Characterizing Automated Handling Equipment Using Discharge Current Measurements II

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Abstract - Characterizing the ESD performance of Automated Handling Equipment (AHE) can be confusing, subjective, sometimes just plain arbitrary, and much of the time wrong. ESD sensitivity of devices is classified by a set of standards that specify an amplitude and type of discharge mode such as Human Body Model (HBM), Charged Device Model (CDM), or Machine Model (MM). Each of the models has unique circuitry of capacitance, resistance and inductance to provide a specific current, rise time and pulse shape of the discharge at a specific voltage. These are fairly repeatable and reproducible measurements while on the other hand, attempts to classify AHEs based on voltage measurements are most often misleading. This paper deals with the additional results of methods for measuring the discharge currents both on the bench and in the equipment and hopefully answers some questions raised in the related publication from the 2004 EOS/ESD Symposium [1].

I. Introduction

More pressure is being placed on Manufacturers of Automated Handling Equipment (AHE) to characterize their products in terms of safely handling devices and assemblies that are increasingly more and more sensitive to ESD. The customer is asking quite frequently "Does this product have the capability to safely place a device rated at 50 volts?" Measuring the voltage levels of the various AHE components (e.g. guides, nozzles, conveyors, and grippers) with electrostatic voltmeters, miniature probes, and field strength meters does not answer the questions because the measured voltage levels do not correlate to the susceptibility rating of the devices. In many cases, the voltage rating provided is a Human Body Model (HBM) rating, which really does not apply to the AHE world because humans are not touching parts in this environment. Many customers will only specify their components using the HBM since that is the only rating available to them. The Machine Model usually does not apply either, if the AHE is properly designed and grounded since there should not be a charge on the AHE component to discharge to the device [2] and [3]. The focus of these studies is mainly from a CDM perspective and the purpose was 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. This work is a follow up to previous work [1] and is ongoing.

II. Experiments

A. Experimental Design

Experiments were conducted to develop methods to charge integrated circuits while in the AHE to simulate a device charged by the process. This was accomplished by directly placing a charge on the leads of the device. Other experiments were to determine if the discharge currents measured in the AHE were similar to those measured on the bench and in a CDM discharge.

1. Current Measurement Placement Board

A printed circuit board was designed to allow placement of packages of various sizes and shapes.

This allows a charged package to be placed onto a ground plane. The current from the discharge of that package is routed through a current probe so it can be measured. The test board the charged device is to be placed on must simulate an actual assembly with ground planes and lands. The board also has to facilitate measuring the discharge current at placement. See Photos 1 and 2. The current probe is shown in place between the two gold colored squares in the photos. A device placed onto square “A” discharges to ground through the current probe and to ground plane “B”.

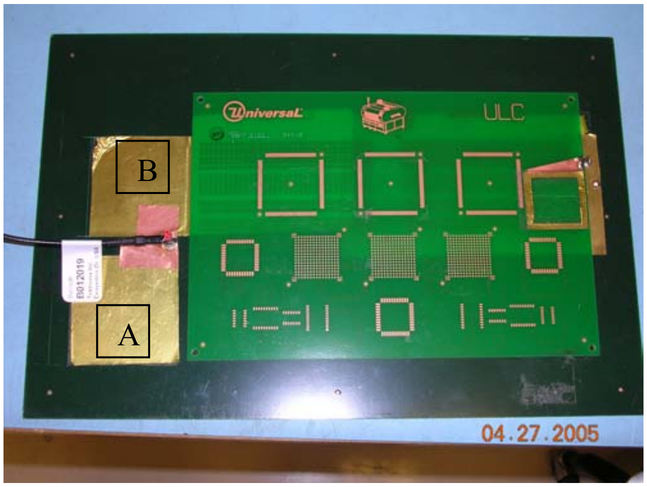


Photo 1

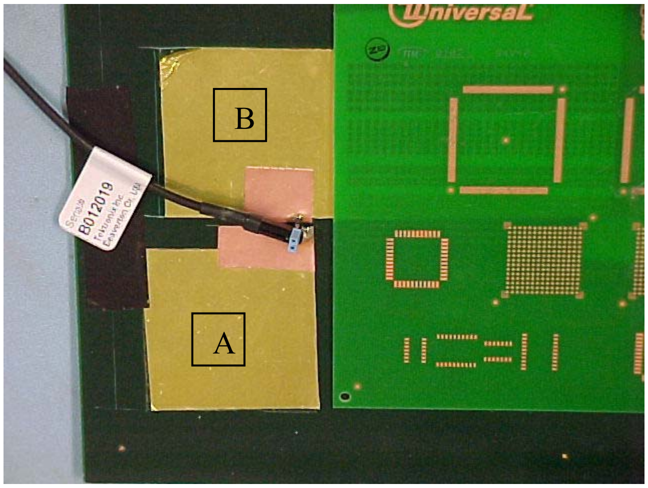


Photo 2

2. Device Charging

Lab experimentation determined that in order to obtain an accurate charge on the IC, the device had to be charged by the leads. That was one of the problems in previous work. The device had been charged by the body and when the leads were measured, they were only about ½ of the charge of the device. This caused a lower discharge current when the leads were discharged. Instead of a 200 volt discharge, it was a 100 volt discharge. In these experiments, the leads of the devices were charged to the test voltage and the leads were discharged. Please see Photos 3,4 and 5.

Photo 3 – applying a charge to a device in a handler

The AHE was placed in a step-by-step mode allowing single functions to occur under operator control. Functions of the handler were conducted one at a time so intervention could be achieved when desired. After the device was picked up and being held by the nozzle, a metal plate tied to a power supply which was set at the desired test voltage (for example 100V) was brought up and placed in contact with the leads of the device (photo 3). This would cause the device to be also charged to 100 volts. The step sequence could then be resumed, placing the now charged device onto the test board illustrated in photos 1 and 2.

3. Discharge Current Measurements in the Handler

In Photo 4, the charged device is then placed on the discharge current measuring pad of the board. The leads are discharged to the pad through the current probe to ground as seen in Photo 5. A storage oscilloscope records the discharge pulse from the current sensor.

Photo 4 – placing charged device onto test board

In Photo 5, the device is shown placed on the measurement pad of the board, the current probe and ground can also be seen.

Photo 5 – device after being placed on test board

B. Test Equipment Used

Tektronix Oscilloscope TDS710 1GHZ/5GS/S 400K DPO	
HP Infinium Oscilloscope 500 MHz / 1 Gsa/S	
Tektronix Current Probe	CT6
Trek Reference Power Supply	605A
Trek Electrostatic Voltmeter	368
Miniature Probes, side aperture	
AdVantis Prototype MFA02	

C. All Devices Tested on the Bench or in the Handler

A variety of different part types was tested, ranging from very small SOT packages to quite large BGAs and many styles in between. Stand alone capacitors were also measured.

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

100 Pin QFP 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

5.6 pF Round Capacitor, 1” dia X .150” thick

21.8 pF Square Capacitor, 2”X.24” thick

Note that all of the devices were tested but not all documented.

III. Results

1. Discharge Current Measurement Board

The board used is the same design as in the previous work with a large grounded ground plane and the discharge measurement pad placed next to the ground plane and connected through the CT6 Current Probe.

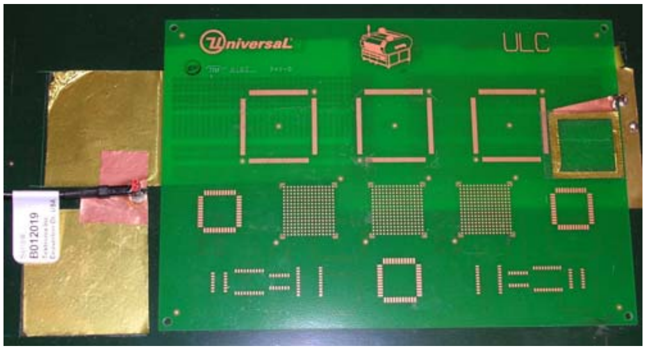


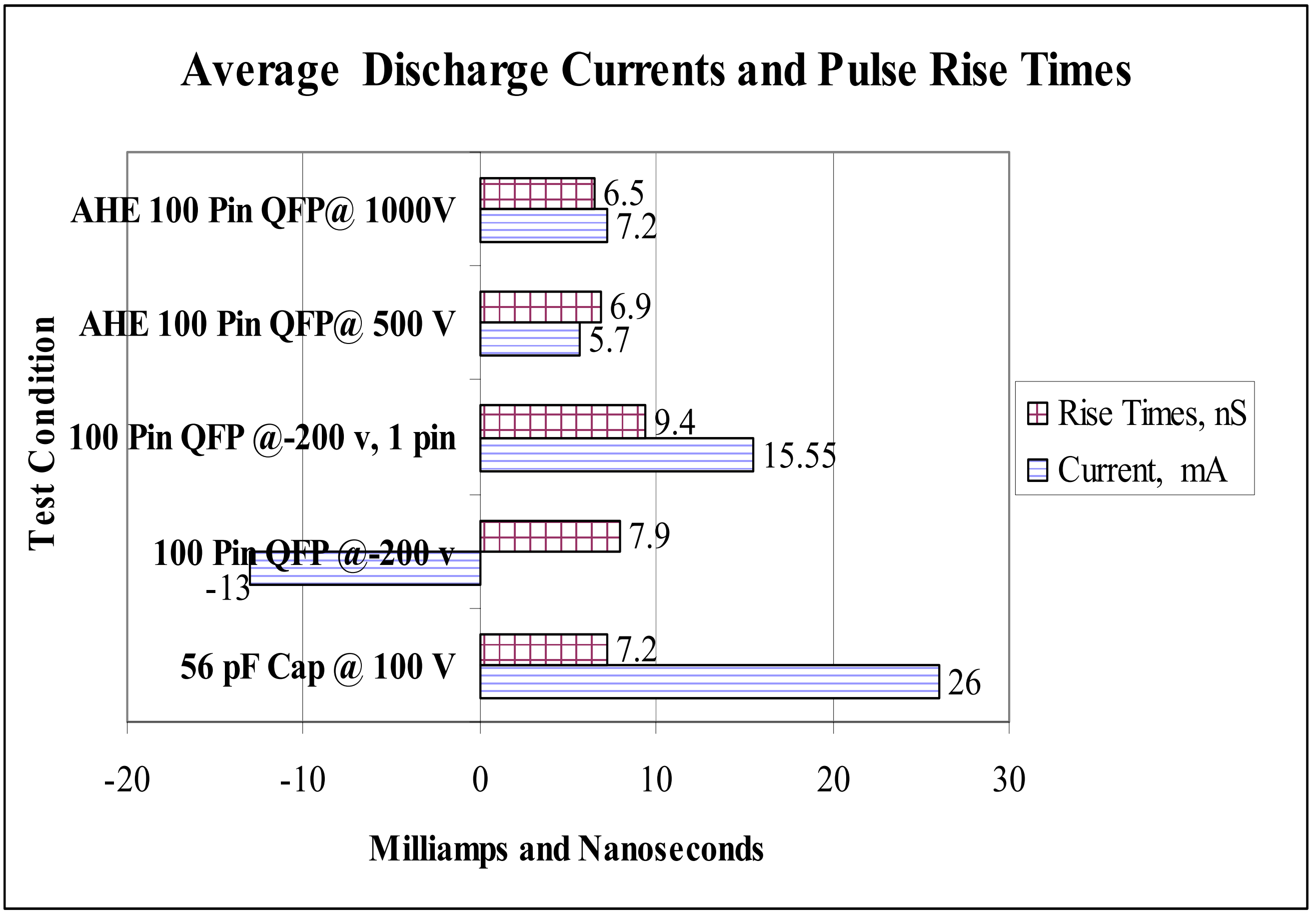
Photo 6

2. Device Charging

To simulate a charged device, an aluminum plate connected to a power source was placed in contact with the device's leads. This produced a reliable and repeatable simulation, ensuring that the device was charged to a known voltage. This technque can be taken one step further by placing a charged plate that the parts are picked from. Please see Photo 3.

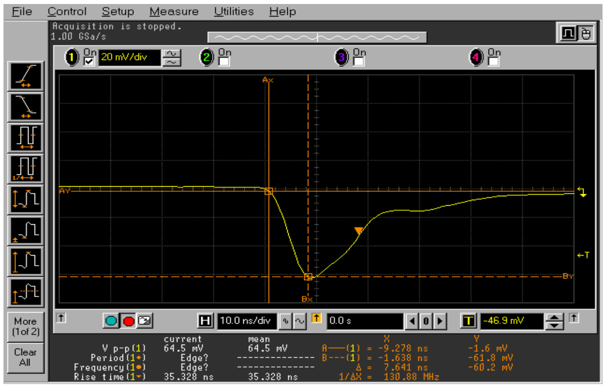
3. Discharge Measurements

Discharge measurements were completed both on the bench and in an actual handler. The bench setup used the plate to charge the device by the leads and the same head as in previous work. The measurements in the Automated Handler are as described under Experiment Designs. The following Graph exhibits the results.



Graph 1

As seen in Graph 1, both the average Discharge Currents and the Rise Times of the discharge pulse are shown for each category of the testing and measurements completed. The three bottom categories listed on the Vertical Axis of the Graph under Test Conditions are the measurements taken on the Bench. The top two are measurements taken on or in the Automated Handler. The following figures are typical waveforms captured during the measurements.



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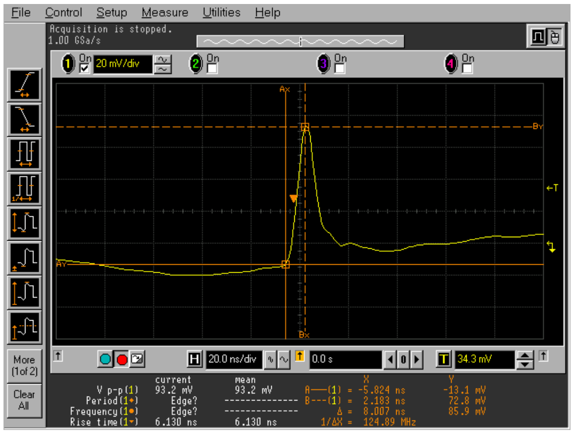
```
                current        mean              X                  Y
      V p-p(1)  64.5 mV        64.5 mV         A——(1) = -9.278 ns   -1.6 mV
     Period(1)     Edge?   --------------- B---(1) = -1.638 ns  -61.8 mV
  Frequency(1)     Edge?   ---------------       Δ =  7.641 ns  -60.2 mV
  Rise time(1)  35.328 ns      35.328 ns        1/ΔX = 130.88 MHz
```

Figure 1

The waveform in Figure 1 is from a 100 Pin QFP charged to -200 Volts and has an amplitude of 12 milliamps and a rise time of 7.64 nanoseconds.



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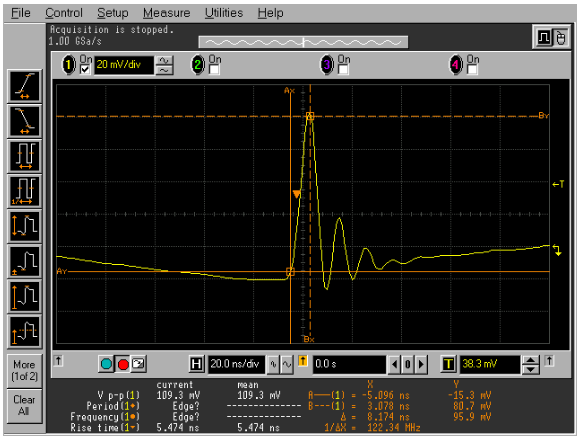
                current        mean              X                  Y
      V p-p(1)  93.2 mV        93.2 mV         A——(1) = -5.824 ns  -13.1 mV
     Period(1)     Edge?   --------------- B---(1) =  2.183 ns   72.8 mV
  Frequency(1)     Edge?   ---------------       Δ =  8.007 ns   85.9 mV
  Rise time(1)  6.130 ns       6.130 ns         1/ΔX = 124.89 MHz
```

Figure 2

Figure 2 is a waveform from a 100 Pin QFP charged to -200 volts and discharged through 1 pin bent down and measured on the bench. The amplitude is 17.22 milliamps and a rise time of 10.5 nanoseconds.



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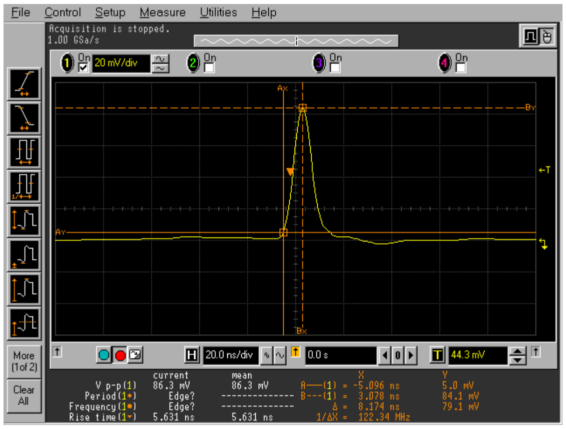
```
                current        mean              X                  Y
      V p-p(1)  109.3 mV       109.3 mV        A——(1) = -5.096 ns  -15.3 mV
     Period(1)     Edge?   --------------- B---(1) =  3.078 ns   80.7 mV
  Frequency(1)     Edge?   ---------------       Δ =  8.174 ns   95.9 mV
  Rise time(1)  5.474 ns       5.474 ns         1/ΔX = 122.34 MHz
```

Figure 3

Figure 3 is the same condition as in Figure 2 and has an amplitude of 19 milliamps with a rise time of 8.1 nanoseconds.



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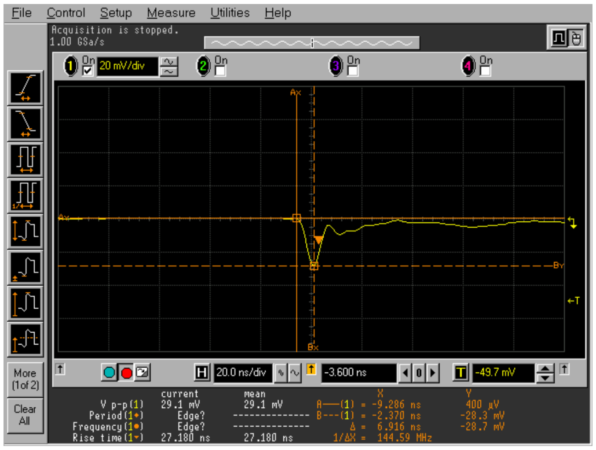
```
                current        mean              X                  Y
      V p-p(1)  86.3 mV        86.3 mV         A——(1) = -5.096 ns    5.0 mV
     Period(1)     Edge?   --------------- B---(1) =  3.078 ns   84.1 mV
  Frequency(1)     Edge?   ---------------       Δ =  8.174 ns   79.1 mV
  Rise time(1)  5.631 ns       5.631 ns         1/ΔX = 122.34 MHz
```

Figure 4

Figure 4 is a waveform from a 100 Pin QFP charged to -200 Volts and discharged through one pin with a placement velocity of 35 inches per second on the bench. The amplitude and rise time are 15.8 milliamps and 8.1 nanoseconds, respectively.

Note that Figure 5, and the remaining figures of waveforms are a result of measurements in the handler using a 100 Pin QFP charged to -500 and +1000 volts. The waveform amplitudes are lower than were seen during the bench testing while the rise times are slightly slower. The Automated Handler was stepped through to achieve the measurement as indicated in the Experimental Design section above.

As indicated in Figure 5, the amplitude of the pulse is 5.74 milliamps with a rise time of 6.9 nanoseconds as a result of -500 volt charge.



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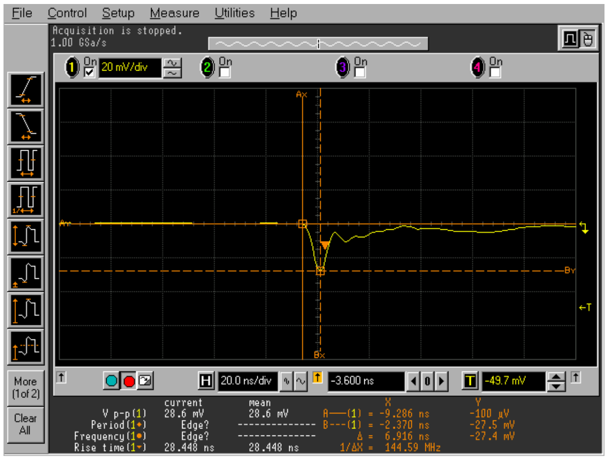
```
                current        mean              X                  Y
      V p-p(1)  29.1 mV        29.1 mV         A——(1) = -9.286 ns   400 µV
     Period(1)     Edge?   --------------- B---(1) = -2.370 ns  -28.3 mV
  Frequency(1)     Edge?   ---------------       Δ =  6.916 ns  -28.7 mV
  Rise time(1)  27.180 ns      27.180 ns        1/ΔX = 144.59 MHz
```

Figure 5



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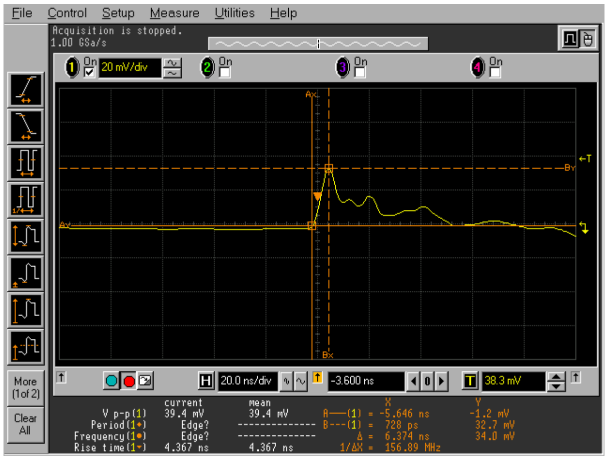
```
                 current        mean                          X              Y
    V p-p(1)     28.6 mV        28.6 mV        A——(1) = -9.286 ns        -100 µV
   Period(1◆)       Edge?     -------------- B---(1) = -2.370 ns        -27.5 mV
Frequency(1●)       Edge?     --------------       Δ =  6.916 ns        -27.4 mV
Rise time(1▾)    28.448 ns      28.448 ns        1/ΔX =  144.59 MHz
```

Figure 6

Figure 6 is a waveform also from a of a 500 volt charge with an amplitude of 5.48 milliamps and a rise time 6.9 nanoseconds.

Figure 7 is a waveform from a 100 Pin QFP charged to +1000 Volts and discharged in the handler during placement. The amplitude is 6.8 milliaamps with a rise time of 6.3 nanoseconds.



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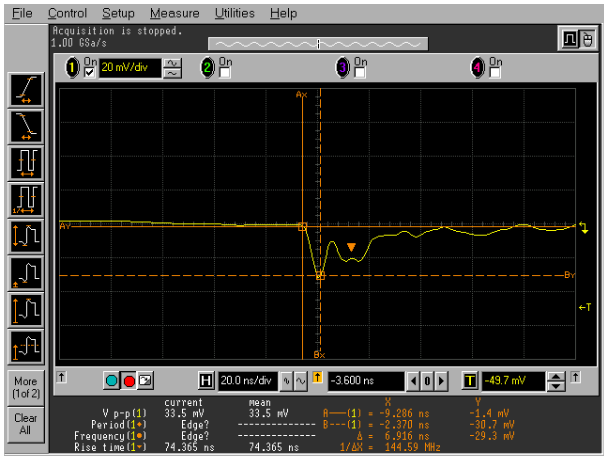
```
                 current        mean                          X              Y
    V p-p(1)     39.4 mV        39.4 mV        A——(1) = -5.646 ns        -1.2 mV
   Period(1◆)       Edge?     -------------- B---(1) =  728 ps           32.7 mV
Frequency(1●)       Edge?     --------------       Δ =  6.374 ns         34.0 mV
Rise time(1▾)    4.367 ns       4.367 ns         1/ΔX =  156.89 MHz
```

Figure 7

Figure 8 is a waveform from a 100 Pin QFP charged to -1000 volts and discharged in the Automated Handler. The Amplitude measured was 5.86 milliamps with a rise time of 6.9 nanoseconds.



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```
                 current        mean                          X              Y
    V p-p(1)     33.5 mV        33.5 mV        A——(1) = -9.286 ns        -1.4 mV
   Period(1◆)       Edge?     -------------- B---(1) = -2.370 ns        -30.7 mV
Frequency(1●)       Edge?     --------------       Δ =  6.916 ns        -29.3 mV
Rise time(1▾)    74.365 ns      74.365 ns        1/ΔX =  144.59 MHz
```

Figure 8

Figure 9

Figure 9 is a picture of a 100 Pin QFP used in these measurements.

IV. Conclusions

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

1. Measurements of the Discharge Current of charged devices can be obtained in the AHE using current probes and high speed Oscilloscopes of at least 1 GHz with 5 GHz being preferred.
2. While the process is similar, there were some differences observed between the measurements on the bench and measurements made in the Automated Handler. The two main differences

were the amplitude of the discharge and the rise time. The waveforms were very similar in shape. Measurements made in the Automated Handler were more consistent in both amplitudes and rise times.

3. These measurements will enable the AHEs and other automated process to be characterized by discharge measurements.
4. More work is needed to refine the test methods and the equipment required.
5. A Standard Test Method or Standard Practice will be needed.

V. Discussion

The conditions reported here are more indicative of a charged device model discharge than either a human body model or machine model discharge. However, the waveforms obtained do not match those given in the CDM standard test method [4]. While the measurement of Discharge Current in the Automated Handler is very possible and has been demonstrated, some questions still remain such as why are the amplitudes so different between this type of measurement and the CDM Measurement and why is the Rise time so much longer [4]? Is it that there is a large difference in capacitance between the CDM Tester, the bench test head, and the Automated Handler? After all in the Automated Handler there is a large area (relative to the board) of relative empty space. The Board is or should be clamped by two grounded rails [2] and as long as the finish of the rails is not an insulator, there should not be a difference[5]. Will these differences in the test environment even influence the measurements? These questions need answering before we can definitively write any type of standard on this measurment method.

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. These standard test methods provide good methods for comparing one device to another in a known, specified environment. There is no guidance however as to how the device will behave in another environment, in this case, the AHE. If the failure of the device is due to the peak current, perhaps the devices will survive much higher charges (voltages) in an AHE – we have shown that the peak current is much less than the CDM test gives. On the other hand, if the failure of the device is due to the total energy delivered by the discharge pulse, or due to some rise time effect, other conclusions may be appropriate. Therefore a direct correlation to CDM is critical. Additional work is necessary to define and establish that correlation. Part of that effort is available through calculations and then case-by-case evaluation but in the future direct current correlation to damage is what is really needed.

VI. Future Work

Detailed measurements so far have given promise that a correlation may be possible. In an attempt to correlate the Discharge Current obtained in the AHE to the current measurement obtained in the CDM, the specific components should be charged to specific voltage levels, and discharged in the AHE and CDM Testers. The measurements obtained should then be compared.

The device samples should include various package styles and should be xrayed to determine the construction of the devices.

A simpler discharge board needs to be designed and obtained.

Since discharge currents in the AHE seem to be much smaller than CDM discharge currents at the same voltage level, it would be interesting to take a device rated for example, 500 volts CDM , charge it up to 500 volts and then discharge it in the AHE. Is it damaged? What is the real AHE damage threshold? In other words, 500 volts CDM may not be the same as a 500 AHE discharge because for one thing, the different grounded surfaces in various orientations relative to the part would provide a much different device capacitance than the CDM setup would. This would mean that the same voltage provides different amounts of charge and thus different discharge currents.

One definite conclusion: there is still plenty of work to do in this area of study.

References

[1] Donn G. Bellmore, Characterizing Automated Handling Equipment Using

Discharge Current Measurements, 2004 ESD Symposium Procceedings, Section 4A.6

[2] Donn G. Bellmore, Controlling ESD In Automated Handling Equipment, 2002 ESD Symposium Proceedings, Section 3B.3

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

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

[5] Donn G. Bellmore, Anodized Aluminum Alloys, Insulators or Not, 2001 ESD Symposium Proceedings, Section 2B.4

Acknowledgements

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