

A Novel Distortion Cancelling Technique Enabling 50-Mbps High Speed Data Transmission for Bus Connected ECUs

Hironobu Akita, Nobuaki Matsudaira, Chao Chen, Takasuke Ito, and Shigeki Ohtsuka
DENSO Corp.

ABSTRACT

With the evolution of automotive features, larger flash program size has been required even at the local electronic control units (ECUs). As the flash programming data rate increases, Ethernet is adopted as a global data port from the external source. However, it can not be applied to the bus type network topology between the domain control unit (DCU) and the local ECUs, because it uses a peer-to-peer type network topology. On the other hand, high speed CAN-FD has been studied recently for this bus topology, but its data rate is limited at the range of several mega bps due to the signal waveform distortion caused by the multiple reflections at the non-terminated stubs.

This paper describes a novel distortion cancelling for the bus topology as the pre-emphasis technique, in which the digital signal processing (DSP) compensates the complicated signal distortion caused by the multiple reflections. Moreover, this complex signal processing block is located only at the DCU, not at the local ECUs. Therefore, the increase in cost can be suppressed effectively for the total system. The DCU determines the signal distortion characteristics for each ECU by training in advance, and accordingly pre-emphasizes the transmission signal. When the pre-emphasized signal arrives at the target ECU, the waveform becomes non-distorted. This enables 50-Mbps data transmission even with the bus topology.

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INTRODUCTION

According to the increase of the automotive features, the number of the ECU and the software code size are increasing drastically [1,2,3]. Because each ECU constitutes the distributed real-time control system, the network connecting them is required to have less latency. In order to meet the requirement, OEMs are developing a new electric and electronic architecture (E/E architecture) which partition the network into the hierarchical topology.

E/E Architecture

For handling the complicated network, a hierarchical architecture has been proposed [4,5,6], in which DCUs are used for the 2nd layer controller. ECUs in the same functional domain are grouped into local networks, and DCUs are connected with each other through the system bus as shown in Figure 1. Ethernet with the switch device will be adopted for this system bus. However, conventional bus topology is preferable for the local network because of its established reliability and its excellently deterministic and predictable latency performance.

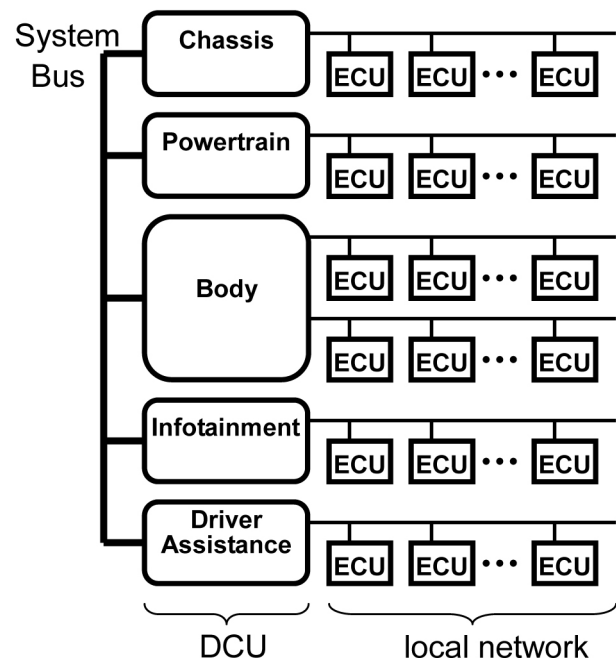


Figure 1. E/E architecture with DCUs.

High Data Rate on Bus Topology

Another requirement for the automotive network is higher bandwidth, especially for the program flashing into the MCU at the ECU [7, 8]. Ethernet has been adopted as a global data port from the external source. However, the low data rate of the local network becomes the bottleneck of the flashing time. Although many studies have been made in order to achieve the higher data rate with the bus topology, they only dealt with the network segmentation using the hub [9,10,11] or message prioritization [12]. The improvement of the physical data rate has not fully been presented yet.

CAN-FD [13] is one of the latest solutions for the physical data rate increase on the bus topology. Figure 2 shows how the effective data rate improves, as the payload data rate increases. In this figure, the improvement of the effective data rate is plotted, normalized by 1-Mbps data-phase case:

Rate of Improvement

$$= \frac{\left[\frac{\text{Number of Bits in Payload}}{\text{Time for Frame}} \right]_{\text{@Target Data Rate in Data-phase}}}{\left[\frac{\text{Number of Bits in Payload}}{\text{Time for Frame}} \right]_{\text{@1Mbps in Data-phase}}} \quad (1)$$

This shows that more than 20-Mbps data-phase is required for the 10× performance improvement even if we choose the frame format properly. When the data rate in the data-phase increases to this level, the signal integrity issue, so-called channel distortion, should be considered in the case of bus topology. As shown in Figure 3, the signal from the transmitter (Tx) arrives at the receiver (Rx) through the multiple paths such as direct path (A), reflection at the stub end (B), reflection at the stub branch (C), and so on. Each path has the different flight time and attenuation level, and cause a signal distortion.

In order to compensate the channel distortion, many equalization techniques have been proposed [14,15,16], in which the distorted signal is sampled by the ADC and compensated by the filter process in the DSP. If these techniques are implemented on the local network, the circuit configuration has to be changed from (a) to (b) in Figure 4. However, the blocks of ADC, DAC, and DSP are relatively larger and more power-hungry, therefore, more expensive circuits to implement in each ECU.

In this paper, we propose the pre-emphasis technique, in which these additional expensive circuits are only located in the DCU as shown in Figure 4(c). The signal transmitted from the DCU is pre-distorted to the most appropriate waveform for the target ECU to cancel the channel distortion, which is called an adaptive pre-emphasis. When this pre-emphasized signal arrives at the target ECU, the waveform becomes non-distorted, and the target ECU can receive the data without the equalization. Therefore, no additional circuits are required at the ECUs and the increase of the system cost can be suppressed, achieving the high speed data transmission.

Since the pre-emphasis is adjusted depending on the target ECU, the signals at other ECUs are still distorted. However the same program is not flashed to the multiple ECUs simultaneously in usual case, this does not diminish the benefit of the proposed technique.

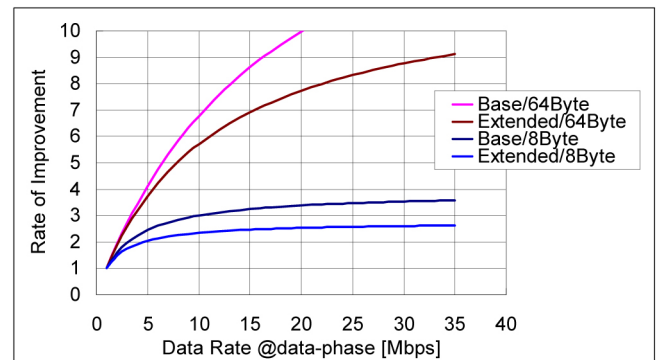


Figure 2. Effective data rate improvement on CAN-FD. Base/Extended indicates ID length at the arbitration-phase in the frame. 64Byte/8Byte indicates the payload data length at the data-phase. Interframe space is assumed to be 3 bits. Bit stuffing is not considered.

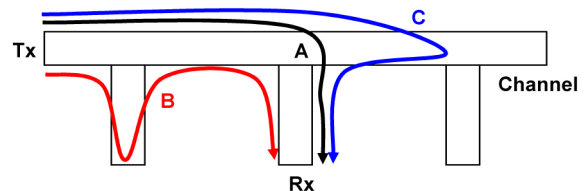


Figure 3. Degradation of signal integrity by the multiple reflections. Actual transmission line is differential. For the simplicity of the figure, single ended transmission line is illustrated.

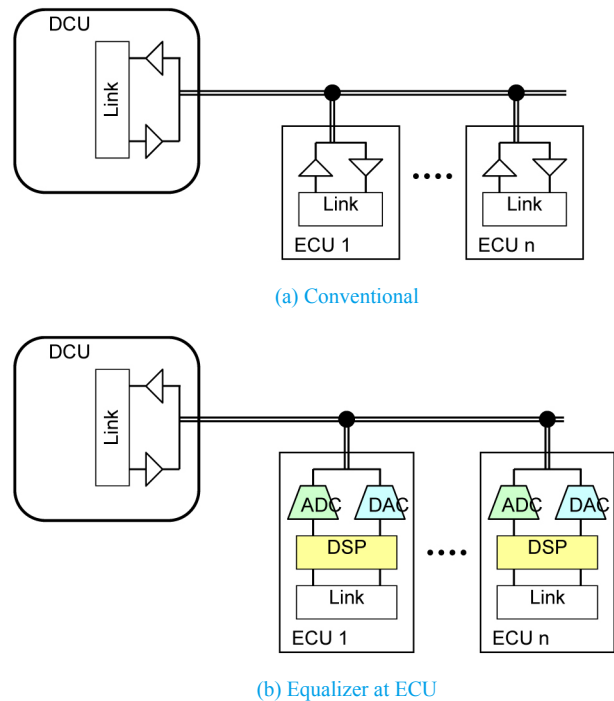


Figure 4. Proposed pre-emphasis system.

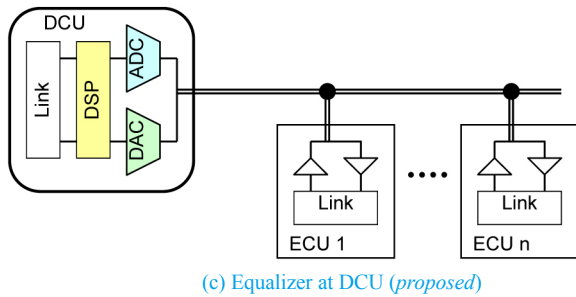


Figure 4. (cont.) Proposed pre-emphasis system.

TECHNICAL PROPOSALS

We have been developing the adaptive pre-emphasis technique for the channel equalization [17], in which the adaptive pre-emphasis is realized by exploiting the reciprocal nature in 2-port S-parameter of the passive element network:

$$S_{21} = S_{12} . \tag{2}$$

This means that the opposite directions' transfer gain (loss) becomes exactly the same even when the network topology is not asymmetric. Thus, both the signal 'A' and 'B' in Figure 5(a) are distorted in the same way. In the pre-emphasis technique, Port 1 characterizes the channel by receiving the training signal 'A' from Port 2 in a training mode, and adjusts the Rx equalizer in Figure 6 in order to cancel the distortion. When Port 1 transmits the data signal 'B' in a normal data mode, the same equalization is applied on the signal at the Tx equalizer as the pre-emphasis. The pre-emphasized data signal 'B' is distorted necessarily at the same level as the training signal 'A'. Since this distortion and applied pre-emphasis cancel each other, the data signal 'B' arrived at Port 2 becomes non-distorted, or same as the original signal. Figure 7 explains this operation in the frequency domain. The filter coefficients of the Rx equalizer are adjusted to have the frequency response that can cancel the channel distortion after the training (Figure 7 (a)). By adopting the similar circuit with the same filter coefficients, the Tx equalizer has the same frequency response as the Rx equalizer. As explained above, the nature of equation (1), the channel characteristics from the DCU to ECU is the same as those from ECU to DCU. Therefore the pre-emphasis by the Tx equalizer can cancel the channel distortion (Figure 7(b)). This 2-port technique can be extended to the multi-node bus topology of Figure 5(b). The DCU characterizes the channel distortion for the respective ECUs from the training mode in advance, and then transmits the emphasized data signal in the normal data mode according to the characterized channel distortion to the target ECUs.

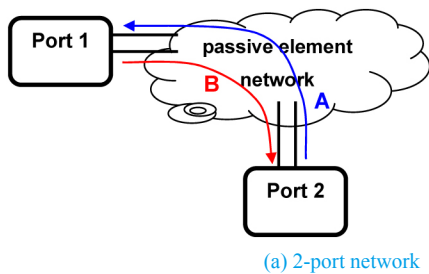


Figure 5.

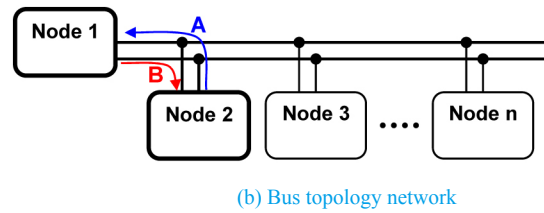


Figure 5. (cont.) Extension of topology. Signal 'A' is for the training. Signal 'B' is for the normal data transmission.

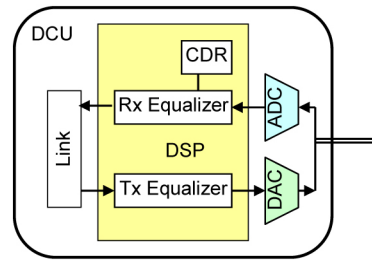


Figure 6. Block diagram of DSP.

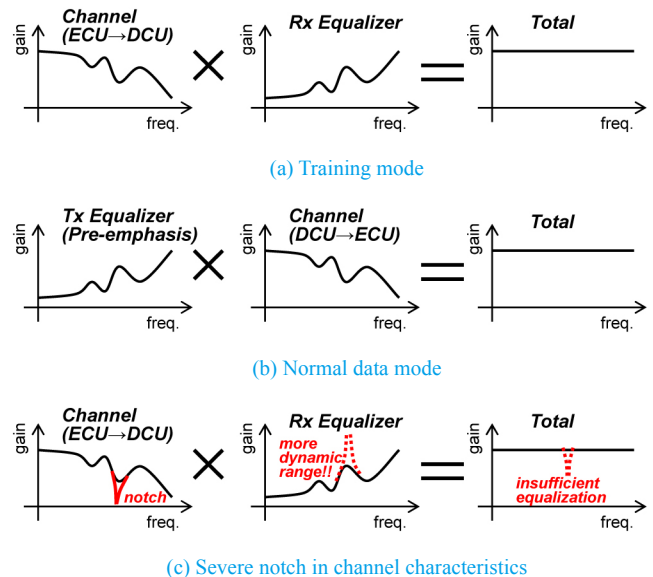


Figure 7. Equalization mechanism.

Reciprocity in Current Mode Communication

Our pre-emphasis technique exploits the nature of equation (1). As shown in Figure 8(a), 2-port S-parameter defines the power input/output relationship ('a' and 'b' in the figure) between two ports of matched load. The transmitted and the received signals are in the power domain. On the other hand, at the bus communication system, current driver and high impedance receiver is commonly used for the Tx and the Rx, respectively [18]. The termination resistors (matched loads) are placed at the end points of the bus. This means that the Tx and the Rx are the high impedance nodes and the transmit signal is driven in the current mode, although the signal is received in the voltage mode. The network behaves as a transimpedance. Termination resistors are included inside the passive element network. In this section, the reciprocity of the transimpedance is derived from the transformation theory of the S-parameter.