Development of Automatic Measurement System for Conducted Emissions

Hiroyuki ARAI
Toshiyasu TANAKA
Yasuhiro HAYAKAWA
Taichi HARA
Hideo HANAMOTO

Abstract

Recently, in pursuit of improving safety, comfort, and environmental-friendliness, electronic control units (ECUs) in vehicles have been rapidly enhancing their higher function, performance and integration. Wireless communications with GPS, ETC, etc. have been growing and technical innovation such as communication networks (LAN) linking those ECUs will never remain the same.

As the technologies for vehicles progress, EMC (electromagnetic compatibility) performance has become an important challenge that the car industry needs to address. Accordingly, car manufacturers request their suppliers to test each ECU for confirmation to ensure EMC performance, and thus man-hours for evaluation are increasing every year.

In these circumstances, in order to curb the increase in evaluation man-hours and ensure EMC quality in product development, FUJITSU TEN has promoted development of EMC evaluation methods since fiscal year 2007. We developed, for the purpose of reducing the man-hours, the system to measure "conducted emissions" which is frequently measured and requires many man-hours in evaluation. This document describes our development of the measurement system that may replace the conventional method.

1 Introduction

1.1 EMC Environment for Vehicles

With the recent development of car electronics, a high-end vehicle is equipped with more than 20 types of signal receivers including radio receivers and TV receivers due to adoption of the weak radio wave applied technology in addition to more than 60 types of ECUs and approximately as many as 2000 types of harness circuits.

The expectation for widespread of eco-cars and advent of the ubiquitous ITS society in the future has advanced the technologies of inter-vehicle communications and road-to-vehicle communications, which leads to a concern of mutual interference of electromagnetic waves. Therefore, a growing number of companies are addressing EMC.

1.2 Endeavor for Evaluation Method Development

Responding to the changing EMC environment for cars, FUJITSU TEN has promoted the development of evaluation methods based on the objectives listed below.

- **Promotion of evaluation methods development synchronized with ECU development, accurately grasping the changing electromagnetic environment in the market and/or for cars**
- **Creation of efficient and accurate EMC evaluation environment**
- **Development of low-cost evaluation methods**

1.3 Reasons for Equipment Development

There are two types of EMC tests: "emissions test" for measuring unnecessary radiation (noise) from ECUs and "immunity test" for checking endurance of ECUs by irradiating electromagnetic waves. This time, we developed a new measurement system for the conducted emissions test that is one type of the emissions test and requires many man-hours and much work in the conventional evaluation.

Conducted emissions is a noise phenomenon that is generated in an ECU and affects a circuit(s) in a device connected with the ECU through a connector, or interrupts a receiver by being radiated through wire harnesses [hereinafter referred to as W/H(s)].

It takes 28 hours to test an engine control ECU and as many as 67 hours to test a navigation system in the conventional conducted emissions test method because there are more than 100 connecter pins in them and we need to check those pins one by one.

1.4 Effect of Conducted Emissions on Receivers

We will explain the conducted emissions evaluation.

Conducted noise generated from an ECU radiates interfering waves from a W/H connected to it and interrupts a receiver (**Fig. 1**). That is the mechanism of noise interference by the conducted emissions.

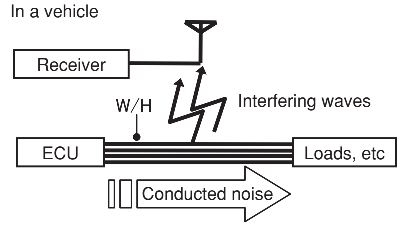

Fig.1 Mechanism of Noise Interference

2 Aim of Our Development

2.1 Problems and Objectives of Conventional Measurement Method

An international standard IEC CISPR 25 (Vehicles, boats and internal combustion engines - Radio disturbance characteristics - Limits and methods of measurement for the protection of on-board receivers) specifies two methods for measuring conducted emissions. An EMI receiver and a spectrum analyzer are defined as basic measuring equipment for both methods. The measurement methods are categorized into two of "voltage method" for measuring noise superimposed on a power wire by using a test circuit network and "current probe method" for measuring noise by clamping signal W/Hs and power W/Hs with a current probe. In both methods, the measured frequency band ranges from about 100 kHz to 108 MHz, and each W/H needs to be connected to a test circuit network or clamped with a current probe. As a result, the measurement requires many hours. **Table 1** shows problems and objectives of the conventional measurement method.

Table 1 Problems and Objectives

	Problems	Objectives
①	Measure W/Hs one by one ⇒much preparation work long measuring time	To cut preparation work To shorten measuring time
②	Limited to power wires (voltage method)	To measure signal wires in the voltage method
③	Narrow measurable frequency band (up to 108 MHz)	To widen measurable frequency band (up to 1 GHz)

2.2 Aims and Targets of New Method

We set the following aims and targets for developing a new measurement method to solve those problems.

①Shorter measuring time: to establish a new noise detection method and to create an automatic measuring system (**Table 2**)

Table 2 Reduction Targets of Evaluation Man-hours

ECU	Evaluation method	Measuring time (H)	More concrete targets	
			Measuring time per W/H (S)	Incidental work (H)
Engine control computer	Conventional method	27.8	280.6	15.3
	New method	5.7	37.3	4.0
	Target	▲ 22.1		
Navigation system	Conventional method	66.9	1970.0	10.6
	New method	8.2	146.7	4.0
	Target	▲ 58.7		

②No limits of measured signals: to develop an system able to measure all W/Hs regardless of power wires or signal wires

③Wider measurable frequency band: to develop an system measurable up to 1GHz

3 Cooperative Development

FUJITSU TEN developed this new method in cooperation with Yokohama National University and Micro Wave Factory Co., Ltd. **Fig. 2** shows the tasks of the three organizations. Yokohama National University worked on theoretical analysis and simulation, Microwave Factory Co., Ltd. materialized hardware and software of the equipment, and we determined the specifications of the equipment and measurement conditions.

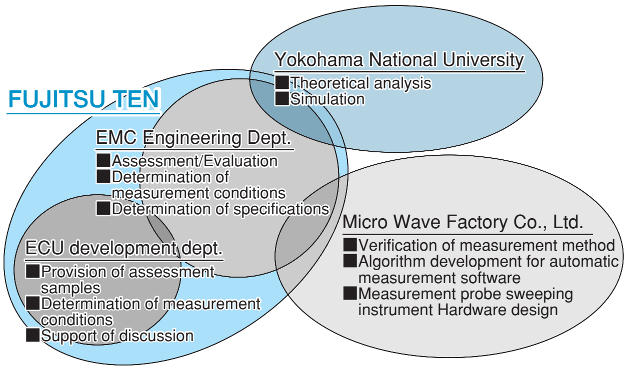

Fig.2 Cooperative Development

4 Noise Detection Method

4.1 Measurement Theory

This system measures voltage above each W/H using a contactless antenna and calculates noise current of each W/H. However voltage induced to the antenna does not only come from the W/H just below the antenna but also from the W/Hs on its right and left.

This section describes the theory of the method for deriving noise current of each W/H in consideration of the mutual interference.

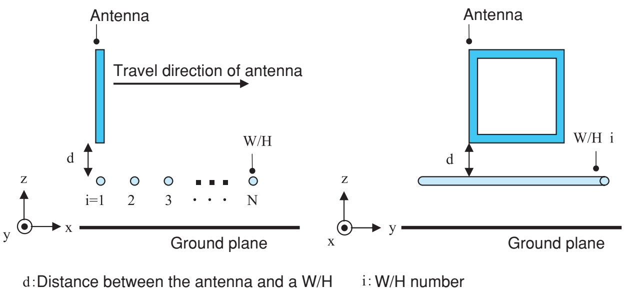

Fig.3 Noise Detection and Measurement System

For creating a noise detection system like the one shown in **Fig. 3**, noise current I_i on W/H i is derived by solving the formula (1), taking into consideration E_0^i, voltage measured above W/H i, and M_{0i}^j, mutual inductance between the antenna and the W/H.

$$\begin{bmatrix} E_0^1 \\ E_0^2 \\ \vdots \\ E_0^N \end{bmatrix} = -j2\pi f \begin{bmatrix} M_{01}^1 & M_{02}^1 & \cdots & M_{0N}^1 \\ M_{01}^2 & M_{02}^2 & & M_{0N}^2 \\ \vdots & \vdots & \ddots & \vdots \\ M_{01}^N & M_{02}^N & \cdots & M_{0N}^N \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ \vdots \\ I_N \end{bmatrix} \qquad (1)$$

Here, M_{0i}^j is the mutual inductance between the antenna and the W/H i of when the antenna is above W/H j.

The mutual inductance M_{0i}^j is calculated from the formula (2) based on the Neumann' law.

$$M_{ij} = \frac{\mu_0}{4\pi} \iint \frac{ds_i ds_j}{d} \qquad (2)$$

4.2 Verification of Theory

This section explains the measurement results of noise derived in accordance with the theory described in the previous section.

4.2.1 Verified Points

In the verification, as shown in **Fig. 4**, we input signals to each W/H at a different level using a signal generator (hereinafter referred to as SG), measured induced voltage of the antenna above each W/H, and then calculated noise current of each W/H based on the measured values. For the verification, the number (N) of W/H was set as five (N=5) and the individual values in The input values to each W/H are indicated in **Table 3**.

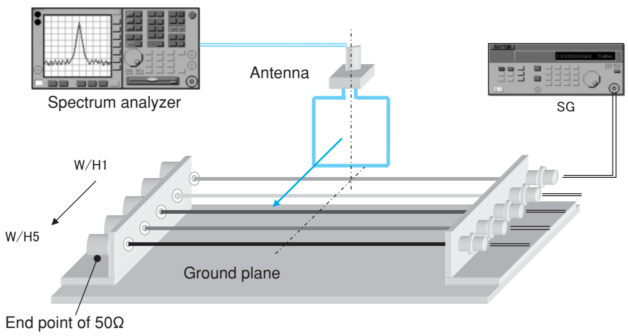

Fig.4 Measurement Environment

Table 3 Value Input to Each W/H

W/H number	1	2	3	4	5
Input value [dB]	0	−6	−20	−10	0

Measurement frequencies: 100 kHz, 20 MHz, 300 MHz, 500 MHz, 700 MHz, 1000 MHz

We calculated inductance matrices both from the theoretical formula (2) and calibration. Using those matrices, we calculated noise current in each wire.

Now, we will explain below the calculating method for the inductance matrix from the calibration.

A signal ($I_1=1$) is input only into W/H 1, and no signals $I_j=0$ ($j\neq 1$) are input for other W/Hs. When V_j is the value measured by the antenna, M_{01}^{j} , an element of the inductance matrix of the formula (1), can be calculated from $M_{01}^{j}=V_j/I_1$. The inductance matrix is completed by repeating the above calculation per W/H.

4.2.2 Verification Results

Tables 4 and 5 show the results of noise current calculated in the conditions defined in Section 4.2.1. For reference, we determined whichever higher value of W/H 1 or W/H 5 as a standard value (0dB).

According to the results, we confirmed that both methods lead to accurate results to some extent (with difference of 6dB or less). However, we found that low-level noise was detected less accurately. A conceivable reason for that is that the measured cable received radiation from neighboring W/Hs and the radiation affected the measured results. Therefore, we improved the antenna by using ferrite cores, as shown in **Fig. 5**, to reduce the effect from the radiation.

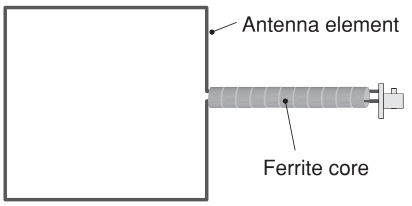

Fig.5 Antenna Structure

Table 4 Noise Calculation Results (Theoretical Formula)

W/H number	1	2	3	4	5
Input value [dB]	0	−6	−20	−10	0
100kHz	0	−6.5	−16.1	−12.3	0
20MHz	−1.3	−6.2	−14.2	−10.3	0
300MHz	0	−4.8	−13.8*	−8.5	−0.2
500MHz	0	−11.5	−16.3	−12.9	−0.6
700MHz	−0.8	−10	−21	−20.1*	0
1000MHz	0	−21.6*	−24.1	−17.5*	−3.7

Table 5 Noise Calculation Results (Calibration)

W/H number	1	2	3	4	5
Input value [dB]	0	−6	−20	−10	0
100kHz	−2.9	−8.1	−18.9	−13.1	0
20MHz	−3	−8	−27.3*	−13.6	0
300MHz	−0.3	−4.5	−18.7	−9.2	0
500MHz	−1.3	−10.8	−17.9	−12.9	0
700MHz	−3.2	−8.3	−13*	−12	0
1000MHz	0	−5.7	−8.3*	−6.3	−0.9

Note (*): values with difference of 6 or more from the input

5 Equipment Development

5.1 Determination of Control Parameters

Using quality engineering for better repeatability of measurement, we determined (1)the height of W/Hs from the ground plane, and (2)the distance between the antenna and a W/H (**Fig. 6**).

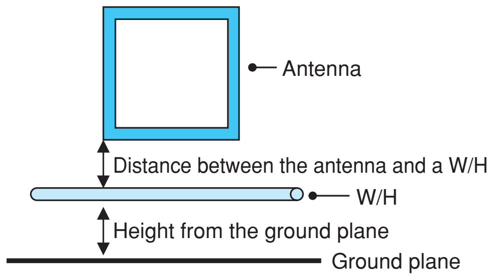

Fig.6 Parameter Control

The final specifications were decided based on the determined parameters and results verified in each development step.

The results of the evaluation for the parameters are shown below. Also, **Table 6** shows control factors used for quality engineering, and **Fig. 7** shows the factor-effect graph.

Table 6 Control Factors

	Factor	Level 1	Level 2	Level 3
A	Position of preamplifier	Antenna	Instrument	—
B	Height of antenna	5mm	10mm	20mm
C	Position of attenuator	Antenna	Instrument	Intermediate
D	Attenuator	3dB	6dB	10dB
E	W/H height from ground plane	15mm	30mm	50mm
F	Position of antenna	Center	Input side	Output side
G	Width of ground plane	500mm	150mm	300mm
H	Cable length	5000mm	7000mm	8500mm

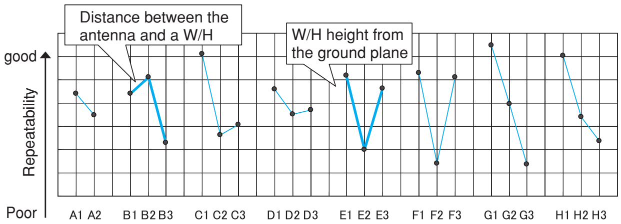

Fig.7 Factor-Effect Chart

①W/H Height

In the beginning, we thought that the W/Hs would be set 50 mm above the ground plane because the height is used in some international standards. However, the results of quality engineering showed us that measured data were more stable when the W/Hs were closer to the ground plane. Moreover, we found in the verification that measured results were more affected by the noise radiated from the tested product when the W/Hs were placed longer distance away from the ground plane because noise came from joints between the ground plane and W/Hs. Therefore, we determined a structure with the W/Hs placed as close as to the ground plane.

②Distance between Antenna and W/H

From the results of quality engineering, we verified that the distance of 10 mm between the antenna and a W/H is has the best repeatability. However, sensitivity of the antenna is reduced by the distance between the antenna and the W/H. Taking those into consideration, we determined to set the distance between the antenna and the W/H at 5 mm because the repeatability at the distance of 5 mm is as good as the one at of 10 mm in despite of being closer to the ground plane than 10 mm.

5.2 Specifications

Table 7 shows the specifications of the system. In this section, we describe some discriminative points of this equipment along with the reasons for determining the specifications.

Table 7 Specifications of System

Antenna	Square loop 100 kHz to 140 MHz:200×200 mm 140 MHz to 1 GHz:25×25 mm
Antenna travel speed	Up to 20 mm/sec
Frequency	100 kHz to 1 GHz
Instrument	Spectrum analyzer
Preamplifier	50 dB gain
Number of measured W/Hs	Up to 50 (Interval:10 mm)
Calibration tool	5 W/Hs 50 Ω-wire
Ground plane (Board)	L2000×W1000×t5 mm (L2000×W1000×H800)
Shield cover	L745×W1000×H600 mm

5.2.1 Structure

In this system, the antenna, W/Hs and calibration tool are placed in a shield cover so that this system can be used in a normal room, just as in a shielded room, without effect from noise radiated from a product and from noise coming from the outside of a test room. That enables accurate measurement of conducted noise even in an environment without a shielded room.

The ground plane that is the base board of the system can be folded, which makes the system compact for storage and allows easier carry than a conventional system.

5.2.2 Measuring Portion

Two different sizes of tiny square loop receiving antennas are adopted for this system in the view of reception sensitivity and repeatability. In addition, measured W/Hs placed in parallel are clamped with ferrite cores to minimize large resonance points for flatter frequency characteristic (**Fig. 8**). Frequencies measured by each antenna are shown in **Table 7**. For reference, "One antenna" in **Fig. 8** shows the case where the square antenna in size of 200×200mm was used.

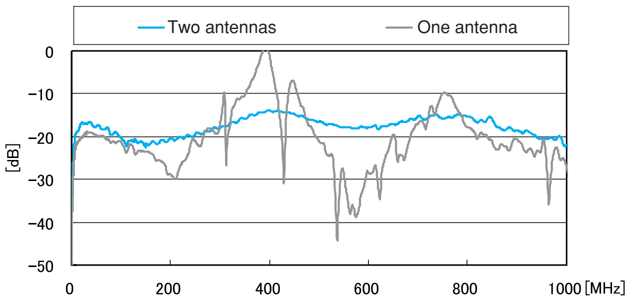

Fig.8 Comparison of Frequency Characteristics

Next, in order to measure as many W/Hs as possible at one time, we set the maximum measurable W/Hs as 50.

Moreover, we determined that up to five specific W/Hs can be analyzed in the method mentioned in Section 4 based on the measured data. From the results of the measurement for a distance affected by a W/H with high noise level, we found that the W/H with high noise level affects the W/Hs within the range of a few W/Hs away from it when they were placed at 10mm-intervals. Therefore, we believe that a W/H must have few effects on ones more away from it.

5.3 Measurement Process

With this system, an approximate noise level of each W/H can be estimated by measuring up to 50 W/Hs at one time and adding antenna factors to the measured data. **Fig. 9** shows the measurement process.

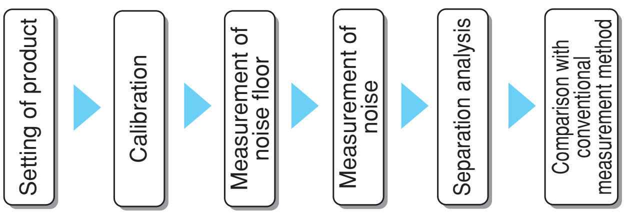

Fig.9 Measurement Process

The results of "noise measurement" were affected by noise from W/Hs adjacent to each W/H so that we added the process of "separation analysis" to understand the noise level more accurately. The analysis scale becomes large and the "separation analysis" takes much time when noise is measured in the entire frequency band and to all the W/Hs. Therefore, we determined to analyze some specific W/Hs, such as right and left W/Hs of the one with noise beyond a threshold, to understand the noise level more accurately.

Moreover, in order to add the process of "comparison with the conventional measurement method," we created a function correcting the difference between the data measured by this method and the one by the conventional method and correlated the measured results in the two methods.

6 Verification Results and Challenges for the Future

6.1 Verification Results

This section describes the results of checking validity of the system by measurement using a test signal generator (hereinafter referred to as a comb generator). A comb generator is an equipment enable to generate signals having constant frequency components by an oscillator.

This time, we checked the validity by inputting artificially-generated signals to a calibration tool with 5 W/Hs placed in parallel to eliminate effects of an encircling W/H. The results of input signals ranging from 30 MHz to 1 GHz are shown in the next section.

6.1.1 Measured Results

Fig. 10 shows the waveform of the actual input signals (hereinafter referred to as theoretical values).

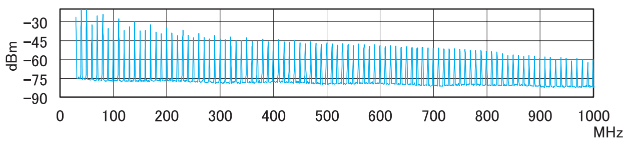

Fig.10 Theoretical Values

Fig. 11 (a) to Fig. 11 (e) show the results measured above individual W/Hs. The results measured above the W/H 5 to which signals were actually input show the almost same waveform as the theoretical values. On the other hand, signals were also measured above the other W/Hs to which signals were not input. Especially, clear signals were measured above the W/H 4. For solving this problem, the "separation analysis" was conducted. The levels of waveforms shown in **Fig.11** are different from the one of the theoretical values because they are the ones before being corrected with the antenna factors.

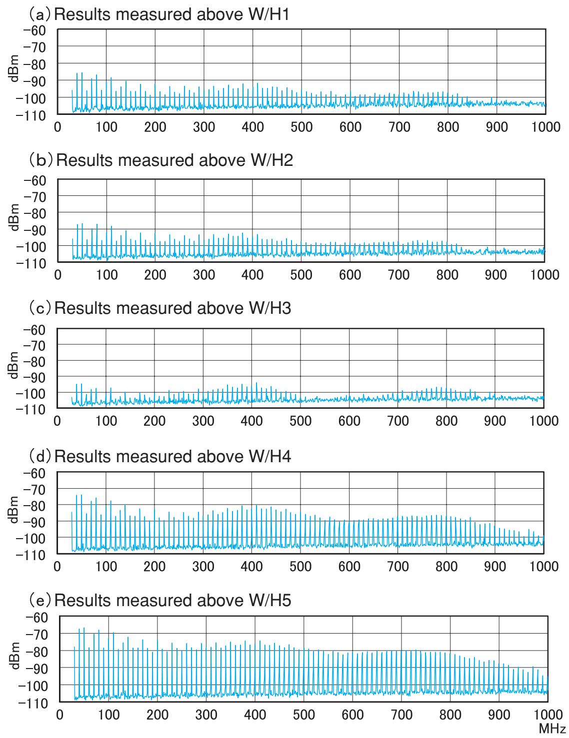

Fig.11 Measured Values (W/H 1 to W/H 5)

6.1.2 Results of Separation Analysis

Fig. 12 (a) to Fig. 12 (e) show the analysis results above individual W/Hs. The graphs in **Fig. 12** indicate that the signals measured above the W/Hs except the W/H 5 are separated by the analysis. In addition, for the W/H 5, the analyzed data is almost the same as the theoretical values.

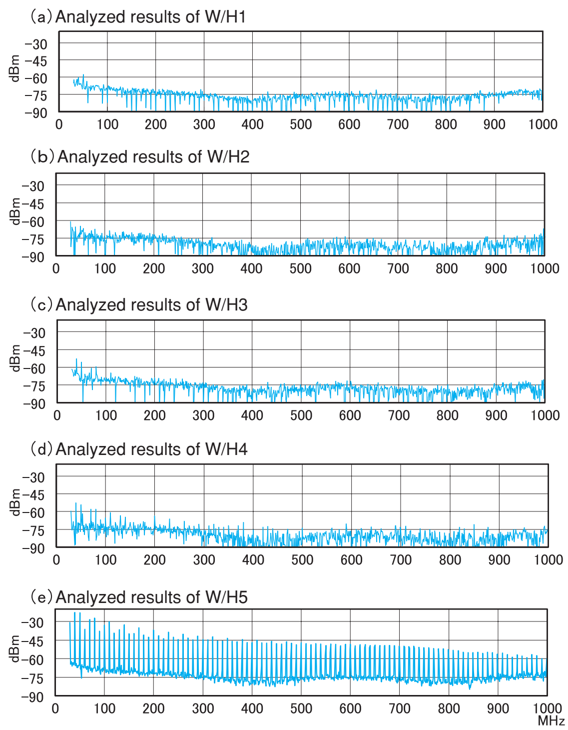

Fig.12 Analyzed Results (W/H 1 to W/H 5)

The data confirmed the validity of the results obtained from the measurement to the analysis by the equipment.

6.1.3 Comparison to Conventional Measurement Method

Fig. 13 shows the comparison of data of the W/H 5 measured in this method to the one in the conventional method. The measurement was conducted with the W/Hs at a height of 50 mm from the ground plane in the conventional method (current probe method). However, the W/Hs were set at 20 mm from the ground plane for the developed equipment. The difference in the measured environment causes the difference in frequency characteristics.

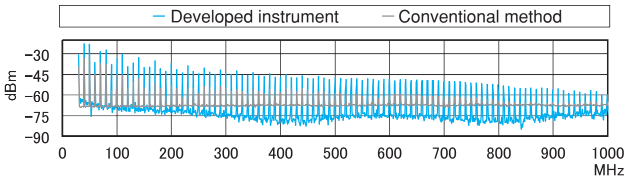

Fig.13 Comparison Results to Conventional Measurement Method

6.2 Achievements

This section shows the achievements of aims and objectives mentioned in Section 2.2.

①Shorter measuring time: preparation work was decreased by automatic measurement. For example, it takes about 15 minutes (900 seconds) to set and remove a current probe in the conventional method to measure 50 W/Hs. This equipment requires only about 30 seconds for the antenna to travel. We achieved to shorten the preparation time to one-thirtieth.

②No limits of measured signals: contactless square loop antennas enabled to measure any type of signals.

③Wider measurable frequency band: measurable frequencies ranging from 100 kHz to 1 GHz was achieved by using two types of antennas.

④Others: the shielded measured portion realized an system not affected by unrelated surrounding noise and, as a result, measurement in a normal room, just as in a shielded room.

6.3 Development in the Future

Now we have a prospect of the practical use of our developed system. We will standardize operating conditions including types of products, W/Hs, load setting for stable measurement conditions. After repeatedly using the system for evaluating ECUs on trial, we will start to use the system for test and evaluation in product design.

7 Conclusion

In this development, we achieved the environment that enables us to ensure EMC quality of our products at earlier period of their design with less capital investment and fewer testing man-hours.

We would like to express our deepest appreciation to all people who extended kind cooperation and support to us for the development of this equipment.

Reference

(1) Hiroyuki Arai, Wire Harness Current Measurement System by Square Loop Antenna, ICONIC, 2009
(2) CISPR 25 (Edition 3.0): Vehicles, boats and internal combustion engines - Radio disturbance characteristics - Limits and methods of measurement for the protection of on-board receivers, IEC (International Electrotechnical Commission), 2008
(3) Naohei Yamada, Denkijikigaku [Electromagnetism], Denkigakkaidaigakukouza, 2001

Profiles of External Writers

Hiroyuki ARAI (Doctor of Engineering)

Research associate in Department of Electrical and Electronic Engineering of Tokyo Institute of Technology in 1982, lecturer in Yokohama National University in 1989, associate professor in Yokohama National University in 1991. Currently, being engaged in research in microwave circuit for electromagnetic wave heating, antenna and radio propagation for mobile communications, EMC/EMI, etc. as professor of Graduate School of Yokohama National University.

Toshiyasu TANAKA

Established Microwave Factory Co., Ltd. in 2003. Since then, has engaged in the business related to radio waves such as designing and building radio anechoic rooms/shielded rooms, designing of high-frequency inspection instruments, etc. Currently, being CEO of Microwave Factory Co., Ltd.

Profiles of Writers

Yasuhiro HAYAKAWA

Joined the company in 1984. Since 1998, has engaged in introducing EMC test equipment into FUJITSU TEN and development of their assessment technology at Nakatsugawa Technical Center by way of manufacturing-related work at Nakatsugawa Manufacturing Operations. Currently, in the EMC Engineering Dept, Common Technology Group.

Taichi HARA

Joined the company in 2005. Since then, has engaged in development of EMC assessment technology. Currently, in the EMC Engineering Dept, Common Technology Group.

Hideo HANAMOTO

Joined the company in 1978. Since then, has engaged in business planning by way of development, quality control, and prototyping of in-vehicle electronic devices. Currently, Department General Manager of the EMC Engineering Dept, Common Technology Group and Department General Manager of Nakatsugawa Technical Center.