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PROPAGATION CHARACTERISTICS OF ESD-INDUCED ELECTROMAGNETIC PULSES MEASURED USING OPTICAL E-FIELD SENSOR

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Abstract: This paper describes the propagation characteristics of electromagnetic pulses induced by electrostatic discharge (ESD) in the far field. ESD energy spectra measured with an electric field sensor using a Mach-Zehnder interferometer are analyzed for the frequency band DC-1GHz by Short-Time Fourier Transform (STFT).

Analytical results show that ESD energy in high frequency band (100MHz-1GHz) decrease more rapidly in proportion to the distance from a source point.

1. INTRODUCTION

Electrostatic discharge (ESD) occasionally causes serious problems in electronic apparatus. It is usually accompanied by two phenomena:

1) The injection of discharge currents and the radiation of electromagnetic pulses.

2) The discharge caused by radiated electromagnetic pulses is known as indirect ESD which can cause transient electrical interference.

The electromagnetic interference (EMI) resulting from indirect ESD is generally considered to be an unreproducible phenomenon because it depends on many environmental conditions such as discharge voltage[1], humidity, and temperature. On the other hand, EMI effects have been detected at a great distance (up to several kilometers) from a source point. The propagation characteristics in the near field have been well researched and reported in many papers[2]. But the characteristics in the far field have never been analyzed clearly[3].

This paper describes experimental and analytical results for electromagnetic pulses caused by indirect ESD, namely ESD pulses. It clarifies the relationship between EMI effects caused by ESD and the distance from the ESD source. ESD pulses were measured with an electric field sensor using a Mach-Zehnder interferometer (an optical E-field sensor)[4] in the time domain and the electromagnetic energy of ESD pulses was analyzed by Short-Time Fourier Transform (STFT).

2. MEASURING SYSTEM

The ESD pulse measuring system is shown in Fig. 1. The distance characteristics were measured in a anechoic chamber with 30-cm-thick RF absorbers on its conductive ground plane. An ESD test generator was used as the source of ESD pulses and experiments were conducted in the anechoic chamber. The generator's capacitance was charged with positive polarity and then the gap length was gradually shotened until discharge occurred. The discharge gaps were set vertically with respect to the ground plane at a height of 0.8 m, and an optical electric field sensor using a Mach-Zehnder interferometer was positioned at 11 points from 0.2 to 3 m away. A digitizer having a bandwidth of DC-1GHz was used. Measurements were carried out at an ambient temperature of 25 (±2) and relative humidity of 62 (±5)%.

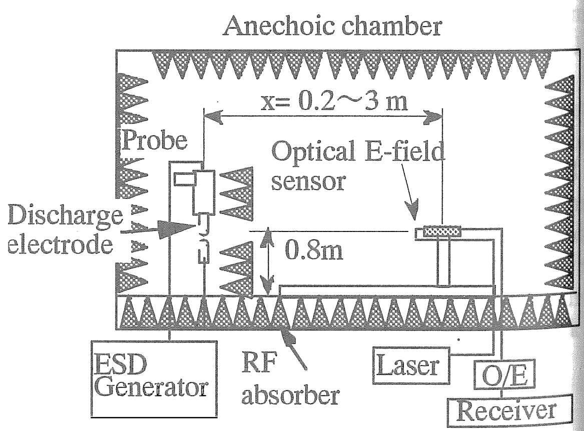

Fig. 1 ESD pulses measurement system

Figure 2 shows the structure of the optical E-field sensor. A pair of sensor elements are aligned, and they are separated by a small gap in which an optical modulator is located. When an electric field is applied to the sensor elements, a voltage is induced across the gap. The optical modulator converts this voltage to an optical signal, and the electric field strength is obtained by measuring the optical signal level with the photodetector.

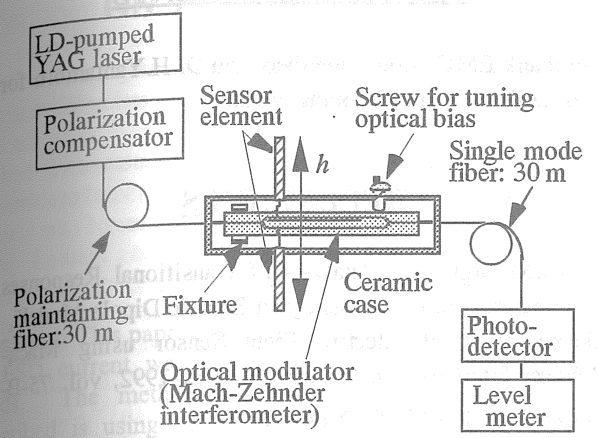

Fig. 2 Configuration of the electric field sensor with very small element using Mach-Zehnder interferometer

The Mach-Zehnder interferometer is formed by Ti diffusion on a Z-cut $LiNbO_3$ substrate 55 mm long, 1 mm wide, and 0.5 mm thick. The half-wave voltage is less than 2 V and the operating bandwidth is from DC to more than 6 GHz. The light source was a 1.3-μm LD pumped YAG laser (25 mW) and the photodetector was a PIN photodiode (HP1198: DC-15 GHz). The connections between the light source and the E-field sensor and between the E-field sensor and the photodetector were made with 30-m-long optical fibers. The optical signal modulated by an external electric field in the modulator was changed to an electrical signal in the photodetector, and the signal was measured with a digitizer (100-ps sampling) controlled by a personal computer.

3. MEASUREMENT AND ANALYSIS RESULTS

3.1 Short-Time Fourier Transform Analysis

Figure 3 shows examples of ESD pulses detected by an optical E-field sensor at discharge voltages of 10 kV. The results show almost no fluctuation because an optical E-field sensor has a broad bandwidth.

The measured voltage data v(t) of ESD in the time domain was analyzed by spectrogram analysis, which is a kind of Short-Time Fourier Transform (STFT). The transform SF(τ,f) is given by

$$SF(\tau,f)=\sqrt{T}\int_{-\infty}^{\infty} x^*(t-\tau)\, v(t) \exp(-j2\pi ft)\, dt \quad (1)$$

where T is the range [τ-T/2, τ+T/2] of the Hamming function $x(t)$ used as a window function for Fourier transforming the ESD pulses at a time τ and $x^*(t-\tau)$ is the conjugate of $x(t-\tau)$. The electric field strength E(τ,f) is expressed using an antenna factor A(f) as

$$E(\tau,f)=A(f)\, SF(\tau,f). \quad (2)$$

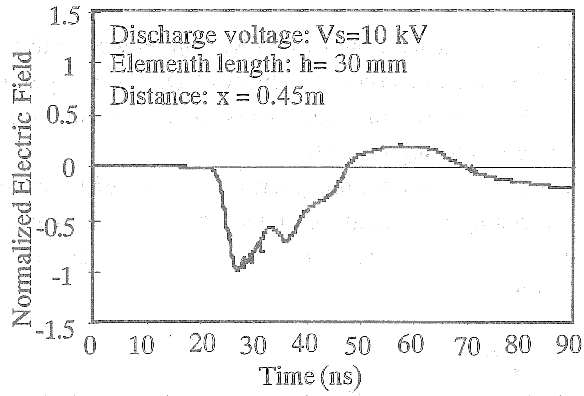

Fig.3 Example of ESD pulses measured by optical E-field sensor(relative humidity=62 ($\pm$5)%).

The value of $E(\tau,f)$ was normalized by the maximum value.

Examples of analyzed results are shown in figures 4 and 5, For a near field (Vh=15 kV, x=0.3 m) and far field (Vh=15 kV, x=3 m), respectively. The vertical axis indicates the frequency range DC-1GHz, the horizontal axis indicates the time range 0-100 ns, and the contour colors indicate the normalized electric field strength.

Comparing figures 4 and 5, we find that the values of $E(\tau,f)$ in the high-frequency band of 400 MHz-1 GHz in the far field are much smaller those in the near field. This means that the high-frequency component of an ESD pulse is rapidly attenuated linearly to become the far field.

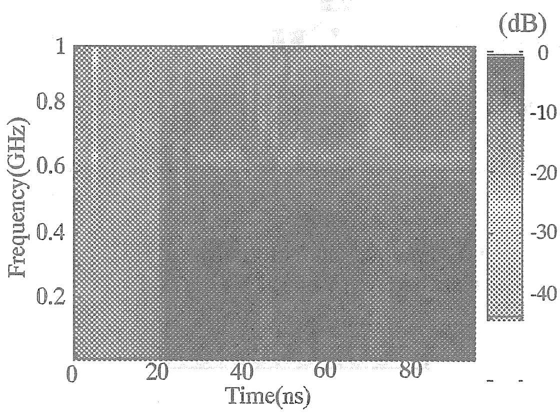

Fig.4 Spectrogram (Vh=15kV, x=0.3m)

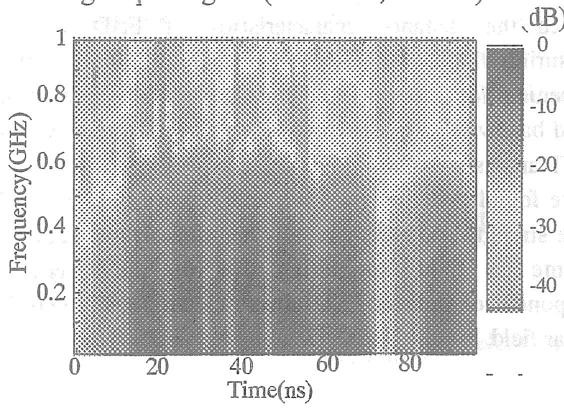

Fig.5 Spectrogram (Vh=15kV, x= 3m)

3.2 Analysis of Electromagnetic Energy

The electromagnetic energy of ESD pulses was analyzed to evaluate the properties of indirect ESD. The recognition of the ESD pulse from its energy is a very important aspect of evaluating its EMI effect.

We analyzed the electromagnetic energy of ESD pulses by integrating the energy spectra of the frequency domain between f1 and f2. The energy of ESD pulses Ei can be defined by:

$$Ei = \int_{f1}^{f2} |E(\tau, f)|^2 df \quad (3)$$

Figure 6 shows the distance characteristics of the electromagnetic energy Ei. ESD pulses were evaluated by measuring ESD pulses five times at each point between 0.2 and 3m at 10, 15, 20 kV. In figure 6 the range of frequency was chosen as f1=100 MHz and f2= 1 GHz in order to evaluate ESD energy in a high-frequency band. The values were normalized by the averaged value at 0.2 m. *Ei* rapidly attenuated in a linear manner to become the far field, suggesting that the low-frequency component of indirect ESD affects electrical equipment in the far field.

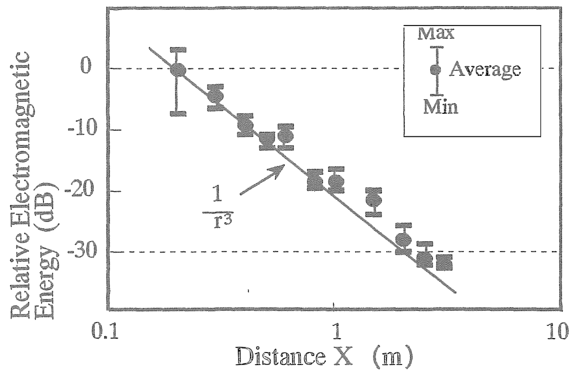

Fig.6. Distance characteristics of ESD inpulses energy(Vh=15kV)

4. CONCLUSION

In order to investigate indirect ESD problems we studied the distance characteristics of ESD pulses, measuring them with an optical E-field sensor, which convenient for direct electromagnetic pulses because of its broad bandwidth. Time domain data was analyzed by the STFT analysis method.

We found that the high-frequency component of ESD pulse strength and energy rapidly and linearly attenuated to become far field, suggesting that the low-frequency component of indirect ESD affects electric equipment in the far field.

ACKNOWLEDGMENTS

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