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Electrostatically Induced Voltage Generated in Different Box Types of Electronic Equipment due to Moving Charged Objects

Norimitsu Ichikawa*, **Tatsuko Maruyama and Kento Yajima**

Department of Electrical Engineering, Kogakuin University, 2665-1, Nakano, Hachioji, Tokyo 192-0015, Japan

Abstract

Although static electricity is commonly utilized in devices such as photocopiers, it often results in malfunction or failure in electronic equipment. When a conductive object housed in a partially opened box is positioned near a charged object, electrostatic induction causes the conductive object to become electrified. For instance, the human body becomes electrified when a person stands up and moves away from a chair. In this experiment, induced voltages generated in different types of boxes were measured using an induction electrode, paired with a spark gap and an electromagnetic wave sensor, as a charged body moved away from the box. The findings indicate that an electrostatically induced voltage ranging from -0.27 to -0.44 times against the voltage of the charged body is generated in the box when the distance between the charged body and the box is 0.02 m. These results are valuable for mitigating the risk of malfunction or failure in electronic equipment.

Keywords: Electrostatically induced voltage • Different box type • Moving charged object

Introduction

Static electricity is a valuable energy source for conservation; however, it can occasionally cause malfunctions or failures in electronic equipment [1-21]. These issues primarily arise owing to the electrostatic current and the voltage induced by the presence of a nearby charged body. When a charged human body comes into contact with a conductive electronic equipment casing, an electrostatic current flows along the external part of the conductive box to the ground. However, in cases where the conductive (metal) box is partially open, an electrostatically induced voltage is generated within the box, provided that a charged body, such as a human, is present and moves in proximity to the conductive box.

Thus, the malfunction or failure of electronic equipment is attributed to both electrostatic current and electrostatically induced voltage [22]. One of the authors has conducted extensive research on the electrostatically induced voltage generated in a partially opened conductive (metal) box. In previous studies, the electrostatically induced voltage was examined in both grounded and ungrounded metal boxes. Specifically, the research focused on scenarios where either one of two conductors housed in the metal box was grounded or both conductors were ungrounded at a floating potential. These studies also considered the effects of various natural conditions on the induced voltage. Thus, the author has published significant findings on the electrostatically induced voltage within partially open metal boxes.

Although several types of mesh-wired boxes, conductive plastic boxes, and non-conductive (insulating) plastic boxes are commonly used, no experimental study has focused on the electrostatically induced voltage generated in these different types of boxes. Recent technological advancements have led to the increasing use of ungrounded equipment, where grounding wire connections are absent. Consequently, the difference in electrostatically induced voltage generated across various types of ungrounded enclosures must be carefully considered. Understanding these differences is critical for designing electronic equipment with minimal susceptibility to electrostatic interference.

***Address for Correspondence:** *Norimitsu Ichikawa, Department of Electrical Engineering, Kogakuin University, 2665-1, Nakano, Hachioji, Tokyo 192-0015, Japan; E-mail: ichikawa@cc.kogakuin.ac.jp*

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In this study, we experimentally measured the electrostatically induced voltage generated in three types of boxes: A mesh-wired box, a conductive plastic box and a non-conductive (insulation) plastic box. All box types had an opening at the front. To measure the electrostatically induced voltage, an induction electrode with a spark gap and an electromagnetic wave sensor were utilized. The method employed allowed for measurements without any electrical connections and the electrostatically induced voltage was also measured using an electrostatic voltmeter. The results revealed that the electrostatically induced voltage reached -0.44 times the potential of the charged body as it moved away from the box, with a distance L of 0.02 m between the front of the partially open box and the charged body. These findings offer valuable insights for the design of electronic equipment to minimize the effects of electrostatically induced voltage.

Materials and Methods

The experimental setup is illustrated in Figure 1. This setup simulates a situation wherein a charged body, such as a charged human body, moves away from the front of a partially opened box of electronic equipment. This setup comprises a charged body, a partly opened box, an induction electrode (Figure 2), an electromagnetic wave sensor and an electrostatic voltmeter. The charged body represents a human body that becomes electrified when it stands up from a chair and moves. This arrangement is intended to replicate the movement of an electrified human body.

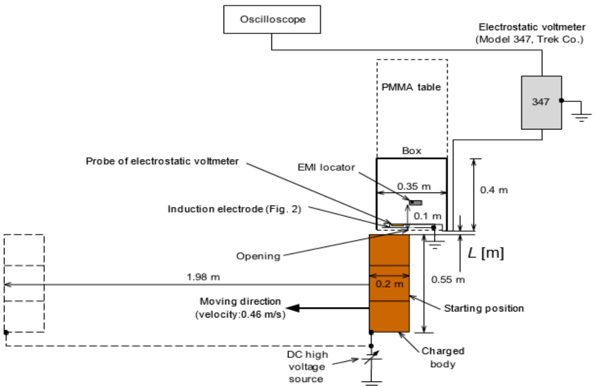

Figure 1. Arrangement of experimental setup.

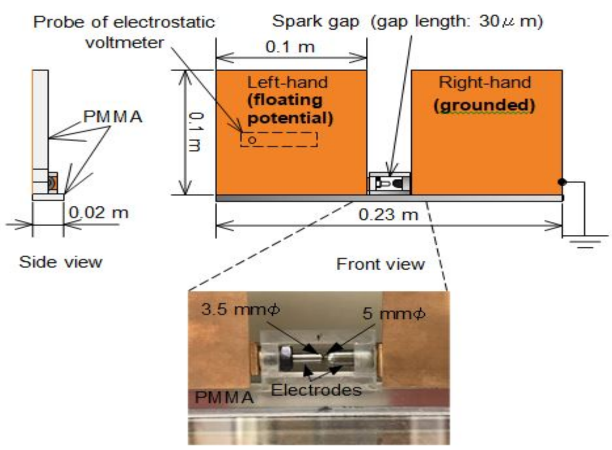

Figure 2. Arrangement of experimental setup.

The charged body was specifically designed to move away from the front of the partially opened box. The charged body comprises a body of Styrofoam and copper tape and is connected to a Direct Current (DC) high-voltage source with negative polarity. The charged body is mounted on a transport stage, with dimensions of 1.8 m in height, 0.55 m in width, and 0.2 m in length. The velocity of the charged body is 0.46 m/s.

The box, representing electronic equipment, was positioned on an acrylic table. This box, with an opening at the front, could be one of three types: a mesh-wired box of the SUS304 of the steel use stainless, a conductive plastic box of the Polyvinyl Chloride (PVC) conductive plastic box or a non-conductive (insulation) plastic box of the PVC (Figure 3). The surface resistivity and the volume resistivity of the conductive plastic box are $10^{1\sim5}$ Ω/□ and $10^{3\sim7}$ Ωm. The box was then placed in an ungrounded condition. The dimensions of each box were 0.2 m in height, 0.35 m in width, and 0.4 m in depth.

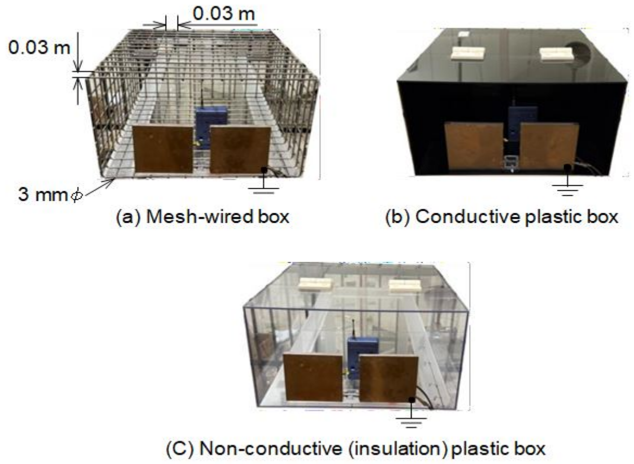

Figure 3. Photo of three box types.

Figure 2 displays the induction electrode used in the experiment. The induction electrode [21], placed at the base of the box, comprises two conductors: A signal line and a ground line. The induction electrode comprises two metal (copper) plates, a spark gap and an acrylic frame. The left metal plate is connected to the left electrode of the spark gap of the induction electrode. The metal plate on the right is accompanied by the induction electrode on the right, while the metal plate on the right side is connected to the ground. A side-view probe of an electrostatic voltmeter (Trek Co, 347) is placed on the back of the left metal plate of the induction electrode. The distance between the side-view probe of the electrostatic voltmeter and the surface of the left metal plate of the induction electrode is 0.002 m. The dimensions of each metal plate of the induction electrode are 0.1 m in height, 0.1 m in width and 0.0001 m in thickness. The gap length of the spark gap of the induction electrode is 30 μm. The average sparking voltage across the gap of the induction electrode is 456 V for all five measurements. The sparking voltage in the spark gap of the induction electrode is measured using a DC power supply. The distance between the front of the induction electrode and the front of the box is 0.01 m. The dimensions of the induction electrode are 0.105 m in height, 0.23 m in length and 0.02 m in depth. The centerline of the induction electrode coincides with the centerline of the box.

Consequently, when the charged body moves away from the front of the left metal plate of the induction electrode in the box, a spark discharge occurs within the spark gap, and the electrostatically induced voltage surpasses the sparking voltage of the spark gap. An electromagnetic wave sensor is employed to detect the electromagnetic waves generated by the spark discharge in the spark gap of the induction electrode.

The electromagnetic wave sensor, the EMI locator ES-300 V (Denshigiken Co.), was placed at the base of a box. The EMI locator has an antenna. The EMI locator was equipped with an antenna and emitted an alarm when the electromagnetic wave generated by a spark discharge was detected by the antenna. This arrangement enabled the detection of spark discharges in the spark gap of the induction electrode. The dimensions of the EMI locator, including the antenna, were 0.14 m in height, with the base measuring 0.06 m in width and 0.025 m in depth. The distance between the front of the EMI locator and the front of the box was 0.1 m, with the antenna of the EMI locator aligned with the centerline of the spark gap in the induction electrode.

Experimental method

The experiments were conducted in the following manner:

а⌠╨ áŤň╨ LʼŤĠɸŞňŃ╨ ļ˚ŃĦ╨ SĠά╨ Σ˚άŧδŧ˚ŞňŃ╨ Ġδ╨ δŤň╨ άδĠɸδŧŞŞ╨ ſ˚LʼĠδŧ˚Ş↓╨ Ġά ŧſſıάδɸĠδňŃ╨ŧŞ╨ [ŧŞıɸň╨a˗╨áŤň╨ſŧŞň╨Ġδ╨δŤň╨ļĠLʼż╨˚ŝ╨δŤň╨LʼŤĠɸŞňŃ╨ļ˚ŃĦ SĠά╨ ĠſŧŞŞňŃ╨ SŧδŤ╨ δŤň╨ ɸŧŞŤδ╨ ňŃŞň╨ ˚ŝ╨ δŤň╨ ſňŝδ╨ ǿňδĠſ╨ ΣſĠδň╨ ˚ŝ╨ δŤň ŧŞŃıLʼδŧ˚Ş╨ňſňLʼδɸ˚Ńň˗

б⌠╨ The voltage of the charged body was then adjusted to a specific Є˚ſδĠŞň╨ſňЄňſ˗

в⌠╨ áŤň╨ɸňάıſδά╨ЄĠſŧŃĠδňŃ╨δŤĠδ╨δŤň╨Є˚ſδĠŞň╨˚ŝ╨δŤň╨ſňŝδ╨ǿňδĠſ╨ΣſĠδň╨Lʼ˚ΣΣňɸ⌠ of the induction electrode, which was at a floating potential, had ŃňLʼɸňĠάňŃ╨δ˚╨ĠΣΣɸ˚ѢŧǿĠδňſĦ╨Я╨Ā˗

г⌠╨ áŤň╨LʼŤĠɸŞňŃ╨ļ˚ŃĦ╨SĠά╨άıļάňΥıňŞδſĦ╨ǿ˚ЄňŃ╨ĠSĠĦ╨ŝɸ˚ǿ╨δŤň╨ŝɸ˚Şδ╨˚ŝ δŤň╨ſňŝδ╨ǿňδĠſ╨ΣſĠδň╨˚ŝ╨δŤň╨ŧŞŃıLʼδŧ˚Ş╨ňſňLʼδɸ˚Ńň╨Ť˚ɪάňŃ╨SŧδŤŧŞ╨Ġ╨ļ˚Ѣ˗

д⌠╨ We verified whether the EMI locator emitted an alarm when the LʼŤĠɸŞňŃ╨ļ˚ŃĦ╨ǿ˚ЄňŃ╨ĠSĠĦ╨ŝɸ˚ǿ╨δŤň╨ŝɸ˚Şδ╨˚ŝ╨δŤň╨ļ˚Ѣ˗

е⌠╨ If the EMI locator sounded an alarm, the voltage of the charged ļ˚ŃĦ╨ SĠά╨ ɸňŃıLʼňŃ˗╨ ; ˚ŞЄňɸάňſĦ↓╨ ŧŝ╨ Ş˚╨ ĠſĠɸǿ╨ SĠά╨ δɸŧŞŞňɸňŃ↓╨ δŤň Є˚ſδĠŞň╨˚ŝ╨δŤň╨LʼŤĠɸŞňŃ╨ļ˚ŃĦ╨SĠά╨ŧŞLʼɸňĠάňŃ˗

- Steps 1) through 6) were repeated.
- Thus, the minimum voltage of the charged body at which the EMI locator sounded was recorded.
- The experiments are performed in 25℃ and 65% R.H.

Results

Figure 4 presents the minimum voltage of the charged body at which the EMI locator sounds. This figure compares results for three different box types: mesh-wired, conductive plastic and non-conductive (insulation) plastic boxes. The vertical axis represents the minimum voltage of the charged body and the horizontal axis represents the distance L between the charged body and the box. The results depict the average values of three measurements, indicating that the minimum voltage of the charged body increases as the distance L increases. Specifically, for the mesh-wired box, the minimum voltage of the charged body rises from 1.5 kV at L=0.02 m to 2.8 kV at L=0.05 m and 3.5 kV at L=0.1 m. For the conductive plastic box, the minimum voltage rises from 1.5 kV at L=0.02 m to 2.0 kV at L=0.05 m and 2.5 kV at L=0.1 m. In the case of the non-conductive (insulation) plastic box, the minimum voltage rises from 1.7 kV at L=0.02 m to 2.0 kV at L=0.05 m and 2.5 kV at L=0.1 m.

Figure 5 plots the ratio of the average sparking voltage (456 V) of the spark gap in the induction electrode (contained within the box) to the minimum voltage of the charged body (Figure 4). This ratio indicates the ratio of the electrostatically induced voltage of the positive polarity generated in the box when a negatively charged body moves away from its front. This ratio is known as the invasion ratio. The invasion ratios obtained using different types of boxes are plotted in Figure 5. The results show an invasion ratio of −0.30 at L=0.02 m when either a mesh-wired box or conductive plastic box is employed. The invasion ratio is −0.27 at L=0.02 m when a non-conductive (insulated) plastic box is used. For the mesh-wired box, the invasion ratio is −0.13 at L=0.1 m, while it increases to −0.18 for the same distance when either a conductive plastic box or a non-conductive (insulation) plastic box is used. Table 1 lists the values of the invasion ratios corresponding to Figure 5.

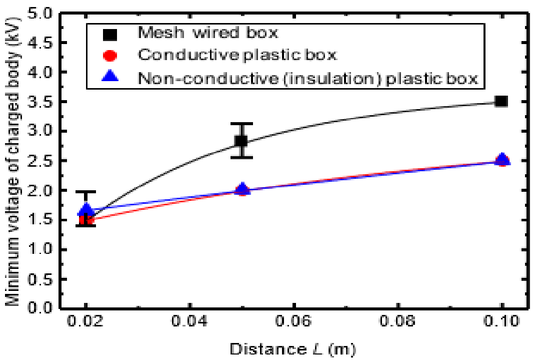

Figure 4. Minimum voltage of charged body when spark discharge occurs in spark gap of induction electrode contained in different type boxes.

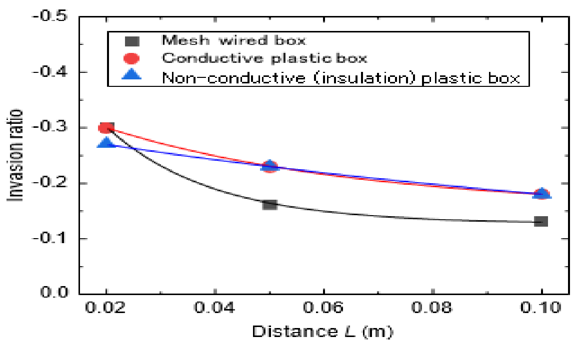

Figure 5. Invasion ratio of electrostatically induced voltage in different type boxes against voltage of charged body.

Distance L (m)	Invasion ratio		
	Mesh wired box	Conductive plastic box	Non-conductive (insulation) plastic box
0.02	−0.30	−0.30	−0.27
0.05	−0.16	−0.23	−0.23
0.1	−0.13	−0.18	−0.18

Table 1. Invasion ratio using spark gap and EMI locator.

Figure 6 presents the invasion ratio of the maximum electrostatically induced voltage relative to the minimum voltage of the charged body (as depicted in Figure 4) when a spark discharge occurs and the EMI locator signals an alarm. The invasion ratio was determined using the maximum electrostatically induced voltage shown in Figure 7 when a spark discharge occurred. According to Figure 6, the invasion ratio is −0.35 for a distance L=0.02 m when a mesh-wired box is employed. Similarly, for the same distance, the invasion ratio is −0.44 when using a conductive plastic box and −0.38 when a non-conductive (insulated) plastic box is used. For a greater distance of L=0.1 m, the invasion is −0.15 when using the mesh-wired box. The invasion ratio further decreases to −0.21 when the conductive plastic box is used and to −0.26 when a non-conductive plastic box is employed. Table 2 provides the invasion ratios shown in Figure 6.

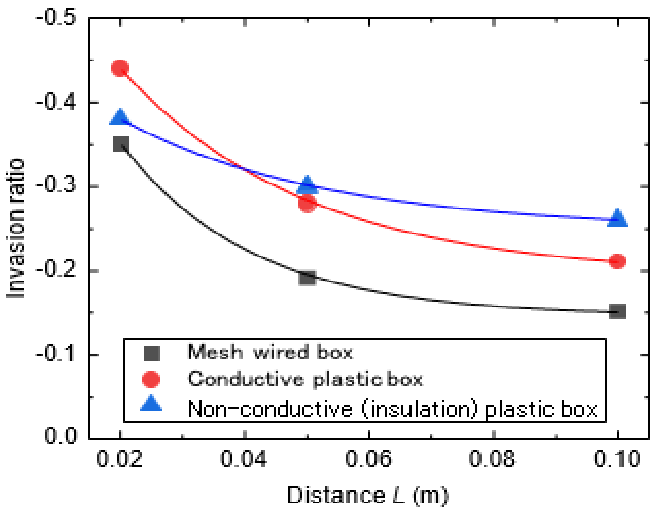

Figure 6. Invasion ratio of maximum electrostatically induced voltage generated in box against voltage of charged body.

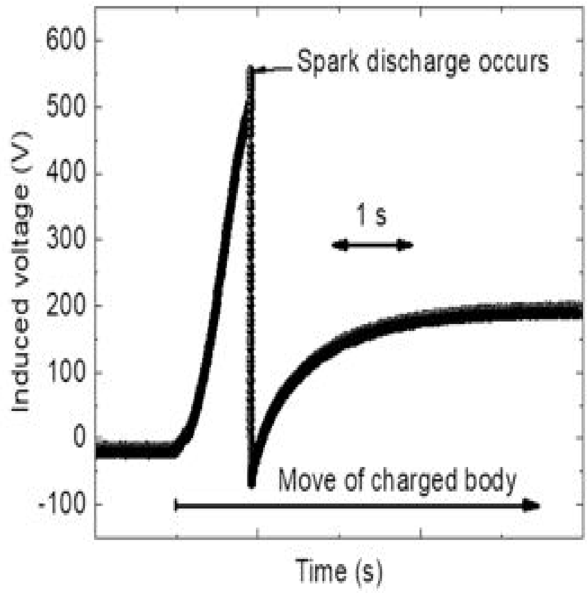

Figure 7. Electrostatically induced voltage generated in mesh wired box when spark discharge occurs and EMI locator sounds for distance L of 0.02 m and charged body of −1.5 kV.

Distance L (m)	Invasion ratio		
	Mesh wired box	Conductive plastic box	Non-conductive (insulation) plastic box
0.02	−0.35	−0.44	−0.38
0.05	−0.19	−0.28	−0.30
0.1	−0.15	−0.21	−0.26

Table 2. Invasion ratio using maximum induced voltage measured by surface voltmeter when spark discharge occurs.

Discussion

The electrostatically induced voltages ranging from −0.30 to −0.35 times the voltage of the charged body were generated in the mesh-wired box when the distance L was 0.02 m, and the charged body moved away from the front of the box. Similarly, electrostatically induced voltages ranging from −0.30 to −0.44 times the charged body voltage were produced in the conductive plastic box for a distance L=0.02 m. For the non-conductive (insulated) plastic box at the same distance, the induced voltages ranged from −0.27 to −0.38 times the voltage of the charged body.

The electrostatically induced voltage can be estimated using the invasion ratios. For instance, if the charged body carried a voltage of −10 kV, a value that could occasionally be observed for a charged human body, the induced voltage could be calculated using Equation (1). For example, if the invasion ratio $R_{invasion\ ratio}$ was −0.44 and the voltage of the charged body $E_{charged\ voltage}$ was −10 kV, the induced voltage generated in the conductive plastic box could be estimated as 4.4 kV when the distance L between the charged body and the box was 0.02 m.

$$V_{induced\ voltage} = R_{invasion\ ratio} \times E_{charged\ voltage} \qquad (1)$$

Where $V_{induced\ voltage}$ denotes the electrostatically induced voltage generated by the different types of boxes, $R_{invasion\ ratio}$ denotes the ratio of the electrostatically induced voltage generated in the box to the voltage of the charged body, and $E_{charged\ voltage}$ denotes the voltage of the charged body.

Figures 5 and 6 reveal a clear trend the invasion ratio for the mesh-wired box is consistently lower than that for either the conductive plastic box or the non-conductive (insulation) plastic box. The variations in these invasion ratios are explored in further detail.

Figure 8 presents the invasion ratio when no spark discharge occurs, as shown in Figure 9 and when the EMI locator does not trigger an alarm. From Figure 8, the maximum invasion ratio was found to be −0.54 when the conductive plastic box was used, with the distance L set at 0.02 m. The invasion ratio ranged from −0.39 to −0.54 for this distance. When the distance was increased to L=0.1 m, the invasion ratio fell within the range of −0.16 to −0.25. The invasion ratios corresponding to Figure 8 are summarized in Table 3.

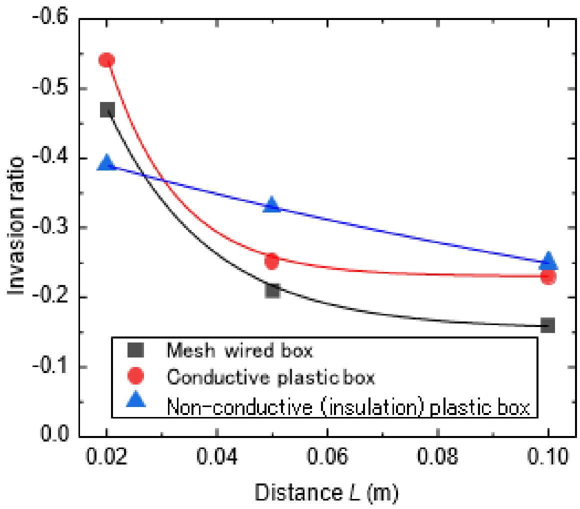

Figure 8. Invasion ratio when spark discharge does not occur.

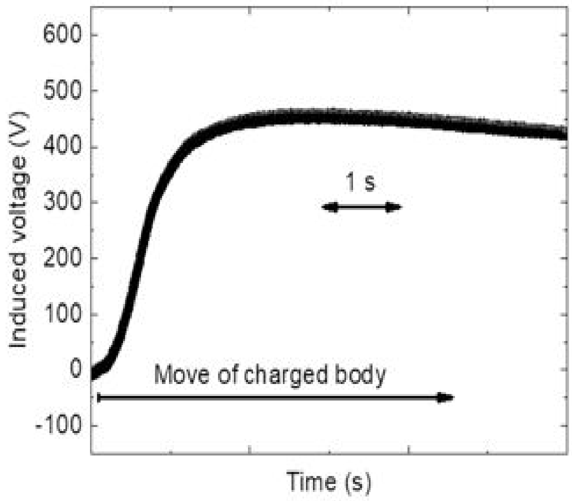

Figure 9. Electrostatically induced voltage generated in mesh wired box when spark discharge does not occur for distance L of 0.02 m and charged body of −1.0 kV.

Distance L (m)	Invasion ratio		
	Mesh wired box	Conductive plastic box	Non-conductive (insulation) plastic box
0.02	−0.47	−0.54	−0.39
0.05	−0.21	−0.25	−0.33
0.1	−0.16	−0.23	−0.25

Table 3. Invasion ratio by surface voltmeter when spark discharge does not occur.

Conclusion

Malfunctions or failures of electronic equipment are occasionally caused by static electricity. In particular, an electric current can flow along the external surface of a conductive (metal) box. When a charged body, such as a charged human body, is in close proximity to a partially opened box, electrostatically induced voltages are generated. Therefore, solutions and preventive measures against such malfunctions or failures due to static electricity are of significant importance.

In this study, we examined the problem of electrostatically induced voltages generated in different types of boxes when a charged body moved away from the front of these boxes. The results demonstrated that electrostatically induced voltages ranging from −0.27 to −0.44 times the voltage of the charged body were produced when the distance between the charged body and the box was 0.02 m. The negative sign indicated that a positive electrostatically induced voltage was generated in the boxes when the charged body had a negative polarity. Furthermore, these induced voltages in the different types of boxes could be estimated by applying the invasion ratio.

These findings are valuable for understanding the causes of malfunctions or failures in electronic equipment and for developing effective preventive measures.

Acknowledgments

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