Characterizing Automated Handling Equipment Using Discharge Current Measurements

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Abstract - Characterizing ESD performances of Automated Handling Equipment (AHE) has always been confusing, subjective, sometimes just plain arbitrary, and most of the time wrong. ESD sensitivity of devices is classified by an amplitude and type of discharge mode. For example, a device may be susceptible to a discharge of 200 volts Human Body Model (HBM), Charged Device Model (CDM), or Machine Model (MM). Each of the models has unique circuitry of capacitance and resistance to provide a specific current and rise time of the discharge at a specific voltage. This is fairly repeatable in most cases. On the other hand, attempts to classify AHEs based on voltage measured at certain points in the product path can be and most often is misleading. This paper deals with the experimental methods of measuring the discharge currents and the results of processing devices through automatic processes and placing them on a special board to promote a discharge.

I. Introduction

Manufactures of Automated Handling Equipment (AHE) are being forced to characterize their products in terms of safely handling devices and assemblies that are increasingly more sensitive to ESD. In addition to customers asking for increased placement rates and accuracy requirements, they also want the handler capable of placing ESDS devices at 25-volt sensitivities and less. It is very difficult to answer that question in the sense that the only methods of monitoring an AHE is by measuring the voltage levels of the various AHE components (guides, nozzles, conveyors, and grippers) with electrostatic voltmeters, miniature probes, and field strength meters [1]. The measured voltage levels do not correlate to the susceptibility of the devices. In many cases, the provided voltage rating of the device is the Human Body Model (HBM) that really does not apply to the AHE world unless operator intervention is required. However, many customers will only specify their components using the HBM since that is the only rating available to them. If the AHE is properly designed and grounded, the Machine Model really does not apply either since there should not be a charge on the machine components to discharge to the device. The purpose of these studies is mainly from a CDM perspective and to determine if the discharge current of charged devices being processed could be measured in the AHE in a repeatable manner using a reproducible method. Several experiments were conducted to develop methods to charge the devices in a controlled manner to specific levels and measure the current discharge at placement on a board specifically designed for this purpose. This work is ongoing and this paper is an update of the work completed on the bench to date. The follow up work will be in a Automatic Handler using these methods described.

II. Experiments

A. Experiment Design

Several experiments were completed to provide a consistent method of charging the device to be placed, a board for the device to be placed on, and the measurement of the discharge current in a consistent manner.

1. Device Charging, Charge Transfer

Charging the device in a controlled and reproducible manner created a few challenges. The charge on the device changed after it was picked prior to placement. The nozzle and change in capacitance were influencing the charge of the device.

To overcome these obstacles, a special nozzle with a resistance of greater than 10e11 Ohms and a conductive nozzle holder insulated from the spindle and ground path was used with a power source connected to the nozzle holder.

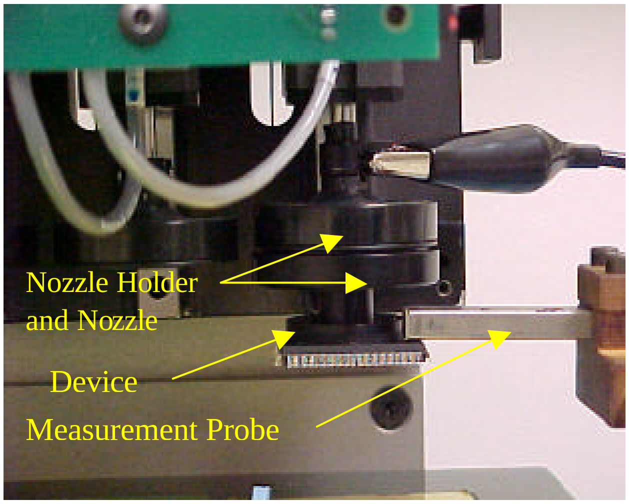


Photo 1

As Shown in Photo 1, measuring the voltage level on the device and adjusting the power source accordingly charged the nozzle holder, nozzle and device.

2. Placement and Consistent Measurements

Consistent current discharge measurements were dependent on the variations in placement parameters such as force, velocity, and deceleration of the placement component. In order to obtain a consistent measurement, the parameters had to be automated, even in the bench experiments. A placement head was mounted in a test stand As Shown in Photo 1, and connected to a controller so that the same placement parameters used in the handler was used in these experiments to place the charged devices.

3. Current Measurement Placement Board

The board the charged device was to be placed on had to simulate an actual assembly with ground planes and lands. In the original board, a ring just large enough to connect the leads was connected to ground through the current probe. See Photo 2. The result was a lot of ringing in the discharge measurement. In order to minimize that effect, a larger pad and a large ground plane was established. The placement pad was connected to the ground plane through the current probe. The ground plane was then connected to a ground. See Photo 3.

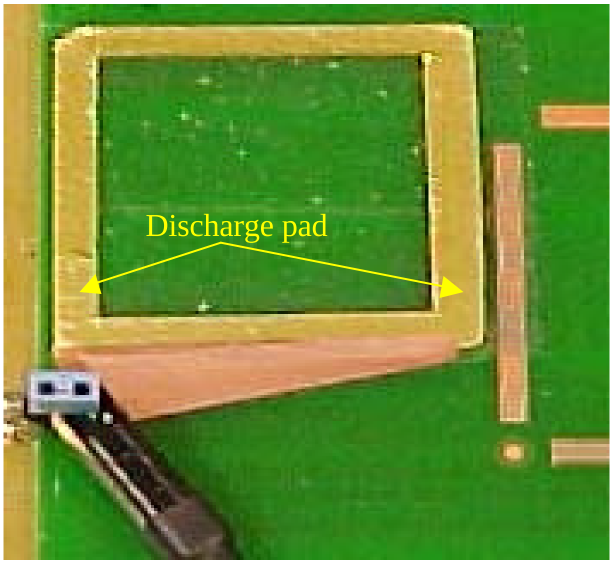


Photo 2

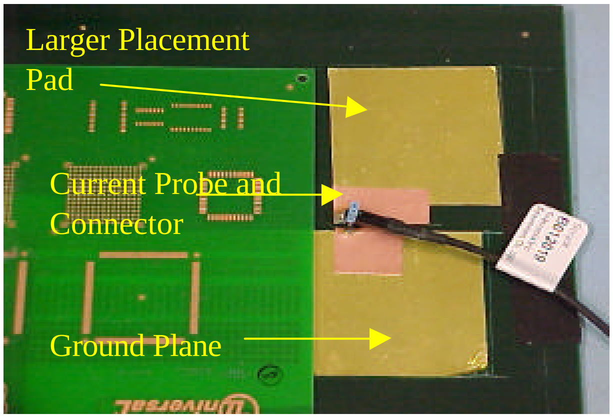


Photo 3

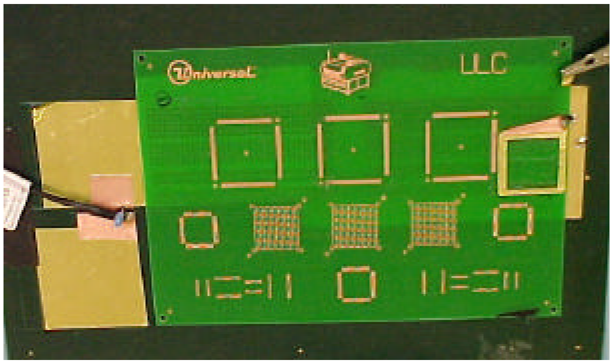


Photo 4

As shown in Photo 4, the ground plane is the whole length of the board and connected to ground.

B. Test Equipment Used

Tektronix Oscilloscope	TDS7104
1GHZ / 5GS/S 400K DPO	
HP Oscilloscope	Infinium
500 MegHz / 1 Gsa/S	
Tektronix Current Probe	CT6
Trek Reference Power Supply	605A
Trek Electrostatic Voltmeter	368
Miniature Probes, side aperture	

C. Devices Tested

8 Pin SOTs 2.8mm X 1.7 mm Encapsulated
208 MQFPs 27.8 mm sq. Encapsulated
44 Pin QFP 16.25 mm sq. Encapsulated
BGA 52.5 mm sq. Conductive top
BGA 47.5 mm sq. Conductive top
BGA 33 mm sq. Conductive top
BGA 27 mm sq. Conductive top

Note that all of the devices were used in all of the experiments but all were not used in the discharge current measurements experiment.

III. Result

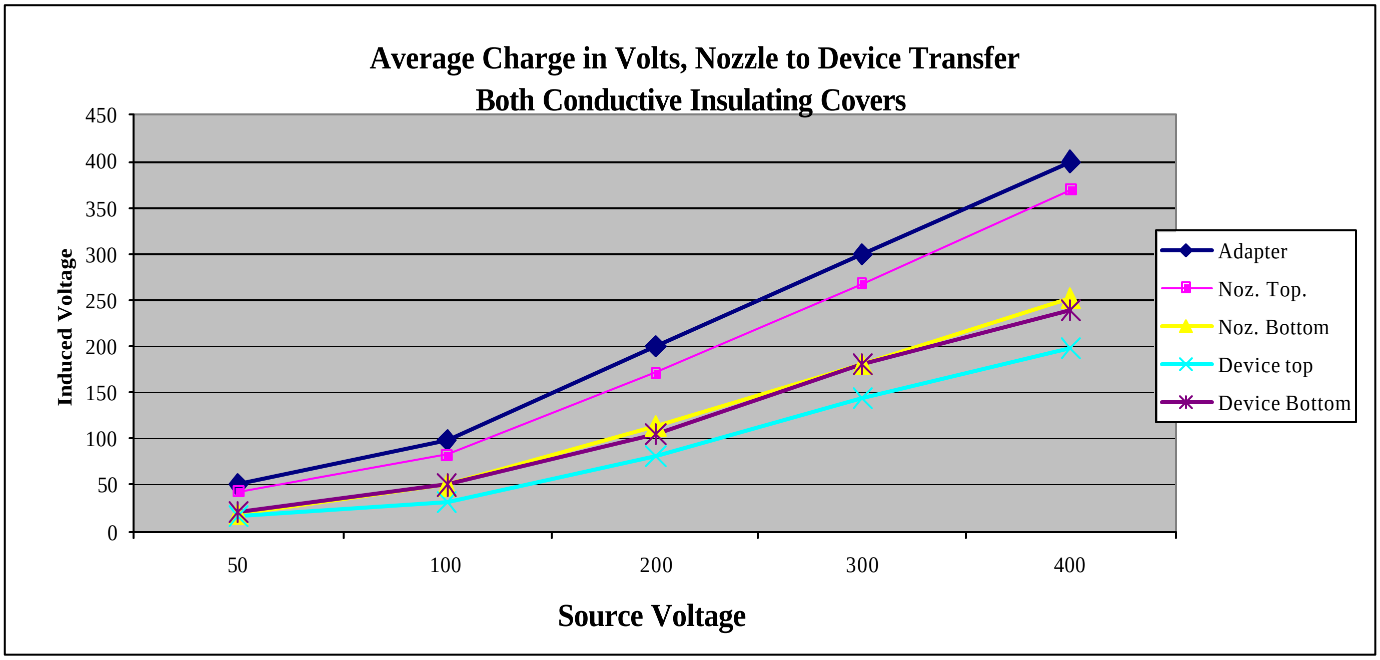
A. Charge Transfer

See Graph 1 and Table 1, for charge transfer results, note this is the average of both conductive and plastic bodied devices per voltage level. The only contact with the device is through the nozzle. There are no other connections.

Average charge transfer and distribution from nozzle to device					
Source V	Adapter	Nozzle Top	Nozzle Bm	Device Tp	Device Bm
50	50	43	19	17	23
100	98	83	50	32	49
200	200	171	112	80	104
300	300	268	180	143	180
400	399	369	253	197	238

Table 1

As shown in the Table 1 and Graph 1, the charge distribution from the nozzle to the device is a proportion of the source voltage level. This is a static or stationary measurement, which means there is no movement of the nozzle or device. Notice in Graph 1, that the nozzle top measurements follows the adapter source measurements closely. Charge similarity is less the farther away from the source. Interestingly, the device top is less than the bottom of the device and the top of the device is in contact with the nozzle.



Graph 1

B. Placement

By using a placement head as shown in Photo 5, set up to simulate the same head in a handler, placement force, velocity, distance traveled and planarity of placement is controlled in a constant manner. The controller controlling the head is also the same controller used in the handler.

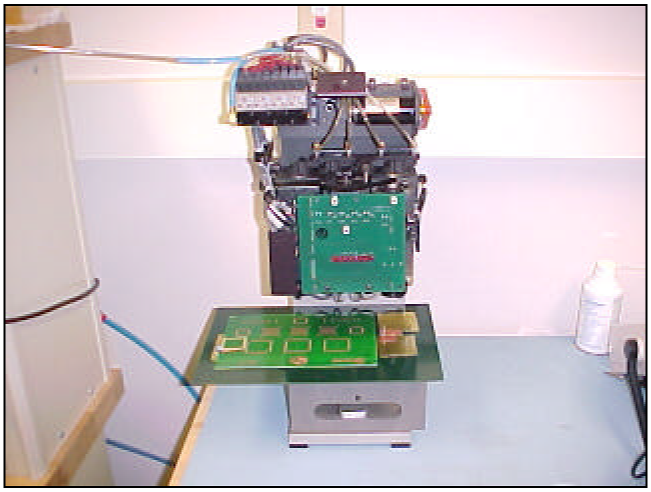


Photo 4

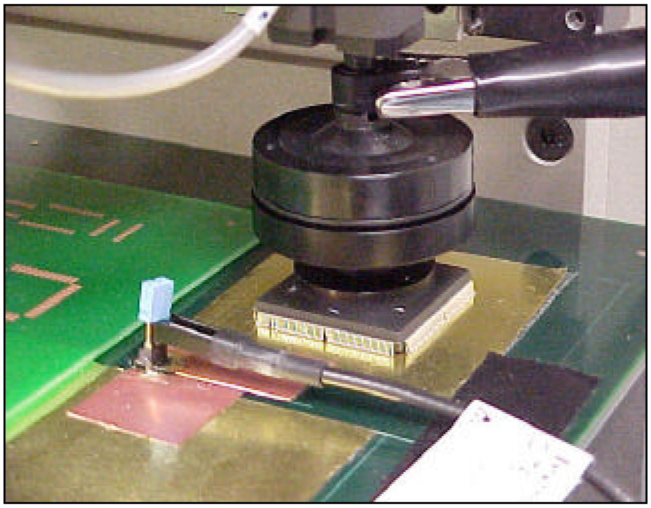


Photo 5

As shown in Photo 6, planarity is a function of the nozzle, spindle, and board alignment.

C. Current Discharge Measurements

The following Graphs and Waveforms are the results of the Discharge Current Measurements.

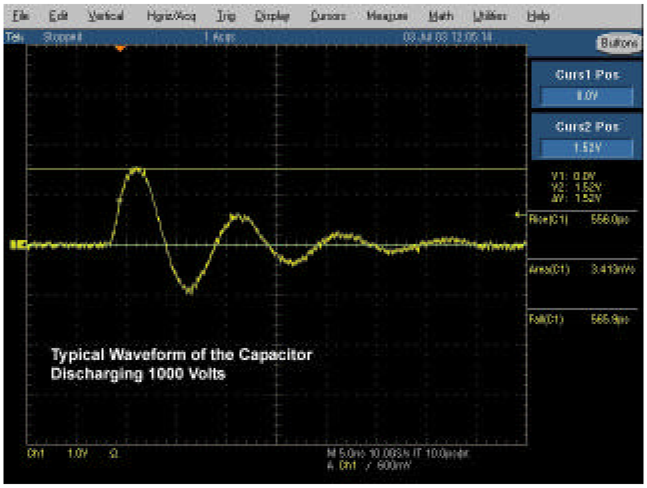


Figure 1

Figure 1 is of the discharge current of the 4.6 pF capacitor charged to 1000 Volts. Discharge Current was 300 milliamps at approximately 2.5 nanosecond rise time.

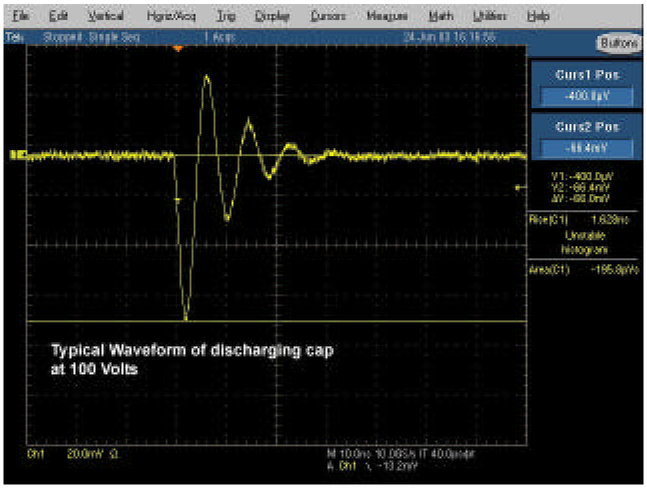
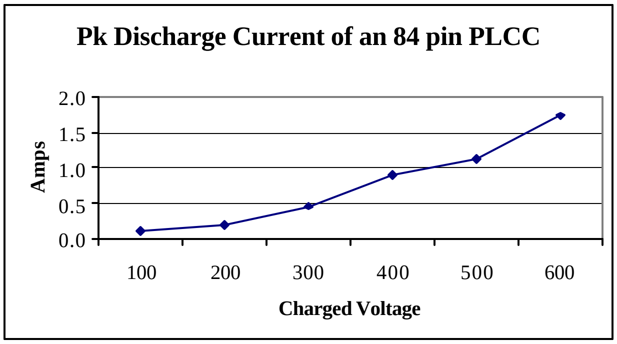


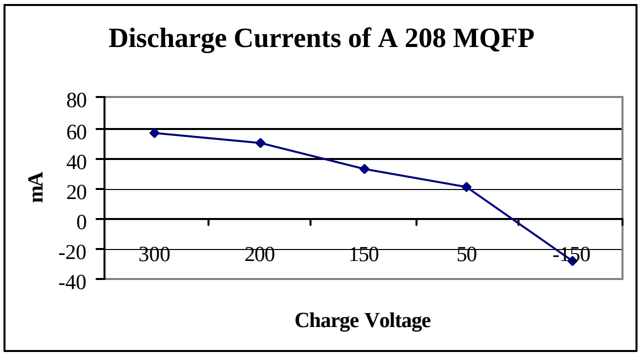
Figure 2

Figure 2 is of the discharge current of the 4.6 pF capacitor charged to 100 Volts. Discharge Current was 13 milliamps at approximately 2.5 nanosecond rise time.



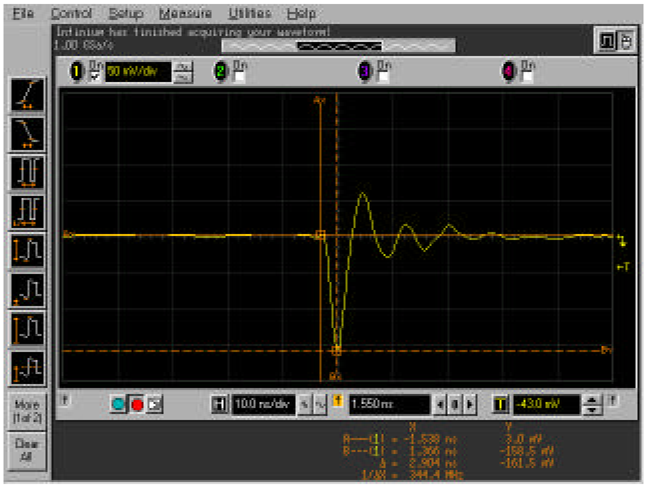
Graph 2

The data in Graph 2 was taken with an environment of 28 % RH at 72.5 Degrees F.



Graph 3

The environment the data was taken in for Graph 3 was 33 % RH at 72 Degrees F.



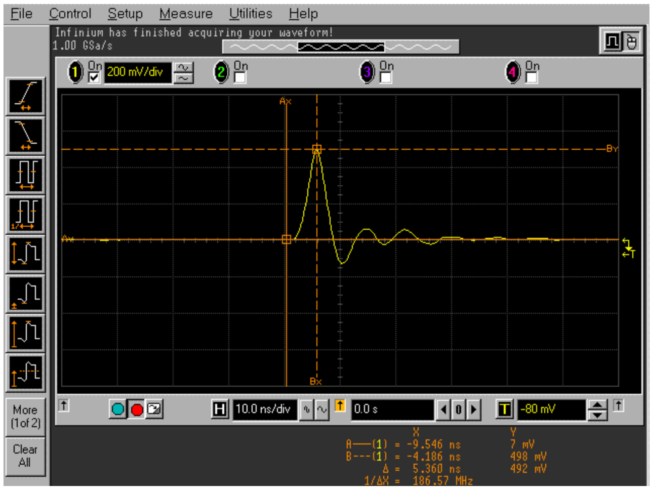
```
                  X              Y
A——(1) = -1.538 ns      3.0 mV
B---(1) =  1.366 ns   -158.5 mV
     Δ =  2.904 ns   -161.5 mV
  1/ΔX =  344.4 MHz
```

Figure 3

Figure 3 is a typical waveform of the current from a discharge of a 208 MQFP charged to 150 Volts. The current of this discharge was 32 milliamps. Rise time was 2.9 nanoseconds.

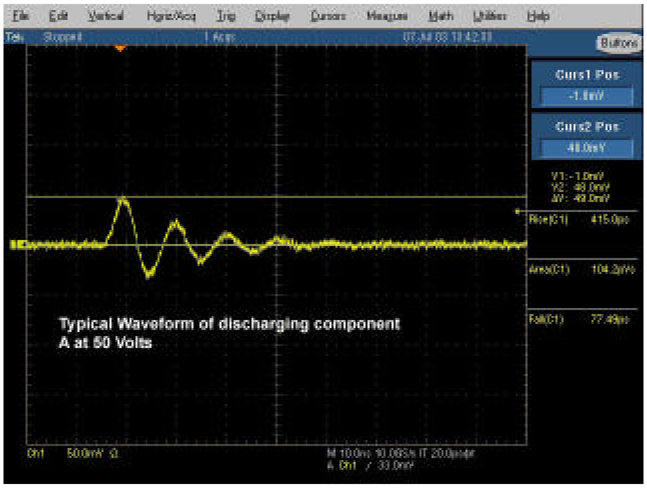
Figure 4, next column, is the discharge current of an 8 Pin SOT charged to 350 Volts and placed on the same size pad as the larger device. The Pk Current is 98 milliamps with a rise time of 5 nS.

The 8 Pin SOT charged to lower voltages resulted in discharge currents too small to measure without noise being a factor.



```
                  X              Y
A——(1) = -9.546 ns      7 mV
B---(1) = -4.186 ns    498 mV
     Δ =  5.360 ns    492 mV
  1/ΔX =  186.57 MHz
```

Figure 4

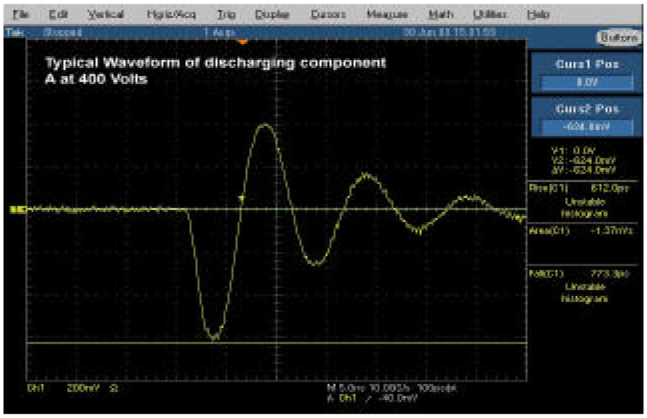


Typical Waveform of discharging component A at 50 Volts

```
V1: -1.0mV
V2:  48.0mV
ΔV:  49.0mV
Rise(C1)   415.0ps
Area(C1)   104.2pVs
Fall(C1)   77.49ps
```

Figure 5

As shown in Figure 5, a 50 Volt charge of device A resulted in a rise time of approximately 5 nS and an amplitude of 9.8 milliamps.

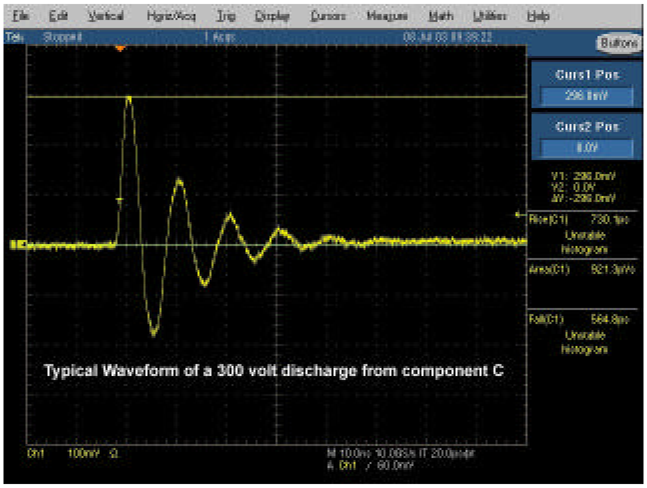


Typical Waveform of discharging component A at 400 Volts

```
V1:  0.0V
V2: -624.0mV
ΔV: -624.0mV
Rise(C1)   612.0ps
     Unstable
     histogram
Area(C1)   -1.37nVs
Fall(C1)   773.3ps
     Unstable
     histogram
```

Figure 6

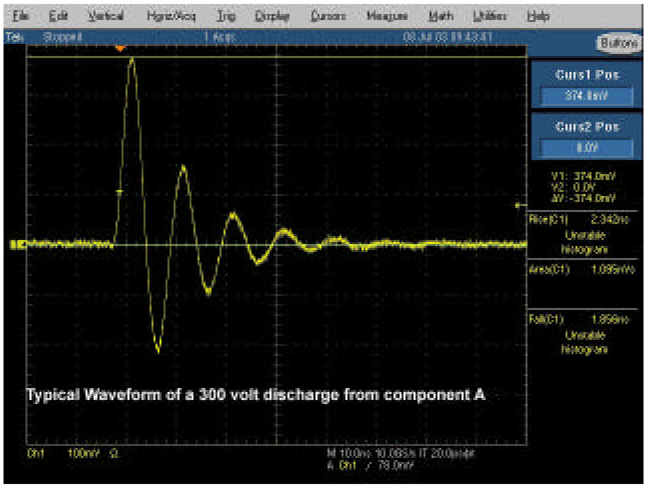
As shown in Figure 6, a 400 Volt charge of device A resulted in a rise time of approximately 2.5 nS and amplitude of 124.8 milliamps.



Typical Waveform of a 300 volt discharge from component C

Figure 7

Figure 7 is a waveform of a component C charged to 300 Volts resulting in a discharge current of 59.2 milliamps with a rise time 2.5 nanoseconds

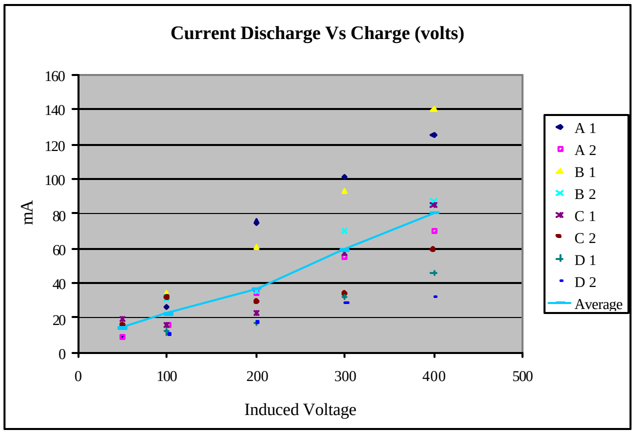


Typical Waveform of a 300 volt discharge from component A

Figure 8

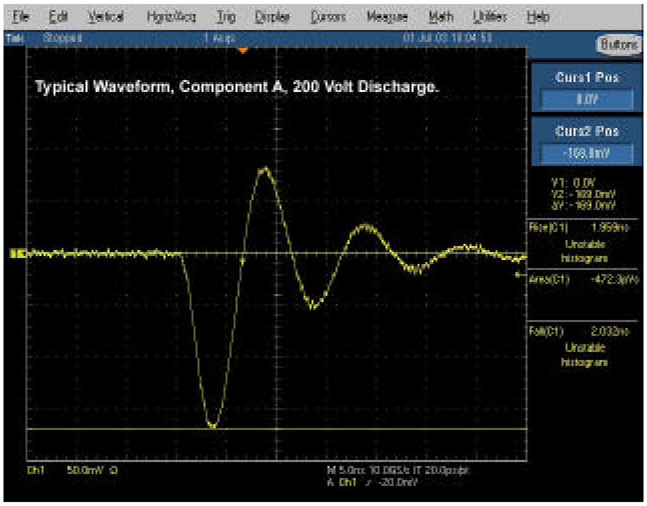
Figure 8 is of a device charged to 300 volts and a discharge resulting in a current of 74.8 milliamps with a rise time of 2 milliseconds.

Graph 4, next column, is the results of charging 8 devices with conductive tops. There were 2 of each of 4 different size devices and capacitances. As Shown in the graph, the discharge current for each device is somewhat linear through the charge voltage levels even though the discharges of similar devices were different.



Graph 4

The values captured in Figures 5 through 12 were used to generate Graph 4.



Typical Waveform, Component A, 200 Volt Discharge.

Figure 9

Typical Waveform of a 200 volt discharge from Component D

Figure 10

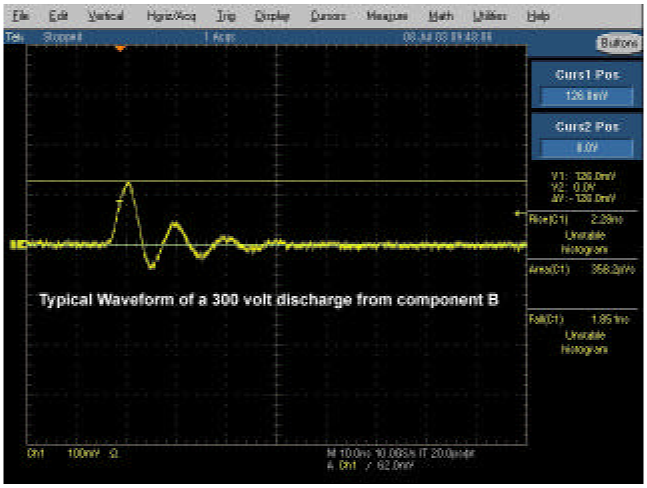


Figure 11

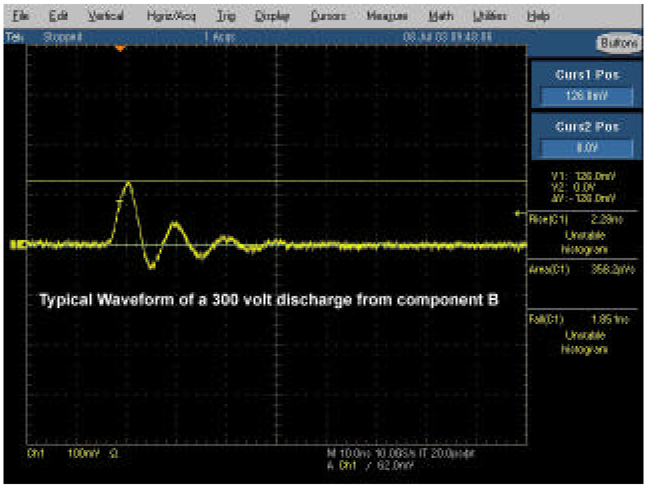


Figure 12

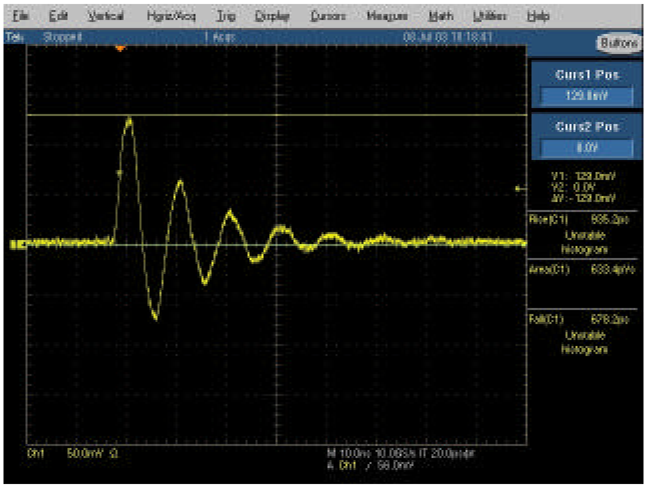


Figure 13

Figure 13 is a waveform of a 208 QFP charged to 200 volts and discharged at placement. The rise time is approximately 2 nanoseconds with a current of 25.8 milliamps.

The following figures are Discharge Current Waveforms taken at different voltages of a number of other devices.

Figure 14

Figure 14 is the discharge current waveform of a 200 pin QFP with a rise time of 2 nanoseconds with a current of 16.8 milliamps. The device was charged to 100 volts.

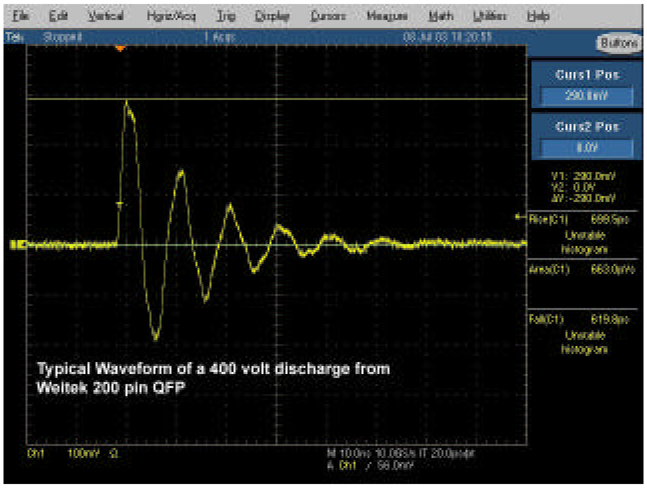


Figure 15

Figure 15 is the discharge current waveform of a 200 pin QFP with a rise time of 2 nanoseconds with a current of 58 milliamps. The device was charged to 400 volts.

Figure 16

Figure 16 is a waveform of a discharge from a 208 QFP device charged to 90 volts from a 5000 volt source 6 inches away. The discharge current is 45 milliamps witha 2 nanosecond rise time.

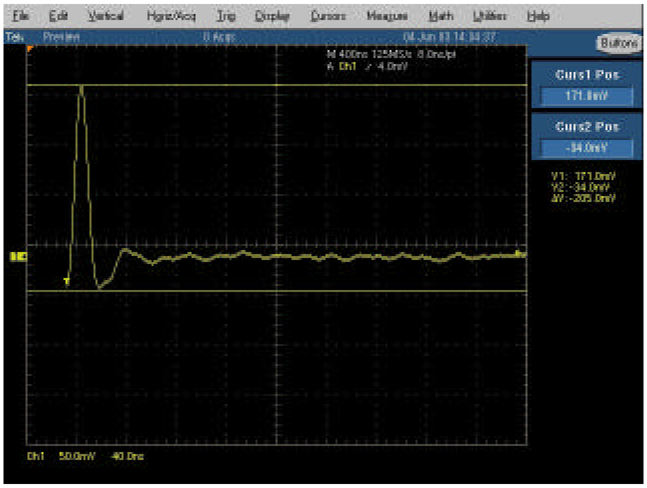


Figure 17

Figure 17 is a waveform of a 180 volt discharge from a 208 pin QFP that was charged by a 3000 volt source at 3 inches away. The rise time is several nanoseconds with a current of 41 milliamps.

Figure 18 is a waveform from a discharge of a 44 pin QFP charged to 50 volts from a 1000 volt source 2 inches away. The discharge current is 18.2 milliamps with a rise time of 2 nanoseconds.

Figure 18

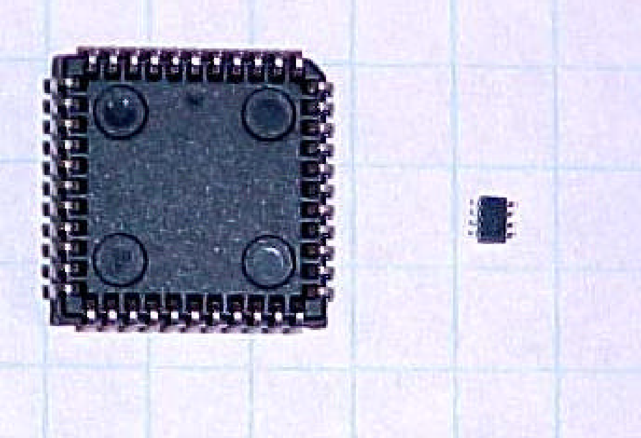


Photo 6

Photo 7 is of the 44 pin device and the 8 pin SOT tested, note the ¼ in (6.35 mm) grid for an indication of size.

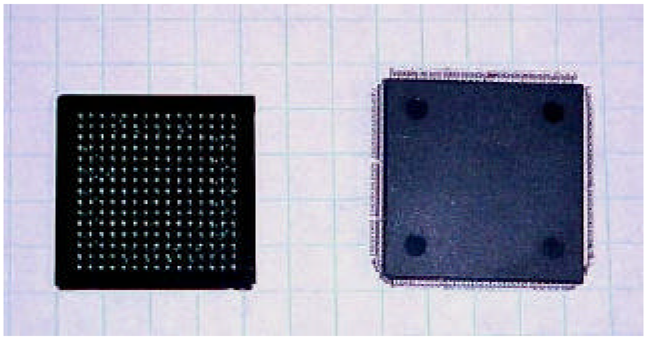


Photo 7

Photo 8 is of the 208 pin and one of ball grid devices tested.

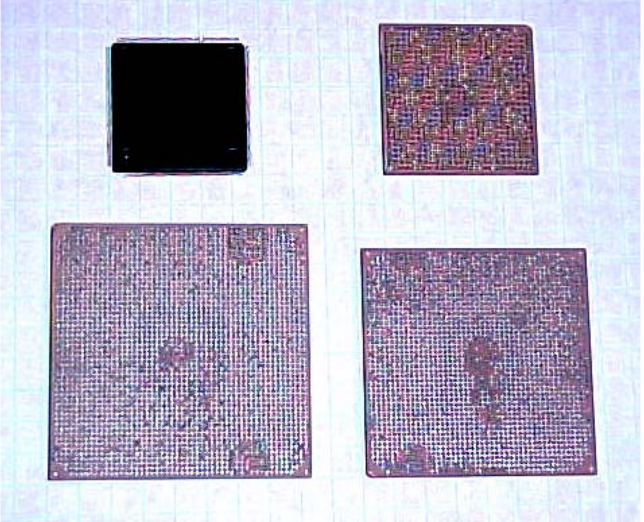


Photo 8

Photo 9 is of the 200 pin and the other ball grid devices tested.

IV. Conclusions

Based on the results of these experiments, the following conclusions have been reached.

1. Measuring the discharge current of devices being processed in a repeatable and reproducible manner is possible.
2. Using the results of the measurements can be used to predict the safety of processing specific ESDS devices through the handlers.
3. Characterizing Automatic Handling Equipment based on these types of measurements can be accomplished for specific devices.
4. No we are not there yet, there is more work needed in the following areas.
    a. Once the test methods require better definition in order to be effective on most Automatic Handling Systems. The test methods used to this point have been to gain experience with these types of measurements. The methods required will be of processing a specific device and measuring the discharge current upon placement or at the end of the process. This is fairly easy when one type of handler is involved but making the method generic enough to be used on most handlers such as a standard practice will require much more work [2, 3].
    b. Defining the discharge surface or substrate the device is placed on is a must for repeatable measurements. As Shown in the waveform figures, there is consistency between waveforms however, there is much more ringing than other CDM discharge waveforms [2,3]. The substrate or circuit the device is placed on is a large factor in the waveform stability.
    c. Correlation is needed between the discharge current amplitudes of these experiments and the amplitudes as seen in Charged Device Model susceptibility testing. Currents in CDM and MM testing are typically much higher than what was seen in this testing of devices with equal voltages [2, 3].
    d. Improvement is needed in the signal to noise ratio in measurements of discharge currents of lower voltage levels of 50 volts and the smaller devices such as the SOTs
5. In categorizing the Automated Handler by discharge current, devices of specific interest will have to be tested in the manner described until enough data is obtained to determine if standardized global methods are appropriate. This should not pose a significant problem since many of the equipment characterization done today are completed on specific devices; vision, lighting, and process issues are a few that are handled by specific parameters based on specific devices.
6. Discharge current of specific devices were not linear to the voltage levels and is probably due to differences in the resistances of the gap and the gap changing with higher current at the discharge.
7. A more appropriate method of categorizing the susceptibility of devices is needed. We currently use Human Body Model, Charged Device Model, and Machine Model to specify the susceptibility of devices, however it is the current at the discharge that damages the device in most cases, particularly in the Automated Handlers. Therefore a direct correlation to CDM is a must. We have part of that now through calculations and then comparing but in the future direct current correlation to damage is what is really needed.

V. Information outside of the scope of this work

Charge transfer between devices and/or handler components and devices should be explored further. It has been stated that insulators charged with more than 2,000 volts at a distance greater than 12 inches [4] will not induce a charge or transfer a charge to a device or assembly. The inverse of that statement then is if less than 2000 volts say 1500 volts or 500 volts can be in very close proximity to devices. That may be the case in the semi-stationary world of workstations and benches, however, in the world of Automated Handlers and Assembly Equipment, with devices moving 80 inches per second and faster, that is not the case. In these experiments, charged insulators were placed in contact with or in close proximity with conductors and other insulators and charges were transferred.

References

[1] Electrostatic Discharge Association Standard Practice 10.1-2000, Automated Handling Equipment

[2] Standardized Direct Charge Device ESD Test for Magnetoresistive Recording Heads, 1 and 2, 2002 ESD Association Symposium Proceedings

[3] ANSI Electrostatic Discharge Association Standard Test Method 5.3.1-1999, Charged Device Model, Component Level

[4] ANSI Electrostatic Discharge Association Standard-20.20-1999, Standard for the Development of an ESD Control Program

Acknowledgements

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