Progress Towards a Joint ESDA/JEDEC CDM Standard: Methods, Experiments, and Results

Alan Righter(1), Terry Welsher(2), Marti Farris(3), Marty Johnson(4), Scott Ward(5), Marcel Dekker(6), Tim Maloney(7), Robert Ashton(8), Leo G. Henry(9), Tom Meuse(10), Jon Barth(11), Evan Grund(12), Theo Smedes(13) and Paul Ngan(14)

(1) Analog Devices, 804 Woburn St MS613, Wilmington, MA 01887, (781) 937-2690, alan.righter@analog.com. (2) Dangelmayer Associates, Gloucester, MA, USA. (3) Intel Corporation, Hillsboro, OR, USA, (4) Texas Instruments, Santa Clara, CA, USA. (5) Texas Instruments, Dallas, TX, USA. (6) MASER Engineering, Enschede, the Netherlands. (7) Intel Corporation, Santa Clara, CA, USA. (8) ON Semiconductor, Phoenix, AZ, USA. (9) ESD/TLP Consultants, Fremont, CA, USA. (10) Thermo Fisher Scientific, Wilmington, MA, USA. (11) Barth Electronics, Boulder, NV, USA. (12) Grund Technical Solutions, San Jose, CA, USA. (13) NXP Semiconductors, Nijmegen, the Netherlands. (14) NXP Semiconductors, San Jose, CA, USA.

50 Words Abstract – Progress toward a joint ESDA/JEDEC CDM standard is described. A "10 ohm CDM" test head experiment comparison to JEDEC standard testing is discussed. A second experiment (field plate dielectric thickness variation / ESDA test head) is described. Oscilloscope bandwidth / filtering, test head response, attenuators, and module effects are discussed.

I. Introduction

The device testing working groups of the ESD Association and JEDEC have been working together for the past several years to develop new "harmonized" joint ESDA/JEDEC device testing standard documents, to serve as a common ESD test framework for the electronics industry. The HBM Joint Standard ANSI/ESDA/JEDEC JS-001 [1] was the first harmonized standard which was released in 2010, with revisions in 2011 and 2012. Many of the HBM working group members also participate in the joint ESDA/JEDEC CDM working group and have been in the process of creating a new Joint ESDA/JEDEC CDM standard document. This document, expected to be called ESDA/JEDEC JS-002, Charged Device Model Test Method, is planned for release in 2013.

The Joint HBM Standard, while novel in its description of new test combinations targeted to optimize testing, did not contain a change to the HBM test method hardware, nor its waveform parameters. For CDM, however, the ESDA and JEDEC test platforms differ significantly in both discharge test head and field plate dielectric / calibration module characteristics. These hardware differences cause changes to the CDM waveform profile and also influence corresponding CDM test results on products [2,3]. These hardware differences require a resolution to a single standard CDM tester platform in order for a single standard to be written. This led to the decision that the Joint CDM working group had to choose one existing standard model for reference based on a single waveform characteristic as a basis for comparison. Over 80% of the companies in the working group use the JEDEC CDM method as their standard, believed to be representative of the ESD testing community in general. It was decided by the joint working group that any experimental hardware / data results then be compared against the JEDEC standard waveforms.

This paper will describe several experiments (and results) to evaluate improvements in tester hardware and accuracy at higher frequencies, while maintaining data consistency to the JEDEC CDM method.

II. CDM Tester Hardware Considerations

Prior to the experiments, the CDM JWG developed a list of CDM test hardware issues which could possibly affect the waveform parameters for the test. Section IIa will discuss the issues which were addressed through experiments. Section IIb describes issues which, although important, were not addressed through experiments.

IIa. CDM Tester Issues Addressed by Test Experiments

Although the JESD22-C101E standard CDM test method [4] is widely used in the industry, there are a number of inconsistencies in its hardware implementation.

First, the C101 standard specifies a FWHH (Full Width at Half Height, measured at the 50% value of the first waveform peak) value between 500 ps and

1500 ps, using a 1 GHz bandwidth oscilloscope. The hardware implementation described in the JEDEC standard specifies use of only a 1 ohm series resistor in the test head discharge path (this is true for the ESD Association S5.3 [5] as well). It was discovered early in CDM tester characterization that use of just a 1 ohm resistor by itself produced a peak narrower than the minimum 500ps value of FWHH in the JEDEC standard. To increase FWHH and to meet the 500ps minimum specification, tester manufacturers added either a ferrite, or a section of transmission line, in series with the discharge path. However, the C101 standard was never updated to describe these components, which significantly affect the CDM discharge waveform by adding a high frequency resonance [6].

In addition to increasing FWHH, these added components also increase the high frequency impedance of the discharge path. This is best illustrated by comparing the JEDEC C101 standard, which only specifies 1 GHz measurement, with the ESDA S5.3 standard, which has an option for 3 GHz measurements. As will be shown in Section IIIb, measurements using the JEDEC method at 3 GHz showed significantly less percentage increase in Ipeak (first peak current) from 1 GHz, compared to the ESDA method Ipeak measured at the same frequencies. To allow greater accuracy in CDM waveform measurement at higher frequencies, the CDM JWG determined that a method described by a new joint CDM standard must not include a ferrite, or other unintended components, in the discharge path.

Third, the ESDA and JEDEC CDM standards differ on their calibration module specifications. The ESDA S5.3 standard employs small (4 pF) and large (30 pF) structures consisting of circular metallic "coins" plated on the surface of an FR4 (or RF35) square dielectric (structure is placed dielectric side down), and also specifies an optional second dielectric with thicknesses ranging from "none" to 130 um, placed atop the field plate. The JEDEC C101 standard employs circular metallic coins as well, but only the coins themselves, placed upon a single dielectric that covers the field plate. These JEDEC coins and dielectric (15 mils thick) are sized to create small (6.6 pF) and large (55pF) capacitance to the field plate. The WG decided that tester experiments would consider only the JEDEC coin modules placed upon a single field plate dielectric, to minimize error caused by multiple dielectrics between coin and field plate.

In addition, the oscilloscope itself can be a source of variation. Oscilloscopes, particularly those at the lower end of the standard-specified range such as 1 GHz, can have an effective maximum bandwidth significantly higher than their stated maximum value. CDM is a unique test to capture this effect, as it is not a bandwidth limited signal. For example, oscilloscopes with equivalent bandwidth ratings measuring CDM waveforms can have different characteristics, even though their sampling rates are equivalent [7,8]. As the CDM waveform itself has a very high frequency, the 1 GHz frequency of the oscilloscope is a limiting factor, and an oscilloscope with an effective bandwidth above this will measure peak currents above those specified for the 1 GHz waveform. It was decided by the CDM JWG that a 3 GHz specification for CDM waveform parameters must be included in the standard, and would represent a more accurate representation of the intended CDM waveform compared to 1 GHz. (The 1 GHz specification will remain, but for daily waveform checking only and not for calibration or tester verification). Further, for higher bandwidth oscilloscopes which employ software filtering to limit bandwidth to standard-specified output frequencies, different filtering methods exist which affect the captured output. These methods include sin x / x and Gaussian. One experiment which will be described compared internal oscilloscope software-based filters with external hardware filters designed for CDM standard-specified frequencies.

IIb. Additional Sources of CDM Test Variation

Other CDM tester sources of variation are described here for reference; however, these sources were not investigated in these experiments due to their difficulty to actually measure the impact of just the source itself.

The CDM discharge spark characteristics (modeled by resistance, capacitance and inductance) can vary as a function of humidity, probe tip length and radius, and module / device total discharge energy (integrated charge). For example, the lower total charge associated with low charging voltage levels of small package ICs can result in the discharge probe tip having to come very close to, or make actual contact with, the discharged pin to affect the discharge. Although the presence / absence of the discharge spark or air discharge can be a source of measurement difference, the JWG did not define experiments to evaluate this effect.

Also, the construction of the probe assembly 1 ohm current sensor resistor itself has an effect on its high frequency characteristics. Although the experiments involved testing at 1 GHz, 3 GHz and either 6 or 8 GHz (maximum site scope bandwidths), this was deemed to be a second order effect for a near-term CDM platform solution and therefore the CDM JWG did not define experiments to evaluate current sensor resistor characteristics.

Third, there has been research evaluating the size of the ground plane on the CDM waveform [9]. The ground plane to field plate capacitance is one of the capacitors in the five capacitance model for CDM developed in 2007 [10]. In this paper, both Orion and RCDM testers were used, with the Orion having a 7 cm by 7 cm ground plane size, while the RCDM ground plane is 6 cm by 6 cm. Although this variance existed, these sizes were not changed for these experiments.

III. 10-ohm CDM Experiment

The CDM JWG began exploring the discharge probe assembly as one way to modify the waveform to compare with the JEDEC C101 standard waveform parameters. In a first experiment, the JEDEC test head was modified by removing the ferrite from the discharge probe assembly and replacing the 1 ohm series resistor with a 12.5 ohm series resistor, resulting in a configuration referred to as a "10-ohm" method [11]. The JEDEC and 10-ohm CDM hardware schematics are shown in Figure 1.

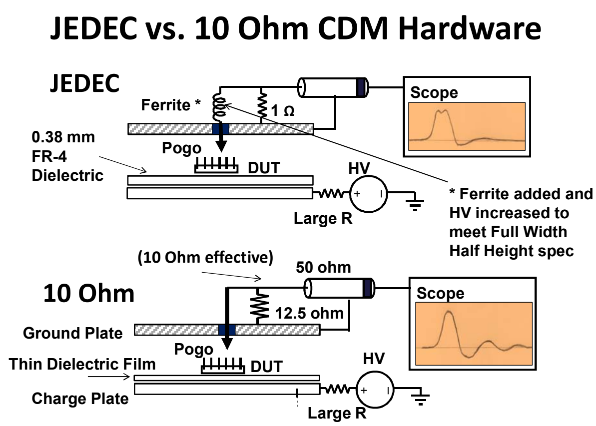

Figure 1. JEDEC CDM and 10 ohm CDM hardware schematics.

In the 10-ohm method, the 12.5 ohm series resistance, in parallel with the 50 ohm termination from the oscilloscope connection to ground, results in a 10 ohm effective resistance for current measurement by the oscilloscope. As the CDM current is measured across 10 ohms instead of 1 ohm, the measured voltage going into the oscilloscope is approximately 10 times that of the JEDEC value, and this requires the oscilloscope measurement to be attenuated by an additional 20 dB (to a total of 40 dB) to ensure the oscilloscope waveform is properly captured. Otherwise, the JEDEC field plate / dielectric and oscilloscope connections match those of the JEDEC method.

IIIa. 10-ohm Multisite Data Experiment

Five companies / test sites participated in a multisite data gathering experiment comparing JEDEC JESD22-C101E and 10 ohm CDM. Table 1 lists the test sites, testers, and oscilloscope models used.

Five 10-ohm test heads, one for each site, were manufactured at Thermo Fisher Scientific from existing ESDA test heads. It was discovered initially in the evaluation process that ferrites existed in four of the five heads, and these were removed for this study, ensuring a ferrite-free probe assembly. The four RCDM3 sites used an effective 12.5 ohm resistance constructed of four 50 ohm resistors in parallel connected to ground. The Orion tester probe assembly did not permit this parallel resistor construction and therefore a single circular 12.5 ohm resistor to ground was used.

JEDEC versus 10 ohm CDM waveform data was taken at 1 GHz and 3 GHz effective bandwidths. On the higher frequency oscilloscopes the internal oscilloscope software filters were used to limit the bandwidth. Both small and large JEDEC coin-shaped test modules were measured, at +/- 250V and +/- 500V, for peak current, rise time, FWHH and integrated charge, with measurements taken on three separate days. The small and large module capacitances to the JEDEC field plate metal were also measured at each test site. The CDM test chamber relative humidity levels were measured at all sites and found to be below 30 percent, in agreement with a recommendation in [12].

Table 1. Test sites / hardware for 10 ohm CDM experiment.

Site	Tester	Scope
Intel, Hillsboro, OR	Thermo RCDM3	Tektronix DPO70804 8 GHz
TI National Site, Santa Clara, CA	Thermo RCDM3	Tektronix DPO70804
Analog Devices, Wilmington,MA	Thermo Orion2	Tektronix DPO70604 6 GHz
Texas Instruments, Dallas, TX	Thermo RCDM3	Tektronix DPO70604
MASER, Enschede, the Netherlands	Thermo RCDM3	LeCroy SDA6000A 6 GHz

IIIb. 10 ohm Vs. JEDEC Multisite Results

Average first peak current (Ipeak) comparing 10 ohm CDM to JESD22-C101E (taken at 1 GHz oscilloscope bandwidth measured with the internal oscilloscope software filter) is shown in Figure 2. Small module

250V first peak current is specified in JESD22-C101E to be 2.875 Amps +/- 15%, and at 500V Ipeak to be 5.75 Amps +/- 15%.

Similarly, large module 250V first peak current is specified to be 5.75 Amps +/- 15%, and at 500V Ipeak to be 11.5 Amps +/- 15%. 1 GHz average results for five sites show good correlation with the small module, and show a slight increase (10%) in 10 ohm readings for the large module compared to JEDEC.

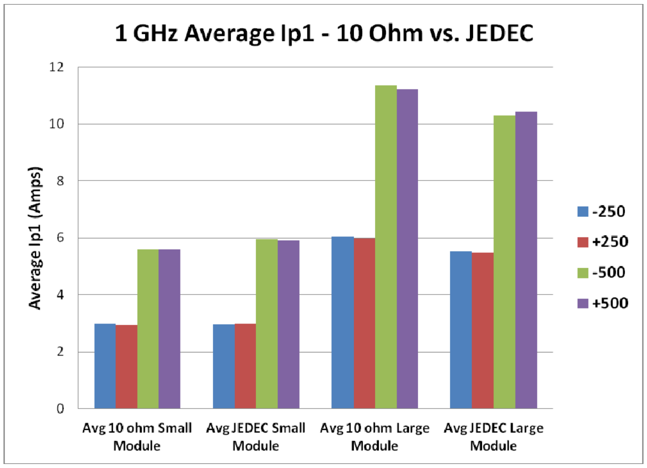

Figure 2. Average first peak current at 1 GHz comparing 10 ohm CDM to JEDEC CDM.

3 GHz I_{peak} comparison of 10 ohm CDM to the JEDEC method is shown in Figure 3. The 3 GHz results show a significant increase in Ipeak, from 22-25 percent for 10 ohm compared to JEDEC JESD22-C101E for the small module, and 25-30 percent increase for the large module. This is primarily due to the ferrite present in the JEDEC test head, which limits the JEDEC head's frequency response. In fact, the 1 GHz and 3 GHz JEDEC I_{peak} values were nearly identical, as can be compared from the "Average JEDEC small module" and "Average JEDEC large module" bar chart values in Figures 2 and 3.

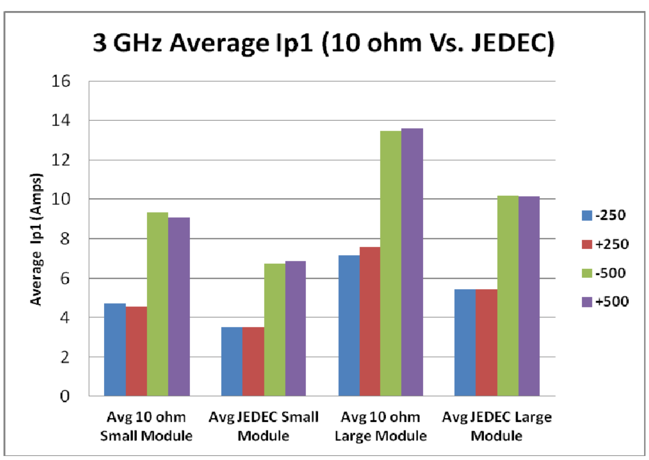

Figure 3. Average first peak current at 3 GHz comparing 10 ohm CDM to JEDEC CDM.

Example +500V 3 GHz waveforms showing the features of 10 ohm vs. JEDEC are shown in Figure 4. The 10 ohm value was shifted to the right to show the FWHH comparison. As can be seen, the 10 ohm waveform tends to have a higher amplitude, a sharper first peak, and a shorter FWHH, compared to the JEDEC waveform. Also, the second JEDEC waveform peak is reduced, and in many cases did not occur at all, for the 10 ohm probe assembly large module measurements.

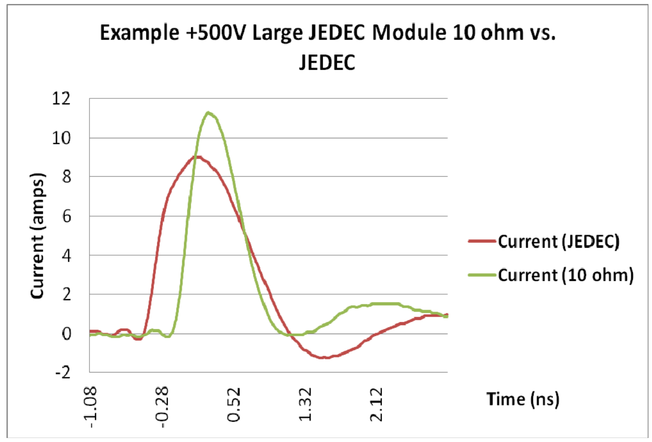

Figure 4. Example +500V 3 GHz JEDEC large module waveforms comparing 10 ohm CDM to JEDEC CDM.

The JEDEC head ferrite also increases the rise time and increases FWHH. Figure 5 shows 10 ohm probe assembly vs. JEDEC standard data taken at 3 GHz oscilloscope bandwidth for rise time. Figures 6 and 7 show 10 ohm probe assembly vs. JEDEC probe assembly standard data taken at 3 GHz oscilloscope bandwidth for FWHH and integrated charge, respectively. (Site ID's for Figures 5 through 7 are not in order of Table 1.) Both rise time and FWHH are observed to decrease for the 10 ohm results compared to the JEDEC results. However, the integrated charge, represented by the integrated area under the first peak waveform, did not change significantly for JEDEC versus 10 ohm CDM.

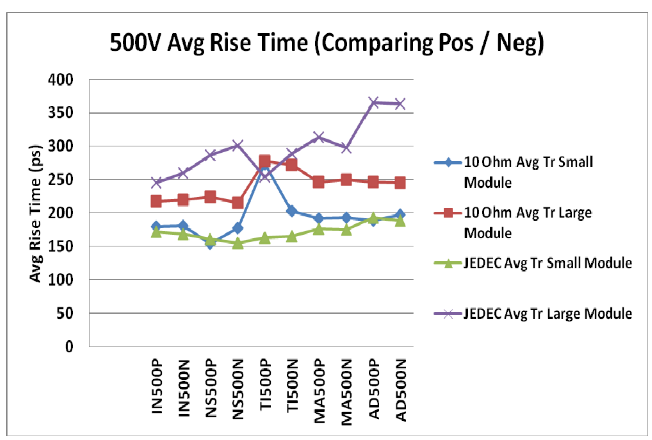

Figure 5. Average 10 ohm vs. JEDEC 3 GHz oscilloscope bandwidth rise time between sites measured at 500V.

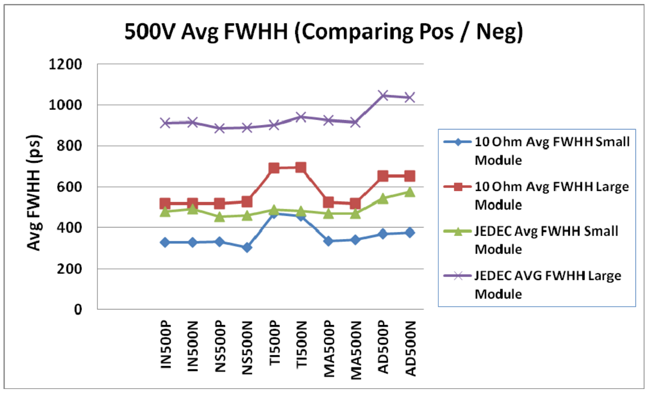

Figure 6. Average 10 ohm vs. JEDEC 3 GHz oscilloscope bandwidth full width at half height (FWHH) between sites measured at 500V.

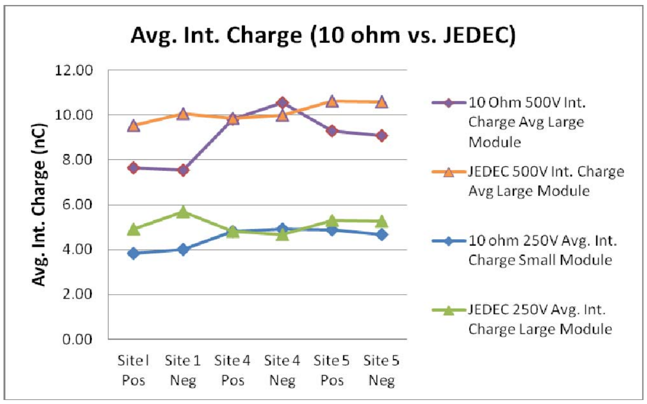

Figure 7. Average 10 Ohm vs. JEDEC 3 GHz integrated charge between sites comparing at 250V and 500V.

A small IC product was tested at one test site comparing the JEDEC and 10 ohm CDM test setups using three fresh parts per voltage step (18 parts for JEDEC and 18 parts for 10 ohm, using 50V voltage steps) in the voltage range between 850V and 1100V. The JEDEC results indicated both powerdown Idd and I/O leakage current began failing at 1100 V. The 10 ohm results indicated I/O leakage current began to fail at 1000 V, with powerdown Idd beginning to fail at 1100 V.

With the 10 ohm probe assembly vs. JEDEC probe assembly Ipeak comparison data at 3 GHz indicating significantly higher current for the 10 ohm method, it was determined that the 10 ohm probe assembly could not be expected to give the same pass / fail levels compared to the regular JEDEC probe assembly method. Additionally, consultation with tester manufacturers indicated an incremental cost for a new tester probe assembly would be needed for replacement at CDM tester sites. Therefore, the CDM JWG determined that further experiments on different aspects of the tester hardware / metrology chain would be needed.

IV. Oscilloscope Bandwidth Filtering

The CDM JWG also investigated bandwidth-limiting internal software and external hardware filters as methods to filter high bandwidth oscilloscope CDM measurement data to the lower frequencies specified in the CDM standards and an eventual joint CDM standard.

Special external hardware filters (connected between the CDM tester oscilloscope cable and the oscilloscope) were developed by a filter manufacturer and used for the experiment. For the 8 GHz oscilloscopes, separate filters which bandwidth limit from 8 GHz to 3 GHz, as well as from 8 GHz to 1 GHz, were used. For the 6 GHz oscilloscopes, similar filters designed for filtering from 6 GHz to 3 GHz and from 6 GHz to 1 GHz were used.

Figures 8 through 10 together show the impact of the various filters on the waveforms of the various oscilloscopes. Figure 8 first shows JEDEC large module 500V 8 GHz waveforms comparing different 18 GHz 20 dB attenuators. The waveform differences are shown to be very minor, indicating the 20 dB attenuator was not a limiting factor in the CDM waveform measurement. Figure 9 again shows 500V large module JEDEC waveforms, but now using 1 GHz external hardware vs. software filters as comparison (again taken with an 8 GHz oscilloscope). The 1 GHz software filtering causes additional peaks both before and after the main first waveform, a characteristic of sin x / x filters. The 1 GHz hardware filter waveform does not contain these additional peaks (nor do 2-pole oscilloscope filters as in [8, 13]), but has a slightly lower peak current.

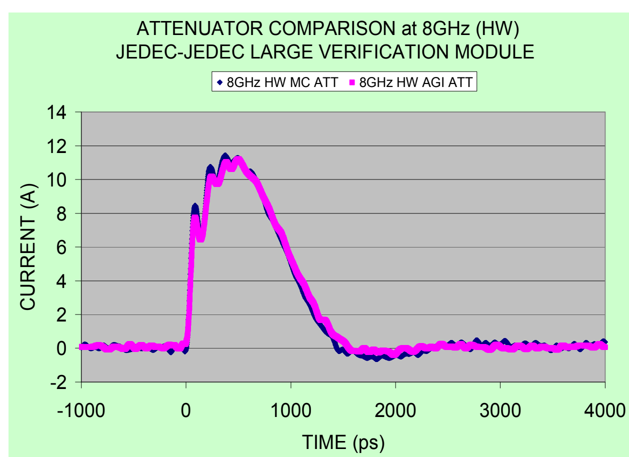

Figure 8. DPO70804 oscilloscope 8 GHz waveforms comparing different 18 GHz 20 dB attenuators.

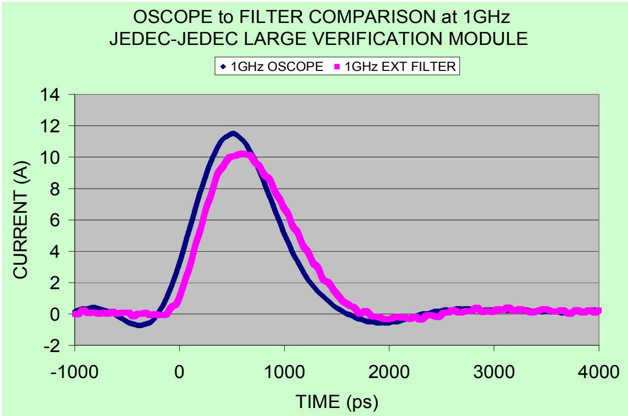

Figure 9. DPO70804 oscilloscope waveform comparison of 1 GHz internal software filter (dark) and external hardware filter (right).

Figure 10 repeats this measurement for 3 GHz filtering on the same tester using the same oscilloscope. Comparing with Figure 8, captured Ipeak at 3 GHz is nearly identical to that at 8 GHz. It is also observed that in the 3 GHz case, the difference between software and hardware filtering is quite small and not significant, with both the peak current, rise time and second peaks being similar, and no significant parasitic filter deviations either prior to or after the peak.

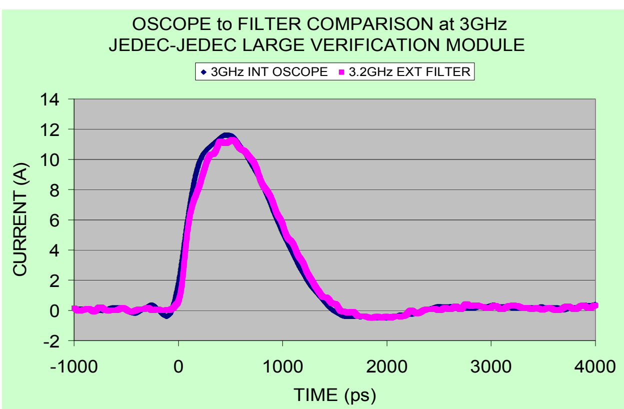

Figure 10. DPO70804 oscilloscope waveform comparison of 3 GHz internal software filter (dark) and external hardware filter (right).

V. ESDA Test Head / Dielectric Thickness Variation

Carey and DeChiaro [14] in 1998 conducted a CDM experiment using a JEDEC test head, evaluating the effect on the CDM discharge waveform when the field plate dielectric thickness was varied. In their experiment, nine different thicknesses were evaluated, with the charge voltage set to +500V. It was found that for the small JEDEC module, peak currents decreased linearly on a log scale of thickness versus peak current for all thicknesses. For the large module, it was found that for lower thickness values, the peak current did not change significantly, but for thicknesses beyond 30 mils, it did change, but at a slower rate. The total charge, measured by taking the module away carefully (so to retain charge) and placing in a Faraday cup, decreased linearly on a log scale at approximately the same rate for both small and large modules.

Based on this, the CDM JWG defined a second CDM experiment to evaluate the waveform characteristic changes from increasing field plate dielectric thickness beyond that specified in the JEDEC C101 standard, in a manner similar to [14], but not extending to very thick dielectrics beyond 60 mm. The JWG theorized that thicker dielectrics beyond this thickness could give peak currents less than the JEDEC standard for both modules based on the results in [14]. Since the ESDA standard test method was known to give higher peak currents than JEDEC, which could compensate for thicker dielectrics, the ESDA probe assembly as described in [5] was used, but the ferrite was removed to ensure a "ferrite-free probe assembly". The experimental parameters were as follows:

- Discharges at +500V only, using the JEDEC field plate, measuring small and large JEDEC modules
- Oscilloscope: High Bandwidth (at least 6 GHz), with waveforms taken at maximum bandwidth, again with a 3 GHz internal oscilloscope software filter and a third time with a internal 1 GHz software filter.
- 100 discharges gathered during each measurement to get min/max and means, for peak current, risetime, FWHH and integrated current (charge).
- Two types of dielectrics, FR406 and FR408, evaluated at the following thicknesses:

  1X JEDEC thickness FR4 (.381mm, 15 mil)
  2X JEDEC thickness FR4 (.762mm, 30 mil)
  3X JEDEC thickness FR4 (1.143mm, 45 mil)
  4X JEDEC thickness FR4 (1.524 mm, 60 mil)

FR406 and FR408 are epoxy laminates for printed circuit boards, similar to FR4, but both FR406 and FR408 can withstand higher temperature, and also have lower dielectric constants, than FR4.

To compensate for the added ferrite and these other JEDEC differences, CDM testers employ a file-based method of adjusting the plate voltage to ensure the peak currents can be calibrated to within the standard Ipeak values. It was found that at all test sites, the

JEDEC field (charge) plate voltage adjustment settings raised the plate voltage by 15% or more to retain compliance to the JESD22-C101E waveforms. The JESD22-C101E standard, however, specifies the plate voltage tolerance at +/- 5%. The first experiment (using the 10 ohm probe assembly) retained the plate voltage adjustment values at each site set for its JEDEC calibration. For the dielectric experiment using the ferrite free probe assembly, the adjustment values for each tester were set so the set voltage was equal to the field plate voltage. Also, at each test site, the charging resistor was checked and the charge delay value was set on each tester to ensure full module charging. Additionally, the same attenuation (20 dB) was used for these experiments, as the probe assembly current sensor resistor was 1 ohm for all experiments.

Va. Module Capacitance Measurement

The 5-capacitance model of the CDM tester [10] consists of the DUT to field plate capacitance, the DUT to probe assembly capacitance, the ground plane to field plate capacitance, and capacitances between field plate and chassis as well as ground plane and chassis. Since the test voltage setting was +500V at all test sites for the dielectric experiment, it was felt that the DUT to probe / series resistor capacitance would not vary as much among the sites, as discharge voltage was not varied. However, the capacitances of the module to field plate, as well as the ground plane to field plate, could be measured. An Orion tester and an RCDM3 tester had these values measured for the JEDEC dielectric and the different FR406 / FR408 dielectrics. Table 2 gives these values.

Table 2. Capacitance values of JEDEC and ferrite free probe assemblies / small and large modules, for different dielectrics, for Orion and RCDM3 CDM testers.

		C (Small Module)		C (Large Module)		C (GP - FP)	
		Orion	**RCDM3**	**Orion**	**RCDM3**	**Orion**	**RCDM3**
JEDEC Probe Assembly / JEDEC Dielectric:		7.3 pF	6.6 pF	56.0 pF	47.7 pF	27.3 pF	47.0 pF
Ferrite Free Probe Assembly / JEDEC Dielectric:						27.8 pF	47.5 pF
Different dielectrics:	FR6-31	4.96 pF	3.8 pF	27.0 pF	26.0 pF	27.1 pF	47.2 pF
	FR6-47	4.4 pF	2.8 pF	16.0 pF	18.1 pF	27.0 pF	47.0 pF
	FR6-59	3.3 pF	2.4 pF	14.7 pF	15.5 pF	26.7 pF	47.2 pF
	FR8-31	4.8 pF	3.4 pF	24.5 pF	24.0 pF	27.2 pF	47.1 pF
	FR8-42	4.0 pF	2.8 pF	18.2 pF	18.4 pF	27.3 pF	47.2 pF
	FR8-59	3.7 pF	2.4 pF	14.8 pF	15.0 pF	26.8 pF	47.3 pF

In Table 2, RCDM3 ground plane to field plate capacitance is significantly higher than for the Orion. This may be due the distance the probe tip extends from the Orion ground plane compared to the RCDM3. However, the RCDM3 module to field plate capacitance is smaller than that of the Orion for the small module, but basically equivalent with the large module for the FR406 and FR408 dielectrics.

Vb. Dielectric Experiment Test Data

Dielectric experiment test data was taken at two sites, one site having an Orion tester and one having an RCDM3. Small JEDEC module data showing Ipeak and rise time measurements at 1 GHz bandwidth as a function of dielectric thickness using the ferrite free probe assembly, compared to JEDEC dielectric / JEDEC test head (Jed_Jed), is shown in Figure 11. Figure 12 shows small module FWHH and integrated charge taken for different dielectrics, also at 1 GHz bandwidth. Figures 13 and 14 repeat the same types of data as in Figures 10 and 11, but for a 3 GHz bandwidth. Ipeak at 1 GHz (Figure 11) is shown to decrease significantly as the dielectric thickness is raised. Rise time is basically constant. However, Ipeak taken at 3 GHz, as shown in Figure 13, is shown to be above that of JEDEC for the thinnest FR406 and FR408 dielectrics and also does not have as steep a reduction as dielectric thickness increases. Rise time also is basically constant with dielectric thickness for the 3 GHz bandwidth compared to 1 GHz.

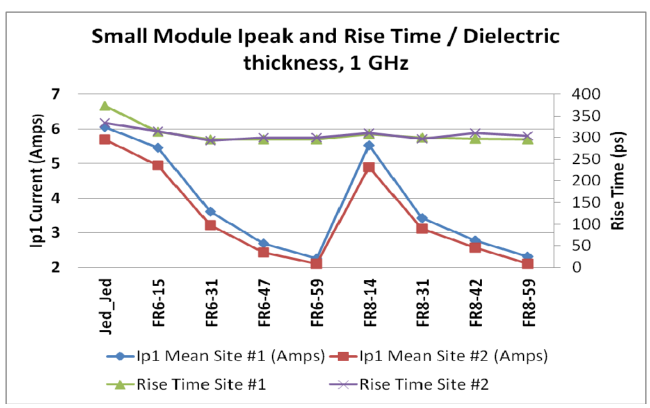

Figure 11. Small module Ipeak and rise time as a function of dielectric thickness, 1 GHz measurement.

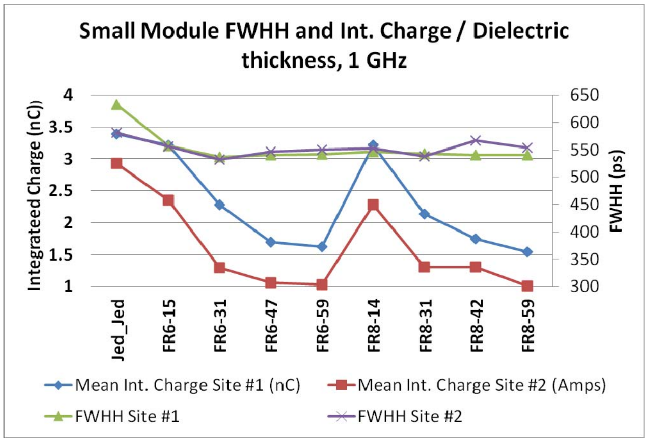

Figure 12. Small module FWHH and integrated charge as a function of dielectric thickness, 1 GHz measurement.

Comparing FWHH in Figure 12 for 1 GHz with Figure 14 at 3 GHz, the FWHH stays essentially constant for all dielectrics at 1 GHz, but decreases significantly at 3 GHz as the dielectric thickness increases. This is a clear indication of the filtering function. Integrated current (charge), while slightly different between the two sites, shows the same decreasing trend as the dielectric thickness increases, for both 1 GHz and 3 GHz measurements.

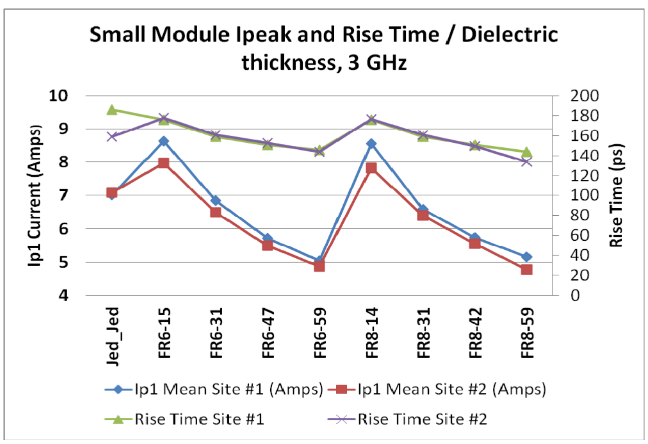

Figure 13. Small module Ipeak and risetime as a function of dielectric thickness, 3 GHz measurement.

Large JEDEC module measurements at 1 GHz bandwidth as a function of dielectric thickness using the ferrite free probe assembly, compared to JEDEC dielectric / JEDEC test head (Jed_Jed), is shown in Figure 15. Figure 16 shows large module FWHH and integrated charge taken for different dielectrics, also at 1 GHz bandwidth. Figures 17 and 18 repeat the same types of data as in Figures 15 and 16, but for a 3 GHz bandwidth.

As in Figure 11 for the small module, Ipeak at 1 GHz for the large module shown in Figure 15 is also seen to decrease significantly as dielectric thickness is increased (approximately 25% decrease, but less than the 65% decrease shown in Figure 11). Rise time shows a slight decrease for the different dielectrics at 1 GHz, but is only slightly faster than JEDEC.

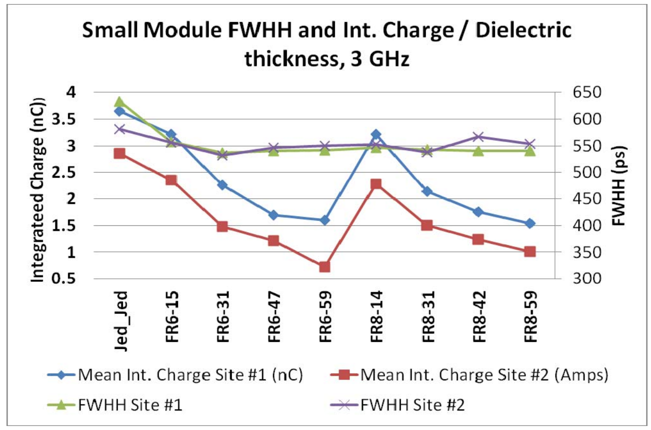

Figure 14. Small module FWHH and integrated charge as a function of dielectric thickness, 3 GHz measurement.

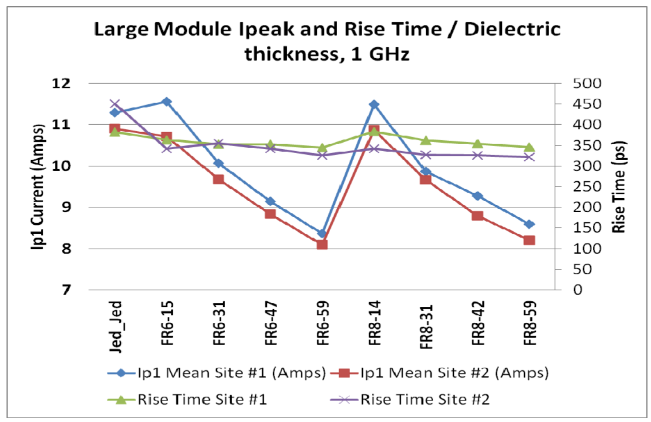

Figure 15. Large module Ipeak and rise time as a function of dielectric thickness, 1 GHz measurement.

However, Ipeak taken at 3 GHz, as shown in Figure 17, is shown to be above that of JEDEC for the thinnest FR406 and FR408 dielectrics and also does not have as steep a decrease as dielectric thickness increases, remaining slightly above JEDEC values at 31 mil dielectric thickness. Rise time shows a significant decrease with the thinnest FR406 and FR408 dielectrics at 3 GHz compared to JEDEC, but essentially staying within this range for the other FR6 and FR8 dielectrics.

Comparing FWHH in Figure 16 for 1 GHz with Figure 18 at 3 GHz, FWHH stays essentially constant for all dielectrics at 1 GHz, but decreases significantly at 3 GHz as the dielectric thickness increases. Integrated charge, while slightly different between the two sites, show the same trend for 1 GHz (Figure 16) as in 3 GHz (Figure 18) and the values at each dielectric thickness are approximately the same.

Maximum bandwidth (either 6 or 8 GHz) is not shown here, but the integrated charge values for all tester combinations above were virtually identical at higher bandwidths to those at 3 GHz. Corresponding Ipeak,

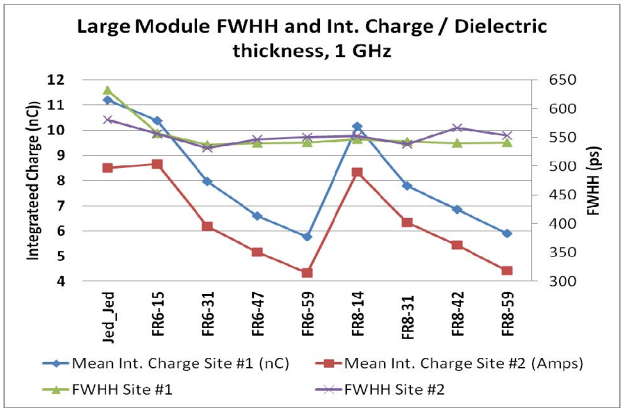

Figure 16. Small module FWHH and integrated charge as a function of dielectric thickness, 1 GHz measurement.

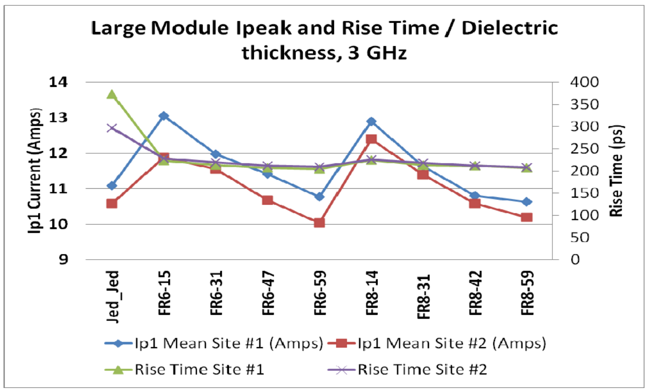

Figure 17. Small module Ipeak and rise time as a function of dielectric thickness, 3 GHz measurement.

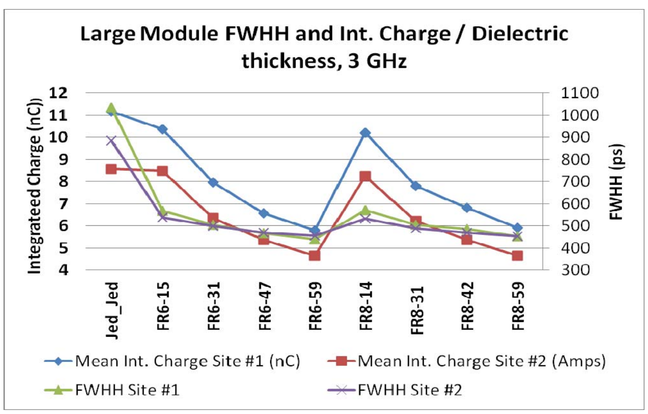

Figure 18. Large module FWHH and integrated charge as a function of dielectric thickness, 3 GHz measurement.

FWHH and rise time values were slightly lower at the higher bandwidths than at 3 GHz.

VI. Discussion / Future Work

The results from both CDM tester probe assembly variation experiment (JEDEC versus 10 ohm) and dielectric thickness variation experiment (comparing the JEDEC probe assembly / JEDEC dielectric with ferrite free 1 ohm probe assembly / different dielectrics) illustrated the differences in CDM waveform characteristics due to tester hardware differences and oscilloscope characteristics.

The 10 ohm experiment compared the JEDEC probe assembly (with a ferrite) with a probe assembly consisting of an effective 10 ohm resistor and no ferrite. This resulted in 10 ohm data taken with a 1 GHz oscilloscope bandwidth being similar to that of the JEDEC standard waveform data. However, 3 GHz bandwidth data showed 10 ohm peak current significantly above that of the JEDEC standard. In addition, modification of a probe assembly to add components, such as different resistors, adds an additional hardware cost to the CDM tester.

In contrast, use of a thicker dielectric combined with a ferrite-free 1 ohm probe assembly can produce peak currents at 3 GHz similar to that of the JEDEC standard, with the additional benefit of slightly reduced rise time. The only change to the ESDA or most JEDEC probe assemblies is to remove the ferrite, which can be easily done.

Reviewing the dielectric data at 3 GHz, Figure 13 (small module Ipeak) and Figure 14 (large module Ipeak) show that the 31 mil dielectric produces an Ipeak value slightly less than that of the JEDEC-JEDEC tester for a small JEDEC module, while it produces an Ipeak value slightly greater than that of the JEDEC-JEDEC tester for a large JEDEC module. This is achieved at a minimal additional tester component cost (simply changing the dielectric).

The min / max Ipeak data for the JEDEC method versus the 31 mil dielectric at 3 GHz was compared. For 100 discharges of the small module, the Orion tester recorded a JEDEC method min / max of 6.24 and 7.36 Amps respectively, with mean of 7.02 Amps. The 31 mil dielectric / ferrite free probe assembly recorded a min / max of 5.94 and 7.28 Amps respectively, with a mean of 6.84 Amps. Comparing 100 discharges of the large module, the Orion tester recorded a JEDEC method min / max Ipeak of 10.24 and 11.37 Amps respectively, with mean of 11.08 Amps. The 31 mil dielectric / ferrite free probe assembly recorded a min / max of 11.21 and 12.33 Amps respectively, with a mean of 11.98 Amps.

These comparisons appear to show that the peak current range, variance from the mean, and the mean value compared to min and max is approximately the same between the JEDEC method and the ferrite free probe assembly and 31 mil dielectric combination.

The initial dielectric experiment shows a thicker dielectric does decrease the total integrated charge compared to the standard JEDEC measurement. However, it is believed that CDM failure in ICs (and supported by common ESD design practice) is predominantly controlled by first peak CDM current [2], with a sharper rise time measurement being a more accurate indicator of the CDM response. As for total integrated charge, the data show that the RCDM3 and Orion testers have different values, which may be due to the difference in their measured capacitance values. FWHH and first peak integrated charge are good measures for defining the waveform, but not as critical for defining CDM failure in ICs, where the failure is more related to peak current. Therefore, it is encouraging that a first dielectric thickness evaluation has shown comparable Ipeak to the JEDEC method and faster rise time results.

To gather additional data for the joint ESDA/JEDEC CDM standard, the CDM JWG will be conducting additional tests at a single dielectric thickness, most likely the 31 mil FR406 dielectric, using the JEDEC small and large modules for 250 and 500V, and then evaluating CDM pass / fail voltage on products.

In summary, the CDM JWG observes the following:

- 3 GHz is an improved oscilloscope bandwidth to measure CDM waveforms. The use of oscilloscope supplied software or external hardware filters are both sufficient for use for bandwidth limiting of high frequency (6 GHz or greater) oscilloscope waveforms to 3 GHz.
- The 1 GHz specification, if included in the eventual standard, will have peak currents significantly less than those at 3 GHz, should be used for daily waveform checking only, and is not recommended for tester calibration and qualification.
- The use of ferrites, or components other than the current sensor resistor, in the probe assembly should be prohibited.
- The capacitance of the field plate to ground plane, as well as the capacitance of the calibration modules to ground plane, should be a part of the tester initial verification process and should be recorded.

Conclusions

Significant progress has been made towards the realization of CDM tester hardware improvements to support a joint CDM standard, improving the specifications of the CDM metrology chain responsible for the accuracy / repeatability of the CDM test, while preserving the intent of the JEDEC CDM waveform specifications. Experiments evaluating changes in the CDM probe assembly, as well as evaluating CDM waveform dependence on field plate dielectric thickness, have helped define a hardware path towards a new standard. The Joint CDM working group is on track to complete work towards a new joint ESDA/JEDEC CDM standard publication release in 2013.

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