Electromagnetic Field in the Vicinity of Low Voltage ESD Wave Source: Unipolarity and Ultra-Widewand

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Summary

Impulse electromagnetic fields generated in the space near a low voltage indirect electrostatic discharge (ESD) wave source were experimentally analyzed.

The electromagnetic fields exist only for a very short time (below about 100 ps), but in the space, propagate with unipolarity and yet, show frequency distributions on rising and also falling portions of the impulse which are ultra-wideband continuously extending up to 6.5 GHz or higher.

Introduction

When an ESD occurs between metal objects, transient electromagnetic fields are emitted in the space near these metal objects [1].

Digital systems in operation sometimes malfunction with the noise resulting from this unwantedly generated ESD.

Regarding this problem, already the authors developed small-sized "ESD detector" (hereinafter referred to as detector) [2] [3] in 1982 and put it in practical use mainly in the computer fields. Fig.1 is a photograph of this detector.

Fig.1 A photographs of the ESD detector

While the detector was being used in examining the near space around the metal object on the noise source, it was experienced that especially when the ESD voltage is low, the detector showed significantly different responses with the polarity of charge despite of the same voltage, and it was decided to study further in detail.

Experiment

Since the transient electromagnetic fields caused by ESD are the object to be measured, it was decided from the view point of efficient repeatability that copper pipes having a large aspect ratio should be used as the metal objects to construct the wave source. The antenna used to capture the transient electromagnetic fields is a short monopole antenna having a length of the millimeter order, which was ultra-small-sized and ultra-wideband. To insure the faithful catching of the original signal, the measuring system was wide-banded as much as possible in all parts of signal transmission.

Isolated unipolar impulse

Fig.2 shows two copper pipes A and B (200 mm in length, 12.7 mm in diameter, and C = 3 pF in electrostatic, capacity C, each), held upright in series, and their opposing end parts each of which is soldered with a brass sphere of 12.7 mm in diameter) kept at a spacing of 50 μm in between. The copper pipe A is applied with a positive or negative voltage of 600V is applied, and discharged to the copper pipe B at a rate of about 10 times a second.

At a horizontal distance of 20 mm from the end part of the copper pipe A, a short monopole antenna of 5 mm in length (provided with an SMA connector) was placed with its element (center conductor) directed upward in parallel with the copper pipes. From this antenna, a 1m long microwave coaxial cable (provided with an SMA connector for DC to 18.5 GHz) was connected to a real time oscilloscope (TEK 7104) whose bandwidth is 1.0 GHz.

Fig.3 shows an isolated unipolar impulse negative-going from the reference ground level, observed upon one-shot discharge when applied with + 600V. This impulse has an amplitude larger than 600 mV.

Under this condition, the same antenna mentioned above was moved to a point at a horizontal distance of 20 mm from the end part of the copper pipe B. Then, upon one-shot discharge, an isolated unipolar impulse positive-going was observed as shown in Fig.4. The amplitude was again larger than 600 mV.

Then, the copper pipe A was applied with - 600V,

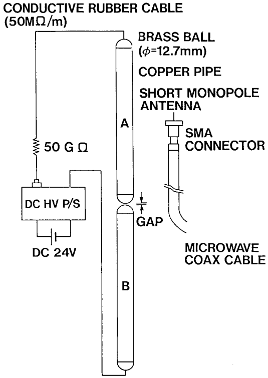

Fig.2 Experimental system

and the same antenna was placed at the same place as in the previous observation. The results are shown in Fig.5 and Fig.6.

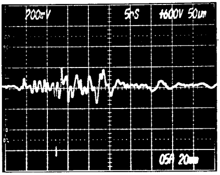

Fig.3 A unipolar impulse (negative-going) (+ 600V)

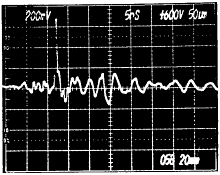

Fig.4 A unipolar impulse (positive-going) (+ 600V)

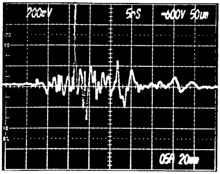

Fig.5 A unipolar impulse (positive-going) (- 600V)

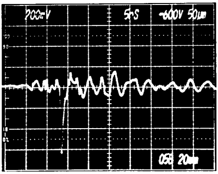

Fig.6 A unipolar impulse (negative-going) (- 600V)

When the antenna is on the side of the copper pipe A, an isolated unipolar impulse, positive-going reverse to the previous case was observed, and when the antenna is on the side of the copper pipe B, an isolated unipolar impulse, negative-going reverse to the previous case was observed.

That is, the polarity of the impulse appearing on the side of the copper pipe A is in the opposite phase to that of the applied voltage, and the polarity of the impulse appearing on the side of the copper pipe B is in the same phase to that of the applied voltage.

Ultra-wideband impulse

Quite the same two copper pipes as used above (200 mm in length, 12.7 mm in diameter and C = 3 pF each) were placed upright in series with their end parts in opposition to each other with a gap of 50 µm in between and the copper pipe A was applied with a voltage of - 1 kV to discharge at a rate of 10 times a second.

At a horizontal distance (d) of 10 mm from the end part of the copper pipe B, the same 5 mm long short monopole antenna as used above was placed in parallel with the copper pipe with its element upward. From this antenna, a 90 mm long microwave semi-rigid cable (UT-141, DC to 18.5 GHz) was connected to a 6.5 GHz bandwidth spectrum analyzer (HP 8561A) by means of an SMA-N conversion connector. No microwave coaxial attenuator was used.

Fig.7 shows the results of these measurements, indicating a continuous spectrum covering an ultra-wideband of frequencies from low (10 kHz) to 6.5 GHz. When the antenna position was changed to the point of 50 mm, the spectrum extends up to 3.25 GHz as shown in Fig.8 under the same measurement conditions.

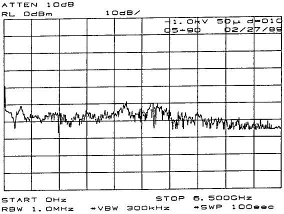

Fig.7 Frequency spectrum for 10 mm antenna distance

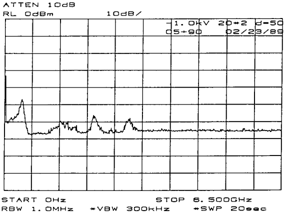

Fig.8 Frequency spectrum for 50 mm antenna distance

Discussion

Unidirectional movement of charges

In a discharge phenomenon between metal objects charged to a low voltage with respect to each other, it is considered that charges move only in one direction. That is, noting the excess and deficiency of charges alone on the metal objects, the direction of charge movement upon discharge is known and the unipolarity of the resulting impulse electromagnetic fields is also determined. For example, assume that the copper pipe A is charged positive. Here, charges are always deficient, and by charge injection from the copper pipe B upon discharge, negative-going electromagnetic fields are generated momentarily in the space near the copper pipe A. At this time, on the copper pipe B, charges become deficient momentarily, so that in the space near the copper pipe B, positive-going electromagnetic fields are generated.

According to the conventional antenna theory, it is assumed that the antenna is excite by the current which is in sinusoidal harmonic motion. With this theory, it is impossible to predict the advent of unipolar electromagnetic fields accompanying the ESD between metal objects charged at low voltages as in the present study.

Further, if a dipole antenna, which assumes similarly that the electromagnetic fields in the space are in sinusoidal harmonic vibration, is used in the reception in this study, it is impossible to catch impulse electromagnetic fields which have positive-going or negative-going unbalanced components in the free space.

From the foregoing, in order to catch unipolar electromagnetic fields involved in the present study, it is essential to use a short monopole antenna and the faster the rate of change of the electromagnetic fields, the shorter the element (center conductor) of this antenna must be.

For example, if a monopole antenna having 5 mm long element is used, it means that in the free space it can handle the electromagnetic field accompanying the ESD which are changed at a rate of up to about 17 ps (5 mm divided by 3 x 10^8 m/s (light velocity)). However, the existing real time oscilloscopes can not follow one-shot phenomena which change themselves at such a high rate (rising or falling of the impulse), and as shown in the following section, measurements in the frequency domain become necessary.

It is considered that the existence of this unipolar impulse may be a cause which significantly governs the reproducibility in evaluating the EMI immunity using indirect ESD testing, and it should be taken up as an important parameter in this test [4].

Occurrence of continuous spectrum

In the measurement of the unipolar impulse using a short monopole antenna and a spectrum analyzer, the spectrum spreads continuously up to 6.5 GHz which is at the observation limit. The behavior of this spectrum is quite different from those of ordinary electromagnetic fields continuously emitted for the purpose of telecommunication. It means that, though momentarily, an electromagnetic phenomenon changing itself at an extremely high rate [5] appeared in the vicinity of copper pipes A and B. Using the relationship (assuming a Gaussian distribution) of the bandwidth-rising (or falling) time product of about 0.35, it is estimated that the rising (or falling) time of the unipolar impulse obtained in the present measurement is about 50 ps. However, as the frequency characteristic of the measuring system improves, this value will be observed further smaller (for example, as 10 ps at 35 GHz bandwidth) [6].

It is worth noting that the ultra-wideband impulse was an impulse which is not generated from any expensive and sophisticated equipment in a research institute, but can be generated universally from a combination between simple static electricity and a metal object (for example, a steel pipe chair) which is present everywhere.

Because, the newest digital systems will react (malfunction) very sensitively with impulse electromagnetic fields caused by ESD between metal objects charged at such a low voltage, rather than when exposed to continuous electromagnetic fields [7] and [8].

Conclusion

The space near a low voltage ESD wave source was examined in detail using a short monopole antenna having a length of the millimeter order. It was found that the transient electromagnetic field generated upon discharge shows up as a unipolar field whose rising (or falling) time is less than 50 ps.

The presence of such a strong single ultra-wide-band impulse has a possibility of directly affecting the reliability and vulnerability of modern electronics operating at high speeds, and it is considered that its further study should be developed.

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