Abnormal-state-discrimination Method for In-vehicle Communication Channel with Power-over-Coax Circuit

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

Soshi Shimomura
Research & Development Group,
Hitachi, Ltd.,
Yokohama, Japan
soshi.shimomura.vs@hitachi.com

Yasuhiro Ikeda
Research & Development Group,
Hitachi, Ltd.,
Yokohama, Japan
yasuhiro.ikeda.tt@hitachi.com

Hidetatsu Yamamoto
AECU Design Division,
Hitachi Astemo Ltd.
Hitachinaka, Japan
hidetatsu.yamamoto.oy@hitachiastemo.com

Hideyuki Sakamoto
Digital Front Division,
Hitachi Ltd.,
Hitachinaka, Japan
hideyuki.sakamoto.br@hitachiastemo.com

***Abstract*—We propose an abnormal-state-discrimination method for the in-vehicle communication channel with a power-over-coax (PoC) circuit. The proposed method uses digital data, such as equalizer parameters and error information, that can be obtained from general serializer/deserializer large-scale integrated circuits. Therefore, no additional components are required to diagnose the abnormal state of the channel. We specifically focus on detecting an anomaly of a PoC filter.**

***Keywords*— PoC; SerDes; Diagnosis; filter; Signal integrity; Coaxial cable.**

2021 IEEE CPMT Symposium Japan (ICSJ) | 978-1-6654-4079-0/21/$31.00 ©2021 IEEE | DOI: 10.1109/ICSJ52620.2021.9648548

I. Introduction

Real-time surround view is necessary in modern vehicles with advanced driver assistance systems (ADASs). In such systems, camera modules strategically placed at multiple locations play an important role in recognizing objects around the outside of the vehicle [1]. The resolution and frame rate of camera modules tend to increase to obtain more detailed external information for more advanced autonomous driving control. As a result, the amount of video data has increased, and the transmission speed of the signal communicating between the camera module and ADAS – electrical control unit (ECU) has also increased rapidly, reaching a speed of as high as 10 Gbps. These camera modules are usually located far from the battery and often do not have direct access to the power supply. Therefore, there is a need to remotely power automotive sensors by using a power-over-coax (PoC) circuit [2,3]. The typical topology of a PoC circuit is shown in Figure 1.

In such a transmission communication system, the number of components constituting the transmission line is larger than that of a conventional communication system, and since it is used in various environments, there can be many abnormal modes specific to high-speed signals during operation. For example, insertion loss of cables deteriorates due to temperature changes and the filter performance of the PoC filter parts used for power-supply superimposition degrades due to excessive power-supply current. Therefore, to provide a highly reliable and safe communication system during operation, it is necessary to detect an abnormality in the system in real time and immediately identify its cause.

We propose an abnormal-state-discrimination method for the in-vehicle high speed communication channel with a PoC circuit. The proposed method uses digital data, such as equalizer parameters and error information, that can be obtained from general serializer/deserializer large-scale integration circuits (SerDes LSIs). Therefore, no additional components are needed to diagnose the abnormal state of the channel. This paper focuses on the detection and discrimination of anomalies in PoC filters.

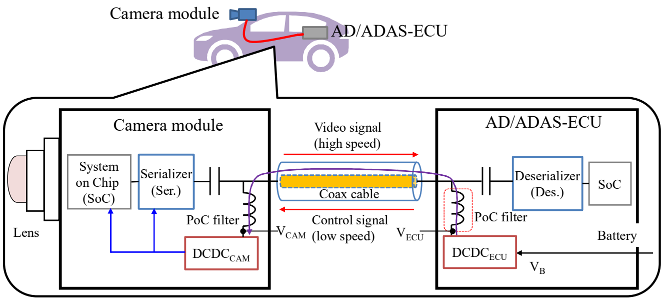


Fig. 1. Typical topology of power-over-coax (PoC) interconnect

II. Failure Modes of PoC Circuit

Figure 2 shows the typical circuit configuration of a PoC circuit. This configuration consists mainly of four components (i–iv), as shown in this figure. Each component has three failure modes (open, short, and degradation).

Table I summarizes the failure modes of these four components and their difficulty of detection. In most cases, open and short failure modes are easy to detect. However, the degradation is difficult to detect by conventional detection means (open/short defect-detection circuit). In addition, some of the latest SerDes LSIs are equipped with a time domain reflectometry function, but this only detects deterioration of the connector (#iii-3), such as a poor connection.

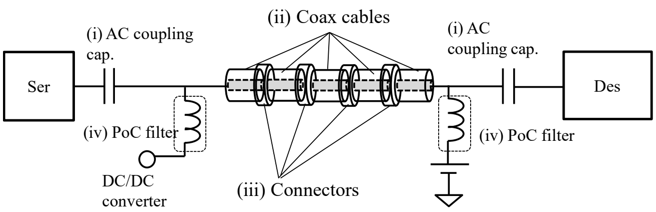


Fig. 2. Circuit configuration of PoC circuit

TABLE I. COMPONENTS AND FAILURE MODES OF POC CIRCUIT

#	Component	Failure mode	Detectability
i-1	AC coupling cap.	Open	Easy
i-2		Short	Easy
ii-1	Coax cables	Open	Easy
ii-2		Short	Easy
ii-3		Degradation	Difficult
iii-1	Connectors	Open	Easy
iii-2		Short	Easy
iii-3		Degradation	Difficult
iv-1	PoC filters	Open	Easy
iv-2		Short	Depend
iv-3		Degradation	Difficult

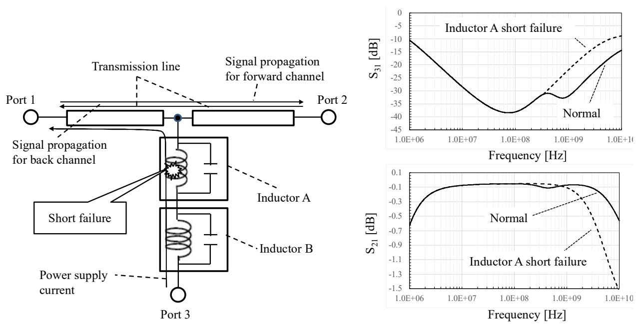
Next, we describe the failure modes of the PoC filter that are specific to the PoC circuit. As shown in Table I, the PoC filter has three failure modes.

Open failure (#iv-1) is a failure in which the current does not flow to the inductors comprising the PoC filter, and since the power supply is not possible, detection is easy.

Short failure (#iv-2) is a failure in which one of the inductors of the PoC filter enters an electrically short state, and the filter performance deteriorates at a specific frequency. Figure 3 shows the state of characteristic deterioration when an inductor for high frequency (inductor A) shorts. In this case, the insertion loss (S_{21}) at high frequency greatly deteriorates due to a significant deterioration in the high-frequency filter performance (S_{31}).

Degradation failure (#iv-3) is a failure in which the performance of the inductors of the PoC filter deteriorates, and the filter performance deteriorates over all frequencies. Figure 4 shows the state of characteristic degradation when a power-supply current exceeds the rated current of the inductors in the PoC filter. The higher the power-supply current, the lower the filter performance at all frequencies, especially at frequencies where the deterioration in filter performance is large.

Difficulties in detecting PoC-filter short failure depend on the filter configuration. As shown in Fig. 3, since inductor A covers the signal band of a high-speed forward channel that transmits video data and inductor B covers the signal band of a slow back channel that transmits a control signal, when each filter fails, a high-speed or low-speed signal error occurs, so such detection is easy.

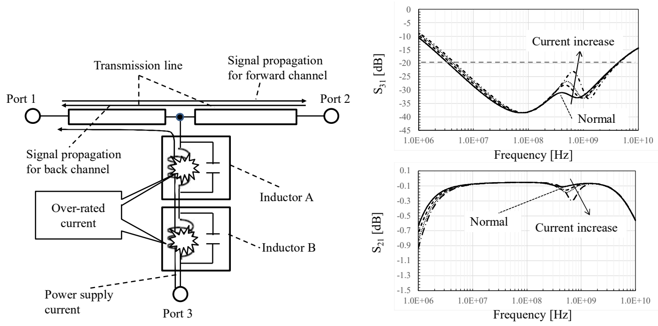


(a) Short failure of PoC filter

(b) Electrical-performance deterioration by short failure

Fig. 3. Short failure mode of PoC filter (a) and impact on electrical properties (b)

In cases such as a 3-stage inductor configuration, failure of one inductor may not result in a complete transmission error. This is described in detail in Section IV.



(a) Rated current over of PoC filter

(b) Electrical-performance deterioration by rated current over failure

Fig. 4. Degradation failure mode of PoC filter (a) and impact on electrical properties (b)

III. PROPOSED ABNORMAL-STATE-DISCRIMINATION METHOD

In this section, we explain our proposed abnormal-state-discrimination method for identifying three abnormal modes, i.e. (#ii-3) coaxial-cable degradation, (#iii-3) connector degradation, and (#iv-3) PoC-filter degradation. The discrimination results of this method through simulation are also described.

The simplest way to identify the above three abnormal modes is to measure the frequency response of the channel transmission line. Figures 5 and 6 respectively show the comparison results of reflection loss and insertion loss of four states (normal, coaxial-cable degradation, connector degradation, and PoC-filter degradation) in the same PoC circuit.

In the three abnormal states, the tendency of the changes in reflection loss and insertion loss from the normal state differ. Coaxial-cable degradation has little effect on reflection loss, but degradation of insertion loss occurs. Connector degradation degrades reflection loss over a wide band, but insertion loss hardly changes. Regarding PoC-filter degradation deterirorate reflection loss and insertion loss, especially at a specific frequency.

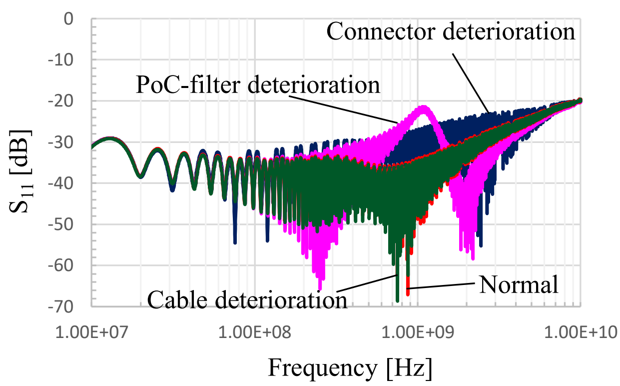


Fig. 5. Comparison of reflection loss of four channels of same PoC circuit with different failure modes

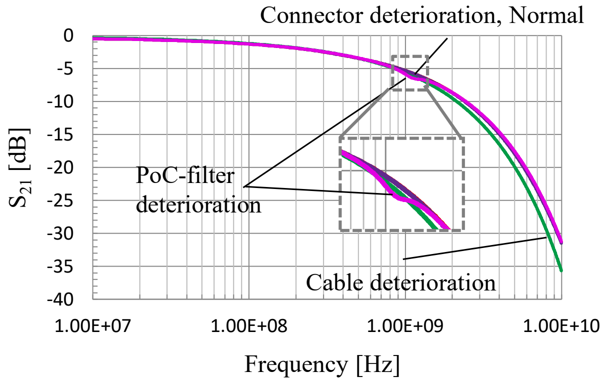


Fig. 6. Comparison of reflection loss of four channels of same PoC circuit with different failure modes

However, it is difficult to measure such a detailed frequency characteristic with an operational transmission circuit. Therefore, our method discriminates abnormal states by capturing the change in the frequency characteristics of this transmission line by the amount of change in the equalizer parameters of the SerDes.

Figure 7 shows a conceptual diagram of waveform compensation for channel degradation by the equalizer function. The SerDes has multiple equalizer functions with different roles, and an automatic adjustment function adjusts the tap coefficient of each equalizer in accordance with the target transmission path so that the waveform at the receiver becomes optimal.

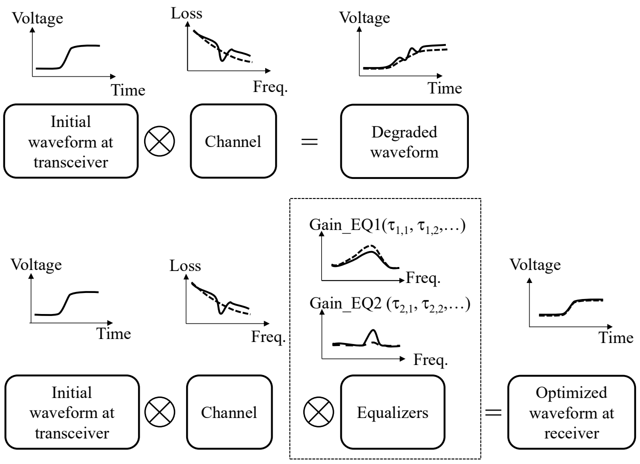


Fig. 7. Role of equalizer

Therefore, the tap coefficient of the equalizer after automatic adjustment represents the state of the transmission line. Furthermore, the difference between the tap coefficient in a normal-state transmission line $Tap_{nor}(i)$ and that in an abnormal transmission line $Tap_{abn}(i)$ represents the amount of degradation of the transmission line. The difference between the two ΔTap (i) can be expressed as

$$\Delta Tap(i) = Tap_{nor}(i) - Tap_{abn}(i)\ , \qquad (1)$$

where i represents the type of equalizer tap that the SerDes has.

The abnormal state is separated from the characteristic amount of the vector of the parameter set of ΔTap (i). In the equalizer function, the feed forward equalizer (FFE) and continuous linear timing equalizer strongly compensate for insertion losses, and the decision feedback equalizer (DFE) is used to compensate for reflection losses [4]. Failure mode type can be expressed as a feature quantity of transmission-line deterioration by the difference in the effect of the tap coefficient on these different equalizers. The parameter set of the tap coefficient composed of N types of equalizers is expressed by an N-dimensional vector such as in the following equation.

$$\overrightarrow{\Delta Tap} = (\Delta Tap(1), \quad \cdots \quad , \Delta Tap(N)) \qquad (2)$$

Next, we discuss the verification results of discriminating the abnormal state by the vector expressed using Eq. (2) through simulation.

Using the PoC-circuit configuration in Fig. 2, we simulated the transmission system between SerDer LSIs and examined the feasibility of the proposed method. We prepared the 18 simulation degradation models (#0-4: coaxial cable degradation, #5-12, connector degradation, and #13-17: PoC-filter degradation).

We used ADS™ of Keysight technology as the simulator and a 1-tap FFE for the SER (transceiver: Tx) side and 6-tap DFE for DES (receiver: Rx) side. We also carried out automatic compensation of the signal waveform using an adaptive equalizer option.

Figure 8 shows the results of hierarchical clustering for 18 sets of tap-coefficient vectors obtained from ADS analysis. We used a dendrogram for hierarchical clustering and the Bray-Curtis distance metric to determine the distance of the cluster [5]. We also used the average of the distance as the linkage criterion.

By setting the threshold to about 0.8, failure mode was classified into three clusters, and each cluster could correctly classify each abnormal mode. As a result, the feasibility of the proposed method was successfully verified.

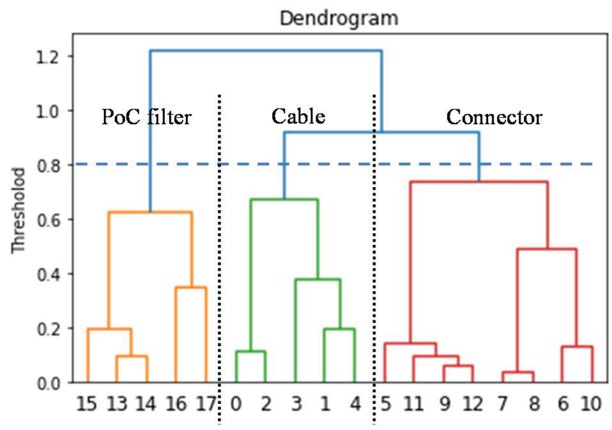
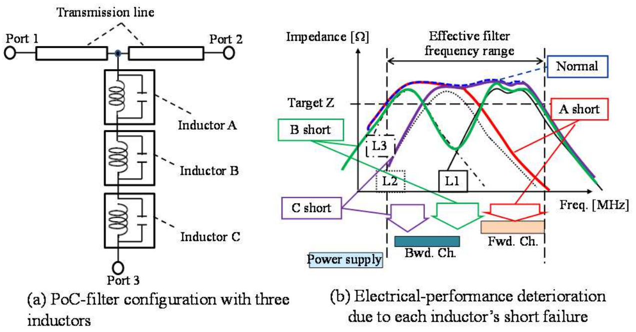


Fig. 8. Hierarchical clustering (dendrogram) results using tap-coefficient difference vector ($\overrightarrow{\Delta Tap}$) of equalizer of each condition

IV. Approach of PoC-Filter Short Failure Diagnosis with 3-Stage Inductor Configuration

In Section II, we discussed that it is difficult to detect a short abnormality for filters with an inductor 3-stage configuration. Figure 9 shows a configuration of a 3-stage-inductor PoC filter and its impact on signal integrity when each component has short failure.



	Inductor A short	Inductor B short	Inductor C short
Fwd. Ch.	Large effect (waveform)	Small effect	Small effect
Bwd Ch.	No effect	Large effect (waveform)	Large effect (at DC)

Fig. 9. Short failure modes of 3-stage PoC-filter circuit and their impact on signal integrity

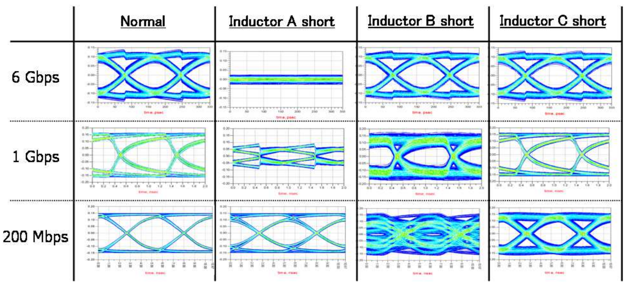


Fig. 10. Eye-pattern simulation results with three types of short failure

When inductor A for high frequency fails, the forward-channel signal deteriorates greatly, so it is possible to determine the failure of the filter component by detecting the communication error. However, it is difficult to detect when inductor B fails at a medium frequency and inductor C fails at a low frequency because there is little effect on the forward-channel signal. Therefore, we propose a method of using a few types of signal frequency to distinguish a short-failure component from the amount of waveform degradation at each signal-data rate.

Figure 10 shows the eye-pattern analysis results before the equalizer was used. The forward-channel-signal speed was defined at 6 Gbps and the backward-channel-signal speed was defined at 200 Mbps. We also added a 1-Gbps signal as a deceleration mode of the forward channel. As shown in Fig. 10, we could distinguish the difference in the waveform behavior in the three types of short-failure modes. Since the parameters of the equalizer change to guarantee this waveform deterioration amount, it is possible to separate the failure mode by capturing the amount of change at each data rate. By using the difference in frequency response in this manner, it is possible to distinguish the short-failure component.

By applying the proposed method using the tap-coefficient difference vector of the equalizer parameter combining different data rates, we confirmed in an actual SerDes interconnect that the abnormal mode of the PoC circuit can be separated.

Figure 11 shows the experimental results of the failure mode clustering based on our proposed method. As can be seen from the figure, we can distinguish three clusters due to different failure mode in this experimental setup. The details of the experimental setup and the results will be reported in a separate paper.

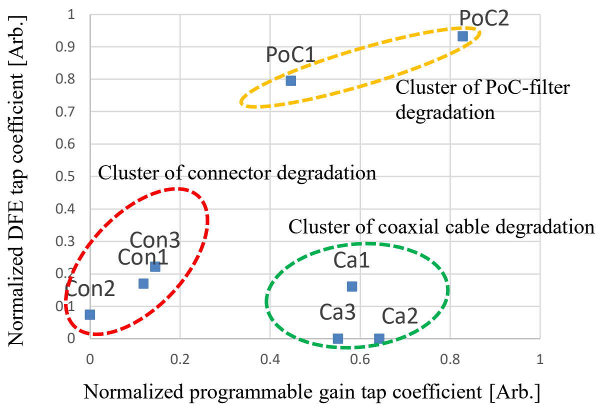


Fig. 11. Experimental results of the failure mode clustering

V. Conclusion

We proposed an abnormal-state-discrimination method for the in-vehicle communication channel with a PoC circuit. We focused on discriminating the failure mode of coaxial-cable degradation, connector degradation, and PoC-filter degradation. We used the tap-coefficient difference vector of the equalizer parameter combining different data rates and verified that the abnormal mode of the PoC circuit can be discriminated. The proposed method uses digital data, such as equalizer parameters and error information, that can be obtained from general SerDes LSIs. Therefore, no additional components are required to diagnose the abnormal state of a channel.

There are a few problems to be solved to apply our method to an actual interconnect system (for example, responding to temperature or process fluctuations and setting criteria when judging that the channel of interconnect is abnormal). These solutions will be reported elsewhere.

Acknowledgment

The authors would like to thank Shungo Okabe for his kind support and helpful technical discussion.

References

[1] S. Dabral, S. Kamath and V. Appria, "Trends in Camera based Automotive Driver Assistance Systems (ADAS)," Proc. IEEE 57th International Midwest Symposium on Circuits and Systems, 2014, pp. 1111–1115, doi: 10.1109/MWSCAS.2014.6908613

[2] Sending Power Over Coax in DS90UB913A Designs, Application Report, Texas Instruments, Dallas, Texas, June 2014.

[3] Gigabit Multimedia Serial Links (GMSL) for ADAS Design Guide, Maxim integrated Products, Inc., October 2018.

[4] T. Toifl *et al.*, "A 2.6 mW/Gbps 12.5 Gbps RX With 8-Tap Switched-Capacitor DFE in 32 nm CMOS," IEEE Journal of Solid-State Circuits, vol. 47, pp.897-910, Apr. 2012.

[5] J. R. Bray and J. T. Curtis, "An ordination of upland forest communities of southern Wisconsin," Ecological Monographs, vol. 27, pp. 325–349, Oct. 1957.