An ESD Demonstrator System for Evaluating the ESD Risks of Wearable Devices

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Abstract - An ESD demonstrator system was designed to demonstrate the levels of transient fields that a wearable device can be subjected to. The system can detect pulses as short as 1-2 ns and was used to evaluate the fields associated with a brush-by discharge from a waist mounted device. The presence of a higher field level at the same voltage for a body worn device discharge indicates a higher risk for body worn devices compared to the HMM discharge specified by the IEC-61000-4-2 standard.

I. Introduction

The ESD related risks that body worn electronic devices are exposed to have not been well characterized and the IEC61000-4-2 test standard does not fully correlate with the ESD related risks a body worn electronic device is likely exposed to. This difference is due to body worn devices being subjected to different postures and situations than other consumer electronics. For example, body worn devices can directly approach a grounded conductor and discharge leading to currents that are up to 4 times larger than the contact discharge defined in the IEC 61000-4-2 [1]. In addition, the removal of a garment can lead to static build up and potentially discharge between layers of clothing [2]. Transient fields generated from the removal of different layers of clothing need to be quantified in order to assess the potential risk for body worn devices. The transient electric and magnetic fields that result from the discharge of a human to ground are not captured as well. In some cases, there can be transient currents on cables that connect different modules in a body worn device which could cause system upset or damage and need to be evaluated. These examples show the potential need for a new ESD test method for body worn electronic devices which calls for the creation of a demonstrator which will educate engineers on the discharge scenarios, associated currents and fields and the resulting risks for such devices. This design not only aims at capturing data, but it is designed as body worn equipment that can be mounted in a variety of positions for demonstration purposes.

Studies have been performed using body worn equipment to assess the risk for some of these cases, but the unique ESD risks for wearable devices have not been fully characterized. The use of a wearable, wireless detector for measuring charge build up on the human body is described in [3]. This approach provides useful data, but does not allow for the measurement of transient fields or currents that is needed to fully characterize the risk for wearable devices. Another study used a body worn, portable oscilloscope with various antennas to assess the induced voltage on a wearable device when a human discharges to ground through a finger [4]. However, this study did not directly quantify the strength of these transient fields from the raw voltage of the various antenna used. A versatile design that allows for the detection of currents, electric fields, and magnetic fields is needed to fully characterize the ESD effects on body worn devices for the various cases considered.

One potential solution is to use a commercially available ESD event detector to characterize the ESD risk. There are several of these devices on the market and in general they measure fields and include a counter to log how many times the fields exceed a certain threshold. Many of these ESD event detectors are small enough to be body worn. One such detector, the 3M EM eye meter, even uses proprietary algorithms to provide approximate voltage values for the various models (CDM, MM, HBM) based on user inputted distance and the raw input voltage received by an antenna. These ESD event detectors are very useful for assessing ESD risks in many cases such as in an IC manufacturing environment as described in [5]. Although many of these ESD event detectors can be used with different probes and antennas, the bandwidth of the system is typically too low to be used for current and magnetic field measurements. Consequently, these ESD event detectors are only useful for evaluating the electric field and thus cannot cover all the areas of concern for wearable devices. Yet, the yes/no result of the ESD event detectors is a very simple and attractive way to determine the worst-case risk for each scenario. The threshold can be set at a maximum allowable level and the event detector system can be deployed to determine if the threshold is exceeded for a specific situation. This objective led to the creation of a threshold detector based design with functionality that addresses the shortcomings of commercial ESD event detectors for use in body worn device evaluation.

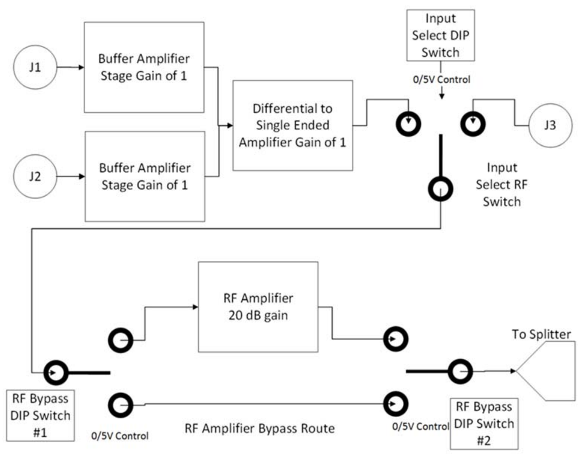


Figure 1: Block diagram for the front-end of the system.

II. Design

A versatile, wearable ESD demonstrator system was designed to assess the fields and currents that a wearable device can be exposed to in different situations. The system can be used with electric field probes, magnetic field probes, and current probes. The system uses ultrafast comparators (Analog Devices ADCMP573) to detect when a signal incident from a probe exceeds a configurable threshold. The comparator is capable of detecting an 80 ps minimum pulsewidth and has an equivalent bandwidth of 8 GHz. However, the overall bandwidth of the system is lower due to the supporting circuitry. The front-end of the system consists of a high input impedance differential to single ended operational amplifier circuit, a RF amplifier, and a RF switch network. Figure 1 shows the functional block diagram for the front end of the system. The RF switch network allows for the system to use the high impedance operational amplifier stage or to bypass it. The bandwidth of the high impedance operational amplifier stage is about 300 MHz. The high input impedance allows for the use of electric field probes with a flat frequency response down to the low kHz range. Bypassing the high impedance amplifier stage increases the upper frequency limit to about 1 GHz. The RF switch network also controls whether the RF amplifier is used. The RF amplifier is a wideband amplifier with a gain of about 20 dB from DC to 2 GHz.

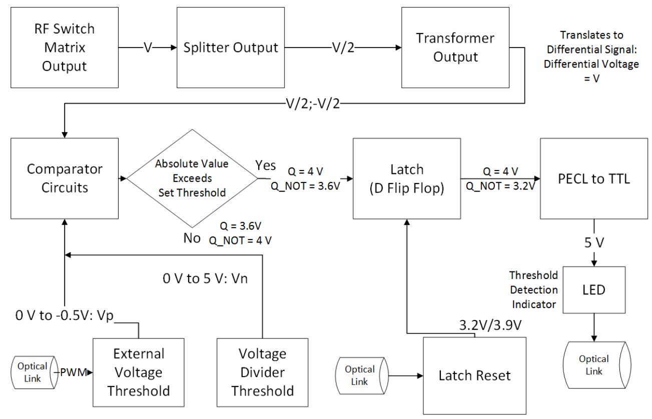


Figure 2: Threshold detection of ESD demonstrator system.

Figure 2 shows the block diagram for the threshold detection portion of the system. The output of the front-end stage is connected to a splitter that splits the signals between the two comparator circuits. A transformer translates the single ended signal to a differential signal and the differential voltage will be equal to the magnitude of the output of the front-end stage. One of the transformers will invert the polarity of the signal with respect to the comparator input pins allowing for negative pulses to be detected. The threshold for the comparator circuit can be set with a PWM signal from an optical link that decreases the initial voltage on the positive comparator input or with a voltage divider that increases the initial voltage of the negative comparator input. If the positive comparator input exceeds the negative comparator input the PECL outputs off the comparator will switch high. The outputs are tied to the clock inputs of a D flip flop and will cause the logic high voltage on the data input of the D flip flop to be latched. This will cause the output of the D flip flop to stay logic high even after the comparator outputs are no longer logic high. Latching is needed because the bandwidth of the transmitter LED is low and many of the signals of interest have a low ns pulsewidth. The logic high outputs of the D flip flop are terminated in a PECL to

TTL converter which will output a logic high TTL voltage of 5V which will drive a transmitter LED. The D flip flop can be reset by applying an optical signal of adequate intensity incident on the reset photodiode.

A battery pack with NiMH rechargeable batteries and a switching regulator is used to power the system. A 3D printed enclosure with copper tape is used to house and shield the printed circuit board assembly.

A. Probe Design

The probes used for the field measurements are characterized using a TEM cell which provides a well-controlled field structure up to 1 GHz.

The E-field probe is loaded with a high impedance to achieve a flat frequency response from about 2 MHz to 2 GHz [6-8].

Figure 3 shows the geometry and the frequency response for the H-field probe. The H-field probe is constructed from a semi-circular segment of coax cable in parallel with four symmetrically placed resistors. Due to the low frequency roll-off of the probe's response, the measured H-field is distorted and needs to be reconstructed by applying deconvolution using the frequency response of the probe. The method used for the reconstruction is well-explained in [9].

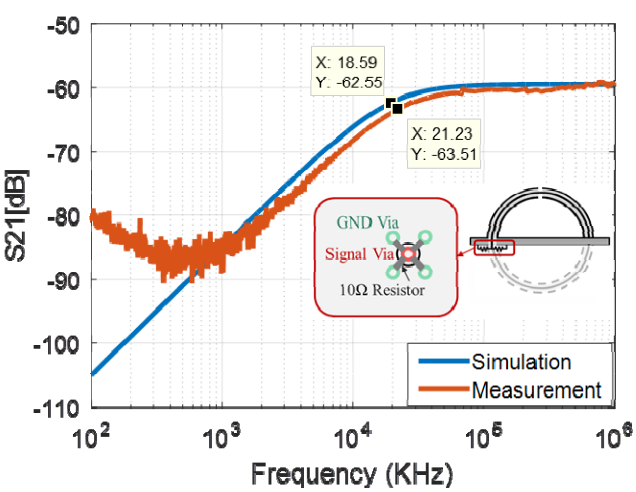


Figure 3: Frequency response for the H field probe. The increase below 1MHz is due to the test setup noise floor

B. Optical Control

Fiber optic cables are used to interface with the ESD demonstrator system remotely. The use of optical signals eliminates the coupling of the fields onto cabling. This ensures that the fields being measured do not disrupt the ESD demonstrator system operation which is essential for the scenarios being evaluated. To set the threshold, a PWM signal is transmitted through a LED transmitter and is sent through a fiber optic cable to a photodiode on the ESD demonstrator system. This photodiode is part of an integrator circuit which allows for the threshold level to be adjusted by varying the duty cycle of the PWM signal. In addition, threshold detection illuminates a transmitter LED on the ESD demonstrator system that is connected to a receiver photodiode via a fiber optic cable. The latch can be reset by transmitting a signal through a LED transmitter to another receiver photodiode on the ESD demonstrator system.

C. Measurement

The minimum signal level that can be detected by the comparators is determined by the internal hysteresis which is set at 50 mV. The optically configured threshold can be set from 0 to 500 mV. If the RF amplifier is used the minimum signal that can be detected is 5 mV while the maximum signal that can be detected is 50 mV. If the RF amplifier is bypassed the minimum signal that can be detected is 50 mV while the maximum signal level that can be detected is 500 mV. A resistor divider that increases the initial voltage on the negative comparator pin allows for further threshold adjustment from 0V to 3V, although not remotely. If the system is calibrated with a specific probe, the voltage threshold level can then be translated to field strength.

The field strength induced by waist worn devices can be different from the field strength produced by the human metal model (HMM) specified in the IEC-61000-4-2. The field measurements for these two scenarios are necessary to provide reference for the field strength level.

Another scenario that needs to be considered is discharges that occur during normal human activity. Charge can accumulate during various activities such as removing a garment and walking on the carpet. The charge accumulation can result in a person being charged up to a voltage of several kV. [9] A discharge can occur between different layers of clothing, especially when the environment humidity is low.

III. Results

A. System Calibration

The ESD demonstrator system was calibrated using the setup shown in Figure 4. A (Transmission line pulser) TLP was used to drive the stripline at a set voltage. The field probe is placed at a set location within the 100 Ω stripline structure and is secured with a magnet while it is connected to the ESD demonstrator system. The threshold level is then adjusted to find the highest threshold level for the field strength. After the threshold voltage is determined, the field probe is connected to an oscilloscope and the voltage response is measured. The probes were previously calibrated using a TEM cell. The relatively flat frequency response of the probe in the frequency range from 20 MHz to 1 GHz allows for the use a single value for the probe factor across the frequency range of interest.

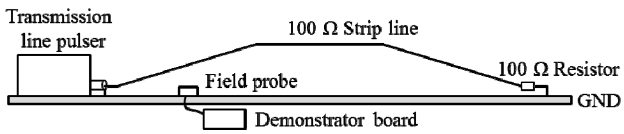


Figure 4: Test setup to obtain the threshold voltage level at the set field strength

Alternatively, if the probes were not previously calibrated, the field level could be calculated from the voltage incident on the stripline divided by the vertical distance from the stripline to the probe. This procedure was repeated for two additional field strengths by adjusting the TLP voltage and repeated for the magnetic field probe. The calibration results are shown in Figure 5.

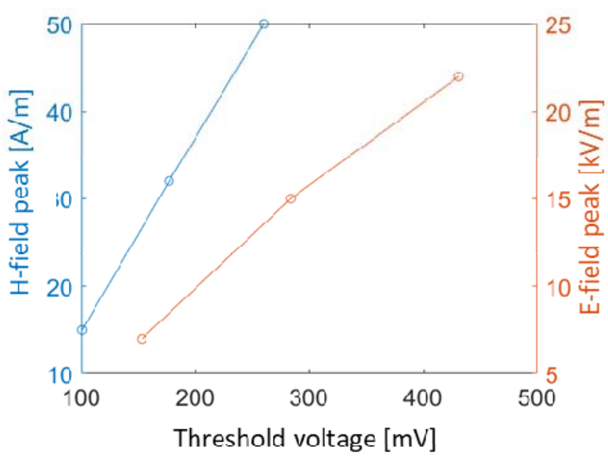


Figure 5: Field Strength vs Threshold Voltage Level

B. Waist Brush-By Testing

The brush-by scenario is when a wearable device approaches a grounded surface and the charge on the person discharges through the device. This test is important to evaluate for wearable devices because the peak discharge current is much higher than the peak discharge current for the IEC61000-4-2 test [1]. In this set-up, the wearable device DUT is mounted on the person's waist because waist discharge was found to have the highest peak discharge [1]. A body worn device can be in direct contact with the human body or it can be isolated. A direct connection is used for this test. The test set-up is shown in Figure 6. A copper plate with a semi-sphere in the center is mounted on the person's waist to simulate a wearable device. Water is used to ensure a good connection between the person's body and the copper plate. The ESD demonstrator system is mounted above the person's waist along with either the E-field or H-field probe. The person stands on a 0.5 mm insulator and is charged up to 1 kV via a high voltage power supply. The person is then discharged through the copper plate when the copper plate contacts the grounded surface. The threshold level is adjusted until the event detection is intermittent, indicating a worst-case field strength. A linear fit of the calibration data is used to convert the threshold levels into field strengths. The results are shown in Table 1.

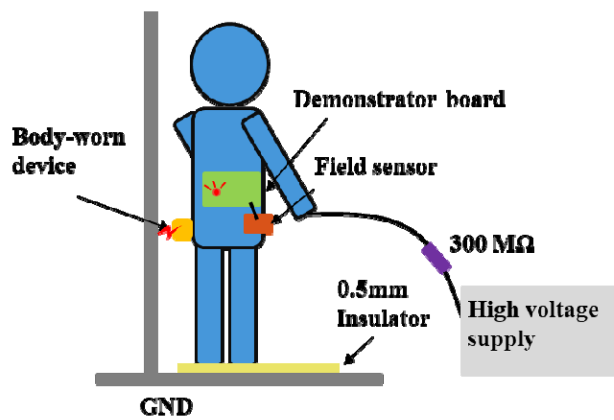


Figure 6: Measurement setup for the waist worn brush-by scenario. The demonstrator is mounted on the human body and the LED will illuminate when the transient event is detected.

1 kV	Threshold Level	Field Strength
E-Field	95.3 mV	6.8 kV/m
H-Field	84.45 mV	6.6 A/m

Table 1: 1 kV Waist Brush-By Results

C. Fields Results Comparison

To characterize the field induced by the waist worn devices, both E-field and H-field probes are used to capture the transient field. The arrangement for the person is the same as shown in Figure 6, however, the probes were instead terminated in an oscilloscope which is in a shielding box with a optical fiber connection to eliminate the coupling noise. The field induced by an ESD event from the HMM scenario is also measured as a reference.

The test was repeated multiple times with different orientations of the field probe to capture a decent sample size of field strength waveforms. Figure 7 and Figure 8 show the waveforms for the electric field and magnetic field respectively. The maximum field strength from the field distributions agree well with values obtained from the ESD demonstrator system. The pulsewidth of the peak portion of the waveform is about 2 ns long. These short pulsewidths validate the ESD demonstrator's ability to detect very short pulsewidths.

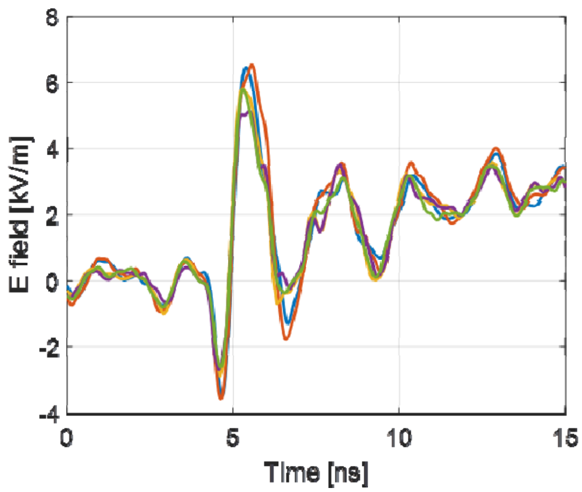


Figure 7: Scope Captured E-Field Waveforms at 1 kV

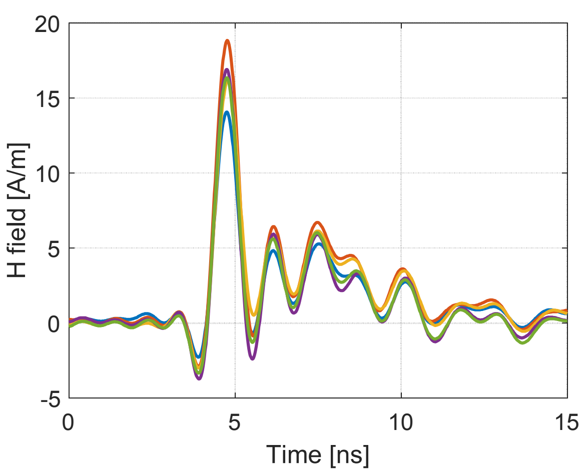
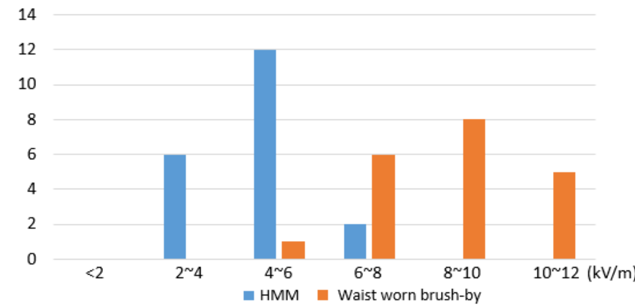
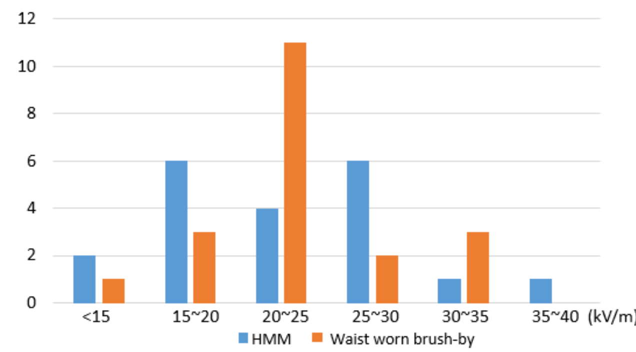


Figure 8: Scope Captured H-Field Waveforms at 1 kV after applying deconvolution

The measurements were repeated at 8 kV for a more representative case of the real world. The statistical graphs for the field peak distribution are shown in Figures 9 and 10. As expected, the maximum field strength present for the waist discharge scenario exceeds the maximum field strength present for a HMM discharge at the same voltage. At 1 kV, the average peak field strength for the waist worn devices can be twice as high as the field strength for the HMM scenario

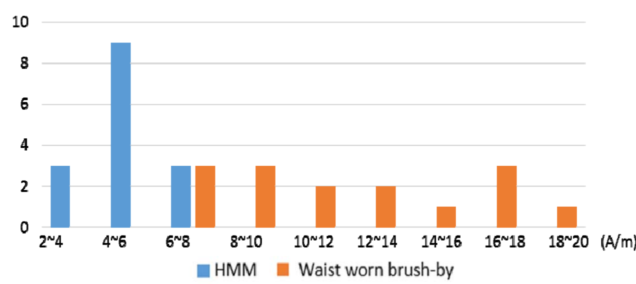


(a) E-field for HMM vs. Waist Worn Brush-by at 1 kV

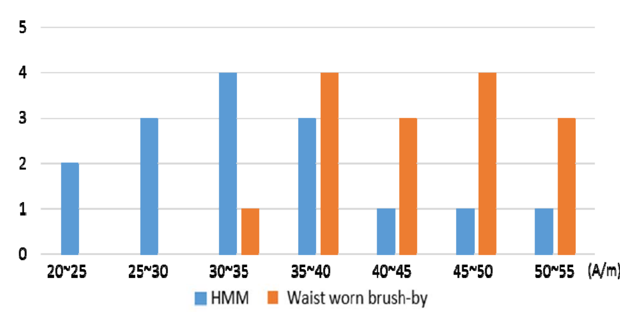


(b) E-field for HMM vs. Waist Worn Brush-by at 8 kV

Figure 9: E-field statistical data comparing the HMM and waist worn brush-by scenarios at different voltages. (a) E-field measured at 1 kV, (b) E-field measured at 8 kV



(a) H-field for HMM vs. Waist Worn Brush-by at 1 kV



(b) H-field for HMM vs. Waist Worn Brush-by at 8 kV

Figure 10: H field statistical data comparing the HMM and Waist worn brush-by scenarios at different voltages. (a) H field measured at 1 kV, (b) H field measured at 8 kV

D. Garment Removal Testing

When a person removes a garment, there can be a discharge between the clothing layers that will induce an electric field. [10] To determine the worst-case field strength the ESD demonstrator system is mounted at various positions on the person. The person removes the garment multiple times and the threshold level is adjusted to determine the highest field strength. The actual process that is occurring during a garment discharge is a collapse of the field. The tribo-charging creates a strong static E-field. However, the probe cannot detect a static field. Its lower 3 dB frequency is around 1 MHz, thus, its output voltage is zero despite the presence of the static field. Once the field collapses, the probe will measure the change of the field. The lower cut-off frequency of the E-field probe again affects the data after 100 ns when the output voltage of the probe returns to zero. The data between 0 and 100 ns is valid data. However, to obtain the actual field, the data should be shifted such that the data around 100 ns shows zero, and the static field level should be added. As most body worn devices do not respond to a static field, and as we do not have the exact static field data we present the data in the form shown.

Because multiple discharges can occur during one garment removal, a fast re-trigger method is used for capturing the successive discharges. The Rohde & Schwarz oscilloscope used for the testing had this capability and they call it “ultra-segmentation”. A set of waveforms, all from the same garment removal, are shown in Figure 11. Each successive E-field waveform captured has a similar fall time in the range of 40-90 ns. The discharges captured during a single activity can be placed in two different groupings. One grouping, which consists of most of the discharges, contains the discharges that have a magnitude of 2-5 kV/m, while there are several pulses that have a field strength of up to 50 kV/m in the second grouping. At least two reasons may contribute to the variation of the field strength: the distance of the discharge to the sensor, and the field strength at the location of the discharge. The longer rise time of the garment discharge when compared to the HMM discharge is most likely caused by the fact that these discharges are occurring between insulating layers of cloth.

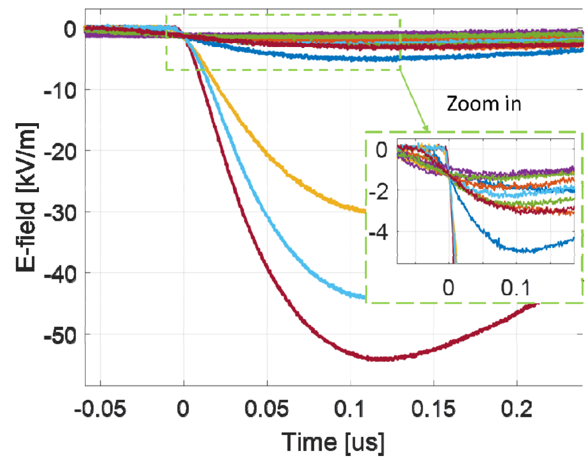


Figure 11: E-field captured during a single activity using ultra-segmentation

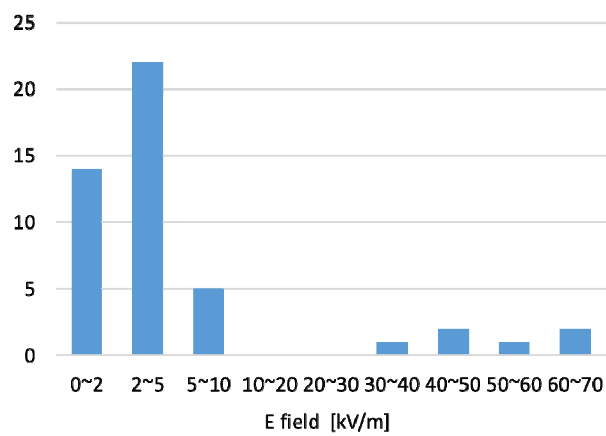


Figure 12 : E field statistical distribution for the garment removal testing

Figure 12 shows the distribution of the field strength for the garment removal testing. Most of the discharges have a field level between 2 kV/m to 5 kV/m. A few of the discharges which induce a strong field can reach a field level of 70 kV/m.

Conclusion

This paper shows the ESD demonstrator system’s ability to detect short ns pulsewidths and its usefulness for demonstrating the worst-case field strengths present in a certain scenario. The ESD demonstrator system can be employed in many real-world scenarios like moving a patient in the hospital. The field strength for the waist worn brush-by scenario shows that body worn devices are subjected to a higher ESD risk compared to the HMM scenario.

Acknowledgment

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