Semiconductor Packing Material Electrostatic Discharge (ESD) Protection

Albert Escusa and Lance Wright *Standard Linear and Logic*

ABSTRACT

Forty-eight-pin TSSOP components that were packaged using Texas Instruments (TI) standard packing methodology were subjected to electrical discharges between 0.5 and 20 kV, as generated by an IEC ESD simulator to determine the level of ESD protection provided by the packing materials. The testing included trays, tape and reel, and magazines. Additional units were subjected to the same discharge, without the protection of the packing material. Test results showed that the packing materials used by TI provide protection up to 20 kV, and that a level of ESD protection is required. The die in the components had a Charge Device Model (CDM) rating of 0.5 kV, and all units experiencing a discharge greater than 500 V sustained sufficient electrical overstress to fail electrical testing when outside of the packing materials.

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1 Introduction

Texas Instruments (TI) ships over 5-billion semiconductor devices on an annual basis. To ensure that these devices reach the customer in good condition, they must be packaged appropriately to withstand the potential damage of shipping. Semiconductor packing materials must protect the units from physical damage, vibration shock, and electrostatic discharge (ESD).

Static electricity is a natural phenomenon. Delicate electronic components are easily damaged by ESD, and subsequent faults in assembled finished products can be costly. Packing media is used to protect against ESD, as ICs are delivered to the customer and include items such as trays, tape and reel, tubes or magazines, boxes, and bags. These items must have a surface resistance in the static dissipate range of greater than $1x10^4$ Ω/sq, but less than $1x10^{11}$ Ω/sq per ANSI/EOS/ESD S11.11-2001, in order to control a discharge. If the surface resistance is too small, a charge can dissipate too quickly and electrically overstress the ICs within the packing medium.

The purpose of this application report is to demonstrate that TI packing methods provide sufficient ESD protection when used in accordance with EIA-541 and EIA-625 material-handling guidelines. Packing methods in use today by TI are tape and reel, tray, and tubes. A typical logic device has minimum ESD criteria, unless approved by a waiver from the Quality department: [Human-Body Model (HBM), 2000 V] [Charge-Device Model (CDM), 500 V]. The testing performed in this study was done using a die meeting these minimum requirements, and the testing performed simulated the CDM. For more information on HBM and CDM, please see the TI application report, *Electrostatic Discharge (ESD)*, literature number SSYA010, located at www.ti.com.

2 Packing Methods

2.1 Tube Packing Method

When a customer receives devices packed in tubes, they receive a carbon-lined cardboard box for surface-mount components. The surface-mount technology (SMT) components are wrapped in bubble wrap that has an antistatic coating if the moisture sensitivity rating is level 1 (MSL 1). If not, the tubes are put in a moisture-barrier bag (MBB) and placed in a cardboard box. For through-hole components, the tubes are shipped inside a carbon-lined bag. Through-hole components are not moisture sensitive and do not require drypack in an MBB.

2.2 Tray Packing Method

Trays are sent to the customer in a stacked arrangement. There is 4+1, 5+1, or 10+1 tray stacking, which means that 4, 5, or 10 trays have units with a top tray that is empty. The top tray acts as a cover. A single carbon-lined cardboard sheet is put on the top and bottom of the tray stack and bound together with a conductive plastic strap. If the devices are moisture sensitive, the bundle is drypacked in an MBB and placed in a box with a carbon-lined insert/sleeve. The top and bottom cardboard sheets and insert provide the Faraday cage (ESD shielding). If the units are not moisture sensitive, the bundle is wrapped in antistatic bubble wrap and placed in a non-carbon-lined box.

2.3 Tape-and-Reel Packing Method

Devices in static-dissipative carrier tape are wound onto an intrinsically static-dissipative reel. This reel, if moisture sensitive, is placed in an MBB and placed in a non-carbon-lined cardboard box. If the devices are not moisture sensitive, the reel is placed in the non-carbon-lined box, without bubble wrap or MBB. The reel has an extra layer of winding at the inner and outer hub to provide the Faraday cage. The customer receives one reel per box.

3 Text Equipment and Materials

The instruments and materials listed in section 3.2 were used to conduct the ESD tests. The packing materials listed were qualified in accordance with TI internal qualification procedures.

3.1 Instruments

1. NoiseKen, ESS-2000 IEC ESD Simulator. This instrument, shown in the background of Figure 2, is used to generate ESD on the packing materials.
2. 3M Event Detector, 37 V. The device is one cubic inch and has a window that turns red when exposed to 37 V, or higher. The window remains black when exposed to <37 V.

3.2 Materials

All the packing materials listed in Table 1 are TI production materials that are qualified in accordance with Quality Standard 007-001.

Table 1. Test Materials

TI PART NUMBER	RATED SURFACE RESISTIVITY	MATERIAL DESCRIPTION
4200101-0001	1x10e7 Ω/sq	Tray, black, PPE
RH Murphy	1x10e5 Ω/sq	Tray, blue, antistatic, dipped, ABS
4204205-0003	1x10e9 Ω/sq	13-in black intrinsically static dissipative reel
4200038-0003	1x10e10 Ω/sq	13-in blue antistatic dipped reel
4041338-0001	1x10e9 Ω	Tube, clear antistatic, PVC
-034 (Burr Brown)	1x10e3 Ω	Tube, black, conductive
4200734-0004	1x10e8 Ω/sq	MBB for tube
4200734-0003	1x10e10 Ω/sq	MBB for tray, aluminum
4200734-0001	1x10e10 Ω/sq	MBB for tape and reel, aluminum
4045704-0025	Interior/exterior: 1x10e10 Ω/sq, Metal: 100 Ω	ESD shielding bag for tape and reel
4045704-0026	Interior/exterior: 1x10e10 Ω/sq, Metal: 100 Ω/sq	ESD shielding bag for tray
1041370-0104	1x10e4 Ω/sq	Conductive insert/sleeve, carbon lined
1041370-0112	1x10e4 Ω/sq	Corrugated conductive pad, carbon lined
1041285-0031	NA	Pizza box, intermediate container for 13-in reel
1041286-0146	NA	Intermediate single JEDEC box for tray
1041286-0117	1x10e4 Ω/sq	Carbon-lined intermediate box for tube
4078201-0001	1x10e4 Ω/sq	Carbon-lined conductive paper bag

4 Test Procedure

ESD testing consists of two tests. The first test uses a 37-V Static Event Detector (SED), manufactured by 3M. The detector is placed within the packing materials (see Figures 1, 4, and 7) to simulate a “packaged” device. The IEC ESD simulator then is used to discharge 0.5 kV to 20 kV on the packing configuration. The detector window turns red if it has been exposed to >37 V. SEDs that experience 37 V indicate that more testing is needed, as the device may be susceptible to damage due to ESD by exposure to voltages greater than 500 V. The minimum voltage chosen was 0.5 kV, as this is the CDM ESD rating standard TI die. The maximum voltage chosen was 20 kV, since it is the maximum value that can be discharged in an exceptionally low-humidity environment when all handling is in accordance with EIA 541/625.

The second test is a repeat of the first test, with known good devices being packed instead of SEDs. Additionally, this device is placed in a test socket (see Figure 11) and the discharge is made directly to the ground pins. For this test, a 48-pin TSSOP package was chosen with a SSTV16857 Rev C die. This die was chosen because it has the minimum allowable values for HBM and CDM, which are 2000 and 500 V, respectively. These two tests relate to ESD sensitivity and are described in detail in TI application report, *Electrostatic Discharge (ESD)*, literature number SSYA010. Devices with lower values must have a waiver from QA prior to production shipping. The premise for this test is that no failures prove that TI packing methodology is sufficient in accordance with the EIA 541/625 ESD packing material and handling guidelines that TI follows.

The ESD simulator chosen in this study complies with the industry specification IEC 61000-4-2 for system-level ESD evaluation. It generates a more severe stress compared to those specified in the JEDEC standards of JESD22-A104 for component-level HBM and JESD22-C101 for component-level CDM. The stress generated by the ESD simulator includes both component-level HBM and CDM stresses. In addition, at a same-stress voltage level, the ESD simulator produces an ESD pulse of a greater magnitude than those of the component-level HBM and CDM stresses. The component-level HBM and CDM tests are specified in the JEDEC standards and are included in the TI internal specifications for device qualification. The minimum requirements are 2000 V for HBM and 500 V for CDM. A device with marginal ESD performance, in accordance with the TI ESD specification, was chosen in this study.

4.1 3M SED Procedure for Trays/Tape and Reel/Tubes

1. Reset all 37-V SEDs by swiping next to a magnet.
2. Distribute the detectors evenly in the packing material as shown in Figures 1, 4, and 7.
3. Shoot the ESD generator at six different spots around the packing material and record the result.
4. Perform the same test on the other packing configurations, as shown in the test matrix.

4.2 IEC ESD Simulator Procedure for Trays/Tape and Reel/Tubes

1. Place five “electrically good” devices in the first packing material to be tested.
   a. Trays: Place in all four corners and at the center of the top tray.
   b. Carrier tape: Place all five in consecutive pockets, with an empty layer of carrier tape on top.
   c. Tubes: Distribute evenly along the length of the tube.
2. Discharge the ESD generator at ten different spots around the packing material and record the results.
3. Perform the same test on the other packing configurations, as shown in the test matrix.

5 Results

5.1 Tray-Stack Test Results

5.1.1 Event-Detector Test Results

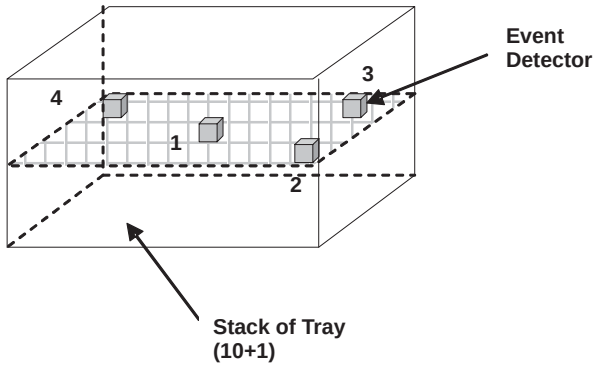

Figure 1. Event-Detector Locations in Tray Stack

Table 2. Event-Detector Feedback for Black PPE-Tray Packing Configurations(1)(2)

IEC ESD GENERATOR VOLTAGE SETTING	PACKING-MATERIAL CONFIGURATION				
	10+1 TRAYS	10+1 TRAYS, CARBON-LINED BOARD (TOP AND BOTTOM)	10+1 TRAYS, CARBON-LINED BOARD, INTERMEDIATE BOX WITH BUBBLE PACK	10+1 TRAYS, CARBON-LINED BOARD, MBB	10+1 TRAYS, CARBON-LINED BOARD, ESD SHIELD BAG
2 kV	1,2,3,4	1,2,3,4	NA	Good	NA
2 kV	1,2,3,4	1,2,3,4	NA	Good	NA
4 kV	1,2,3,4	1,2,3,4	NA	Good	NA
6 kV	1,2,3,4	1,2,3,4	NA	Good	NA
8 kV	1,2,3,4	1,2,3,4	NA	Good	NA
10 kV	1,2,3,4	1,2,3,4	NA	Good	NA
12 kV	1,2,3,4	1,2,3,4	NA	1,2,3,4	NA
14 kV	1,2,3,4	1,2,3,4	NA	1,2,3,4	NA
16 kV	1,2,3,4	1,2,3,4	NA	1,2,3,4	NA
18 kV	1,2,3,4	1,2,3,4	NA	1,2,3,4	NA
20 kV	1,2,3,4	1,2,3,4	NA	1,2,3,4	NA

(1) There are four event detectors used, numbered 1 to 4.
(2) Numbers in the table are the event detector numbers that turned red after the ESD stress test. Red means the 37-V event detector has experienced an ESD >37 V.

Table 3. Event-Detector Feedback for Blue Dipped-Tray Packing Configurations(1)(2

IEC ESD GENERATOR VOLTAGE SETTING	PACKING-MATERIAL CONFIGURATION				
	10+1 TRAYS	10+1 TRAYS, CARBON-LINED BOARD (TOP AND BOTTOM)	10+1 TRAYS, CARBON-LINED BOARD, INTERMEDIATE BOX WITH BUBBLE PACK	10+1 TRAYS, CARBON-LINED BOARD, MBB	10+1 TRAYS, CARBON-LINED BOARD, ESD SHIELD BAG
2 kV	1,2,3,4	1,2,3,4	4	NA	Good
4 kV	1,2,3,4	1,2,3,4	3,4	NA	Good
6 kV	1,2,3,4	1,2,3,4	2,3,4	NA	Good
8 kV	1,2,3,4	1,2,3,4	1,2,3,4	NA	Good
10 kV	1,2,3,4	1,2,3,4	1,2,3,4	NA	Good
12 kV	1,2,3,4	1,2,3,4	1,2,3,4	NA	Good
14 kV	1,2,3,4	1,2,3,4	1,2,3,4	NA	Good
16 kV	1,2,3,4	1,2,3,4	1,2,3,4	NA	Good
18 kV	1,2,3,4	1,2,3,4	1,2,3,4	NA	Good
20 kV	1,2,3,4	1,2,3,4	1,2,3,4	NA	Good

(1) There are four event detectors used, numbered 1 to 4.
(2) Numbers in the table are the event detector numbers that turned red after the ESD stress test. Red means the 37-V event detector has experienced an ESD >37 V.

5.1.2 Tray Packing Results on Live TSSOP Devices Using IED Gun

Table 4. ESD Testing on Live TSSOP Devices for Black PPE-Tray Packing Configurations(1)

IEC ESD GENERATOR VOLTAGE SETTING	PACKING-MATERIAL CONFIGURATION		
	10+1 TRAYS	10+1 TRAYS, CARBON-LINED BOARD (TOP AND BOTTOM)	10+1 TRAYS, CARBON-LINED BOARD, MBB
0.5, 1, 2–20 (2 kV included) kV	No failures	No failures	No failures

(1) The devices used in the test are serialized as shown in the table.

Table 5. ESD Testing on Live TSSOP Devices for Blue Dipped-Tray Packing Configurations

IEC ESD GENERATOR VOLTAGE SETTING	PACKING-MATERIAL CONFIGURATION			
	10+1 TRAYS	10+1 TRAYS, CARBON-LINED BOARD (TOP AND BOTTOM)	10+1 TRAYS, CARBON-LINED BOARD, INTERMEDIATE BOX WITH BUBBLE PACK	10+1 TRAYS, CARBON-LINED BOARD, ESD SHIELD BAG
0.5, 1, 2-20 (2 kV included) kV	No failures	No failures	No failures	No failures

Figure 2. Tray Stack

Figure 3. Tray Stack in Box

Summary of test results:

The 3M event-detector results show that units packed in the tray configuration can experience up to 37 V when not packed in an ESD shielding bag or in an MBB that is exposed to at least 12 kV. As expected, the ESD shielding bag provides the best results. Both tray materials performed about the same. TI does not ship all units in ESD bags because of the expense. The IEC test results show that no units failed or experienced more than 500 V when exposed to 20 kV in any packing configuration. These tests show that the low-cost packing method, when used in accordance with EIA-541 and EIA-625, provides sufficient ESD protection.

5.2 Tape-and-Reel Test Results

5.2.1 Event-Detector Test Results

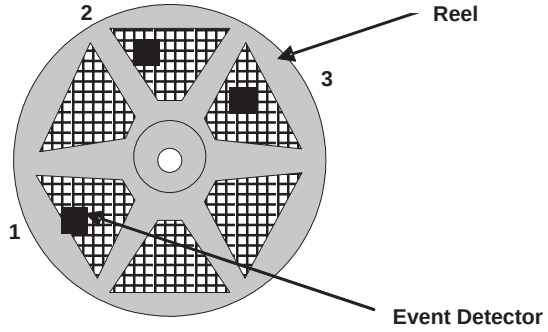

Figure 4. Event-Detector Locations in Reel (Used 3)

Table 6. Event-Detector Feedback for Black Static-Dissipative-Reel Packing Configurations(1)(2)

IEC ESD GENERATOR VOLTAGE SETTING	PACKING-MATERIAL CONFIGURATION			
	1 FULL REEL	1 FULL REEL, PIZZA BOX	1 FULL REEL, MBB	1 FULL REEL, ESD SHIELD BAG
2 kV	2	Good	Good	Good
4 kV	1,2,3	Good	Good	Good
6 kV	1,2,3	Good	Good	Good
8 kV	1,2,3	Good	Good	Good
10 kV	1,2,3	1	Good	Good
12 kV	1,2,3	Good	Good	Good
14 kV	1,2,3	1,2	3	Good
16 kV	1,2,3	1,2,3	1,2,3	Good
18 kV	1,2,3	1,2,3	1,2,3	Good
20 kV	1,2,3	1,2,3	1,2,3	Good

(1) There are four event detectors used, numbered 1 to 4.
(2) Numbers in the table are the event detector numbers that turned red after the ESD stress test. Red means the 37-V event detector has experienced an ESD >37 V.

Table 7. Event-Detector Feedback for Blue Dipped-Reel Packing Configurations(1)(2)

IEC ESD GENERATOR VOLTAGE SETTING	PACKING-MATERIAL CONFIGURATION			
	1 FULL REEL	1 FULL REEL, PIZZA BOX	1 FULL REEL, MBB	1 FULL REEL, ESD SHIELD BAG
2 kV	1,2,3	Good	Good	Good
4 kV	1,2,3	Good	Good	Good
6 kV	1,2,3	Good	Good	Good
8 kV	1,2,3	Good	Good	Good
10 kV	1,2,3	1	Good	Good
12 kV	1,2,3	1,2	Good	Good
14 kV	1,2,3	1,3	1.2,3	Good
16 kV	1,2,3	1,2,3	1,2,3	Good
18 kV	1,2,3	1,2,3	1,2,3	Good
20 kV	1,2,3	1,2,3	1,2,3	Good

(1) There are four event detectors used, numbered 1 to 4.
(2) Numbers in the table are the event detector numbers that turned red after the ESD stress test. Red means the 37-V event detector has experienced an ESD >37 V.

5.2.2 Tape-and-Reel Packing Results on Live TSSOP Devices Using IEC Gun

Table 8. ESD Testing on Live TSSOP Devices for Black Reel Packing Configurations

IEC ESD Generator Voltage Setting	Packing-Material Configuration			
	1 Full Reel	1 Full Reel, Pizza Box	1 Full Reel, MBB	1 Full Reel, ESD Shield Bag
0.5, 1, 2-20 (2 kV included) kV	No failures	No failures	No failures	No failures

Table 9. ESD Testing on Live TSSOP Devices for Blue Dipped-Reel Packing Configurations

IEC ESD Generator Voltage Setting	Packing-Material Configuration			
	1 Full Reel	1 Full Reel, Pizza Box	1 Full Reel, MBB	1 Full Reel, ESD Shield Bag
0.5, 1, 2-20 (2 kV included) kV	No failures	No failures	No failures	No failures

Figure 5. Carrier-Tape Reel

Figure 6. Tape-and-Reel Box

Summary of test results:

The 3M event-detector results show that the reel and pizza box provide some level of protection, but not as much as when the reel is packed in an MBB bag. As with the tray packing, the event detector never experienced 37 V when the reel was packed inside an ESD shielding bag. The static-dissipative reel performed better than the dipped reel. The IEC test results show that no units failed or experienced more than 500 V when exposed to 20 kV in any packing configuration. These tests show that the low-cost packing method, when used in accordance with EIA-541 and EIA-625, provides sufficient ESD protection.

5.3 Tube Test Results

5.3.1 Tube Event-Detector Test Results

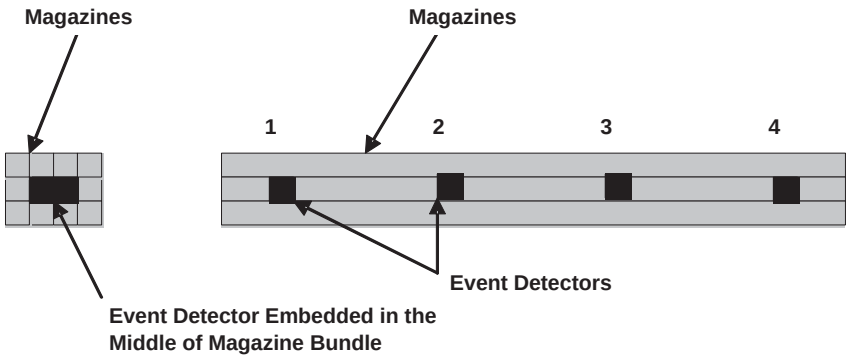

Figure 7. Event-Detector Locations in Magazine Bundle

Table 10. Event-Detector Feedback for Clear Antistatic Tube Packing Configurations(1)(2)

IEC ESD Generator Voltage Setting	Packing-Material Configuration			
	Bundle of Tubes	Bundle of Tubes, Carbon-Lined Intermediate Box	Bundle of Tubes, MBB	Bundle of Tubes, Carbon-Lined Bag
2 kV	1,2,3,4	Good	Good	1
4 kV	1,2,3,4	Good	Good	1
6 kV	1,2,3,4	Good	Good	1,2,3,4
8 kV	1,2,3,4	Good	1,2,3,4	1,2,3,4
10 kV	1,2,3,4	Good	1,2,3,4	1,2,3,4
12 kV	1,2,3,4	4	1,2,3,4	1,2,3,4
14 kV	1,2,3,4	2,3,4	1,2,3,4	1,2,3,4
16 kV	1,2,3,4	1,2,3,4	1,2,3,4	1,2,3,4
18 kV	1,2,3,4	1,2,3,4	1,2,3,4	1,2,3,4
20 kV	1,2,3,4	1,2,3,4	1,2,3,4	1,2,3,4

(1) There are four event detectors used, numbered 1 to 4.
(2) Numbers in the table are the event detector numbers that turned red after the ESD stress test. Red means the 37-V event detector has experienced an ESD >37 V.

Table 11. Event-Detector Feedback for Black Tube Packing Configurations(1)(2)

IEC ESD Generator Voltage Setting	Packing-Material Configuration			
	Bundle of Tubes	Bundle of Tubes, Carbon-Lined Intermediate Box	Bundle of Tubes, MBB	Bundle of Tubes, Carbon-Lined Bag
2 kV	1,2,3,4	Good	Good	1,2,3,4
4 kV	1,2,3,4	1	Good	1,2,3,4
6 kV	1,2,3,4	1	Good	1,2,3,4
8 kV	1,2,3,4	1,2	Good	1,2,3,4
10 kV	1,2,3,4	1,4	Good	1,2,3,4
12 kV	1,2,3,4	1,2,3,4	1,4	1,2,3,4
14 kV	1,2,3,4	1,2,3,4	1,2,3,4	1,2,3,4
16 kV	1,2,3,4	1,2,3,4	1,2,3,4	1,2,3,4
18 kV	1,2,3,4	1,2,3,4	1,2,3,4	1,2,3,4
20 kV	1,2,3,4	1,2,3,4	1,2,3,4	1,2,3,4

(1) There are four event detectors used, numbered 1 to 4.
(2) Numbers in the table are the event detector numbers that turned red after the ESD stress test. Red means the 37-V event detector has experienced an ESD >37 V.

5.3.2 Tube Packing Results on Live TSSOP Devices Using IEC Gun

Table 12. ESD Testing on Live TSSOP Devices for Clear Antistatic Tube Packing Configurations

IEC ESD Generator Voltage Setting	Packing-Material Configuration			
	Bundle of Tubes	Bundle of Tubes, Carbon-Lined Intermediate Box	Bundle of Tubes, MBB	Bundle of Tubes, Carbon-Lined Bag
0.5, 1, 2-20 (2 kV included) kV	No failures	No failures	No failures	No failures

Table 13. ESD Testing on Live TSSOP Devices for Black Tube Packing Configurations

IEC ESD Generator Voltage Setting	Packing-Material Configuration			
	Bundle of Tubes	Bundle of Tubes, Carbon-Lined Intermediate Box	Bundle of Tubes, MBB	Bundle of Tubes, Carbon-Lined Bag
0.5,1, 2-20 (2 kV included) kV	No failures	No failures	No failures	No failures

Figure 8. Bundle of Tubes

Figure 9. Tube Box

Figure 10. Carbon-Lined Bag

Summary of test results:

The 3M event-detector results show that tube packing is not as effective as tray or reel packing. The 37-V event detector tripped more times. The clear antistatic tubes performed significantly better than the black, conductive tubes. However, the question is whether the units experience more than the rated 500 V for live devices. The IEC results show that this is not the case. None of the TSSOP units failed when exposed to 20 kV in any packing configuration. These tests show that the low-cost packing method, when used in accordance with EIA-541 and EIA-625, provides sufficient ESD protection.

5.4 Results of Unpackaged Live TSSOP Devices Using IEC Gun

Table 14. ESD Ground-Pin Test Results

IEC ESD Generator Voltage Setting	Units	Failures
500 V	560-564	0/5
1000 V	565-569	1/5
2000 V	570-574	1/5
4000 V	575-579	5/5
6000 V	580-584	5/5
8000 V	585-589	5/5
10000 V	590-594	5/5
12000 V	595-599	5/5
14000 V	600-604	5/5
16000 V	605-609	5/5
18000 V	610-614	5/5
20000 V	615-619	5/5

Summary of test results:

The unpackaged test results show that live devices begin to fail when exposed to greater than 500 V. When the units are subjected to 4 kV, and greater, 100% of the sample size fails. The failures are expected, since the die has a 500-V CDM rating. For the testing, the units were placed in the test socket shown in Figure 11, with the ground pins wired together. The ground pins were grounded and the IEC gun was discharged on the non-ground pins.

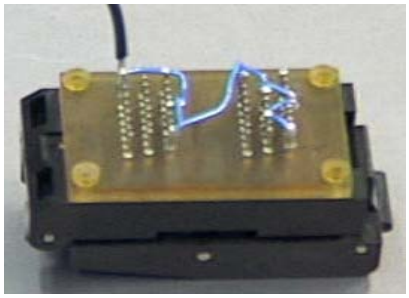

Figure 11. Test Socket for Live Die Testing

6 Conclusion

TI semiconductor packing methods protect standard die, which have minimum HBM and CDM ratings for discharges up to 20 kV. Unpackaged semiconductor devices with standard die begin to fail between 0.5 kV and 1 kV, as expected. A maximum discharge of 20 kV was used, as ESD becomes worse at low humidity. Under certain conditions, 20 kV can be achieved via package handling. The test results conclude that tray, tape-and-reel, and tube packing materials and methods being used at TI are sufficient to prevent ESD damage when the packing medium is handled in accordance with industry-standard guidelines (EIA 541/625).

7 Acknowledgments

The authors would like to thank Tom Diep, TI authority on ESD, for his guidance in setting up and running the experiment and being the technical reviewer of this application report. Tom was gracious enough to let us use his ESD laboratory to do the testing.

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