Active mode-conversion-noise Suppressor with Individual Power-supply Control for Automotive Power-over-data-line Communication

Yutaka Uematsu
Research & Development Group,
Hitachi, Ltd.,
Yokohama, Japan
yutaka.uematsu.ws@hitachi.com

***Abstract*— This paper proposes an active mode-conversion-noise suppressor (AMCNS) for automotive Ethernet using power-over-data-line communication. The AMCNS consists of an adjustable stray capacitance pattern and individual power-supply control for static and dynamic capacity balancing of the transmission path, respectively. This paper also describes the basic principle of the AMCNS and presents the experimental results from using an evaluation board, which showed the suppression of mode-conversion noise for more than 5 dB at frequencies over a 10 MHz.**

Keywords—Ethernet, power over data line, mode conversion loss, high-speed signaling.

I. INTRODUCTION

Power over data line (PoDL) refers to the technology of supplying power through data-communication lines [1]. It generally allows data to be transmitted and received using communication cables (e.g., Ethernet cables or USB cables) while simultaneously delivering power through the same cable. This eliminates the need for a separate power cable, making it convenient and efficient, especially in locations with complex power-supply requirements or limitations. PoDL is used in various industries and applications. An example is Power over Ethernet, which is used to power the electrical control units (ECUs) of automobiles.

Automotive networks have strict electromagnetic compatibility (EMC) requirements. With Ethernet, EMC standards have become more stringent up to higher frequencies due to improvements in communication speed [2,3]. One factor that degrades EMC performance, such as radiated emission increase, is the conversion from normal mode to common mode and vice versa caused by slight asymmetries in the differential transmission path, so-called mode conversion loss (MCL) [4]. One measure of this conversion is the longitudinal conversion loss (LCL), which describes the degree of conversion from common mode to normal mode measured at the near end of the network. Compared with conventional data communication, PoDL communication has the following additional technical problems that are more likely to increase LCL due to the electrical imbalance of the differential signal lines in an ECU.

Since different bias voltages are applied to the electronic components connected to the positive (P)-side and negative (N)-side of the differential signal line,

1. the electrical characteristics of each component may differ.
2. the deterioration curves of the electrical characteristics of each component differ, and the electrical characteristics of the components may differ over time.

To solve these problems, we propose an active mode-conversion-noise suppressor (AMCNS), which consists of an adjustable stray capacitance (ASC) pattern for static capacity balancing and individual power supply control (IPSC) to suppress the mode-conversion noise from the ECU for more than 5 dB at frequencies over 10 MHz without disconnecting the power cables. We describe the basic principle of the AMCNS and present the results form using an evaluation board.

II. BASIC PRINCPLE OF AMCNS

This section describes the basic principle of the AMCNS.

A. *Circuit composition of AMCNS*

Figure 1 shows the circuit composition of a conventional PoDL communication. Data communication between ECU-1 and ECU-2 takes place as bidirectional signal transfer via cables between the master physical (PHY) and slave PHY devices. Power is transmitted from the power-supply equipment (PSE) to the power device (PD) on the same transmission path via the PoDL filter. A common mode choke coil (CMCC) for suppressing common-mode noise [5] cannot pass a large electric current due to its limited rated current. Therefore the CMCC is placed between the PoDL filter and PHY device. The electro-static discharge (ESD) protection device for static electricity countermeasures is mounted on the cable side rather than the mounting position of the PoDL filter.

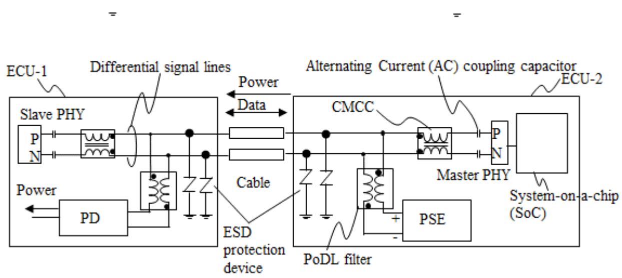

Fig. 1. Circuit composition of conventional power over data line (PoDL) communication

Figure 2 shows the circuit composition of the AMCNS and its installation example. The AMCNS is based on the fact that the MCL at high frequencies strongly depends on the imbalance of the capacitance component of the differential transmission lines, and the point is to control the balance of the stray capacitance of the ESD protection device, which is the main component of the transmission-line capacitance. The principles and details of the ASC pattern and IPSC are described in subsections B and C, respectively.

979-8-3503-1798-5/23/$31.00 ©2023 IEEE

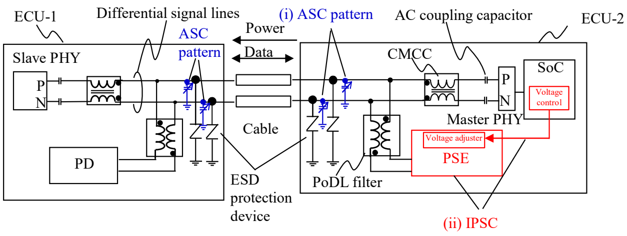

Fig. 2. Circuit composition of PoDL communication with proposed active-mode-conversion-noise suppressor (AMCNS).

B. Principles of ASC pattern

Figure 3 shows the bias-voltage dependencies of the stray capacitance of a typical varistor-type ESD protection device. Applying a bias voltage slightly reduces the stray capacitance relative to the no-bias condition. Therefore, in PoDL communication, a difference occurs in the stray capacitance between the ESD protection device connected to the P-side and that connected to the N-side. In the example shown in Fig. 3, a 1% stray-capacitance difference occurs under the bias-application condition of 12 V. The stray capacitance of the ESD protection device is about 0.1 to 1 pF, and a 1% difference in this leads to deterioration in MCL of several dB.

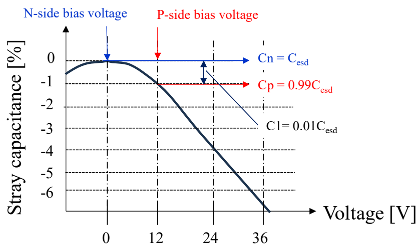

Fig. 3. Bias-voltage dependencies of stray capacitance of ESD protection device

The ASC pattern is designed to reduce the effect of this capacitance difference on the printed circuit board (PCB) by adding an artificial stray capacitane by the PCB pattern. Since the capacitance to be adjusted is very small (< 0.1 pF), there is an advantage in that it can be constructed without taking up area on the PCB. Examples of ASC pattern designs are described in the next section.

C. Principles of IPSC

Figure 4 shows the time dependencies of the stray capacitance of a typical varistor-type ESD protection device. The red line shows a low-voltage bias condition, and the blue line shows a high-voltage bias condition. Under high-temperature, high-humidity and high-bias conditions, the speed of deterioration of electronic components is generally high. Therefore, it is expected that the difference in the amount of deterioration will increase over time, and the capacity difference will expand.

IPC involves the optimization of the bias voltage of both P- and N-sides of an ESD protection devices while maintaining voltage difference. Because the change in stray capacitance due to the bias voltage to the ESD protection device is not linear, it is possible to control the balance between the P- and N-sides of stray capacitance under the voltage conditions of the P- and N-sides while maintaining the same voltage difference.

Figure 5 shows an example of controlling the stray capacitance by changing the bias-voltage conditions. Three different capacitance values can be obtained with the same P-N voltage difference of 12 V.

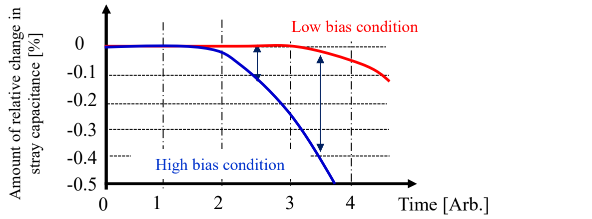

Fig. 4. Time dependencies of stray capacitance change of ESD protection device

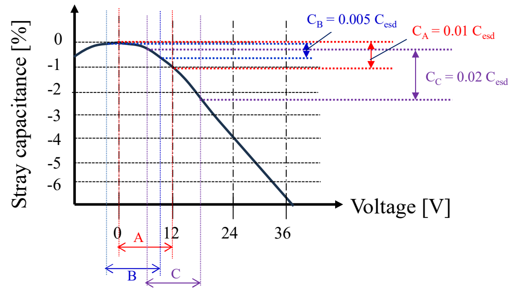

Fig. 5. Bias-voltage dependencies of stray capacitance of ESD protection device with three different bias conditions.

III. Evaluation of AMCNS

This section describes the experimental evaluation results of the AMCNS. We developed an evaluation board with an ASC pattern. We also constructed a measurement setup for measuring S-parameters while applying different voltages to the P- and N- sides of ESD protection devices and verified the effectiveness of IPSC.

A. Design of ASC pattern and evaluation

Figure 6 shows the ACS pattern of the PCB. In this design, five pads of different sizes are prepared on the PCB, and the artificial stray capacitance can be adjusted on the basis of the connection condition with these pads. By using this pattern, the stray capacitance can be adjusted from 0.05 to 0.8 pF.

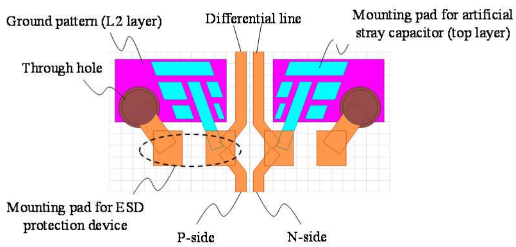

Fig. 6. Designed ASC pattern for evaluation board

Figure 7 shows the experimental results of MCL, $S_{cd,11}$, using the evaluation board. The red lines show measurement data without connection of ASC-pattern pads, blue lines show simulated data with the ASC pattern, and orange lines show measurement data with connection of ASC-pattern pads. The figure also shows examples of the minimum capacitance change (0.05 pF, condition #1) and maximum capacitance change (0.8 pF, condition #2). The MCL for higher frequencies (> 10 MHz) is strongly affected by the connection condition of the ASC-pattern pads. Figure 8 shows the change in MCL, $\Delta S_{CD,11}$, by adding stray capacitance, C_{add}, to the P-side of the ASC pattern. The figure also indicates that the relationship between $\Delta S_{CD,11}$ and C_{add} shows the behavior of a linea function. As can be seen from both figures, it was experimentally verified that the ASC pattern can effectively control MCL.

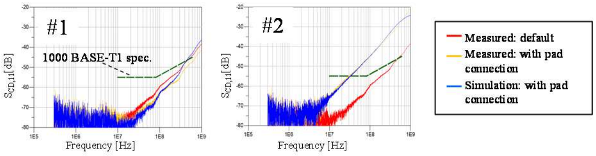

Fig. 7. Experimental results of mode conversion loss (MCL), $S_{cd,11}$, using evaluation boad

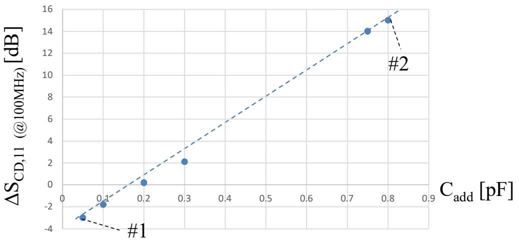

Fig. 8. ASC-pattern-capacitance dependencies of change in MCL, $\Delta S_{cd,11}$

B. Evaluation of IPSC

Figure 9 shows the measurement setup for measuring S-parameters while applying different voltages to the P- and N-sides ESD protection devices. We use a bias-T function in the vector network analyzer to deliver power through the same coaxial cable. The ground of the regulated power supply is connected to the ground pattern of the evaluation board. Figure 10 shows experimental results of MCL using the evaluation board under different voltage-bias conditions. The figure shows four bias conditions; (i) no bias, (ii) P-side: 6 V, N-side: -6 V), (iii) P-side: 12 V, N-side: 0 V, and (iv) P0side: 14 V, N-side: 2V. The results suggest that about 2-dB MCL control can be achieved with the same voltage difference of 12 V.

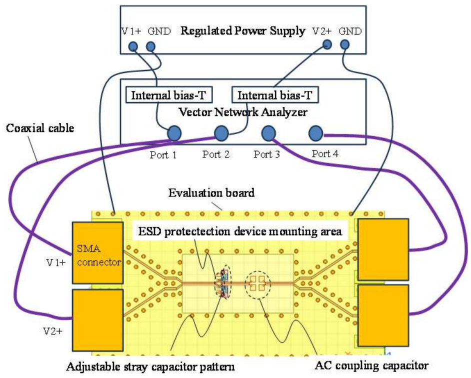

Fig. 9. Measurement setup for IPSC using evaluation board

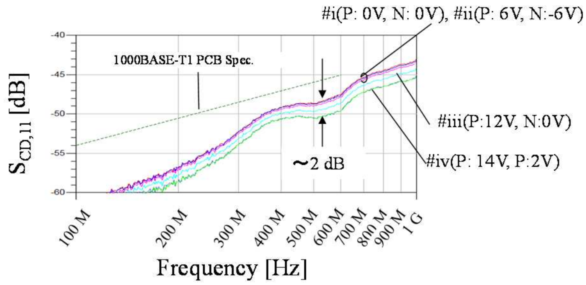

Fig. 10. Experimental results of MCL under different voltage-bias conditions

C. Evaluation of AMCNS

To verify the MCL reduction with the AMCNS, we measured the MCL reduction effectiveness of combining the ACS pattern and IPSC. Figure 11 (a) shows the experimental results of MCL under various bias-voltage and ASC pattern conditions with 12-V power-supply. The ASC pattern is also shown in Fig. 11 (c). Figure 11 (b) shows the conventional method (P-side: 12 V, N-side: 0 V, w/o ASC), with which MCL was slightly over the automotive Ethernet 1000BASE-T1 MCL specification by around 500 MHz. With both ASC and IPSC (AMCNS), MCL reduction of up to approximately 5 dB was achieved, and sufficient noise margin to the 1000BASE-T1 MCL specification was obtained.

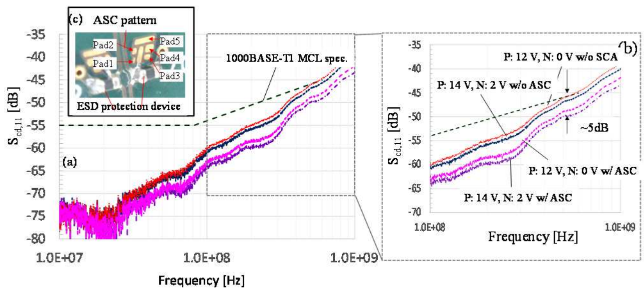

Fig. 11. Experimental results of MCLwith AMCNS

IV. Conclusion

To suppress the common-mode noise for automotive PoDL communication, we proposed an active mode-conversion-noise suppressor (AMCNS). The AMCNS consists of an adjustable stray capacitance pattern (ASC) and individual power supply control (IPSC) for static and dynamic capacity balancing of the transmission path, respectively. We described the basic principle of the AMCNS that utilizes a bias voltage dependency of stray capacitance of the ESD protection devices. We also presented the experimental results from using an evaluation board. The results indicate the suppression of mode-conversion noise for more than 5 dB at frequencies over 10 MHz.

Acknowledgments

The authors would like to thank Shungo Okabe of Hitachi Information & Telecommunication Engineering, Ltd., for his kind support and helpful technical discussion.

References

[1] "IEEE Standard for Ethernet--Amendment 8: Physical Layer and Management Parameters for Power over Data Lines (PoDL) of Single Balanced Twisted-Pair Ethernet," IEEE 802.3bu, 2016.

[2] "IEEE Standard for Ethernet Amendment 4: Physical Layer Specifications and Management Parameters for 1 Gb/s Operation over a Single Twisted-Pair Copper Cable," IEEE 802.3bpTM (1000BASE-T1), 2016.

[3] "1000BASE-T1 EMC Measurement Specification for Transceivers ver. 1.0," Open Alliance, 2017.

[4] Seungyong Baek, Seungyoung Ahn, Jongbae Park, Joungho Kim, Jonghoon Kim, and Jeong-hyeon Cho, "Accurate High Frequency Lossy Model of Differential Signal Line Including Mode-Conversion and Common-mode Propagation Effect," in *Proc. International Symposium on Electromagnetic Compatibility*, Aug. 2004.

[5] Sanaz Mortazavi, Detlef Schleicher, and Friedel Gerfers "Characterization of Common-Mode Choke for Automotive Ethernet Networks Enabling 100 Mbit/s," in *Proc. the 2017 International Symposium on Electromagnetic Compatibility EMC EUROPE 2017*, Sept. 2017.