Experimental investigation of communication quality degradation of 1000BASE-T1 by pulse disturbance

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Abstract: Adverse effect of pulse disturbances on the communication quality is investigated experimentally on in-vehicle Ethernet (1000BASE-T1, IEEE 802.3bp). Common- and differential-mode pulse disturbances were injected into communication cables by a method referring to the coupling network described in IEC 62228-5. As a result, it was revealed that steep change of differential signal due to pulse disturbance degrades the communication quality at a specific pulse width.

Keywords: in-vehicle Ethernet, 1000BASE-T1, immunity, pulse disturbance

Classification: Electromagnetic compatibility (EMC)

References

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1 Introduction

Recently, in-vehicle Ethernet is attracting attention as a high-speed and large-capacity communication method, and communication systems from 10 Mbps to multi-gigabit are being discussed for practical use. Since automotive networks require high-reliability and safety, immunity testing is essential. However, conventional automotive electromagnetic compatibility (EMC) test standards do not support high-speed communication systems.

The transient disturbance and the system-level test methods defined by ISO 7637-2 [1] and ISO 7637-3 [2] do not enough cover possible disturbances that should be considered in recent automotive environment.

The purpose of this research is to clarify the dominant characteristics of disturbances which degrade communication quality of in-vehicle Ethernet, and to propose an appropriate EMC evaluation method for it. In the previous study [3], as a first step, we focused on 100BASE-TX which is commonly used as a consumer Ethernet and investigated what degrades its communication quality. As a result, experiments demonstrated that pulse disturbances with durations of about 1-symbol transmission time of the signal affected the communication quality the most.

In this paper, as the second step, we focus on an in-vehicle Ethernet (1000BASE-T1 [4]) and investigate the adverse effect of pulse disturbances on the communication quality and the appropriate test method.

2 Pulse disturbance injection

For in-vehicle Ethernet, a single unshielded twisted pair (UTP) cable is used for a communication line to reduce its weight. Disturbances couple to the cable as common mode, and it is converted to differential mode due to the imbalance of cables, connectors, electronic components, and board wiring. The differential-mode disturbance causes communication quality degradation.

In this investigation, we adopt an injection method using the coupling network (CN) described in IEC 62228-5 [5] to simulate both the common- and differential-mode disturbances. As a parameter of the pulse disturbance, we change the pulse width at which the peculiarity result has obtained in [3]. The degradation of the communication quality is evaluated using frame error rates (FERs).

2.1 Immunity test system

Fig. 1 shows an overview of the immunity test system used in this study. Two communication modules are connected by two UTP cables through the CN. Each of the modules is connected to the ports of an Ethernet tester (MT1000A, Anritsu) by using optical fiber cables (i.e., 1000BASE-SX). Ethernet frames are transmitted from one of the tester port and are received by the other port through the 1000BASE-T1 communication system.

Pulse disturbances are generated by a pulse generator (M8195A, Keysight) and are injected into the communication system via the CN. The modules, the cables, and the CN are placed at 50 mm in height over the system ground.

To investigate the dependence on the cable length \( l \), two lengths of the cable,
3.0 m and 6.4 m for each, are used.

Normally, in [5], communication errors due to differential-mode disturbance, which is caused by slight mode conversion of −40 dB or less, are evaluated; however, in this study, the amount of mode conversion is set to larger to build a test system without an expensive RF amplifier. The resistance and capacitance values of the CN are changed from [5]. The values of resistance are 0 and 300 Ω, and the values of capacitance are 4.7 nF. In this case, the amount of mode conversion at the CN is −16 dB.

The impedance inserted into the differential line increases from 240 Ω [5] to 300 Ω; as a result, the insertion loss in the frequency band of 1000BASE-T1 communication (375 MHz) decreases from 1.62 dB to 1.31 dB.

2.2 Measurement of FER
Each of the communication modules is set to master- and slave-mode, respectively. The FERs on the master and slave side are individually measured by the Ethernet tester.

The preamble length is 8 bytes, the Ethernet frame length is 100 bytes, the interframe gap is 12 bytes, and the test period for each FER measurement is 30 s. Since the communication speed of both 1000BASE-SX and 1000BASE-T1 is 1 Gbps (125 MBps), a total of $3.125 \times 10^7$ frames are transmitted and received in 30 s; therefore, the PER of about $10^{-7}$ can be evaluated.

The transmission period of the frame is 960 ns, and the repetition rate of the pulse disturbance (as stated later) is 1000 ns, the disturbance thus collides about once per frame.

2.3 Pulse Width and Communication Quality
The parameters of the pulse generator are set as follows: the pulse repetition period $T = 1000$ ns, the peak-to-peak amplitude of the source voltage $V_i = 250$ mV, and the rise and fall times $t_r = t_f = 0.7$ ns. The pulse width $t_p$ is a variable.

Fig. 2 shows the relationships between $t_p$ and the FER. In this result on
1000BASE-T1, the FER changes depending on the pulse width as a similar change in 100BASE-TX [3]; moreover, the dependency on the cable length is also seen.

As seen in the region “A”, the FER increases by more than two orders of magnitude at a specific \( t_p \), and in the region “B”, the FER becomes almost constant regardless of \( t_p \). However, the FER increases with \( t_p \) longer than 1-symbol time of 1000BASE-T1 (1.33 ns). This is different from the experimental result of 100BASE-TX [3] (i.e., the result that the pulse disturbance with the duration of about 1-symbol time of the signal degraded the communication quality most).

Lengthening \( l \) shifts "A" in the direction of increasing \( t_p \). When \( l \) is 3.0 m and 6.4 m, \( t_p \) of 25 and 50 ns degrade the FER most, respectively. Besides, the overall increase in the FER depending on \( l \) is due to the decrease in differential signal level with the long cables.

The causes of the pulse width dependence and the cable length dependence are clarified in the next subsection.

![Fig. 2. Pulse width and communication quality.](image)

### 2.4 Causes of Pulse Width and Cable Length Dependence

The common-mode voltage \( V_{\text{com}} \) and the differential-mode voltage \( V_{\text{diff}} \) shown in Fig. 3 are observed at different positions shown in Fig. 1. \( V_{\text{com}} \) and \( V_{\text{diff}} \) are measured at the input connector of the CN and the on-board connector of the module, respectively.

We conclude that the drastic increase in the region "A" is causes by the steep change of \( V_{\text{diff}} \) as seen in Fig. 3(b), and the convergence to constant values in the FER in the region "B" is due to the cancellation of \( V_{\text{diff}} \) caused by common-mode reflection and mode conversion as seen in Fig. 3(f). The causes are described below.

According to the pulse width, a peculiar change is seen in \( V_{\text{diff}} \) due to the common-mode reflected wave and the mode conversion. Figs. 3(a)–(e) show the waveforms when \( l \) is 3.0 m.

Fig. 3(a) shows the waveforms when \( t_p \) is 10 ns, and a reflected wave in \( V_{\text{com}} \)
is observed from the time of 23 ns, which corresponds to the round-trip time of the common-mode disturbance propagating along the 3.0 m cable. For $V_{\text{diff}}$, the first rising edge is observed at 16 ns after $V_{\text{com}}$ is injected. The time 16 ns corresponds to the one-way propagation time of the differential mode from the injection point of disturbance to the end of the cable at 3.0 m. From 39 ns, the second rising edge of $V_{\text{diff}}$ is observed in the negative direction, which corresponds to the reflected $V_{\text{com}}$ reaching the injection point and mode-converted to differential mode.

Fig. 3(b) shows the waveforms when $t_p$ is set to 25 ns. The falling edge of the first $V_{\text{diff}}$ and negative rising edge of the second $V_{\text{diff}}$ almost coincide; consequently, the variation of disturbance waveform on $V_{\text{diff}}$ becomes steep. When $t_p$ is 25 ns, the FER increases drastically as shown in the region “A”, so we speculate that pulse disturbances with a steep change degrades the communication quality.

Fig. 3(c) is for $t_p = 50$ ns. $V_{\text{diff}}$ keeps nearly zero from 39 ns until 66 ns. This is because the first and second $V_{\text{diff}}$ cancel each other. When $t_p$ is longer than the pulse width which generates the steep change, only the cancellation period is changed even if $t_p$ is changed; in other words, the degradation of the communication quality occurs equally in terms of the pulse collision probability. We thus infer that the convergence to constant values seen in the region "B" is due to the cancellation.

Figs. 3(d)–(f) show the voltages when $l$ is 6.4 m. The longer $l$ increases the propagation delay. Consequently, when the $t_p$ is around 50 ns, the steep change of $V_{\text{diff}}$ occurs as seen in Fig. 2(e). When the $t_p$ is longer than 50 ns, the cancellation...
occurs as seen in Fig. 2(f).

3 Conclusion

We investigated experimentally the relationship between the communication quality of 1000BASE-T1 and the pulse width of the disturbance. As a result, FER increased by more than two orders of magnitude with a specific pulse width. It was clarified that the differential-mode pulse disturbance changes steeply at the specific pulse width due to the common-mode reflection and the mode conversion. Therefore, we concluded that the pulse disturbance with the steep change significantly degrades the communication quality.

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