cases} \quad (8)$$

After that, substitute A_1 and A_2 into (4) and (6), the formula used to show the voltage and current in the whole cable with the voltage and current at the beginning end is get:

$$\begin{cases} U = \dfrac{U_0 + I_0 Z_C}{2} e^{-\gamma x} + \dfrac{U_0 - I_0 Z_C}{2} e^{\gamma x} \\ I = \dfrac{U_0 + I_0 Z_C}{2Z_C} e^{-\gamma x} - \dfrac{U_0 - I_0 Z_C}{2Z_C} e^{\gamma x} \end{cases} \quad (9)$$

If the length of the twisted-pair line is l, the voltage and current at the terminal end can be obtained form (6):

$$\begin{cases} U_l = \dfrac{U_0 + I_0 Z_C}{2} e^{-\gamma l} + \dfrac{U_0 - I_0 Z_C}{2} e^{\gamma l} \\ I_l = \dfrac{U_0 + I_0 Z_C}{2Z_C} e^{-\gamma l} - \dfrac{U_0 - I_0 Z_C}{2Z_C} e^{\gamma l} \end{cases} \quad (10)$$

We can see form (9) that both the voltage and current at the point x is the sum of two components. One of them declines while x increases the other increases while x increases. The item with $-\gamma$ is the incident electrical voltage wave or the current wave, while the other is the reflecting wave. So the equations (9) become:

$$\begin{cases} U = U_{\text{incidence}} + U_{\text{reflect}} \\ I = I_{\text{incidence}} - I_{\text{reflect}} \end{cases} \quad (11)$$

When we take the ratio $\dfrac{U_{\text{incidence}}}{I_{\text{incidence}}}$ and $\dfrac{U_{\text{reflect}}}{I_{\text{reflect}}}$ we can find that $\dfrac{U_{\text{incidence}}}{I_{\text{incidence}}} = \dfrac{U_{\text{reflect}}}{I_{\text{reflect}}} = Z_C$ .From this we can know that the ratio of the incident voltage wave and current wave, as well as the ratio of the reflective voltage wave and current wave are the same constant, which equals the characteristic impedance of the cable. Reflective voltage wave and current wave both affects the signal inside the wire, such as causing the increase of the energy expending, and the distortion of the signal, which are both essential reasons for the deterioration of the network signal. Following equations can be got from (10):

$$\begin{cases} U_0 = \dfrac{U_l + I_l Z_C}{2} e^{-\gamma l} + \dfrac{U_l - I_l Z_C}{2} e^{\gamma l} \\ I_0 = \dfrac{U_l + I_l Z_C}{2Z_C} e^{-\gamma l} - \dfrac{U_l - I_l Z_C}{2Z_C} e^{\gamma l} \end{cases} \quad (12)$$

The last item above is the reflective wave. With the purpose of eliminate the reflective wave, $U_l = I_l Z_C$ shall be insured. In other words, the terminal impedance needs to be properly installed, and ensure $Z_C = \dfrac{U_l}{I_l} = Z_T$ .In this kind of condition electrical voltage and current vary obeying the exponential law. Impedance at every point equals the characteristic wave impedance. In the process of design matching impedance, only in the case of equality between termination impedance (Z_T) and wave impedance (Z_C), the reflective wave can eliminate, in the other cases, reflective phenomena can appear. In non- uniformity circuitry, the size of reflection is expressed by the reflective coefficient, which is $P = \frac{U_{\text{incidence}}}{U_{\text{reflect}}}$. The value of this coefficient is decided by the difference between the fore-and-aft of reflective point. The bigger the wave impedance of the reflective point is, the bigger the ratio between reflective wave voltage and incidence voltage is, the stronger the reflection is, and the more serious the signal interference in twisted-pair line is.

III. REFLECTION IN CAN BUS

A. *Reflection in branch structure*

In Fig.3, both of the two branch structures have been applied in the engineering, nevertheless, they are greatly different in the quality of the signal transmission in spite of the same topology. It is clear that the length of the branch in the first is much longer than the other, which leads to that the error rate in it is much higher, even impossible to successfully communicate. The reason that the branch structures effect on the bus communication is that the signal reflection effects on it. When the signal transferred by the bus node reaches the branch point, it faces the parallel impedance, which is lower than the impedance of one single bus. In such situation, when the negative reflection reverses to the source end, the other part of the signal spreads in the two branches. At the time when the signal in the branch reaches the end it goes back to the branch point, then reflects to the end, etc.

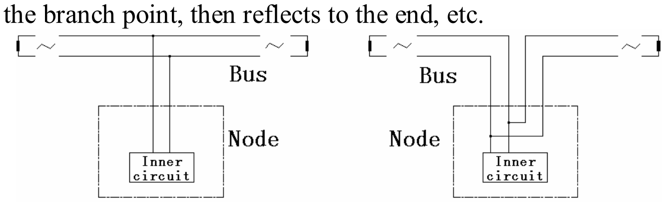

Fig.3. Two branch structures

In Fig.4, the signal 1 is obtained at the baud rate of 250k, in the bus with one transmitting node, one receiving node, and a branch of 10cm, while the signal 2 is obtained in the bus with a branch of 20cm. The original signal is transferred by CAN card which is the product of Vector cop. The thrust down at raising edge is the effect of reflection: when the high electrical lever reaches the branch point, part of the energy goes towards the end of branch. According to the function above, the reflection signal becomes negative electrical level. As a result of that, a sharp corner is generated. The same thing happens at the falling edge. The reason for the tardiness at the falling edge is the effect of the reflection. In usual situation, signals transfer at the rate of 0.2m/ns in the twisted-pair line. Much material recommended that the length of branch should be below 0.2m when the raising time of the square wave is 10ns. The actual CAN signal of 1M baud transferred by the CAN card has a raising time of about 14ns, which matching to a branch of shorter than 0.28m. This result is corresponding with the recommended value of 0.3m in ISO 11898-2.

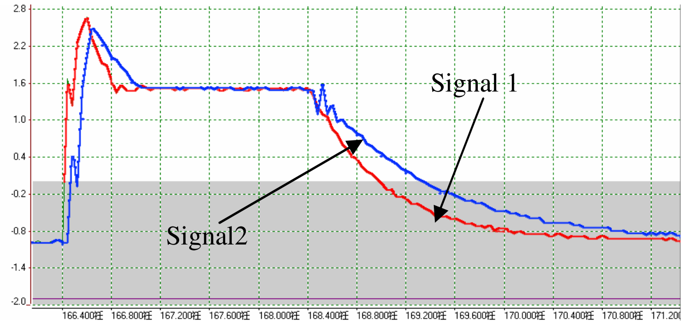

Fig.4.Signals in the branch (By Vector CANscope)

B. *Reflection by capacitive load*

The value of the capacitive load effects greatly in the signal reflection. Fig.5. is got by adding capacitance using Vector CANstress, simulating the distributed capacitance as well as the inner capacitance of the node. In the Fig.5, baud rate is 250kbps. As a result of the capacitance, the pattern of the signal is: the falling edge slows down as the increase of the capacitance, while the thrust down at both raising edge and the falling edge is more serious as the increase of the capacitance.

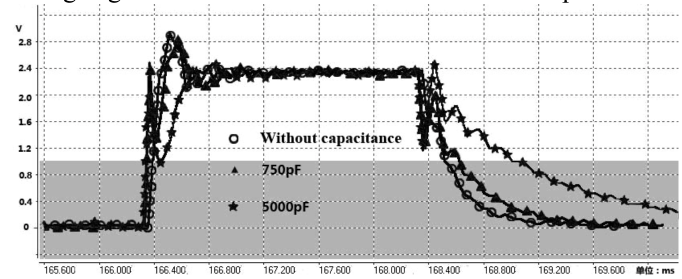

Fig.5.Reflection by capacitive load (By Vector CANscope)

The palliation of the falling edge is because that when the high electrical level developed, twisted-pair cable or the nodes of the bus, which equals capacitance of certain value, is charged. The larger the capacitance between the two wires is, the slower the change of voltage is. Seeing that, as the length of the twisted-pair cable would effects the capacitance, so the length of the twisted-pair cable would effects the length of the falling edge. When the net nodes are collecting the analog signals, the palliation of the falling edge could cause the failure of the signal gathering. All of these are to slow down the speed and to decline the stability of the signal transmission.

The thrust down in both raising edge and falling edge is because of the signal reflection. The source signal is regular, nevertheless, after the reflection at the end of the bus, signal returns towards the source end. When reaches the capacitance again, signal with negative value goes back to the remote end. These signals reflected to the receiving nodes have negative voltage, and causing the decline of the electrical level.

C. *Reflection by inductive impedance*

Similar to the reflection caused by the capacitive impedance, the inductive impedance is also able to cause reflection wave, which will degenerate the signal wave. Moreover, there is certain difference between them, as shown in Fig.6.

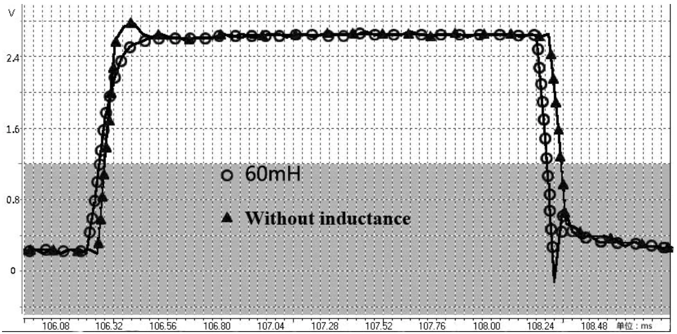

Fig.6.Reflection by inductive impedance (By Vector CANscope)

The inductive impedance causes the thrust down the same as a capacitive one. In addition to that, bus signal with much terminal inductance may lead to the oscillation of the voltage at high electrical level. The voltage shows non-monotone oscillation, that is the change above and below the standard voltage. This phenomenon itself may not cause the integration problem of the CAN signal, but mistaking trigger can be caused if there is a sampling point is right at the oscillation point.

IV. SOLVING METHODS FOR REFLECTION PROBLEM

The reason for the reflection problem is the failure of matching between the terminal impedance and the twisted-pair cable character impedance.

1) To match terminate impedance: Its value equal the value of twisted-pair cable character impedance. First insure that the amplitude values are the same, and then insure the consistency of the phase, terminate impedance should be pure resistance.

2) To reduce parameter mutation of transmit-medium: select uniform material for twisted-pair line, and less impedance material for connectors.

3) To reducing the number of reflection point: Adopt Bus structure in Fig.3 in the branch points to reduce the length of the branch.

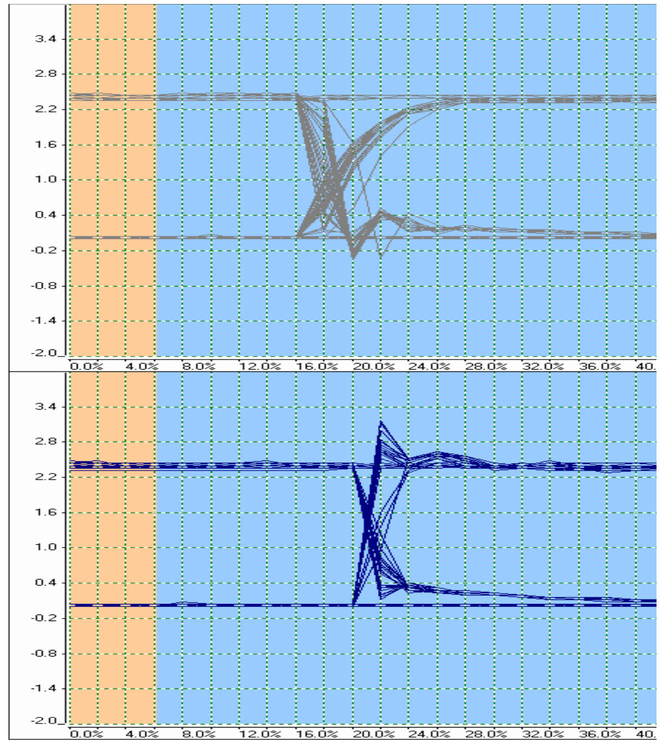

Fig.7.Adaptation for the CAN terminate impedance (By Vector CANscope)

Fig.7. is one of the eye diagrams for certain CAN bus used in engineering. The diagram above is uncompensated while the other is compensated. We can see that the influence of the compensation: the thrust down is greatly declined.

V. SUMMARY

This article analyses mathematics modeling of the CAN Signal in Transmission Line, and educes some influencing factors and researches familiar problems about twisted-pair line application, for instance, the branch structure, adaptation of twisted-pair cables and terminal impedances, and so on. The issues frequently met in the engineering application, can be solved in the methods brought out in this article. May the content of this article could help in the future CAN bus applications.

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