

Non-Contact Measurement Method for High Frequency Impedance of Load at the End of Wire Harness

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ABSTRACT

To avoid a trial and error adjustment for designing EMI filters, clarifying load impedance of operating condition, i.e., dynamic impedance of equipment is very useful. Therefore the need to a non-contact measurement method of the impedance connected to a wire harness is increasing rapidly.

A measurement method using a network analyzer with two current probes was previously proposed. However, it was confirmed only up to 30 MHz. Many radio equipment operate above 30 MHz such as FM receivers and GPS receivers installed in vehicles. So increasing the measurement frequency is necessary in the auto industry.

At first, we tried to expand the applicable frequency to 100 MHz, i.e., FM band. In this study, we applied the transmission line theory using the non-contact measurement method. Furthermore, in order to use the theory, the characteristic impedance and phase constant of the wire harness are required. So we made an additional measurement to estimate them.

As a result, the load impedance was measured with a 10% error up to 100 MHz and the validity of the newly proposed measurement method was confirmed experimentally. Accordingly the possibility of an appropriate EMI filter design in the FM band was found.

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1. INTRODUCTION

Corresponding to the recent shift to electric vehicles, the increase of internet usage and the evolution of driving support functions, on-vehicle electronics are increasing. For vehicles emphasizing safety and reliance, EMC design robustness is important and forced to be strengthened more and more in the future.

Regarding the EMC performance of a vehicle, not only noise sources or victim devices but also the wire harness connected to these devices need to be considered. Any noise from the noise source can radiate through the connector and onto the wire harness which acts as an antenna and radiates the noise to the inside and outside of the vehicle. When outside noise is induced on the wire harness, it can flow into the device through the connector and cause a malfunction of on-vehicle electronics.

For these reasons, the load impedance of the circuit connected to the wire harness is critical in determining the values of the EMI filter taking emission and immunity into consideration and the accurate estimation is treated as important [1]–[3]

In conventional research, a non-contact measurement method of the load impedance was previously proposed [4]. However it was confirmed only up to 30 MHz. There are many radio equipment installed in the vehicle operating at a frequency above 30 MHz, such as FM and GPS receivers.

In this study, we first tried to expand the applicable frequency to 100 MHz, the frequency band for FM receivers. Specifically, we represented the wire harness by a distributed constant circuit and, proposed to expand the non-contact impedance measurement method to the high frequency using transmission line theory. We then verified the results experimentally.

In [section 2](#) of this study, we introduced a conventional non-contact impedance measurement method. In [section 3](#), we expanded the applicable frequency of the non-contact measurement method to the high frequency by applying transmission line theory to the wire harness and proposed a method to estimate the characteristic impedance and phase constant of the wire harness. In [section 4](#), we verified the experiment to validate proposed method. This paper concludes in [section 5](#).

2. NON-CONTACT MEASUREMENT METHOD OF LOAD IMPEDANCE

2.1. Summary of Non-Contact Measurement Method

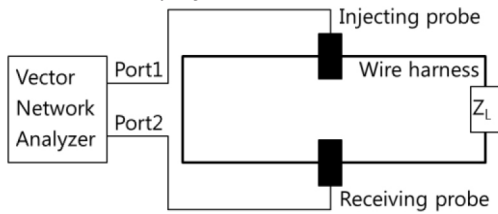


Figure 1. Non-contact measurement method of a load impedance

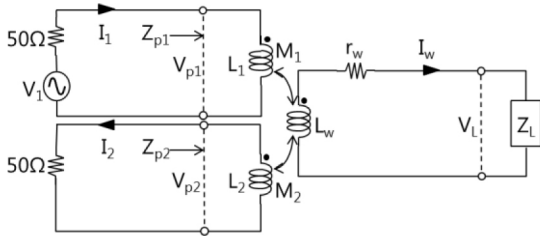


Figure 2. Equivalent circuit of the measurement system

Figure 1 shows a non-contact measurement setup for the impedance of a load Z_L connected to an end of a wire. The measurement setup consists of an injection current probe, a receiving current probe and a vector network analyzer. The injection current probe was connected to Port 1 of the network analyzer and generated an AC current into the closed loop of the wire. The receiving probe was connected to Port 2 and was used to measure the current.

Figure 2 shows an equivalent circuit of the measurement system. In this figure, L_1 and L_2 are the inductances of the injection current probe and the receiving current probe, respectively. V_{p1} is the signal source voltage of Port 1 and V_{p2} is the received voltage at Port 2. Z_{p1} and Z_{p2} are the input impedances of the two probes, respectively. L_w and r_w are the inductance and resistance of the wire. M_1 and M_2 are the mutual inductances between the wire and, the injection and receiving current probes, respectively. I_w is the current flowing through the closed loop of the wire. For the equivalent circuit in Figure 2, the Equation can be described as follows:

$$\begin{bmatrix} 1 \\ 0 \\ -V_L \end{bmatrix} = \begin{bmatrix} 50\Omega + Z_{p1} & 0 & -j\omega M_1 \\ 0 & 50\Omega + Z_{p2} & j\omega M_2 \\ -j\omega M_1 & j\omega M_2 & r_w + j\omega L_w \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_w \end{bmatrix} \quad (1)$$

By rearranging Equation (1) to eliminate I_1 and I_2 , the load impedance Z_L was determined as follows:

$$Z_L = K \left(\frac{p1}{p2} \right) - Z_{setup} \quad (2)$$

where, K and Z_{setup} are the calibration factors that represent the characteristics of the measurement system and are functions of M_1 , M_2 , Z_{p1} , Z_{p2} , L_w , r_w and the transfer impedance Z_{T2} of the receiving

current probe. Next, using S_{11} and S_{21} measured with the network analyzer, it was possible to determine the voltage ratio V_{p1}/V_{p2} using the following Equation.

$$\frac{p1}{p2} = \frac{S_{11} + 1}{S_{21}} \quad (3)$$

In addition, the calibration factors K and Z_{setup} were determined using the following steps prior to the measurements:

- Measured S_{11} and S_{21} using the network analyzer with the ends of the closed loop connected to a 0Ω resistor and determined the voltage ratio V_{p1}/V_{p2} using Equation (3).
- Measured S_{11} and S_{21} using the network analyzer with the ends of the closed loop connected to a known calibration resistor R_{std} and determined the voltage ratio V_{p1}/V_{p2} using Equation (3).
- Calculated the calibration factors K and Z_{setup} that represent the characteristics of the measurement system by using the following Equations:

$$K = \frac{Z_L|_{Z_L=R_{std}}}{\frac{p1}{p2}|_{Z_L=R_{std}} - \frac{p1}{p2}|_{Z_L=short}} \quad (4)$$

$$Z_{setup} = K \frac{p1}{p2}|_{Z_L=short} \quad (5)$$

When the calibration factors K and Z_{setup} were determined for the measurement system, it was possible to determine the impedance of an unknown load connected to an end of a wire by measuring S_{11} and S_{21} and substituting them into Equations (2) and (3).

2.2. Problem of Non-Contact Measurement Method

With wires whose lengths are electrically short with respect to wavelength, we worked to confirm the influence on the measurement result.

For the non-contact measurement method, we focused on the load connected to a wire. In this case, the wire can be treated as a transmission line. The load impedance on the wire as seen by the current probe is determined as follows [5]:

$$Z_{in} = Z_0 \frac{Z_L + jZ_0 \tan(\beta d)}{Z_0 + jZ_L \tan(\beta d)} \quad (6)$$

where Z_0 and β are the characteristic impedance and the phase constant of the transmission line, respectively. d is the wire length between the measurement point and the load.

The circuit simulation model developed to quantify the influence of the transmission line is shown in Figure 3. The S parameters of the loop which includes the transmission line (RLCG in Figure 3) and the