

Research on FM Band Radio Noise Visualization System for Hybrid Vehicle

Toshiyuki UEMORI* Masami SUNAGA*

ABSTRACT

Research has been conducted on a system enabling visualization of FM band radio noise produced by the high-voltage components in a hybrid vehicle.

The system is composed of an electromagnetic field detection device that detects electromagnetic radiation noise, a measuring device and interface that scan the output of the electromagnetic field detection device, a spectrum analyzer that analyzes the frequency of the electromagnetic radiation noise, and a PC that processes the data.

The system employs a camera mounted above the high-voltage components in the hybrid vehicle. The camera records images of the components. In combination with the measuring device, this enables noise to be detected in each operating state of the high-voltage components. Electric field strength data that has been analyzed for frequency by the spectrum analyzer and photographic data are then synthesized to produce contour diagrams, enabling noise sources to be identified.

This method has enabled simple identification of noise sources and noise frequency bands, thereby reducing the time needed to identify a noise source and apply a countermeasure to one-third against conventional methods.

1. Introduction

Today's spiraling crude oil prices and increasing concern towards the protection of the environment are generating greater demand for hybrid vehicles, given their high fuel efficiency and effectiveness in reducing CO₂ emissions.

In the development of hybrid vehicles, the FM band (76-108 MHz) radio noise produced by the high-voltage components in the vehicles represents an issue from the perspective of commercial appeal. The common mode noise and differential mode noise produced by the high-voltage components propagates through the vehicle body, cables, and harnesses, and is radiated as electromagnetic radiation noise. This electromagnetic radiation noise is received by the radio antenna, and introduces extraneous noise to the audio output of the radio, thus affecting the consumer appeal of the radios in the vehicles.

In order to contribute to a resolution of this issue, research was conducted on an FM band radio noise visualization system that would enable identification of

noise sources among the high-voltage components and rapid verification of the effectiveness of countermeasures. This paper will discuss the development concept and the developed visualization technology.

2. System Concept

Figure 1 shows a flow chart for conventional noise source identification. Figure 2 shows the conventional method of identification and different types of noise. In the conventional process, frequencies at which noise increases are identified through hearing tests, manual measurements of noise in the high-voltage components are taken using an electromagnetic field probe, and a spectrum analyzer is used to analyze the frequencies, after which countermeasures are implemented. This method uses hearing tests to determine noise increases, without identifying noise increases in other components or other frequency ranges. Due to the repetition of the process, a certain amount of time is needed for the identification of noise sources and the adoption of countermeasures.

* Automobile R&D Center

The developed system is the product of research on an evaluative system enabling rapid visual quantification of noise sources.

The system concept was established as follows:

- (1) Able to automatically measure the common mode noise produced between the high-voltage components and vehicle body ground and the differential mode noise produced between the circuits, and to identify noise sources via a visual display
- (2) Able to specify and analyze the frequency of the noise source

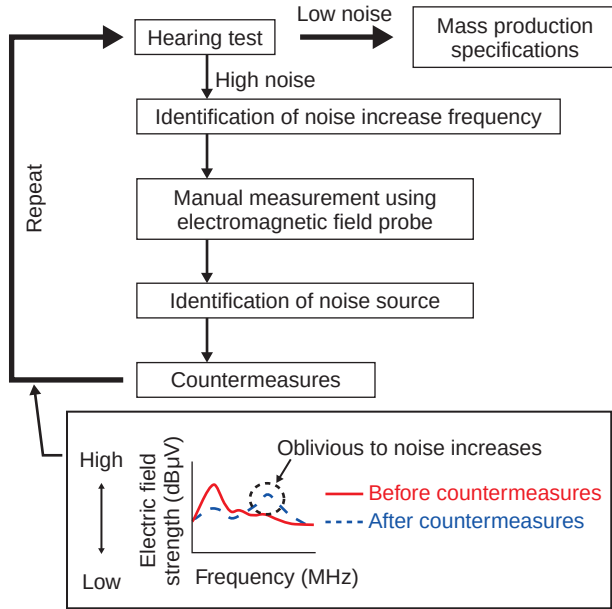


Fig. 1 Noise source specific flow chart

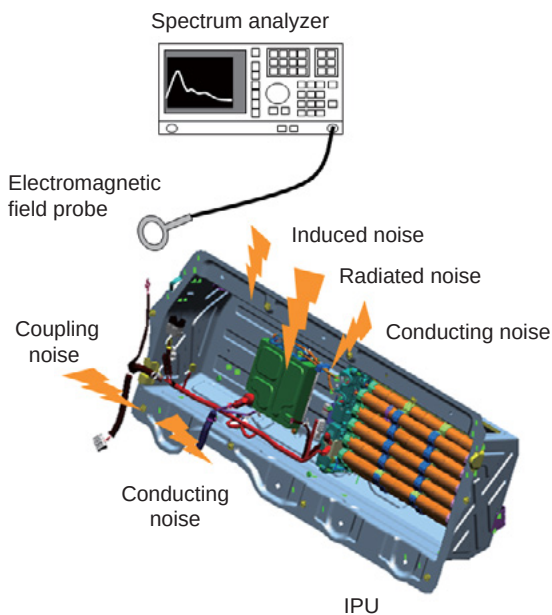


Fig. 2 Conventional method and kind of noise

3. System Overview

The Intelligent Power Unit (IPU), a high-voltage component fitted in a hybrid vehicle, is made up of a Power Control Unit (PCU), a high-voltage battery, and a junction board. The PCU is made up of a Power Drive Unit (PDU), a DC-DC converter, and an ECU. The configuration of the units is shown in Fig. 3.

The noise produced by these units propagates through the cases, covers, harnesses, cables, and the vehicle body, and is radiated.

3.1. System Configuration and Specifications

Figure 4 shows the configuration of the developed system. An electromagnetic field detection device is positioned above the high-voltage components in a hybrid vehicle and measures electromagnetic radiation noise by conducting scans in an X-Y plane. A spectrum analyzer is used to analyze the frequency of the noise. The analyzed noise electric field strength data is synthesized with a photograph of the high-voltage components that has been taken separately, to enable the distribution of the electric field strength of the noise to be visualized and displayed as a contour diagram, thereby enabling identification of the noise source.

Table 1 shows the specifications of the developed FM band radio noise visualization system.

3.2. Configuration of Measuring Device

The measuring device has both large and small configurations, which can be selected depending on the area in which the measurements will be conducted. In order to increase the measurement sensitivity of the probe, both the large and small devices are able to be moved up

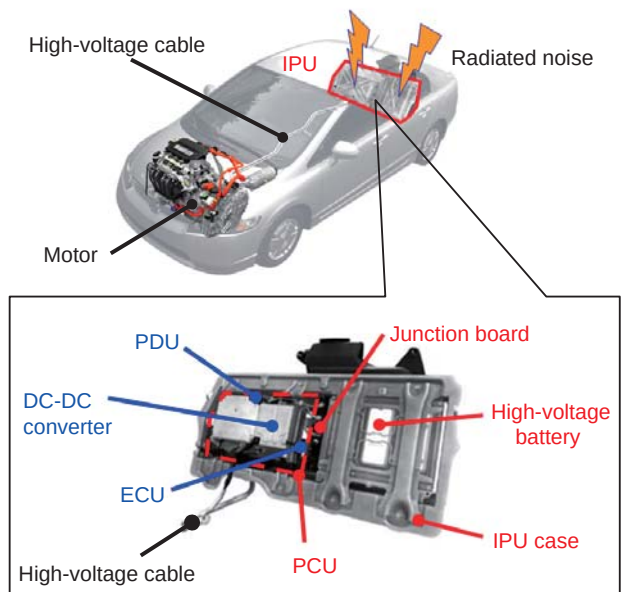


Fig. 3 IPU configuration

Table 1 Noise visualization system specifications

Item	Specification	
	Large measuring device	Small measuring device
Measurement object	High-voltage electronic components	Small electronic components and harness
Electromagnetic field detection device	4 probes in array configuration	3 probes in series configuration
Sweep method	X-Y plane	Y axis
Z axis movable range	50 (mm)	50 (mm)
Measurement area	500 × 600 (mm)	60 × 100 (mm)
Detailed measurement area	Arbitrarily set	Arbitrarily set
Measurement prohibition area	Arbitrarily set	—
Pitch measurement	1, 2, 4, 5, 10, 20, 50 (mm)	1, 2, 4, 5, 10 (mm)
Probe type	Vertical magnetic field probe Horizontal magnetic field probe Electric field probe	
Amplifier amplification rate	40 dB	
Measurement frequency bandwidth	76 - 108 MHz	
Frequency resolution	1001 point	
Display resolution	Electric field strength is displayed by dividing the range of the maximum value and the minimum value into 8 sections.	

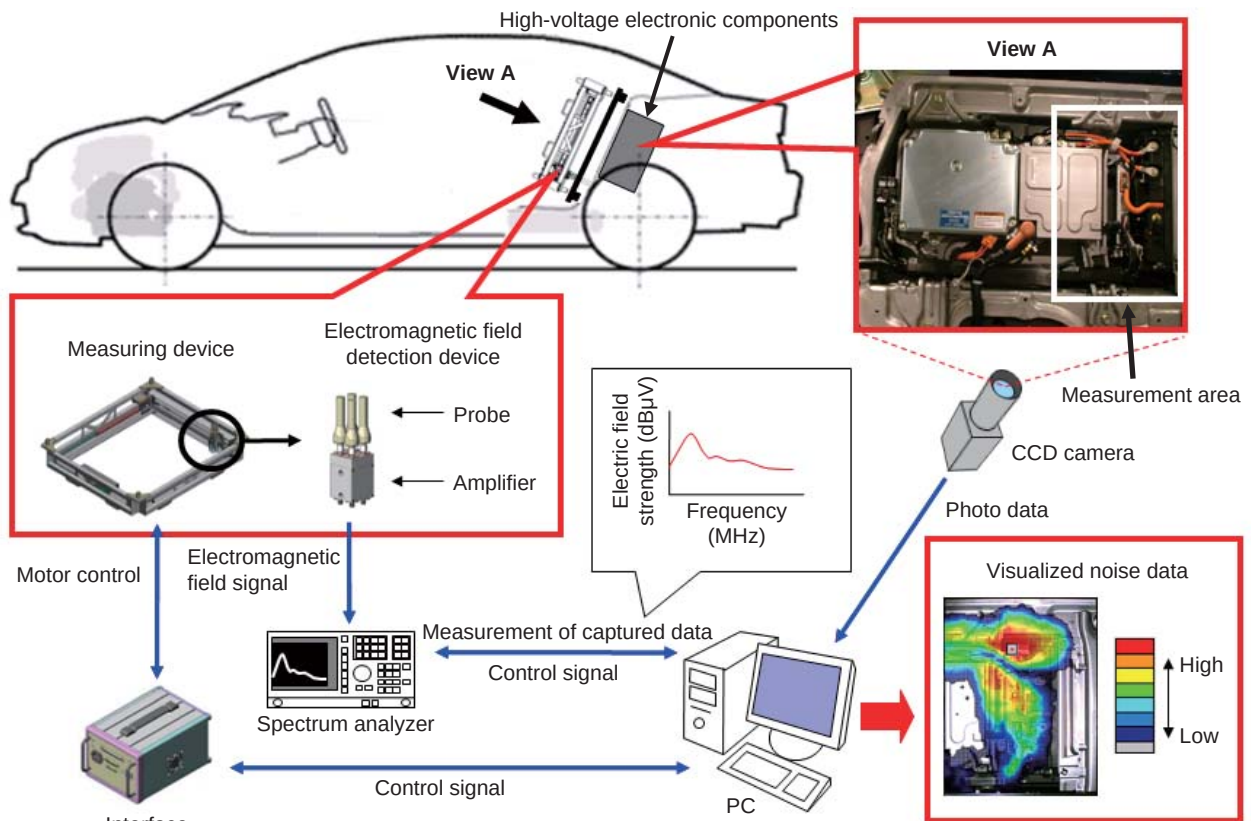


Fig. 4 Configuration of noise visualization system

and down along the Z axis in order to bring the probe closer to the object of measurement.

The mechanism enabling vertical motion along the Z axis in the large measuring device is a plunger, fitted to the amplifier of the electromagnetic field detection device, that enables the height to be adjusted in 5 mm increments from 0 to 50 mm, thus allowing adjustment of the distance between the high-voltage components and the probe. The device can therefore be adjusted for different vehicle layouts. The configuration of the large measuring device is shown in Fig. 5.

The small measuring device is provided with four feet, the height of which can be independently adjusted using feed screws, to enable adjustment of the distance of the probe and positioning of the device in relation to the raised and recessed sections of the structures being measured, thus enabling measurements of harnesses and small electronic components. The height can be adjusted from 0 to 50 mm, and each single rotation of a foot adjusts the height by 0.7 mm. The device is also provided with a quick release mechanism for rougher adjustments, and pressing buttons at the sides of the feet enables the height of the device to be changed rapidly. Figure 6 shows the configuration of the small measuring device.

The electromagnetic field detection device is made up of a probe and an amplifier. In order to increase the sensitivity of the probe and match its impedance to the impedance of the 50Ω spectrum analyzer coaxial cable,

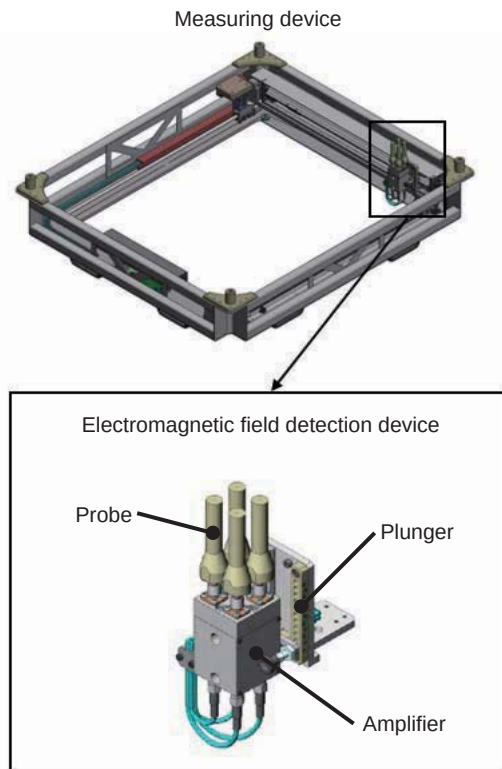


Fig. 5 Configuration of large measuring device

the amplifier is positioned directly below the probe. Figures 5 and 6 show the configurations of the electromagnetic field detection devices.

In order to increase measurement speed and reduce measurement time, the large measuring device employs four probes positioned in an array, enabling four sections of the object of measurement to be measured with each movement of the probes in the X-Y plane.

Because the purpose of the small measuring device is to conduct measurements of harnesses and small components, it employs three probes arranged in a line, enabling the measurement area to be set narrow, and helping to ensure that measurement accuracy does not decline. The specifications of the probes have been selected to enable measurement of vertical magnetic fields, horizontal magnetic fields, and electric fields. Figure 7 shows the internal configurations of the probes.

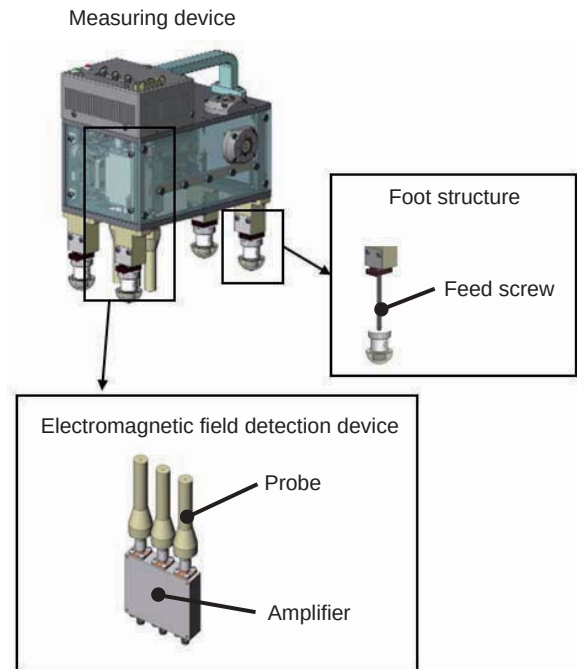


Fig. 6 Configuration of small measuring device

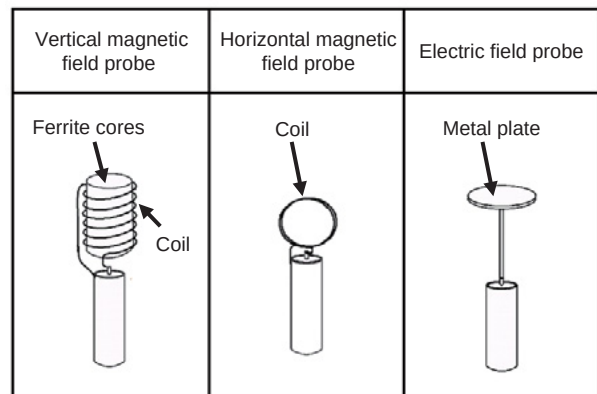


Fig. 7 Internal configuration of probes

4. Details of Visualization Technology

4.1. Mechanism of Generation of Electromagnetic Radiation Noise

When high-frequency current passes through a conductor, a magnetic field is generated. Through the principle of electromagnetic induction, changes in the magnetic field produce electromotive force, and this

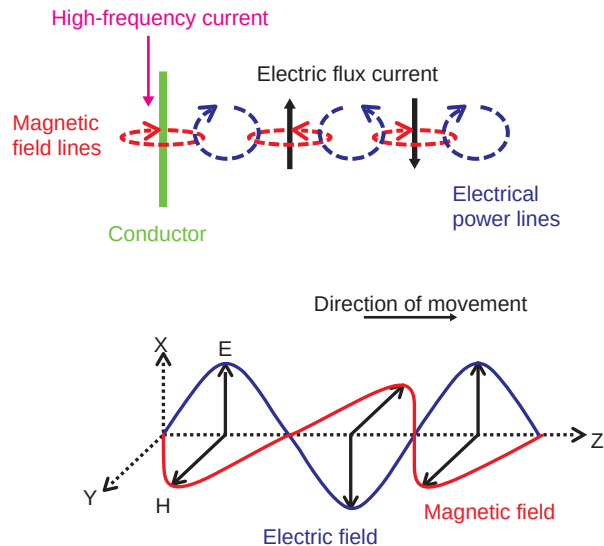


Fig. 8 Mechanism of generation of electromagnetic radiation noise

generates an electric field. Changes in the electric field produce an electric flux current, generating a magnetic field. In this way, electric fields and magnetic fields are formed successively in a chain reaction, and spread through space as electromagnetic radiation noise ^{(1),(2)}. The mechanism of generation of electromagnetic radiation noise is shown in Fig. 8.

4.2. Principle of Noise Visualization

Measurement areas are established in the high-voltage components. The electromagnetic field detection device scans the measurement areas in the X-Y direction, and the frequencies of the detected electromagnetic field noise are analyzed by a spectrum analyzer. Data for each area are input into a PC at a resolution of 1001 points on the frequency axis, and the data for all areas is saved. The peak levels are isolated for either the entire measured frequency range or a specified range, and the noise electric field strength data for each area are displayed as strength distribution diagrams.

Figure 9 shows the principle of visualization, assuming 9 (3 × 3) measurement areas. In terms of the resolution of the displayed data, the range between the maximum and minimum points for each area is divided into eight equally-spaced intervals, which are distinguished by color; the areas of highest electric field strength noise are shown as red, and the areas of lowest electric field strength noise are shown as blue or uncolored. Software is employed for interpolation

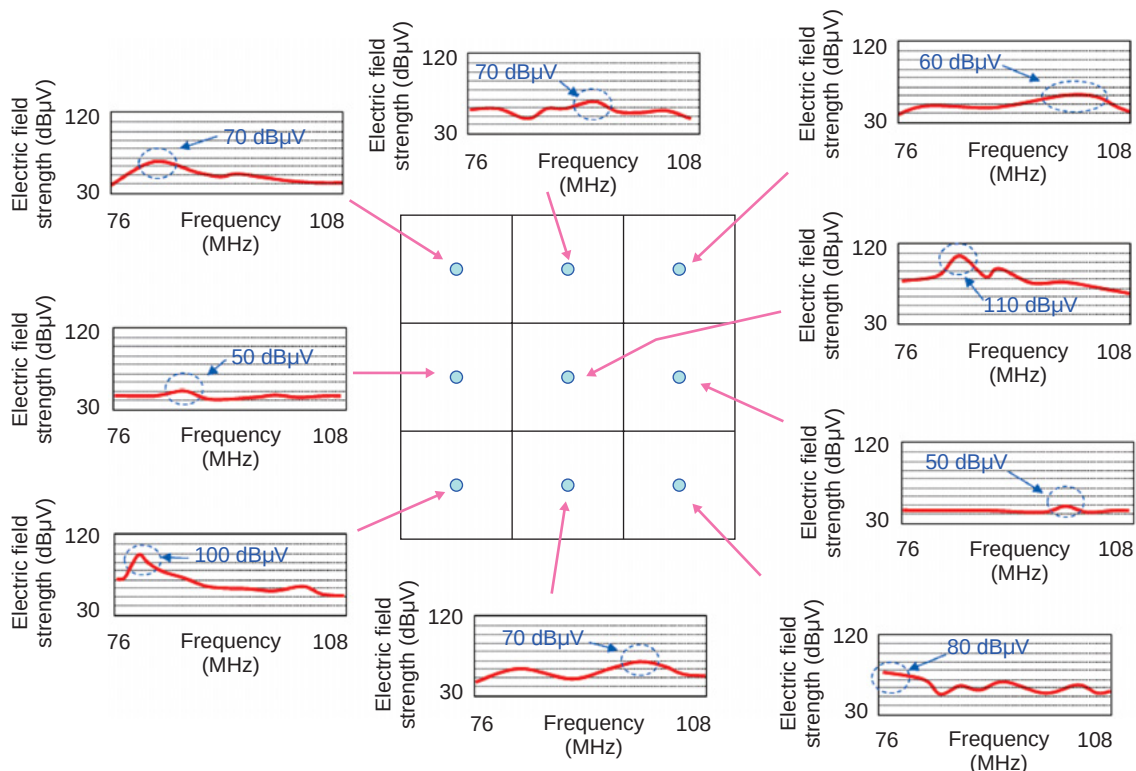


Fig. 9 Principle of visualization

processing of the obtained strength distribution diagrams, enabling a smooth contour diagram to be displayed. The interpolation program linearly interpolates strength levels with adjacent strength levels, and calculates intermediate strength levels and positions.

Figure 10 shows a conceptual diagram of interpolation. The level of strength of the electric fields at the centers of each measurement area (shown in bold) are connected to the strength levels of the adjacent areas in eight directions by straight lines, and the level of difference in strength is calculated at equal intervals. The density of change differs depending on the magnitude of the level of difference. The smaller font figures shown in Fig. 10 are intermediate levels obtained from calculations. Identical levels obtained using this processing method are connected using identical colors, enabling a diagram of the distribution of strength levels to be formulated. The processing is applied to all the measurement areas in order to calculate intermediate levels and formulate a strength distribution diagram.

4.3. Measurement Resolution and Specification of Areas

The developed system enables identification of noise sources by superimposition of the noise electric field

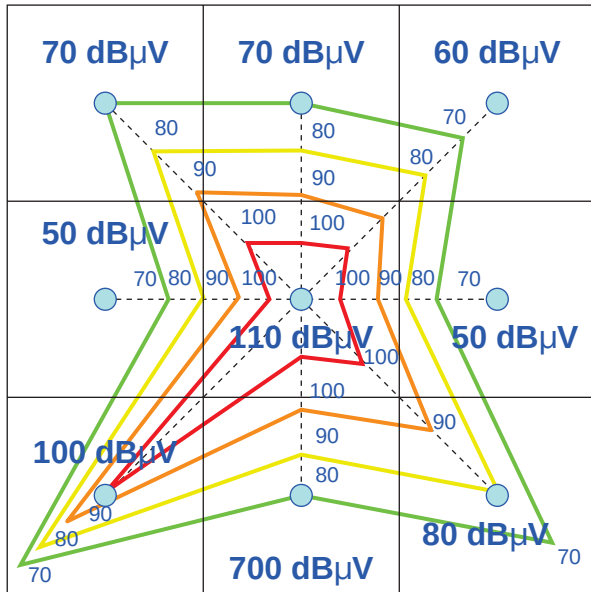


Fig. 10 Concept of interpolation

Parts	Size (mm)	Pitch measurement (mm)					
		10	20	30	40	50	60
PCU	600						
PDU	200						
DC-DC converter	150						
Connector	50						
Cable	10						
Harness	2						

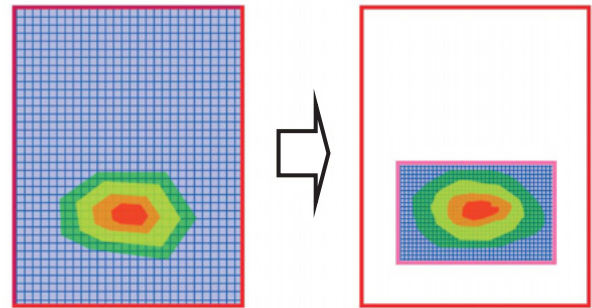
Fig. 11 Pitch measurement

strength data on a photograph of the object of measurement. This makes measurement resolution an important factor. As shown in Fig. 11, the resolution tolerances for the measuring device in relation to the size of the high-voltage components were studied, and resolution tolerances of 1, 2, 4, 5, 10, 20, and 50 (mm) were set for the device. Measurement of a measurement area of 500 x 600 (mm) at a minimum resolution pitch of 1 mm would take an enormous amount of time, and would therefore be impractical. Therefore, the area producing noise is first rapidly identified at a rough resolution, with a maximum pitch of 50 mm. Next, a measurement resolution is selected on the basis of the size of the components in the area producing noise, and the noise source is identified with more detailed measurements. This method has enabled measurement time to be reduced.

The developed system therefore incorporates, in addition to a function enabling measurement resolution to be set, a function enabling the measurement area to be freely set. Figure 12 shows an image of a detailed measurement.

4.4. Frequency Analysis

A pointer indicating the maximum area of noise electric field strength in the relevant bandwidth appears on the noise electric field strength distribution displayed as a contour diagram, and the spectrum of this area is determined. The system is also provided with a function enabling the pointer to be freely moved in order to enable the spectrum of each area to be determined. In addition, the system enables the range of frequencies for visualization and display as contour diagrams to be freely specified, and results can therefore be restricted to the frequencies at which noise increases in hearing tests and



	Measurement area: 500 × 600 mm
	Detailed measurement area: (Ex)
	Pitch measurement: 50 mm
	Pitch measurement: (Ex) 10 mm

Fig. 12 Image of detailed measurement

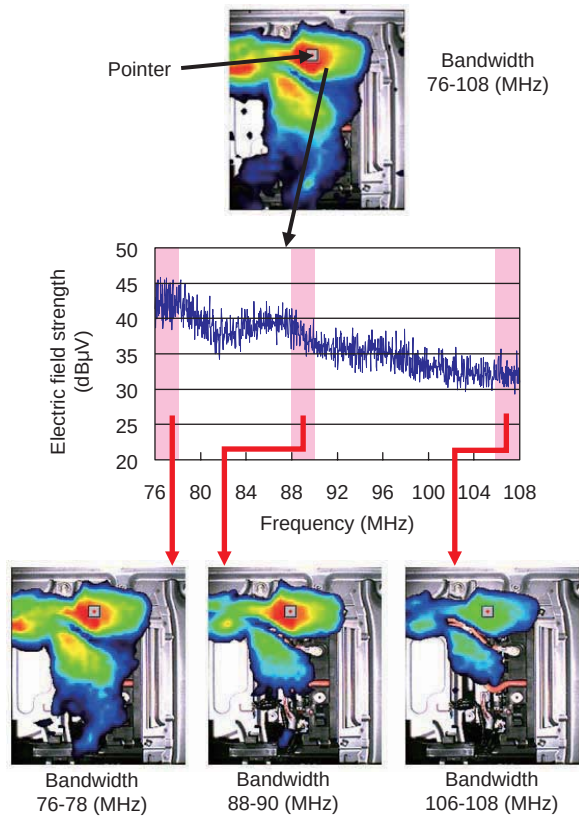


Fig. 13 Frequency analysis

the electric field strength distribution at these frequencies rendered as contour diagrams, thus enabling detailed noise source identification. Figure 13 shows a contour diagram and spectrum analysis data for the entire bandwidth, and contour diagrams for specific partial bandwidths.

5. Results of Verification

The effectiveness of the developed system was verified using a 2009 model year INSIGHT. The tests demonstrated the effectiveness of the system in identifying

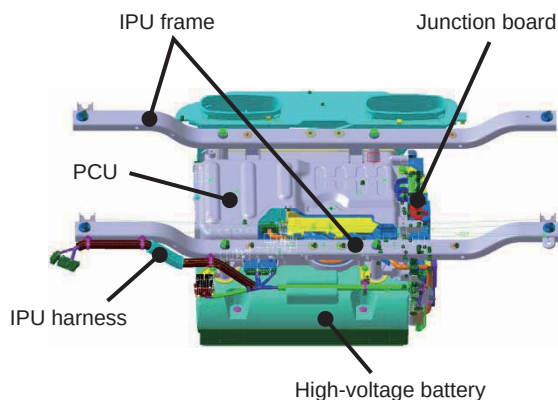


Fig. 14 IPU configuration

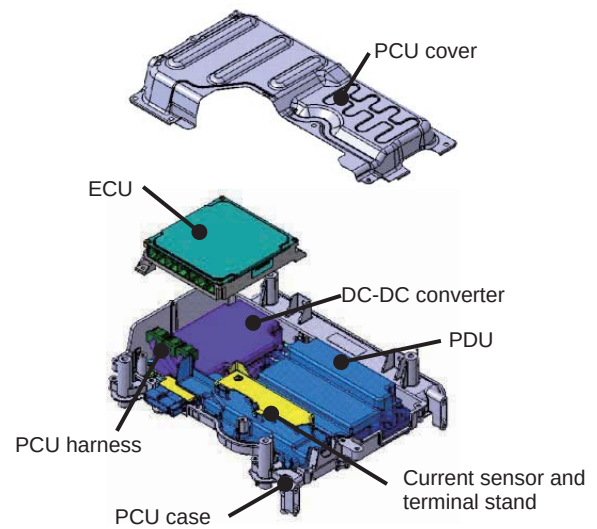


Fig. 15 PCU configuration

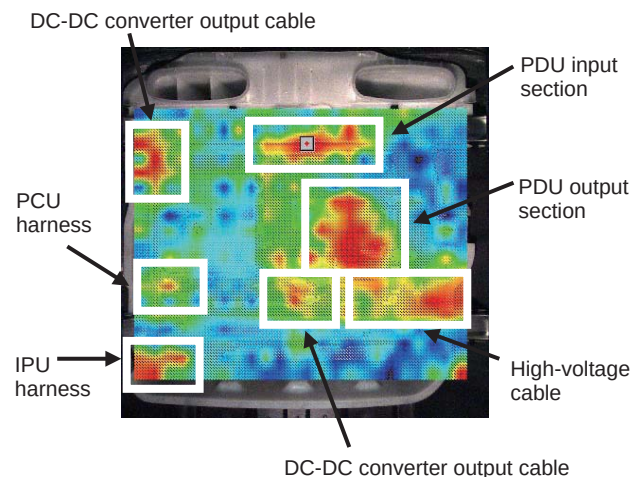
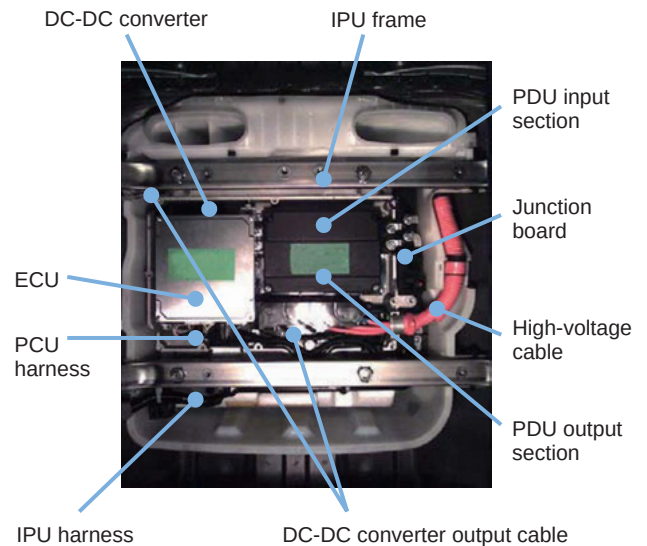


Fig. 16 Identification of noise sources

noise sources and propagation paths. In addition, the system enabled identification of noise sources in one-ninth or less than one-ninth of the time and implementation of countermeasures in one-third or less than one-third of the time required by the conventional method.

The high-voltage components of the 2009 model year INSIGHT used in the verification are shown in Figs. 14 and 15. The IPU is made up of a PCU, high-voltage battery, junction board, IPU harness, and IPU frame. The PCU in the IPU is made up of a PDU, DC-DC converter, ECU, PCU harness, PCU case, and PCU cover.

5.1. Identification of Noise Sources and Propagation Paths

A large measuring device was positioned above the IPU, and measurements were conducted of the interior of the PCU with the PCU cover removed, in order to identify which of the components were noise sources, and which harnesses and cables were propagation paths.

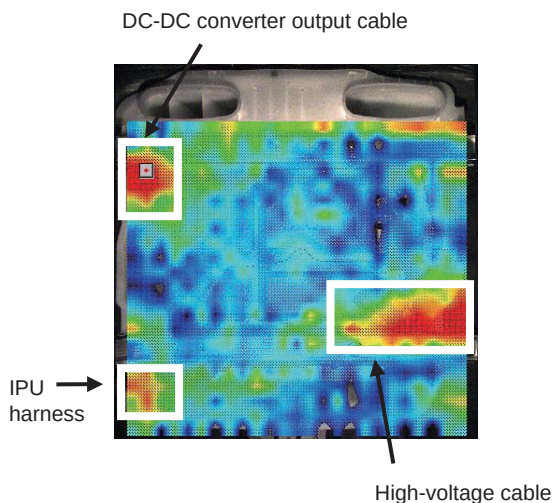
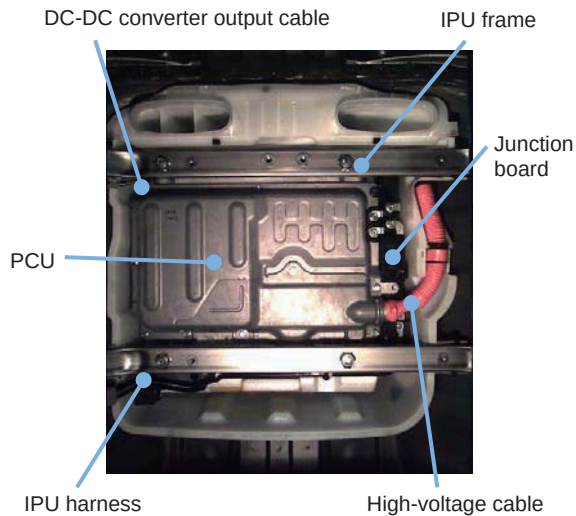


Fig. 17 Identification of propagation route

Figure 16 shows the results of measurement of the noise electric field strength distribution of the electromagnetic field noise radiating from each component in the PCU. The results show that the system was able to conduct a detailed identification of noise sources in the IPU, with noise being identified as being produced by the input and output sections of the PDU, the output section of the DC-DC converter, the PCU harness, IPU harness, DC-DC converter output cable, and high-voltage cable.

Next, the PCU cover was replaced, and the system was used to determine which paths the noise produced by each of the components inside the PCU was propagating along and radiating from. Figure 17 shows the noise electric field strength distribution. These results show that the

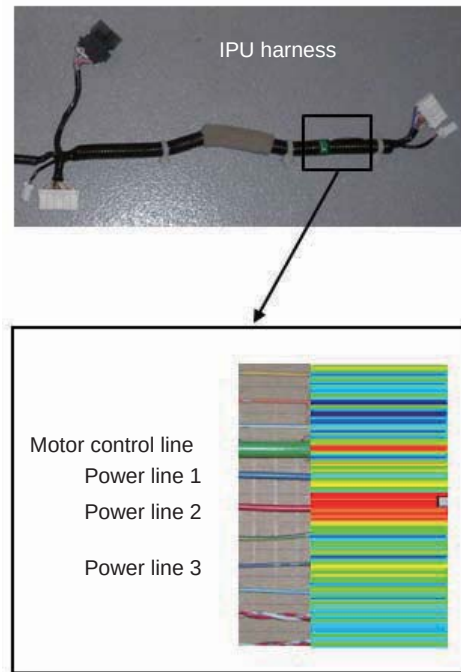


Fig. 18 Measurement results for harness

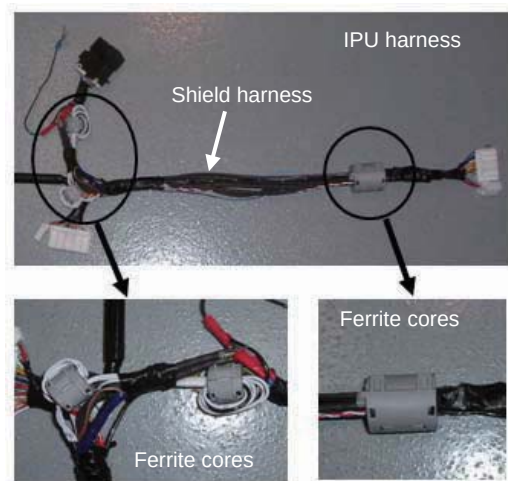


Fig. 19 Countermeasures

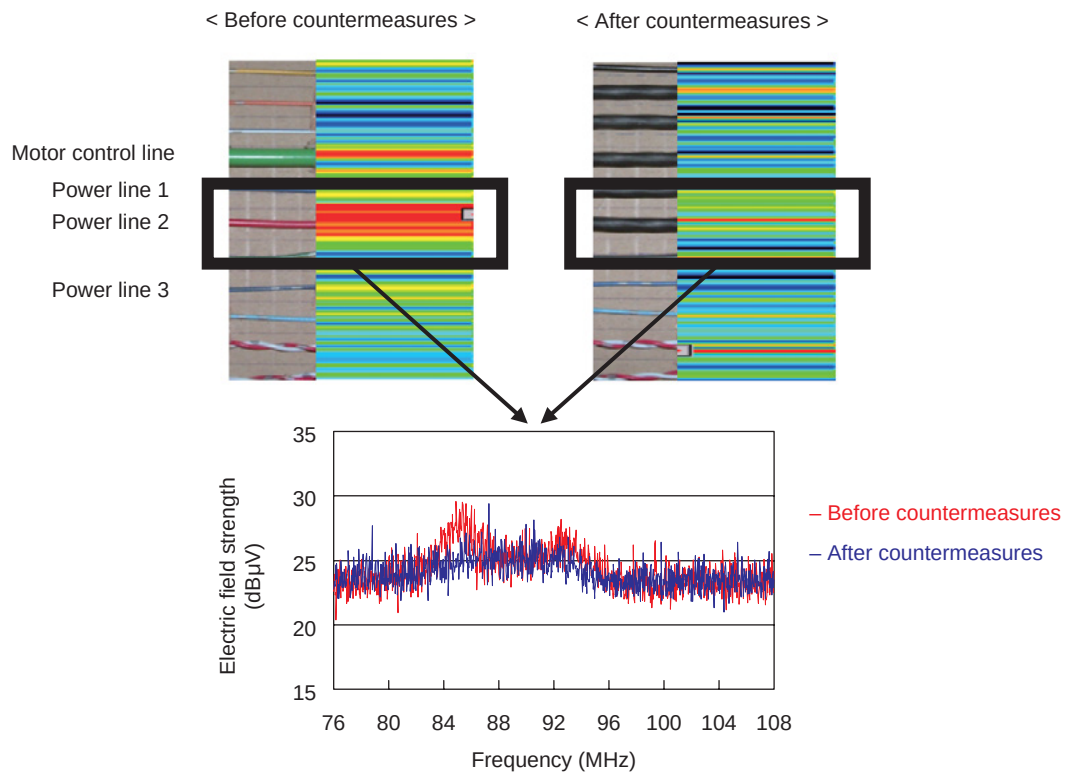


Fig. 20 Noise reduction effect of IPU harness

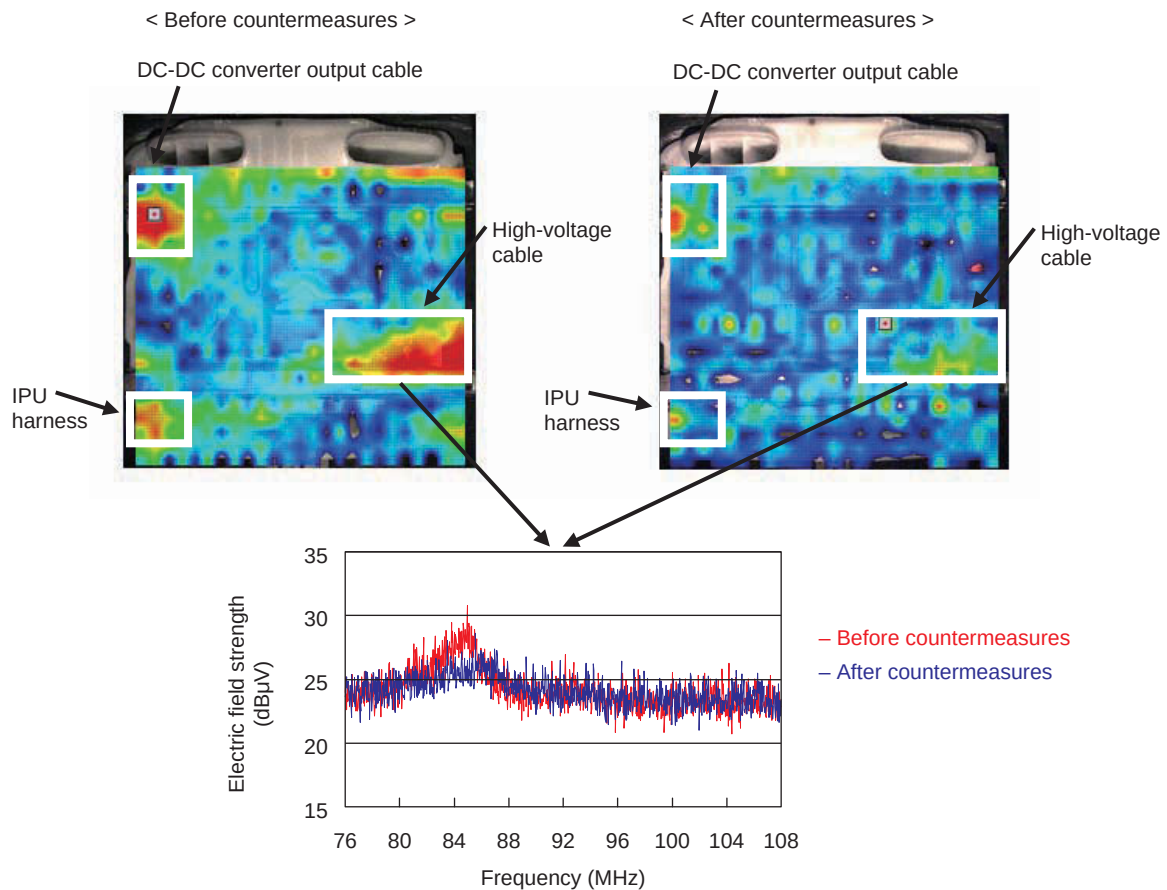


Fig. 21 Noise reduction effect of IPU unit

noise produced by the PDU and the DC-DC converter is shielded by the PCU cover, and propagates along and radiates from the IPU harness, the DC-DC converter output cable, and the high-voltage cable. The system was therefore able to verify the noise reduction effect of the PCU cover, and identify noise propagation routes.

The small measuring device was then used to identify noise propagation circuits in the IPU harness. Figure 18 shows the results of measurement of the noise electric field strength distribution in the IPU harness. As the results show, the system was able to identify noise propagation from the power lines between the PDU and ECU in the PCU and the motor control line.

These results verify that the use of the large and small measuring devices, depending on the area being measured, enables detailed identification of noise sources and propagation routes.

5.2. Frequency Analysis

The frequency analysis function of the system is used to enable optimum countermeasures to be applied for the frequencies at which noise was aurally perceived as increasing.

In the 2009 model year INSIGHT, the bandwidth in which noise increased in the IPU harness noise propagation route was identified, and the noise-reducing components that would have the greatest noise reduction effect in that bandwidth were selected and reflected in the vehicle specifications.

In this case, a shield harness and ferrite cores were selected for use, and the number of windings in the core was specified. These countermeasures against noise propagating through the IPU harness are shown in Fig. 19, and their noise reduction effect is shown in Fig. 20. Figure 21 shows the noise reduction effect in the IPU unit achieved by the employment of the IPU harness as a countermeasure. This noise reduction in the IPU as a whole occurs as a result of reducing the ground impedance of the PCU and controlling fluctuations in the electric potential of the ground by grounding the drains at both ends of the shield harness against the PCU case and vehicle body.

6. Conclusion

Research was conducted on an FM band radio noise visualization system, with the following results.

- (1) Fitting the measuring device in the vehicle enabled identification of noise sources in relation to the load on the high-voltage components.
- (2) The employment of automatic measurement, the use of probes positioned in an array, and the employment of detailed measurement functions enabling the measurement resolution to be set and the measurement area to be specified reduced measurement time.
- (3) The display of contour diagrams and pointers enabled

noise sources to be identified instantaneously, and enabled frequency components to also be identified.

- (4) The system was able to clearly identify noise sources, and enabled accurate selection of specifications and components to act as countermeasures to the specific frequency bandwidths of the noise sources.

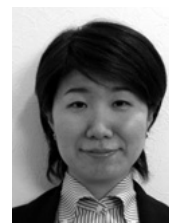
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■ Author ■



Toshiyuki UEMORI



Masami SUNAGA