Shielding Performance of High-Voltage Wiring Harnesses - Comparison between European and Japanese Technologies -

Ole ADAM*, Hiroyuki KODAMA, Yoshio MIZUTANI and Hirokazu KOSEKI

Electric vehicles and hybrid vehicles have a high potential to reduce CO_2 emissions. Currently we are developing and producing wiring harnesses to connect high-voltage components that are not used in conventional vehicles. For a high-voltage and large-current circuit, compatibility with the generally used 12 V system is important to avoid electro-magnetic compatibility problems, and thus, the development of shielding technology for the high-voltage wiring harnesses is essential. This paper introduces a shielding measurement system based on the transfer impedance method used mainly in Europe. The measurement result showed that our aluminum pipe shielded wiring harness has excellent shielding performance.

Keywords: high-voltage wiring harness, electro-magnetic shielding, transfer impedance method, current probe method

1. Introduction

Electric vehicles or hybrid electric vehicles that enable reductions in fuel consumptions and CO_2 emissions*1 are highly interesting from the viewpoint of the global environment. In Europe, in order to meet the regulations of CO_2 emissions, which is getting harder to achieve, automakers have prioritized developing advanced technologies for down-sized combustion engines and clean diesel engines. Currently, in parallel, “E-mobility,” such as electrical vehicles and fuel cell vehicles, is being studied intensively as the next generation technology as well.

In this kind of technology, a high-voltage circuit is necessary for motor driving and energy regenerating, in addition to a conventional 12 V system. Sumitomo Electric Group develops and manufactures high-voltage wiring harnesses that correspond to these kinds of components[(1)-(4)]. Especially for the high-voltage wiring harnesses, it is important to include excellent electro-magnetic shielding compatible with sensitive devices, such as the radio control system and high speed communication system.

Clearly, a measurement method of the shielding performance is necessary for developing high-voltage wiring harnesses. In this paper, a newly established measurement system using a transfer impedance method is reported. Also, the high correlation between the data by this measurement system, the theoretical calculation, and the accuracy of these measurement results are shown. Furthermore, comparison results of shielding performance for various high-voltage wiring harness are reported.

2. Measurement Method of Shielding Performance

The measurement method of shielding performance can be generally categorized into either an “indirect-method” or a “direct-method.” The former is a method in which when signal is input into an internal conductor, radiated noises penetrated through the shielding layer are detected by devices, such as sensors or antennas. One of typical methods is the current probe method. On the other hand, the latter is one in which the coupling state between an internal conductor and a shielding layer is directly observed by measuring the voltage of the internal conductor inducted by the current flowing through the shielding layer. One of typical methods is the transfer impedance method. Japanese and European automakers typically prefer the former and latter methods, respectively. This section explains both measurement methods.

2-1 The current probe method

(1) Outline

This method is standardized by the international specification CISPR25*2 for the shielding performance of components within the automobile field. Sumitomo Electric Group is, thus, quite familiar with this measurement method.

(2) Measurement system

Figure 1 shows the measurement system using a spectrum analyzer with a built-in tracking generator*3. In order to protect from external electro-magnetic disturbances, the whole measurement system is placed inside a shielded room. Two kinds of probe are applied to pick up the noise radiated from samples depending on the frequency. This measurement is operated on a copper plate for the purpose of a securing common and stable ground of the whole measurement system.

The principle of the measurement is the current probe senses the radiated noise penetrated through the shielding layer, when the input signal comes from a spectrum ana-

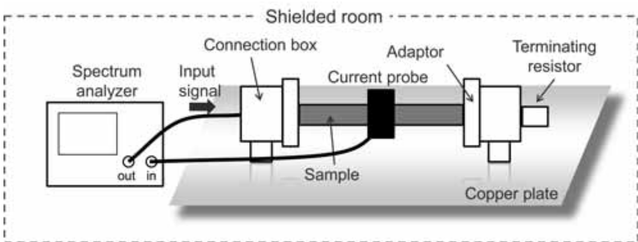

Fig. 1. Measurement system for the current probe method

lyzer to the internal conductor of a sample through a connection box. The measurement parameter in this method is the power ratio of the input signal and output signal;

the measured value (dB) = <the output power from the current probe> / <the input power into the sample>, then the shielding performance is calculated as the difference between the shielded and non-shielded samples.

With this system various types of samples can be measured by applying the particular adaptors to match with the interface of the connectors.

2-2 The transfer impedance method

(1) Outline

This method is standardized by the international specification IEC61196-1[*4] for a coaxial cable testing, which is a method to test the shielding performance common mainly in Europe. **Figure 2** shows the definition of the transfer impedance.

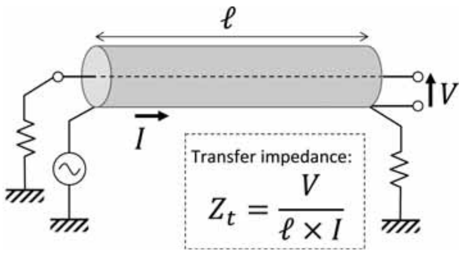

Fig. 2. Definition of transfer impedance

(2) Measurement system

The principle of the measurement is the spectrum analyzer detects the inducted voltage of the internal conductor, when the input signal comes from the spectrum analyzer to the shielding layer of the sample through the injection wire. The measured value is the power ratio between input and output signals, as in the current probe method.

Figure 3 shows the established measurement system. A 50Ω coaxial cable is used for injecting the signal to the shielding layer, and the output signal of sample at the far-end is measured with a spectrum analyzer. As it affects the transfer impedance measurement, the common ground is not used for the measurement. With the measurement system in **Fig. 3**, the transfer impedance can be calculated as the **following equation**.

$$Z_t = \frac{2}{\ell}\sqrt{R_0 \cdot R_3} \cdot 10^{A_T/20} \quad \cdots\cdots (1)$$

Z_t: the transfer impedance(Ω/m), A_T: the power ratio between input and output signal(dB), R_0 : the terminating resistance of the injection line(Ω), R_3: the terminating resistance of the sample(Ω), ℓ: the sample length(m)

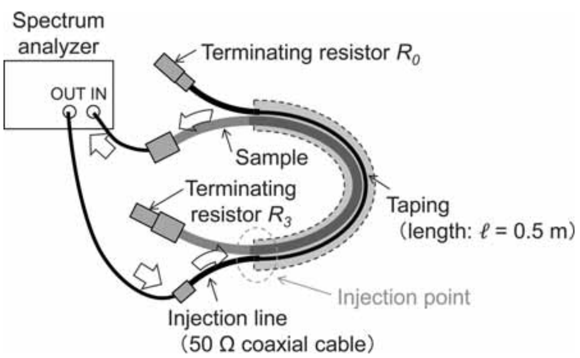

Fig. 3. Measurement system for the transfer impedance method

3. The Verification for the Measurement System of the Transfer Impedance

As noted in section 2, the current probe method is well proven among Japanese automakers, and also well established in our laboratory. However, not as much knowledge is available for the transfer impedance method, because this measurement system was only first utilized for high-voltage wiring harnesses. Therefore, it was necessary to carefully verify the accuracy of the measured values. In this section, the accuracy of the measurement value was verified using shielded wire samples as follows.

3-1 Measurement samples

Figure 4 explains the cross sectional structure of shielded wire samples of 4 mm^2, 4 mm^2 × 2-cores and 16 mm^2 for this measurement. These wires are designed for connecting high-voltage components, such as high-voltage battery circuits and motor circuits.

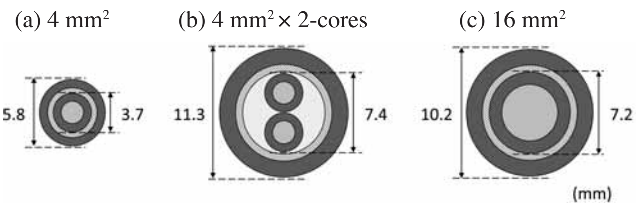

Fig. 4. Measurement samples of shielded wire

3-2 Consistency with the theory

From the theoretical point of view, the DC resistance of a shielding layer strongly affects the transfer impedance as the frequency becomes lower.

$$Z_t \approx R \text{ (in case of extremely low frequency)} \quad \cdots\cdots (2)$$

R: DC resistance of shielding layer (Ω/m)

Table 1 shows the comparison results between measured transfer impedance at 10 kHz of a shielded wire and DC resistance of the shielding layer. We confirmed the comparison results and **Eq. (2)** are consistent with each other, as shown in **Table 1**.

In order to confirm the tendency of the transfer impedance dependency on frequency, the comparison results

Table 1. Comparison between transfer impedance and DC resistance

	Transfer Impedance at 10 kHz	DC resistance
4 mm²	12 mΩ/m	12.6 mΩ/m
4 mm² × 2-cores	6 mΩ/m	5.6 mΩ/m
16 mm²	6 mΩ/m	5.3 mΩ/m

between measurement and calculation data based on a simulation model[5] are shown in **Fig. 5**. These graphs show the relationship of transfer impedance and frequency, and smaller transfer impedance values mean better shielding performance. The results showed the measurement and calculation data have a positive correlation in each sample.

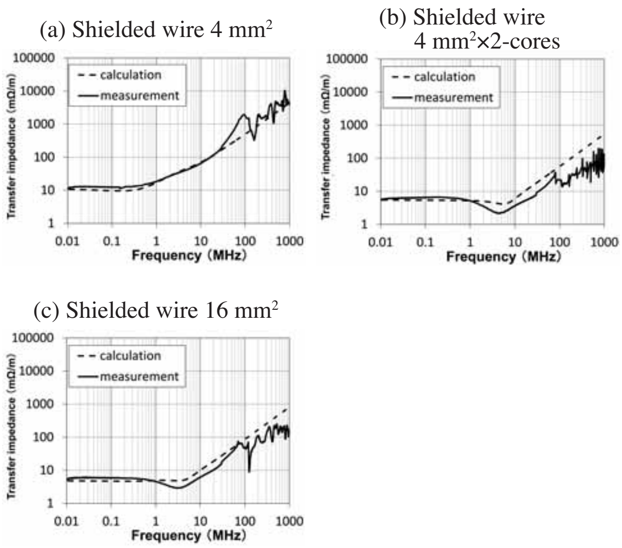

Fig. 5. Comparison between measurement and calculation

3-3 Correlation between the transfer impedance method and the current probe method

Figures 6 and 7 show the measurement results of each shielded wire with the transfer impedance method and the current probe method, respectively. Note the larger values of shielding performance mean better shielding ability in **Fig. 7**.

Although the graph shapes indicating relationship between shielding performance and frequency with both methods are different, the relative behavior of each sample for both methods is quite similar when comparing **Figs. 6 and 7**. For example, the shielded wires 4 mm² × 2-cores and 16 mm² have nearly the same level at all frequency ranges, and the difference between shielded wire 4 mm² and the other wires is significantly large over 1 MHz.

These results in subsections 3-2 and 3-3 are evidence that our measurement system of transfer impedance method has been launched correctly, because the measurement re-

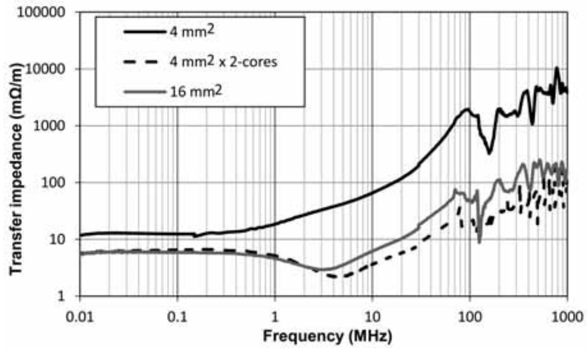

Fig. 6. Measurement results of shielded wire with the transfer impedance method

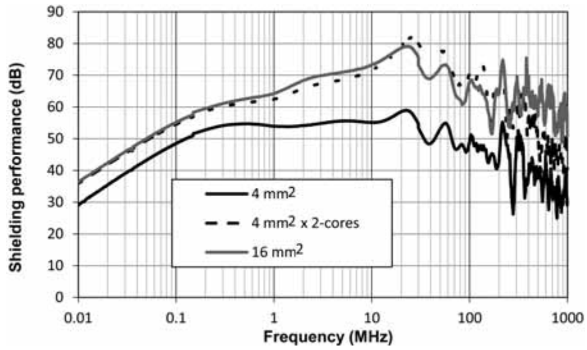

Fig. 7. Measurement results of shielded wire with the current probe method

sults are consistent with the theory. Furthermore, they have the same tendency as the current probe method.

4. Application of the Transfer Impedance Method to High-Voltage Wiring Harnesses Measurement

The transfer impedance method was originally developed for measuring the shielding performance of shielded wires, and did not consider high-voltage wiring harness samples that have connectors attached to the wire. Therefore, we modified the measurement system explained in section 3 so that high-voltage wiring harnesses can be measured correctly.

4-1 Measurement system

Figure 8 shows the measurement system that was modified based on **Fig. 3**, in order to measure high-voltage wiring harnesses. The difference is the position of the injection point has been changed onto the connection box from on the wire, in order to consider the influence of connectors at both ends of the shielded wire. Due to this modification, the input signal flows through the shielding shell that is the shielding layer for the connector, thereby making it possible to measure the shielding performance of the whole high-voltage wiring harness, including connectors.

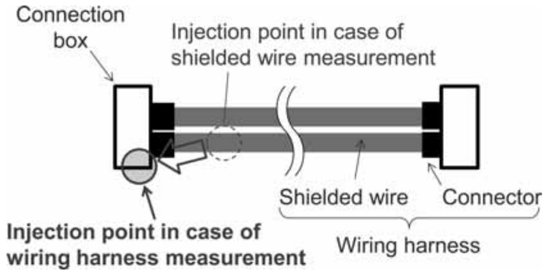

Fig. 8. Transfer impedance method for wiring harness

4-2 Correlation between the transfer impedance method and the current probe method

Two high-voltage wiring harness samples were prepared for this study, as follows.

- 35 mm^2 shielded wire with connector A at both ends of the shielded wire. Connector A used plug type terminals.

- 35 mm^2 shielded wire with connector B at both ends of the shielded wire. Connector B used bolted terminals.

Figures 9 and 10 show the measurement results with the transfer impedance method and the current probe method, respectively. As for the results, both methods have a very high correlation, the same results as in subsection 3-3.

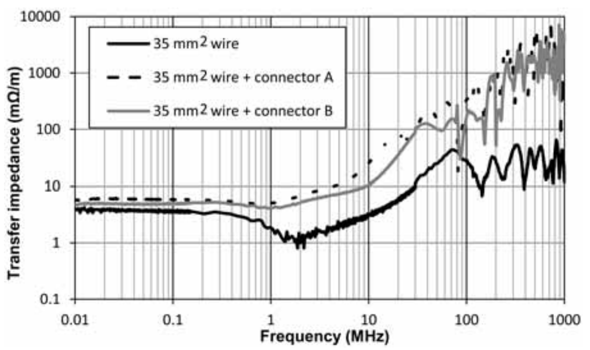

Fig. 9. Measurement results of high-voltage wiring harness with the transfer impedance method

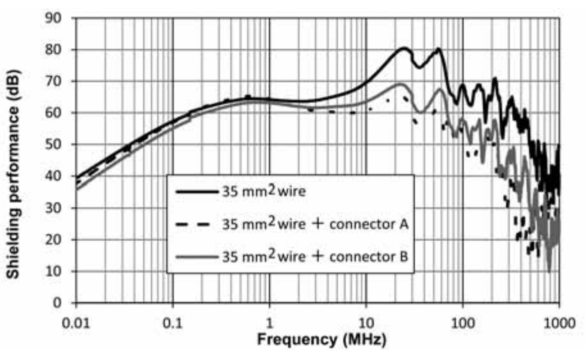

Fig. 10. Measurement results of hith-voltage wiring harness with the current probe method

Under 1 MHz, there is no remarkable difference among all the samples. On the other hand, the high-voltage wiring harnesses have worse performance compared to the shielded wire sample over 1 MHz. These tendencies were confirmed from results of both methods.

Possible reasons for this tendency are, in case of under 1 MHz, contact between the shielding layer of the shielded wire and the shielding shell of the connector has very low resistance. Over 1 MHz, it is estimated the noise is radiated from the shielding shell. In comparison of two connector types, connector B is slightly better than connector A, because connector B has a one-piece shielding shell, while the shielding shell of connector A consists of several parts, and the connection between these parts of the shielding shell is estimated to negatively affect the shielding performance. As the measurement results of both methods have a very good correlation with each other, even with this small difference of each connector type, we believe the transfer impedance method is capable of making a measurement while considering the influence of connectors, as the current probe method does.

From these results, we determined that the transfer impedance method can be applied to high-voltage wiring harnesses as well as for simple shielded wire.

5. Comparison of Each High-Voltage Wiring Harness

This section explains the measurement results of each high-voltage wiring harness type with the transfer impedance method explained in the previous section.

There are mainly two kinds of shielding structures for high-voltage wiring harnesses: an individual shielding structure, for separately shielding each wire, and a bundle shielding structure, applied as a common shielding layer to all the wires. Currently, European automakers, especially German automakers, prefer the former type, while Japanese automakers, depending on the kind of circuit, prefer the latter type.

As the material of the bundle shielding structure, braided wires[(2)] or pipe made out of some metal is typically applied. Especially for high-voltage wiring harnesses, an aluminum pipe shielding structure[(3), (4)] is preferably applied, due to stronger mechanical protection and heat shielding, as well as the electro-magnetic shielding function. Aluminum pipe needs some flexible parts at the ends of pipe taking productivity into account, such as easy installation into vehicles or an acceptability of the production tolerance. Braided wire shielding structure is one example of flexible parts used.

Figure 11 shows the measurement samples of the individual, the bundle braided and the aluminum pipe shielding structures.

Figure 12 shows the measurement results of each high-voltage wiring harness type with the transfer impedance method. From this measurement, it was found that the aluminum pipe shielding structure had the best performance among three shielding types at the frequency range as wide as 10 kHz - 1 GHz. In the case of under 100 kHz, the bun-

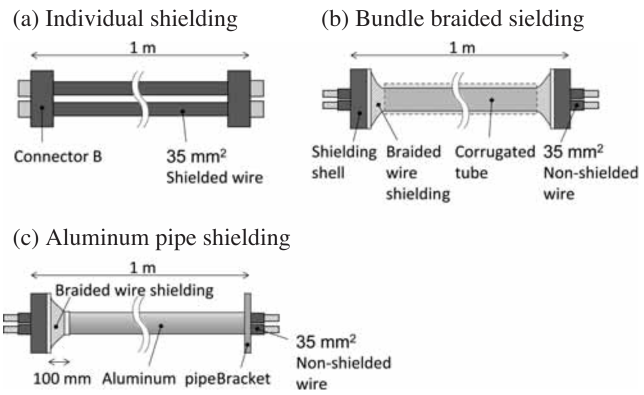

Fig. 11. Measurement samples of each high-voltage wiring harnesses

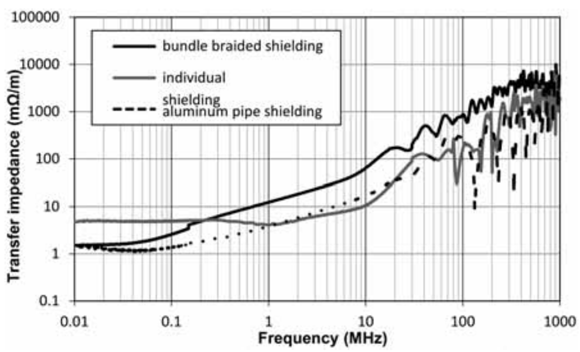

Fig. 12. Measurement results of high-voltage wiring harness with the transfer impedance method

dle braided wire shielding structure was relatively good. On the other hand, at over 1 MHz, the individual shielding structure had nearly the same performance as the aluminum pipe shielding structure.

In general, shielding performance was strongly affected by the DC resistance of the shielding layer if the frequency was low enough, as explained in subsection 3-2. However, as the frequency moved higher, a high surface density structure of the shielding layer, namely, the shielding layer structure that covers the wire surface without space, was advantageous for shielding performance. This measurement proved that the aluminum pipe shielding structure is suitable for both these frequency ranges.

6. Conclusions

(1) The measurement system for the transfer impedance method has been established as a valid measurement method for the shielding performance of high-voltage wiring harnesses.
(2) The aluminum pipe shielding structure had the best shielding performance among the three shielding types for high-voltage wiring harnesses.

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Technical Terms

*1 CO_2 emissions: European committee regulated that the average CO_2 emissions per vehicle that are available within Europe should be less than 120 g / km by 2015. Furthermore, it is under discussion at the moment, whether it should be less than 95 g / km by 2020.

*2 CISPR25: The specification that was regulated by the special committee "*Comité International Spécial des Perturbations Radioélectriques*" (CISPR, English: International Special Committee on Radio Interference) belonging to the International Electrotechnical Commission (IEC) regarding "Vehicles, boats and internal combustion engines - Radio disturbance characteristics - Limits and methods of measurement for the protection of on-board receivers."

*3 Spectrum analyzer with a built-in tracking generator: The measurement device that measures the magnitude of an input signal versus frequency within the full frequency range of the instrument. A tracking generator outputs the signal synchronized with a spectrum analyzer.

*4 IEC61196-1: The IEC specification regarding coaxial communication cables, including the measurement method for shielding performance.

References

(1) "High-Voltage Wiring Harness Employed in New Model Hybrid Vehicle," SEI WORLD vol. 340(Jan. 2006)
(2) Sho Miyazaki, Souji Kihira, Takao Nozaki, "New Shielding Construction of High-Voltage Wiring Harnesses for Toyota Prius – Winning of Toyota Superior Award for Cost Reduction-," SEI technical review, no. 61, pp. 21-23 (Jan. 2006)
(3) Yoshio Mizutani, Oliver Weiss, "Pipe Shield High-Voltage Wiring Harness," 26th International Electric Vehicle Symposium, Los Angeles, California (May 2012)
(4) Yasushi Itani, Yoshio Mizutani, Masanori Kuwahara, Shogo Hashimoto, "Aluminum Pipe Shielded High-Voltage Wiring Harness," SEI technical review, no. 79, Oct. 2014 planned
(5) T. Kley, "Optimized Single-Braided Cable Shields," IEEE Trans. Electromagn. Compat., vol. EMC-35, no. 1 (Feb. 1993)

Contributors (The lead author is indicated by an asterisk (*).)

O. ADAM*
- Project Engineer, SEI ANTech-Europe GmbH

H. KODAMA
- Project Engineer, SEI ANTech-Europe GmbH

Y. MIZUTANI
- Assistant Senior Manager, Hybrid Vehicle R&D Division, AutoNetworks Technologies, Ltd.

H. KOSEKI
- General Manager, SEI ANTech-Europe GmbH