特集 ESD Current Measurement Using the Near Magnetic Field *

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In order to evaluate the robustness of automotive ECU's against electrostatic discharge, a conventional method where electrostatic discharge pulses are applied to connector parts on a printed circuit board is commonly used.

However, until now quantitative re-designing principles to improve the static electricity tolerance that fully utilize the test data shown below have not been made clear because the propagation mechanism of static electricity on a circuit board was not clear.

This paper describes the ESD current measurement technique which detects the near magnetic field generated by ESD currents. We developed a technique to measure the ESD currents using a new loop antenna on the circuit board. The ESD current, was generated with the static electricity applied to a model circuit pattern in conformity with IEC and ISO standards and measured using the antenna. It was also possible to visualize how static electricity energy would propagate through the circuit board. We concluded that ESD current measurement via the near magnetic field and using a small shielded loop antenna was effective

Key words: ESD current measurement, Near magnetic field, Shielded loop antenna

1. INTRODUCTION

In static electricity testing of vehicle-mounted ECU's, static electricity is applied to the connectors of ECU circuit board to evaluate their static electricity characteristics. However, this evaluation method is capable of identifying the effects of static electricity only when an element malfunctions or is destroyed. With this method, it is difficult to clarify how the energy generated by static electricity has propagated on a circuit board. Therefore, it is currently difficult to quantify countermeasure results.

This paper discusses the method of detecting energy generated by application of static electricity as a high-frequency current, using a magnetic probe. When static electricity is applied to an ECU connector, this probe non-contactually detects the near magnetic field generated by current flowing in the circuit board pattern.

In a static electricity discharge test based on the human body model defined in the IEC and the ISO standard, the discharge current waveform has a rise time usually on the order of several nanoseconds, forming a wide-band signal. In addition, the strong electric field that the discharge gun produces around itself tends to affect the test duringdischarge. We downsized the shielded loop antenna for near magnetic field detection and reinforced the shielding effect, making the antenna less susceptible to the effect of an electric field. We also developed a shielded loop antenna enabling us to accurately detect the near magnetic field generated by current flowing on a circuit board at the time of static electricity discharge. These efforts led to successful measurement of static electricity discharge current.

We also confirmed that this measuring method enables quantitative evaluation of the effect of a bypass capacitor attached as an anti-static-electricity measure, as well as visualization, at the time of static electricity discharge, of discharge current propagation on an ECU circuit board.

2. MEASUREMENT OF CURRENT AT TIME OF STATIC ELECTRIC DISCHARGE

Figure 1 shows the discharge current measured at static electricity discharge toward a target, as specified by the IEC standard, which assumes the human body to have an

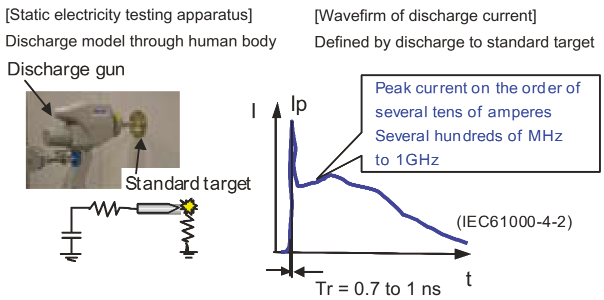


Fig. 1 Static electricity dischage test

electrostatic capacity of 330 pF and a discharge resistance of 150 Ω. The discharge current is characterized by an impulse current waveform with a rise time of several nanoseconds and a wide-band feature. According to the ISO standard, the human body has an electrostatic capacity of 330 pF; or with a human body assumed to have an electrostatic capacity of 150 pF, the resistance of a human body comes to 2 kΩ. Although this increases the time constant at time of discharge, the rise time associated with discharge is still represented by an impulse current waveform with a rise time of several nanoseconds.[1)]

In one method for measuring static electricity discharge current, the discharge current value is measured using the voltage drop on the standard target, which develops when static electricity is discharged toward the standard target, the low resistance shown in **Fig. 1** being the only way of defining the current waveform at the time of static electricity discharge. With this method, however, it is difficult to measure the current waveform appearing as the result of static electricity application to an actual ECU circuit board.

3. PRINCIPLE OF DISCHARGE CURRENT MEASUREMENT USING THE NEAR MAGNETIC FIELD

Static electricity applied to an ECU circuit board propagates on the circuit board pattern in the form of high frequency current or voltage. Regarding propagation in the form of voltage, it is known that an EO (ElectroOptic) probe has entered the early stage of practical application and that the possibility of its use for static electricity measurement is foreseen; these subjects will be taken up later. This section describes the method of measuring current.

In the field of noise measurement, an apparatus has been commercialized that measures noise distribution on an ECU circuit board by scanning it with a micro loop antenna and measuring the distribution of noise radiated from the circuit board.[2)-4)] We examined the possibility of measuring the distribution of static electricity by a similar method.[5)-7)]

Figure 2 shows a method of measuring high frequency current flowing in a circuit board pattern. In this method, high frequency current flowing in the circuit board is measured using a shielded loop antenna that measures the magnetic field generated by the current flowing in the pattern. When the distance to the circuit board pattern is known, the value of the current in the pattern can be

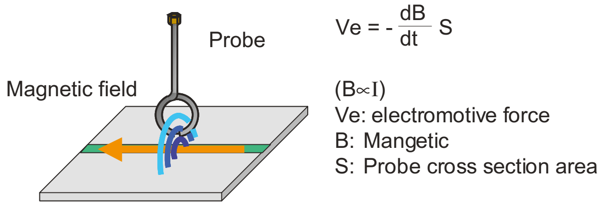


Fig. 2 Measurement of near magnetic field

estimated. The result of measurement obtained using a magnetic field detecting antenna represents a value obtained by differentiating the value of the current flowing in the circuit board pattern. This method is suitable for measuring a single spectrum, such as radiated noise. However, measurement of a current waveform taking an impulse waveform under static electricity discharge requires measurement result correction using the frequency characteristics of the probe employed.

Confirming that the newly developed magnetic probe has a differentiating characteristic over a several GHz wide band, we decided to subject the magnetic probe measured waveforms to integration correction.

4. NEAR MAGNETIC PROBE FOR MEASURING DISCHARGE CURRENT

4.1 Probe structure

The probe structure shown in **Fig. 3** is commercialized for measuring noise on a circuit board.

This magnetic probe consists of a substrate composed of three layers, the first and the third of which form the GND layers and the second the signal line, embodying a shielded loop antenna, usually comprising a coaxial cable, with a multi-layer substrate. It can be foreseen that, when this probe is used to measure static electricity, it allows an electric field to enter easily in the direction of its thickness,

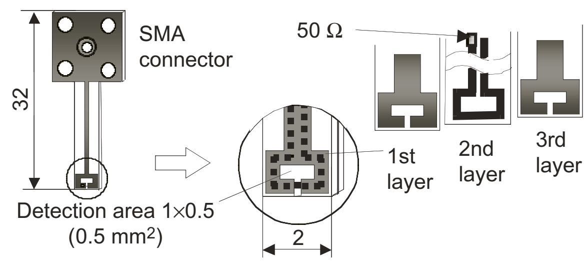


Fig. 3 Near magnetic probe

resulting in lower detection accuracy. To eliminate this problem, we adopted a structure that only allows use of the probe end portion for detecting a near magnetic field; specifically, a structure whose first and third layers are connected, to reinforce the shielding effect in the direction of substrate thickness. The shielding in the loop at the tip of the magnetic probe is also reinforced so that its structure might be physically identical to that of a coaxial-structured shielded loop antenna. In addition, the entire magnetic field antenna is molded with resin to prevent discharge to the antenna during static electricity discharge **(Fig. 4)**.

4.2 Probe performance

To verify the effect of the reinforced shielding, high frequency current was fed to the magnetic probe to measure the magnetic field generated near the magnetic probe. **Figure 5** shows the measurement result. Magnetic field x- and y-components were measured and combined. The results verified that GND layer reinforcement allowed only use of the magnetic probe loop tip for detecting a magnetic field.

We used the component configuration shown in **Fig. 6** to measure the frequency characteristic of the probe with reinforced shielding. The magnetic probe was placed on the microstrip line; the other end of the microstrip line, to which high frequency signals were input, was terminated to ensure matching. Under this condition, high frequency signals underwent sweeping to measure the probe frequency characteristic; the results are shown in **Fig. 7**, where output is seen to increase proportional to the frequency and the gain gradient is 20 dB/dec. This shows that the probe is of the magnetic-field detecting type. Lastly, **Figure 8** shows the results of magnetic probe spacial resolution measurement.

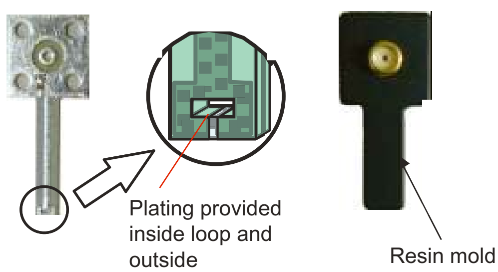


Fig. 4 Refinement to near magnetic probe

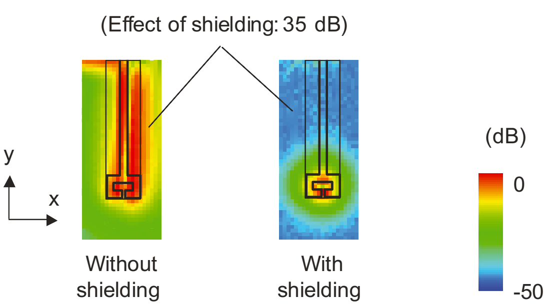


Fig. 5 Near magnetic probe shielding performance

Measurement is conducted 1.0 mm above the circuit board.

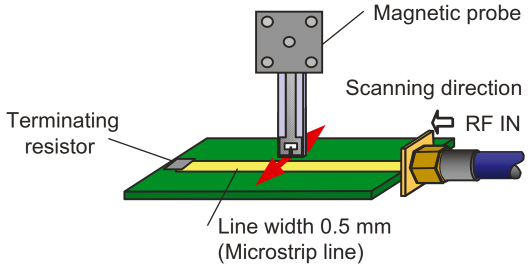


Fig. 6 Method of measuring frequency characteristic and resolution

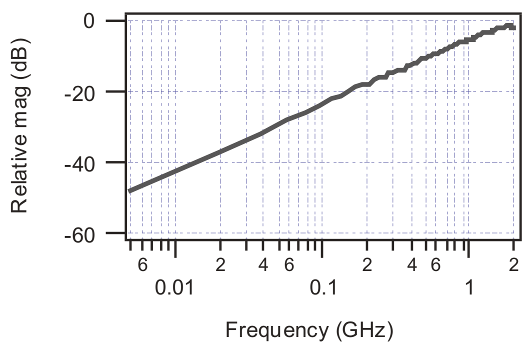


Fig. 7 Frequency characteristic of magnetic probe

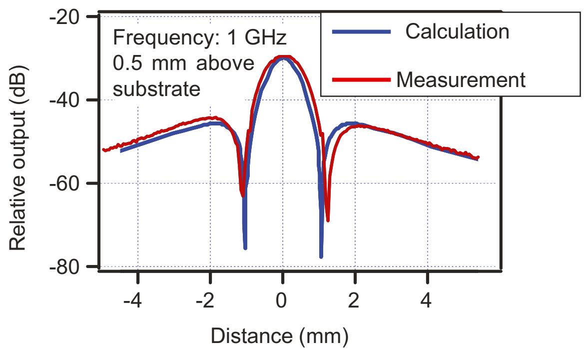


Fig. 8 Spacial resolution of magnetic probe

These were obtained by moving the magnetic probe in a direction orthogonal to the microstrip line and measuring probe output at different positions. The curves were plotted using relative values with reference to output on the microstrip line. The spacial resolution obtained was about 0.5 mm.

5. DISCHARGE CURRENT MEASURING ACCURACY

The test bench shown in **Fig. 9** was made to measure discharge current appearing under static electricity discharge.

With the discharge gun kept in contact with the printed circuit board terminal, static electricity was applied to the terminal and discharge current was allowed to flow to the terminating resistor via the straight-line pattern. In this condition, the magnetic probe was placed on the circuit board pattern while the high frequency current-measuring probe measured the discharge current flowing in the pattern. The results are shown in **Fig. 10**.

The magnetic probe measurement results were multiplied by a correction factor obtained by integrating the magnetic probe output. This yielded a result that approximated the result obtained using the high frequency probe. Regarding the voltage waveform, we measured difference in voltage across the terminating resistor during discharge, as shown in **Fig. 11**, using an EO probe. The result is shown in **Fig. 12**. Obtaining a voltage waveform nearly similar to the discharge current waveform, we concluded that the discharge current and difference in voltage had been measured accurately.

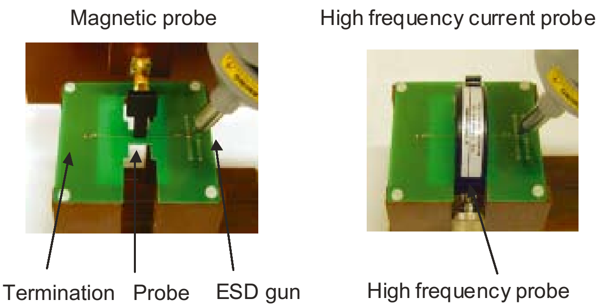
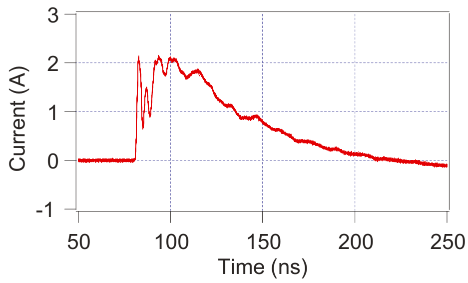
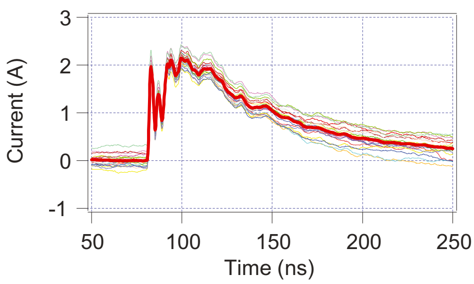


Fig. 9 Measurement method of discharge current



(a) Current waveform measured by magnetic field probe



(b) Current waveform measured by high frequency probe

Fig. 10 Discharge current

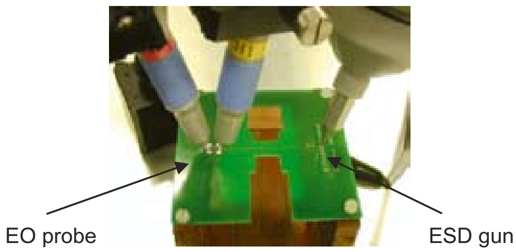


Fig. 11 Measurement method of difference in voltage

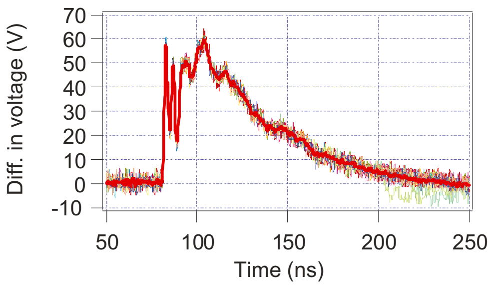


Fig. 12 Difference in voltage measured by EO probe

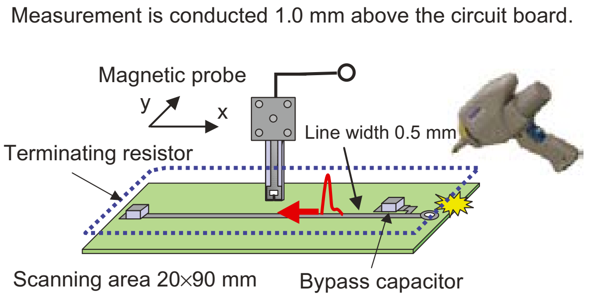


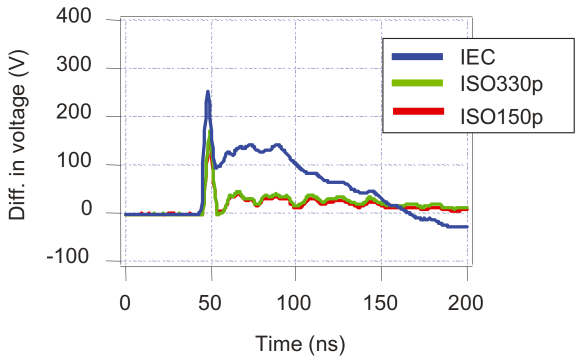
Fig. 13 Measurement method of discharge current on circuit board

6. MEASUREMENT OF DISCHARGE CURRENT INTENDED FOR AN ECU CIRCUIT BOARD

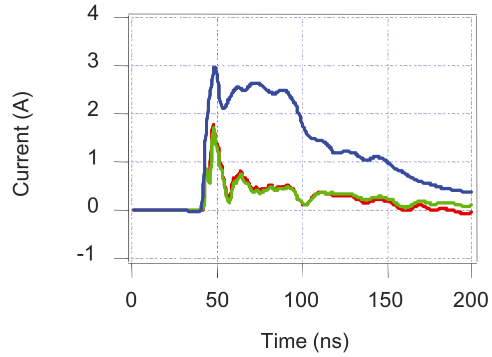
Figure 13 shows a model circuit board intended for measurement of an ECU circuit board using a near magnetic probe, a system for measuring discharge current under the application of static electricity. With a resistor connected to the termination, static electricity was applied to the terminal; the discharge current flowing on the pattern in between was measured by the magnetic probe.

With the discharge gun set in accordance with IEC61000-4-2 and the ISO standard, the waveforms of current flowing in the circuit board pattern were measured; the results are shown in **Fig. 14**, which also shows the EO probe measurement results for difference in voltage across the terminating resistor. This was measured concurrently with the current waveform. The result shows that measurement based on the IEC standard, which specifies a lower discharge resistance of 330 Ω, resulted in larger discharge current, while measurement based on the ISO standard, which specifies a higher discharge resistance of 2 kΩ, resulted in smaller discharge current.

Next, we measured the discharge current distribution in the pattern of the model circuit board, placed on a biaxially movable stage shown in **Fig. 15**, by sweeping the circuit board with the magnetic probe at every occurrence of discharge. The results are shown in **Fig. 16**. **Figure 16 (a)** shows the discharge current distribution on the circuit board with no bypass capacitor attached, showing that the absence of a bypass capacitor allows the discharge current to flow to the terminating resistor. In contrast, **Figure 16 (b)** shows the discharge current distribution on the circuit board with a 0.047 μF bypass capacitor attached, showing that the discharge current is bypassed by the bypass capacitor, so



(a) Difference in voltage across the terminating resistor w/o capacitor



(b) Discharge current w/o capacitor

Fig. 14 Discharge current and voltage on circuit board

does not reach the terminating resistor. This static electricity discharge current distribution measurement enabled us to quantitatively estimate how the discharge current flows, and the effectiveness of a bypass capacitor or the like. We also measured the frequency characteristic distribution in the pattern of the model circuit board. This distribution was measured S21 between feeding point and magnetic probe by sweeping the circuit board at every position. The results are shown in **Fig. 17**.

7. STATIC ELECTRICITY DISCHARGE CURRENT MEASUREMENT IN AN ECU CIRCUIT BOARD

Lastly, **Figure 18** shows the measurement results for current distribution in an actual ECU circuit board under static electricity discharge. With 3 kV of static electricity applied to the connector terminal of a vehicle-mounted control system computer, a plane 3 mm from the circuit board pattern surface was swept with a magnetic probe to detect the X-direction and the Y-direction components of the magnetic field. The combined current waveforms

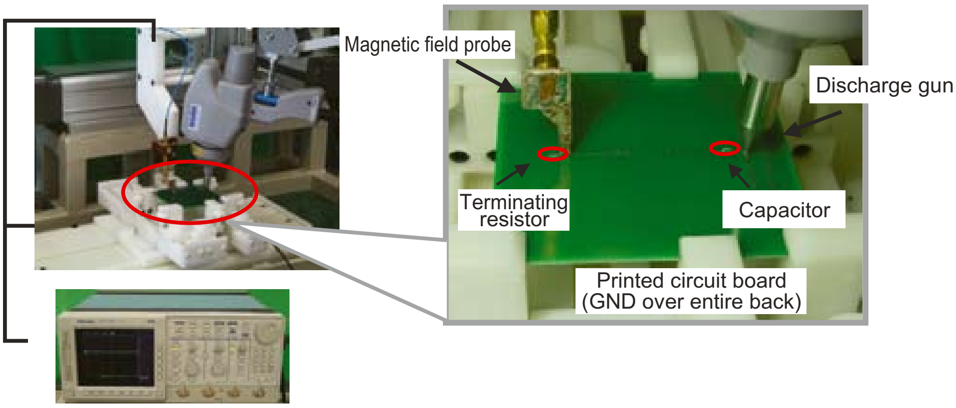
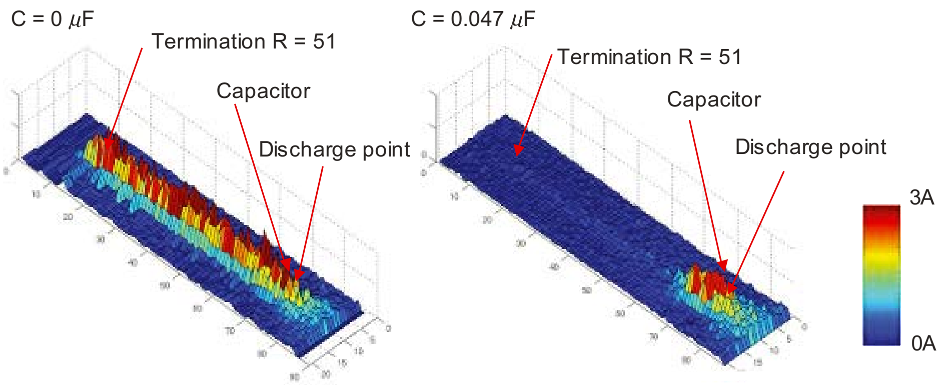


Fig. 15 Device for measuring discharge



(a) Discharge current distribution with no bypass capacitor attached

(b) Discharge current distribution with bypass capacitor attached

Fig. 16 Discharge current distribution on circuit board

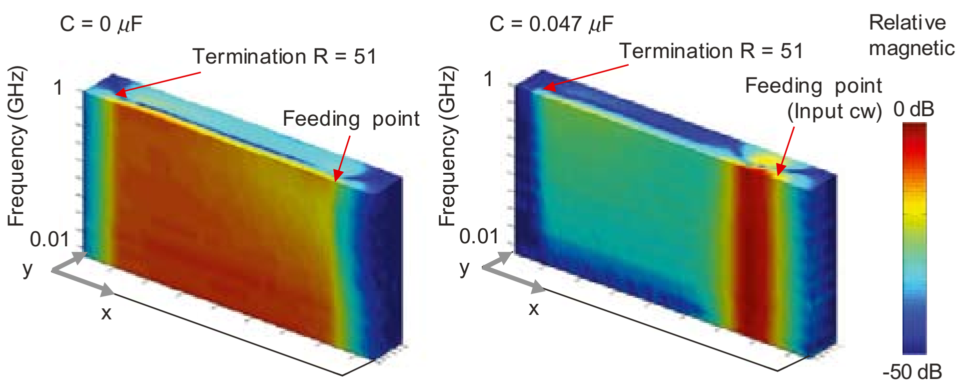


Fig. 17 Frequency characteristic distribution on circuit board

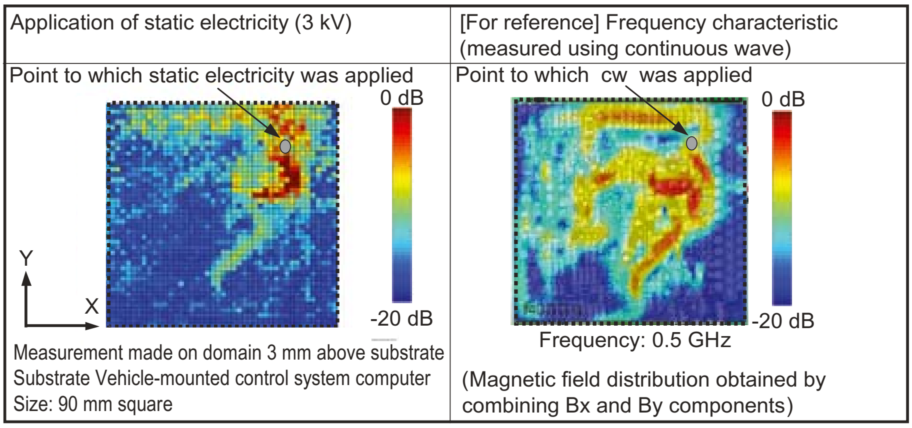


Fig. 18 Discharging current distribution in actual ECU substrate

were then calculated, and their peak current values plotted. **Figure 18** also shows the propagation characteristics of a high frequency signal with a frequency of 500 MHz, obtained by a similar measurement, done using a magnetic probe with high frequency signals applied to a connector terminal to which static electricity was applied. Since the distribution of discharge current generated by static electricity discharge has a wide spectral band, comparison between the figures makes it clear that the propagation of discharge current from the static electricity-applied connector terminal to connectors in the vicinity, and to the signal line connected to the connectors, is almost identical to the high frequency signal propagation.

8. CONCLUSION

This paper proposed and verified a technique by which the discharge current produced by application of static electricity to an ECU circuit board can be measured using a small, insulation-reinforced shielded loop antenna. Applying static electricity to the model circuit board under the conditions specified in the IEC and ISO standards enabled us to clarify differences in the discharge current. In addition, we succeeded in determining the effect of a bypass capacitor by moving a magnetic probe at every occurrence of discharge, thereby measuring discharge current distribution on a model circuit board. Lastly, we measured discharge current distribution on actual ECU circuit boards under the application of static electricity, thereby successfully visualizing the propagation of static electricity in an ECU circuit board. This enabled us to confirm the validity of the countermeasure.

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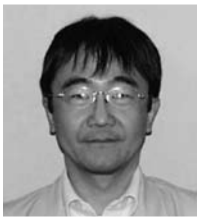

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