

Spark-less Electrostatic Discharge (ESD) on Display Screens

Atieh Talebzadeh¹, Yingjie Gan², Ki-Hyuk Kim¹, Yiqiang Zhang³ and David Pommerenke¹

¹ EMC Laboratory, Missouri University of Science and Technology, Rolla, MO,

² School of Science, Wuhan University of Technology, Wuhan, China,

³ Nokia, Communication Company, Beijing, China

Abstract—An electrostatic discharge (ESD) to a display screen may lead to sparking into the phone's structure, e.g., via the glue that connects the different glass layers of the touching panel/LCD, or it may just cause surface charging. The latter is the most likely case for a well-designed display, as the insulation design usually prevents any sparking to the electronics. Even if no spark is visible, strong surface charging occurs. These charges couple via displacement current and via their magnetic field into the display electronics. Most phone and tablet manufacturers currently suffer from damages or upsets caused by this type of spark-less ESD. As far as we know, no data has been published showing the magnitude, rise time and total charge parameters of these surface discharges for displays. In this paper, discharges to different displays have been measured at ± 4 , ± 8 , ± 10 and ± 14 kV. The discharge currents are measured using an F65 current clamp. Five different types of display screens have been tested and the results of transient current discharges are compared in this paper. During the experiments, repeatability of results is investigated. Moreover, the effects of touch position as well as dirty screens (i.e., presence of finger prints, etc) are investigated.

Keywords— *Electrostatic discharge (ESD), portable device, display screen, rise time;*

I. INTRODUCTION

Electrostatic discharge (ESD) is a severe source of interference in electronic products and can produce damage or upset failures. In different areas, ESD has been studied. In [1], decay times of ESD events caused by garment removal and sitting/standing motions from a chair are presented. In [1]–[6], ESD in data centers caused by various types of human activities—walking, sitting/standing from a chair, and garment removal—have been studied at different dew points (various temperature-relative humidity). Presently, many manufacturers of portable electronic devices which utilize display screens including mobile cell phones, smart phones, multimedia players, etc., are facing severe ESD related problems which demands ESD protection, [7]–[10]. In most of these products, LCD, LED, or electronic ink screens are utilized. Generally, ESD on electronic products might occur when the device itself becomes charged by triboelectrification and approaches another conducting object. Other types of ESD occur when a human, charged by triboelectrification, touches the electronic product. Thus, it can be said that the ESD can either produce a spark (e.g., to the body of the cell phone), or it can be a spark-less corona charging the glass display screen. Therefore, there

is high interest in the understanding of ESD events on the display screens of portable electronic products.

This paper presents measurements of spark-less discharges to displays. The ultimate goal of this work is to understand the mechanisms that allow the spark-less discharges to upset or destroy display or touch screen circuits. A prerequisite to this is to understand the current magnitudes, rise times, and total charges associated with an ESD event and their dependence to parameters like polarity, voltage, and different display types. Further, quantifying the current densities through display glass and the current density distribution is important. This paper reports on measurement and analysis of the governing parameters for spark-less surface discharges to displays. The distribution of the deposited charges can be further illustrated using the Lichtenberg dust figure method [11]–[14], which is known that related to the discharge voltage level, polarity, etc.

II. MEASUREMENT SET-UP

Fig. 1(a) shows the measurement set-up. An ESD gun or generator connected to voltage source is used to create the desired discharges to the device under test. A current clamp, F65 (Fischer Custom Communications), having a transfer impedance of 1 ohm, is used to measure the discharge current. Five different displays are compared, including displays released in 2014. In the real application the displays are connected to the main PCB of the device by flex cables. These nets have ESD protection, so it is reasonable to assume that these nets act as if they are connected to the system ground. For the displays which are tested without being integrated into a functional system, the flex cable connectors are grounded. Furthermore, the displays usually back against a metallic frame of a cell phone, tablet, etc. These frames are connected to a large ground plane. Electrically, the consequence is that part of the displacement current that flows through the glass can flow via the touch and LCD flex cable to ground, and part will reach the back metal structure. As of now, the ratio of currents is not known, but the touch circuit's ITO layers have a high resistance, such that the current fraction through these layers maybe small. The ESD generator is grounded to the metal plane, which is also connected to the oscilloscope shield. A current clamp, shown in Fig. 1(b) is placed around the air discharge ESD generator tip. A coaxial cable via a bulk-head SMA connector is connected to the current clamp to divert any common mode current away from the oscilloscope. As further

protection, a 20dB attenuator is used. The experiment is conducted by approaching the display with the ESD generator (in air discharge mode). As seen in Fig. 1(c), five display screens are utilized for experiments, and are labeled as screen #1 to #5. To perform the experiments, charge voltages of ± 4 , ± 8 , ± 10 , and ± 14 kV were used. The surface of the screens can be clean or dirty. The touch location and approach speed were varied. Three approximate approach speeds were used, and are referred to as “slow”, “medium”, and “fast”. The slow approach speed was in the range 1cm/sec, and the fast approach was close to the speed which may break the glass. Thus, the medium approaching speed was used in most experiments. As shown in Fig. 2 for voltage of +8 kV, the influence is strong and the slow approach has the lowest discharge current and the fast approach has the highest current. While achieving constant speed was difficult, each experiment was repeated several times for each experiment. Further, a phenomenon observed from discharge current is a double peak, shown in Fig. 3 for screen #1 to #3, at +8 kV. It shows that the 1st rise time is faster than the 2nd.

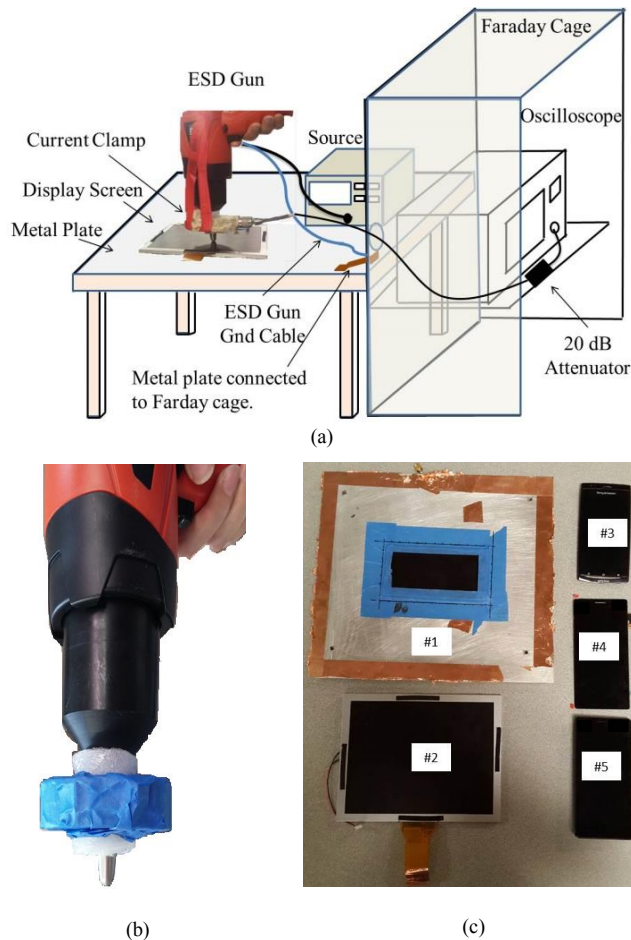


Fig. 1. (a) Measurement set-up of ESD on display screens, (b) ESD gun with current clamp, and (c) display screens under test.

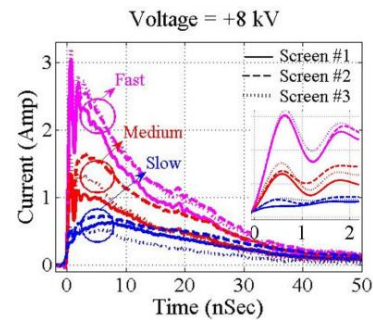


Fig. 2. Compare the approaching speeds.

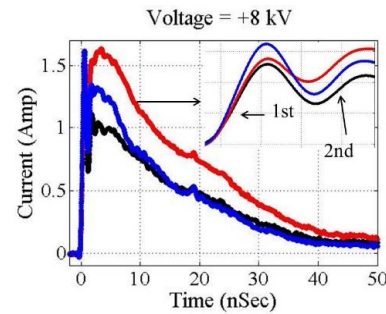


Fig. 3. Illustration of the 1st and 2nd rise times.

III. MEASUREMENT RESULTS AND DISCUSSIONS

A. Repeatability

To understand the natural and experimentally induced variations of these discharges, repeatability testing was performed. Each discharge measurement was repeated at least 3 times using medium approach speed to the center of the screen. Tests were repeated over three days. The results are presented in Fig. 4. From the results, variation of the peak current are seen which might be due to variation of approaching speed (i.e., faster approaching often gives higher current, and faster rise time), humidity and temperature [1], fine layer of moisture, spark initiation, etc. Comparing all the screens together shows that screen #1 experiences the highest peak currents and screen #2 has the lowest peak currents. Generally, these currents show a fast rise (< 2 nSec) and a slower decay. The decay to 50% of its amplitude is about 20-30 nSec. The amplitudes are highly voltage dependent but reach a few amperes for +10 kV, which explains their potential to disrupt or damage displays. This is true for human metal discharges (IEC 61000-4-2 or also called HMM). A discharge from the skin (Human Body Model-HBM) shows much lower currents. Thus, this paper provides data related to ESD tests in which a metal part is used to touch the screen. The current rise times and peak values determine the current derivative which quantifies the magnetic fields which may induce voltages in the screen electronics. Thus, two mechanisms may lead to disturbances: the current derivative induced voltages, and the displacement currents. The total charge, peak current, and 1st and 2nd rise time parameters are presented for +4kV in Table I. The numbers show the average of results for different days. Both mean value (μ) and standard deviation (σ) are presented to illustrate the repeatability. For reasons presently unknown,

but suspected to be related to the glass thickness and grounding of the touch and LCD structure, it is observed that screen #1 has the largest average peak current (0.7 Amp, +4 kV) and screen #2 has the lowest average peak current (0.31 Amp). This again indicates that the design of screen #1 may contain features that will create more difficulties in passing IEC 61000-4-2 tests. The average peak current from all the screens is around 0.45 Amp. Also, screen #2 showed the lowest peak current but the largest transferred charge (7.67 nC) on its surface. As there is no conduction current flowing through the

glass, these charges are deposited on the glass surface. Also, the lowest transferred charge (3.6 nC) was measured on screen #4. The average charge transfer at +4 kV was around 6.3 nC. The first peak showed an average rise time of 0.49 nSec. This value may already be influenced by the 1 GHz bandwidth of the current probe. The second peak current rose in 1.35 nSec (screen #4). The slowest rise of 0.48 nSec was observed on screen #2. The average rise time for the second peak was 2.49 nSec.

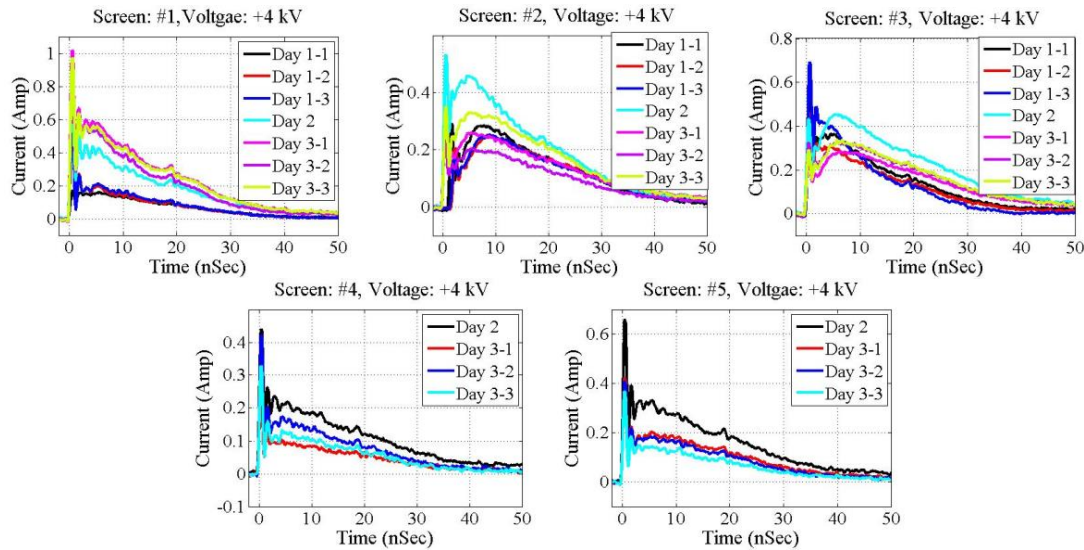


Fig. 4. Repeatability of measurements for various display screens, screen #1 to #5, at +4 kV ESD voltage generator during different time.

TABLE I. LISTING OF MEASUREMENT RESULTS FOR REPEATABILITY BASED ON +4 kV DATA.

	Parameters	Screen #1	Screen #2	Screen #3	Screen #4	Screen #5	All Screens
Peak Current (Amp)	μ	0.7	0.31	0.44	0.35	0.47	0.45
	σ	0.3	0.07	0.15	0.09	0.13	
Charge (nC)	μ	7.65	7.67	6.8	3.6	5.7	6.3
	σ	3.97	2	1.63	1.4	2.06	
1 st Rise Time (nSec)	μ	0.48	0.56	0.5	0.47	0.47	0.49
	σ	0.04	0.01	0.003	0.046	0.015	
2 nd Rise Time (nSec)	μ	1.63	4.85	3.13	1.35	1.49	2.49
	σ	0.058	0.94	1.34	0.05	0.045	

B. Dirty vs. Clean Screen

The presence of fingerprints (i.e., a more realistic case than a clean screen) causes a thin layer of oil, dust, etc. which can lead to changes in the amount of current or transferred charge on the screen. Thus, it is interesting to analyze the discharge behavior for the case of dirty screens and compare them with clean ones. To do this, three screens were selected: screen #1, #4, and #5. The ESD source voltage level was set on +4 kV. The discharge measurements were repeated three times at

medium speed at the center point of the screens. As seen in Fig. 5, the presence of fingerprints or dust on the display screen has little effect on the discharge behavior. A double rise is observed again for all cases. The results are combined together in Table II. As seen, the mean values of the peak current amplitude for a clean (0.97 Amp) and a dirty (1.04 Amp) screen for screen #1 are similar. However, around 0.1 Amp difference is observed for screen #4 and #5. Moreover, dirty screens showed a higher transferred charge (about 1 nC higher). The first and second rise times remain about the same.

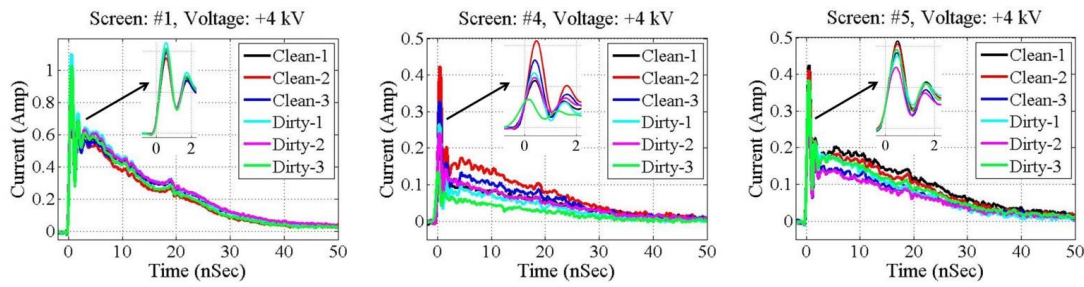


Fig. 5. Dirty vs. clean display screen for screen #1, #4 and #5 with +4 kV for ESD generator.

TABLE II. LISTING OF MEASUREMENT RESULTS FOR DIRTY VS. CLEAN SCREEN BASED ON +4 kV DATA.

Parameters		Screen #1	Screen #4	Screen #5
		Clean / Dirty	Clean / Dirty	Clean / Dirty
Peak Current (Amp)	μ	0.97 / 1.04	0.33 / 0.21	0.40 / 0.30
	σ	0.05 / 0.05	0.09 / 0.07	0.03 / 0.04
Charge (nC)	μ	12.1 / 11.3	2.9 / 1.82	4.2 / 3.6
	σ	0.80 / 0.89	0.66 / 0.59	0.79 / 0.44
1 st Rise Time (nSec)	μ	0.47 / 0.46	0.47 / 0.51	0.47 / 0.45
	σ	0.0001 / 0.0013	0.06 / 0.08	0.0018 / 0.01
2 nd Rise Time (nSec)	μ	1.52 / 1.57	1.40 / 1.43	1.53 / 1.50
	σ	0.03 / 0.057	0.07 / 0.28	0.065 / 0.083

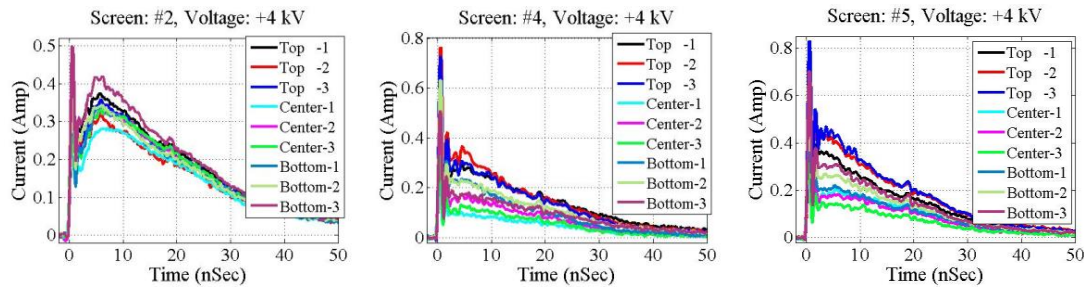


Fig. 6. Position (touch location) effect for screen #2, #4 and #5 at +4 kV.

C. Position

If a large portion of the current would flow via the ITO layers of the touch-screen or the LCD structures, then a discharge position towards the interfaces would have a lower resistance path, and would lead to a higher current. As seen in Fig. 6, three different positions including top, center, and bottom were tested at different times. No large variation was observed when testing three screens (screen #2, #4 and #5) at +4 kV using a medium approach speed and clean surface. This indicates that a large portion of the current might flow as displacement current through the display to the metallic backing structure.

D. Polarity and voltage level

The dielectric response of the glass, and the conductivity of metal structures is linear with respect to voltage and polarity.

While ESD protection structures usually are not symmetrical, it is unlikely that this asymmetry can be seen in the current of the spark-less discharge, as all ESD protection of the touch and LCD probably turn on, resulting into a virtual short. However, it is known that surface discharges may strongly depend on the polarity due to the large difference in the velocity of electrons, relative to ions. This motivated us to compare the currents for both polarities. Strong difference may indicate a higher likelihood of failures in one polarity.

Here, a medium approach speed and a discharge location in the center of a clean screen were selected. Each experiment was repeated 3 times for all the voltages. Fig. 7 presents the current waveforms for positive charge voltages (A to D), and for negative charge voltages (E to H). The peak current dependency as well as charge for positive/negative voltages is shown in Fig. 8 (H to J).

There are strong differences between negative and positive charge voltages. While the rise times are similar, the peak current for negative charge voltages is more than 10 times smaller than positive charge voltages (compare Fig. 7: A to E, B to F, C to G, D to H).

In addition, the peak current increased, reaching 4 Amp for voltages up to +10kV for the positive case (Fig. 8, I), however, within the limited range of our present observations from -4 to -14kV, the largest peak current was measured at -4kV, while -8 to -14kV showed the same peak currents (Fig. 8, K).

Moreover, the distributed charges are much larger for the positive case. The charges increased to about 70 nC (+10 kV, Fig. 8, J). The negative voltages led to charges up to -6 nC (Fig. 8, L).

In all but the very slow approach speed case, positive charge voltages let to a double peak in the rising edge, this was rarely observed for the negative voltage.

Beside, screen #1 showed the highest peak currents (Fig. 7, A to D). The design details of the screen are not known,

however it indicates that this design maybe more ESD susceptible due to the higher currents.

Multiple possible consequences can be supported from the results. If the failure mechanism is polarity independent and related to rise time, no polarity dependence would be expected. However if the total transferred charge is relevant (e.g., melting of a trace), or the peak current is critical, then the robustness will be less for positive polarity discharges. To analyze these results with respect to the current density of the displacement current that leads to currents on the ITO layers and in the LCD, an additional fact needs to be considered. It is known that the charge distributes over a much smaller area for negatively charged electrodes. Although the peak current is less for the negative charge voltage, it might be stronger concentrated in one area. On the other hand, if the peak current correlates to the failure mechanism, then positive polarity is worse than negative polarity for failure level. Also if the total transferred charge matters (e.g., a trace burns out), then positive polarity should be worse than negative polarity.

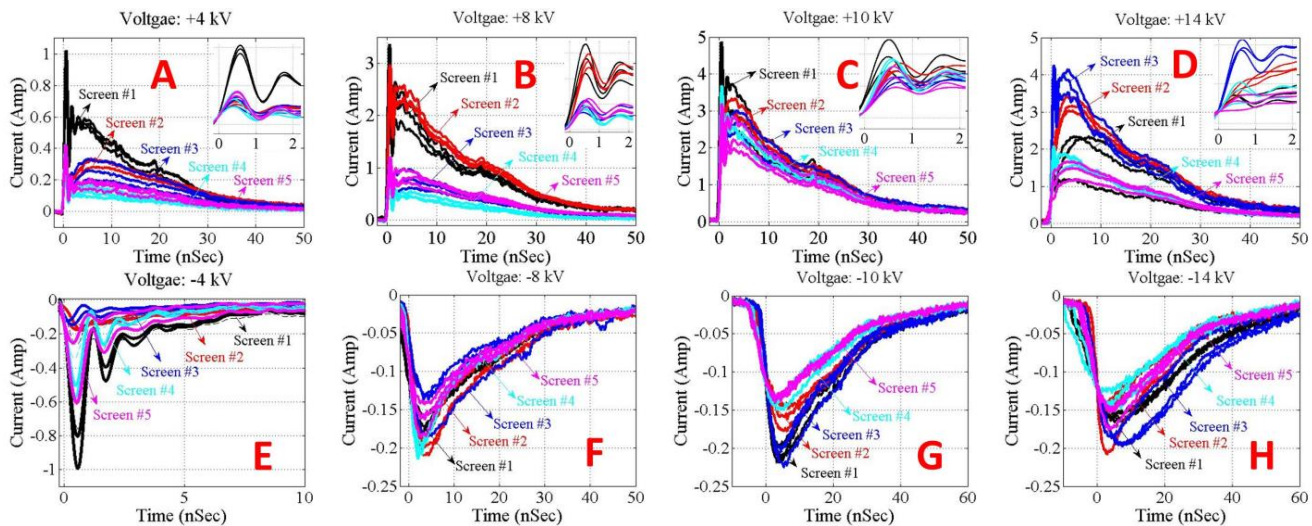


Fig. 7. Positive and negative polarity at different voltages.

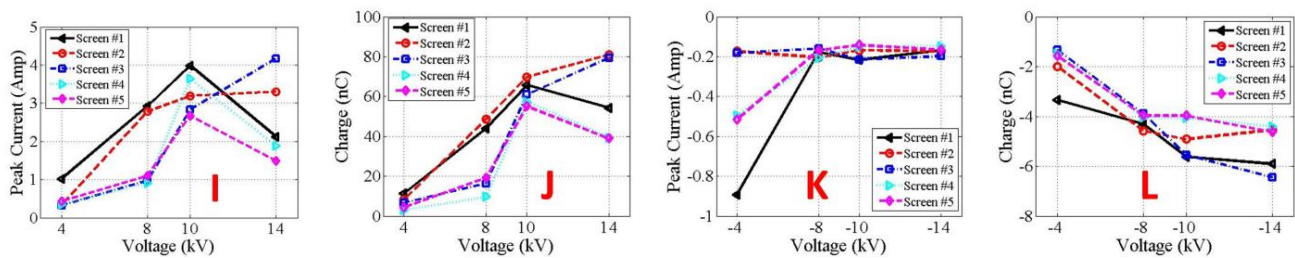


Fig. 8. Voltage dependency of peak current and transferred charge.

IV. CONCLUSION

In this paper, measurement results from spark-less electrostatic discharge on five display screens are presented. Using an ESD generator in air discharge mode, the currents are measured at ± 4 , ± 8 , ± 10 and ± 14 kV using a current clamp.

The surface discharge waveform shows a fast double peak rise (< 2 nSec), and 50% amplitude decay in about 20-30 nSec for positive voltages, and much lower currents for negative cases. The presence of fingerprints had negligible effect on the current waveform and transferred charge. Different discharge locations on the display showed similar current waveforms. At

+14kV, a charge transfer of about 60 nC and a peak current of 5 Amp was measured. These currents are sufficient to damage or disrupt the display. These peak currents depend non-linearly on the voltage and may not even increase with increased voltage. This research will be continued by modeling the current distribution in the display between the touch and LCD connections relative to the displacement current that flows through display to the metallic body of the grounded system.

ACKNOWLEDGMENT

This material is based upon work supported partially by the National Science Foundation under Grant No. IIP-1440110 and the work is supported in part by the scholarship from China Scholarship Council (CSC).

REFERENCES

- [1] A. Talebzadeh, M. Moradian, Y. Han, A. Patnaik, D. E. Swenson, and D. Pommerenke, "Electrostatic charging caused by standing up from a chair and by garment removal", *IEEE Symposium on Electromagnetic Compatibility and Signal Integrity*, Santa Clara, USA, pp. 57-62, 2015.
- [2] A. Talebzadeh, M. Moradian, Y. Han, A. Patnaik, D.E. Swenson and D. Pommerenke. 2015. Dependence of ESD charge voltage on humidity in data centers: part I—test methods. *ASHRAE Transactions*, 121(1):58-70.
- [3] A. Talebzadeh, A. Patnaik, X. Gao, M. Moradian, D.E. Swenson and D. Pommerenke. 2015. Dependence of ESD charge voltage on humidity in data centers: part II—data analysis. *ASHRAE Transactions*, 121(1):37-48.
- [4] X. Gao, A. Talebzadeh, M. Moradian, Y. Han, D. E. Swenson, and D. Pommerenke, "Dependence of ESD Charge Voltage on Humidity in Data Centers (Part 3 - Estimation of ESD-Related Risk in Data Centers Using Voltage Level Extrapolation and Chebyshev's Inequality)", *ASHRAE Transactions*, 121(1):49-57.
- [5] Moradian, M., A. Patnaik, Y. Han, F. Wan, X. Gao, D. Pommerenke and D.E. Swenson. 2014. Determination of the effect of humidity on the probability of ESD failure or upset in data centers. *ASHRAE Transactions* 120(2):25-41.
- [6] Wan, F., M. Hillstrom, C. Stayer, D.E. Swenson and D. Pommerenke. 2013. The effect of humidity on static electricity induced reliability issues of ICT equipment in data centers—motivation and setup of the study. *ASHRAE Transactions* 119(2):341-357.
- [7] S. Caniggia, and M. Francescaromana, "Circuit and numerical modeling of electrostatic discharge generators," *IEEE Transactions on Industry Applications*, Vol. 42, no. 6, pp. 1350-1357, 2006.
- [8] P. Tamminen, T. Viheriäkoski, T. Reinvuo, L. Sydanheimo, and L. Ukkonen, "Field collapse event ESD test method," *36th Electrical Overstress/Electrostatic Discharge Symposium (EOS/ESD)*, pp. 1-6, 2014.
- [9] P. Tamminen, "System level ESD discharges with electrical products," *34th Electrical Overstress/Electrostatic Discharge Symposium (EOS/ESD)*, pp. 1-10, 2012.
- [10] J. Xiao, D. Pommerenke, J. L. Drewniak, H. Shumiya, J. Maeshima, T. Yamada, and K. Araki, "Model of secondary ESD for a portable electronic product," *IEEE Transactions on Electromagnetic Compatibility*, Vol. 54, no. 3 pp. 546-555, 2012.
- [11] D. C. Faircloth, and N. L. Allen, "High resolution measurements of surface charge densities on insulator surfaces." *IEEE Transactions on Dielectrics and Electrical Insulation*, vol. 10, no. 2, pp. 285-290, 2003.
- [12] M. A. Abdul-Hussain, and K. J. Cornick, "Charge storage on insulation surfaces in air under unidirectional impulse conditions," *IEE Proceedings A (Physical Science, Measurement and Instrumentation, Management and Education, Reviews)*, vol. 134, no. 9, pp. 731-740, 1987.
- [13] Y. Murooka, and S. Koyama, "Nanosecond surface discharge study by using Dust figure techniques." *Journal of Applied Physics*, vol. 44, no. 4, pp. 1576-1580, 1973.
- [14] Y. Murooka, T. Takada, and K. Hiddaka, "Nanosecond surface discharge and charge density evaluation part I: review and experiments," *IEEE Electrical Insulation Magazine*, vol. 17, no. 2, pp. 6-16, 2001.