National Aeronautics and
Space Administration

Electronic Parts and Electrostatic Discharge

Gaps and Mitigation Strategies
Lessons Learned

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In this artist's concept, NASA's Ingenuity Mars Helicopter stands on the Red Planet's surface as NASA's Mars 2020 Perseverance rover (partially visible on the left) rolls away.

Image credit: NASA/JPL-Caltech

Why Electronic Parts and Electrostatic Discharge, ESD, Need a Fresher Look – Gaps

- NASA has been supporting Defense Logistics Agency (DLA) audits of the supply chain.
- During the audits, it was observed that the ESD requirements in MIL-PRF-38535, specification for microcircuits, were practically nonexistent.
- Microcircuit pin count has increased significantly (e.g., Xilinx Virtex Field Programmable Gate Arrays, FPGAs, have 1752 columns). Manufacturers are striving for still higher counts.
- Current qualification standards were developed years ago with pin counts in the twenties.
- Applying these old device testing standards to modern high-pin count products can cause severe problems (e.g., testing times increase dramatically).
- Furthermore, microcircuit part production is no longer under one roof, but landscape of supply chain is multiple specialty houses (see next slide).

Need to update standards

A Changing Landscape (Shipping/Handling/ESD Challenge)

A New Trend – Supply Chain Management
Ensuring gap-free alignment for each qualified product
(All entities in the supply chain must be certified/approved)

Manufacturer A	Die design
Manufacturer B	Fabrication
Manufacturer C	Wafer bumping
Manufacturer D	Package design and package manufacturing
Manufacturer E	Assembly
Manufacturer F	Column attach and solderability
Manufacturer G	Screening, electrical and package tests
Manufacturer H	Radiation testing

More Stops — More Places with ESD Risk

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Electronic Parts and Electrostatic Discharge (ESD) – Gaps and Mitigation Strategies

- **Gaps have evolved because of new technology and inconsistencies of standards development (e.g., three zaps vs. one zap per pin for testing). Parts have continued shrinking to smaller sizes & growing in complexity. Consequently, they are more susceptible to ESD and require more testing effort.**
- **Costs cannot be ignored—per unit price for advanced devices is approaching $100k. ESD mitigation costs are minute compared to the device unit costs.**
- **Mitigation strategies include ESD surveys, observations during audits, standards updates (including harmonization of standards), & outreach to the military & space communities.**
- ***There is always a latency risk from ESD.***

Human Body Model (HBM)
883 vs JEDEC Test Methods

- **Per MIL-PRF-38535, they are equivalent.**
- **883 requires 3 zaps per pin, JEDEC 1 zap per pin. No data showing equivalency. NASA did limited testing.**
- **Initial Results of ESD Testing**
  - Tests performed on
    - Parts from same manufacturer
    - Same function
    - Same lot
    - Testing done in increments of 250V
  - Test Results
    - Human Body Model (HBM) per MIL-STD-883
      - 3 units tested
      - All 3 failed at 250V
    - Human Body Model (NBM) per JEDEC standard
      - 3 units tested
        - 2 units failed at 250V
        - 1 unit failed at 500V
- **Discussion**
    - Misclassification is a concern
- **Next Step**
  - Test additional units at smaller voltage increments?

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Human Body Model (HBM)
MIL-STD883 vs JEDEC Test Methods

- **Repeat experiment using smaller voltage increment (50V, 100V, 200V, 300V…) instead of +250V increment**
  - Same test house, same test procedure, same date code.
  - MIL-STD883 = 3 consecutive pulses per polarity per pin (1 second interval)
  - JEDEC = 1 pulse per polarity per pin (0.3 second interval)

- **Results**
  - Part failed HBM based on MIL-STD-883. Best is 200V
  - Part demonstrated 50V HBM based on JEDEC. Best is ~500V
  - MIL-STD-883 is more sensitive ➔ gross ESD failures across majority of I/O pins.
    - ❖ Need to specify test method when quoting value for HBM
  - Both methods identify a common weak ESD protection network located in upper section of the chip.
    - ❖ Proper ESD handling necessary as per NASA/JPL Doc 34906 ESD Technical Requirements Rev-N.

- **Discussion**
  - Additional data needs to be taken by the community/manufacturers
  - A major manufacturer has agreed to take data
    - ❖ Testing will be done when they qualify a new device later this year

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JC-13/DLA ESD Activities

- **JC-13 Started a Task Group (TG) on ESD**
  - The fact that it is a JC-13 task group means that it has the highest level of attention and applies to all commodities
  - The TG was very helpful in bringing ESD awareness and adding ESD requirements for discrete (19500), hybrids (38534) and microcircuit (38535) commodities. It was closed last month.

- **JEDEC/ESDA Are Continuing Joint Effort**
  - JESD 625B and S20.20 Harmonization telecons and face-to-face meetings
  - Participation by NASA and the Aerospace Corporation
  - Has been on hold because the team leader had to discontinue his participation
  - A new lead person has been identified and it is hoped that this effort can be wrapped up by the end of this calendar year

- **Facilitated Technical Talk on ESD**
  - By On Semiconductor
    - At January 2020 JC-13 meeting

- **ESD Standards Updates**
  - On-going activity
    - See example in back-up section

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ESD Outreach by NASA

- **NASA Is Highlighting ESD in *EEE Parts Bulletins***
  - Released several special editions on ESD.
  - The first dealt with the need to upgrade specifications related to ESD and suggestions for better ESD practices wherever parts are manufactured, stored, or prepared for shipment.
  - The second ESD special issue focused on a parts failure investigation that ultimately concluded that ESD was the most likely cause of the failure. The second issue also included an important reminder about regular ESD testing.
  - The third issue provided an example demonstrating the importance of maintaining ESD discipline and a high-level risk analysis related to electrostatic discharge.
  - The fourth issue was a Compendium.
  - The fifth issue was on ESD testing
  - A guidelines document is planned.

- **Invited ESD Talks**
  - NASA has been instrumental in arranging invited talks at JC-13/CE-12 meetings.

NASA ESD Surveys of Microcircuit Supply Chain

- **NASA ESD Surveys**
  - Benefits not only NASA but the whole community
    - Especially vendors processing very expensive new technology parts (where the **per unit price could approach $100k)**
  - Candidate companies are identified during DLA audits—but not a DLA activity
  - Conducted by NASA ESD experts
    - The survey findings and corrective actions have been merely suggestions for improvements (but, in all cases, were implemented by the vendors)
  - Very well received
    - Some vendors have requested re-surveys every two years
  - Working with Suppliers and DLA to incorporate NASA ESD Surveys into DLA audit agendas
    - Make efficient use of resources
    - Was done a few times, worked well

NASA ESD Surveys are Meeting Greater ESD Challenges for Electronic Parts

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Examples of NASA ESD Survey Findings

- **Findings**
  - ESD Protected Areas (EPAs) were not designated as such
  - The so called ESD-safe curtains and cabinets were not safe! They needed shielding/grounding
  - In several cases, chairs were noted to be non-ESD Safe
  - Non-ESD items found on ESD work benches
    - Binders, plastic bottles, mouse pads
  - CRT monitors were found near parts in engineering test. They are charge generators. CRT displays are not recommended.
  - Cloth wrist straps were used. Prohibited per JPL 34906.
  - Operator retraining certifications had lapsed
  - Waste Bins/Bin Liners were found to hold or generate charge

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Potential ESD Issue Identified During Customer Source Inspection (CSI)

- **Cleanroom Humidity Nonconformance**
  - A customer source inspection (CSI) was performed recently
  - During the routine check of temperature and relative humidity in the cleanroom, humidity was seen to be 26.5%
    - ❖ Mil spec requires 35-65%
  - The manufacturer to notify DLA of their nonconformance
  - Further follow-up thru NEPAG
    - ❖ A NASA ESD Survey was conducted and recommendations were made

Device Design Enhancements – An Ongoing Process

- **A major manufacturer enhanced ESD protection networks**
  - To improve thresholds for HBM and CDM
  - To get higher yields
  - Four devices affected
  - Qualification data was reviewed by microcircuits Qualifying Activity (QA) which includes DLA, The Aerospace Corporation and NASA

NASA ESD Mitigation Going Forward (Plan)

- **Mitigate Existing and Possible Future ESD Issues by Supporting Efforts in Nine Categories:**

  1. NASA ESD surveys
     - We would like to see the ESD requirements to go in MIL-PRF-38535 so DLA can add ESD to their audit of the supply chain.
     - Responsibility for mitigating the risks from non-DLA audited sources will require a different approach. We know in a significant number of cases, we will not be permitted access to monitor such facilities. This is a significant gap!
  2. Independent evaluations of new technologies (e.g., GaN, SiC, others) is needed. Determine ESD thresholds per Human Body Model (HBM) and Charged Device Model (CDM).
  3. Clarify 883 vs. JEDEC test method equivalencies for HBM
  4. Low-ESD-threshold parts mitigation, e.g., very high speed microcircuits (GHz range) -- make recommendations
  5. Continue working with industry groups (e.g., JC13, JC14, ESDA, EC-11, EC-12)
  6. Harmonize ESDA 20.20 and JEDEC 625 standards
  7. Continue updating military standards (Support DLA)
  8. Encourage manufacturers to add ESD data to their datasheets
  9. Develop the next generation of ESD specialists

Note: NASA Is Part of the Qualifying Activity (QA) for Space microcircuits.

Electronic Parts and ESD FY21

- **Activities**
  - (ON HOLD) Continue NASA ESD Surveys of Supply Chain
    - Align with DLA audits
    - GaN supplier(s) of interest to NASA (new technology), others
  - ESD Test Data (Deliverable: Test Report)
    - Limited testing on Si based and GaN samples.
    - HBM per 883/3015 vs JEDEC 001. Data shows 883 test is worse of the two.
  - ESD Program Implementation
    - Review ESD test data and issue internal guidelines
  - Mil Standards Update
    - MIL-PRF-38535. ESD CDM. NASA and the Aerospace Corporation would like CDM testing made a requirement (rather than a recommendation). No surety which test method is worse, CDM or HBM. Most IC manufacturers perform both tests. For those who don't test for CDM, they could justify it in their QM plan which QA would review on a case-by-case basis.
    - HBM test method used should be explicitly stated, whether 883/3015 or JEDEC 001.
    - Should the package capacitance be stated?
    - What about the high speed pins?
    - ESD Latency is another concern.
  - Continue to support JC-13 Task Group
    - Present at meetings
    - Facilitate Technical Talks
  - Other Organizations
    - JC-14, ESDA
    - Develop working relations
  - Status Meetings, Bulletins and Guidelines document
    - Released several NASA bulletins
    - Have had monthly status meetings
  - Questions from Designers
    - Mostly related to overshoot/undershoot, undefined parameters in SMDs

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Summary

- NASA brought many ESD concerns to the attention of the parts community
- All types of commodities affected for both military and commercial parts
- COTS hardware could be affected more severely
- Harmonization of 625 and 20.20 is in progress.
- NASA to continue ESD Surveys
- Parts community must promote an ESD-safe environment!
- Unknown ESDS of Class Y, 2.5D/3D, others…
- Low measured values for older technologies
- M38535 has added a number of ESD updates but more needs to be done. There are other military documents that will require updates.
- Be mindful of ESD when shipping / handling parts and hardware!
- Develop next generation of ESD engineers.

Electronic Parts and ESD Team

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http://nepp.nasa.gov

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BACK – UP

Examples of MIL-PRF-38535 Updates, and
***a NASA EEE Parts Bulletin* ESD Special Issue**

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DLA Specific Activities

ESD Changes Summary (Already Implemented by DLA)

- **Ref: MIL-PRF-38535 Revision L, Dated December 6, 2018**
  - Para 2.3. Updated HBM, added CDM
  - Para 3.2.1. Added S20.20 as an alternate
  - Para 3.12. Updated program control requirements
  - Para 3.6.7.2. Updated sensitivity identifiers for HBM, added CDM
  - Para 4.2.3. Updated ESD requirements
  - Para A.3.4.1.4. Updated references
  - Para A.3.6.9.2. Updated test requirements
  - Para 4.4.2.8. HBM update
  - Table H-IIA. Updated HBM reference
  - Table H-IIB. Updated HBM reference
- **Updated MIL-STD-883, Test Method 1014**
  - Added Para 2.2.1d. “ESD Protective Tubes shall be utilized to ensure the system is ESD safe…”
- **Added requirement in 38535K for post column attach electricals**
  - To catch handling/ESD related problems

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DLA Specific Activities (Cont’d)

- **ESD Changes (Submitted)**
  - Suggested solution: Replace “Devices” with “Wafers/Dice/Devices” such as in Para A.4.4.2.8:
  - A.4.4.2.8 Electrostatic discharge (ESD) sensitivity. ……..Wafers/dice/devices shall be handled in accordance with the manufacturer's in-house control documentation, which shall be maintained by the manufacturer……...

Mars 2020 is ready for its voyage.

NASA EEE Parts Bulletin
Special Edition: Comparison of Test Methods for Human Body Model (HBM) Electrostatic Discharge (ESD)

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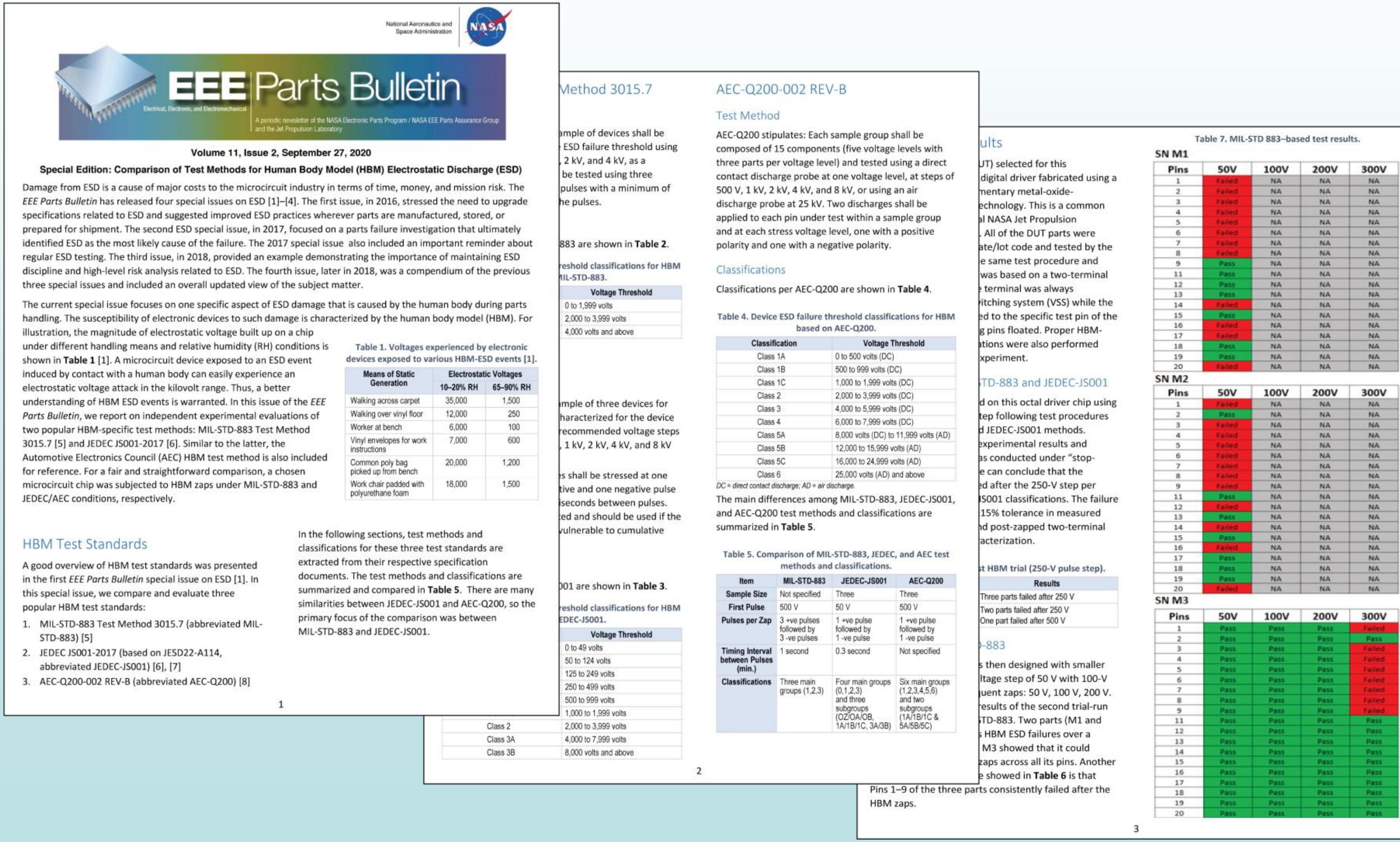

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Special Edition: Comparison of Test Methods for Human Body Model (HBM) Electrostatic Discharge (ESD)

Damage from ESD is a cause of major costs to the microcircuit industry in terms of time, money, and mission risk. The *EEE Parts Bulletin* has released four special issues on ESD [1]–[4]. The first issue, in 2016, stressed the need to upgrade specifications related to ESD and suggested improved ESD practices wherever parts are manufactured, stored, or prepared for shipment. The second ESD special issue, in 2017, focused on a parts failure investigation that ultimately identified ESD as the most likely cause of the failure. The 2017 special issue also included an important reminder about regular ESD testing. The third issue, in 2018, provided an example demonstrating the importance of maintaining ESD discipline and high-level risk analysis related to ESD. The fourth issue, later in 2018, was a compendium of the previous three special issues and included an overall updated view of the subject matter.

The current special issue focuses on one specific aspect of ESD damage that is caused by the human body during parts handling. The susceptibility of electronic devices to such damage is characterized by the human body model (HBM). For illustration, the magnitude of electrostatic voltage built up on a chip under different handling means and relative humidity (RH) conditions is shown in **Table 1** [1]. A microcircuit device exposed to an ESD event induced by contact with a human body can easily experience an electrostatic voltage attack in the kilovolt range. Thus, a better understanding of HBM ESD events is warranted. In this issue of the *EEE Parts Bulletin*, we report on independent experimental evaluations of two popular HBM-specific test methods: MIL-STD-883 Test Method 3015.7 [5] and JEDEC JS001-2017 [6]. Similar to the latter, the Automotive Electronics Council (AEC) HBM test method is also included for reference. For a fair and straightforward comparison, a chosen microcircuit chip was subjected to HBM zaps under MIL-STD-883 and JEDEC/AEC conditions, respectively.

Table 1. Voltages experienced by electronic devices exposed to various HBM-ESD events [1].

Means of Static Generation	Electrostatic Voltages	
	10–20% RH	65–90% RH
Walking across carpet	35,000	1,500
Walking over vinyl floor	12,000	250
Worker at bench	6,000	100
Vinyl envelopes for work instructions	7,000	600
Common poly bag picked up from bench	20,000	1,200
Work chair padded with polyurethane foam	18,000	1,500

HBM Test Standards

A good overview of HBM test standards was presented in the first *EEE Parts Bulletin* special issue on ESD [1]. In this special issue, we compare and evaluate three popular HBM test standards:

1. MIL-STD-883 Test Method 3015.7 (abbreviated MIL-STD-883) [5]
2. JEDEC JS001-2017 (based on JESD22-A114, abbreviated JEDEC-JS001) [6], [7]
3. AEC-Q200-002 REV-B (abbreviated AEC-Q200) [8]

In the following sections, test methods and classifications for these three test standards are extracted from their respective specification documents. The test methods and classifications are summarized and compared in **Table 5**. There are many similarities between JEDEC-JS001 and AEC-Q200, so the primary focus of the comparison was between MIL-STD-883 and JEDEC-JS001.

1

AEC-Q200-002 REV-B

Test Method

AEC-Q200 stipulates: Each sample group shall be composed of 15 components (five voltage levels with three parts per voltage level) and tested using a direct contact discharge probe at one voltage level, at steps of 500 V, 1 kV, 2 kV, 4 kV, and 8 kV, or using an air discharge probe at 25 kV. Two discharges shall be applied to each pin under test within a sample group and at each stress voltage level, one with a positive polarity and one with a negative polarity.

Classifications

Classifications per AEC-Q200 are shown in **Table 4**.

Table 4. Device ESD failure threshold classifications for HBM based on AEC-Q200.

Classification	Voltage Threshold
Class 1A	0 to 500 volts (DC)
Class 1B	500 to 999 volts (DC)
Class 1C	1,000 to 1,999 volts (DC)
Class 2	2,000 to 3,999 volts (DC)
Class 3	4,000 to 5,999 volts (DC)
Class 4	6,000 to 7,999 volts (DC)
Class 5A	8,000 volts (DC) to 11,999 volts (AD)
Class 5B	12,000 to 15,999 volts (AD)
Class 5C	16,000 to 24,999 volts (AD)
Class 6	25,000 volts (AD) and above

DC = direct contact discharge; AD = air discharge.

The main differences among MIL-STD-883, JEDEC-JS001, and AEC-Q200 test methods and classifications are summarized in **Table 5**.

Table 5. Comparison of MIL-STD-883, JEDEC, and AEC test methods and classifications.

Item	MIL-STD-883	JEDEC-JS001	AEC-Q200
Sample Size	Not specified	Three	Three
First Pulse	500 V	50 V	500 V
Pulses per Zap	3 +ve pulses followed by 3 -ve pulses	1 +ve pulse followed by 1 -ve pulse	1 +ve pulse followed by 1 -ve pulse
Timing Interval between Pulses (min.)	1 second	0.3 second	Not specified
Classifications	Three main groups (1,2,3)	Four main groups (0,1,2,3) and three subgroups (0Z/0A/0B, 1A/1B/1C, 3A/3B)	Six main groups (1,2,3,4,5,6) and two subgroups (1A/1B/1C & 5A/5B/5C)

Classification	Voltage Threshold
Class 2	2,000 to 3,999 volts
Class 3A	4,000 to 7,999 volts
Class 3B	8,000 volts and above

2

	Results
	Three parts failed after 250 V
	Two parts failed after 250 V
	One part failed after 500 V

Pins 1–9 of the three parts consistently failed after the HBM zaps.

Table 7. MIL-STD 883–based test results.

SN M1

Pins	50V	100V	200V	300V
1	Failed	NA	NA	NA
2	Failed	NA	NA	NA
3	Failed	NA	NA	NA
4	Failed	NA	NA	NA
5	Failed	NA	NA	NA
6	Failed	NA	NA	NA
7	Failed	NA	NA	NA
8	Failed	NA	NA	NA
9	Pass	NA	NA	NA
11	Pass	NA	NA	NA
12	Pass	NA	NA	NA
13	Pass	NA	NA	NA
14	Failed	NA	NA	NA
15	Pass	NA	NA	NA
16	Failed	NA	NA	NA
17	Failed	NA	NA	NA
18	Pass	NA	NA	NA
19	Pass	NA	NA	NA
20	Failed	NA	NA	NA

SN M2

Pins	50V	100V	200V	300V
1	Failed	NA	NA	NA
2	Pass	NA	NA	NA
3	Failed	NA	NA	NA
4	Failed	NA	NA	NA
5	Failed	NA	NA	NA
6	Failed	NA	NA	NA
7	Failed	NA	NA	NA
8	Failed	NA	NA	NA
9	Failed	NA	NA	NA
11	Pass	NA	NA	NA
12	Failed	NA	NA	NA
13	Pass	NA	NA	NA
14	Failed	NA	NA	NA
15	Pass	NA	NA	NA
16	Failed	NA	NA	NA
17	Pass	NA	NA	NA
18	Pass	NA	NA	NA
19	Pass	NA	NA	NA
20	Failed	NA	NA	NA

SN M3

Pins	50V	100V	200V	300V
1	Pass	Pass	Pass	Failed
2	Pass	Pass	Pass	Pass
3	Pass	Pass	Pass	Failed
4	Pass	Pass	Pass	Failed
5	Pass	Pass	Pass	Failed
6	Pass	Pass	Pass	Failed
7	Pass	Pass	Pass	Failed
8	Pass	Pass	Pass	Failed
9	Pass	Pass	Pass	Failed
11	Pass	Pass	Pass	Pass
12	Pass	Pass	Pass	Pass
13	Pass	Pass	Pass	Pass
14	Pass	Pass	Pass	Pass
15	Pass	Pass	Pass	Pass
16	Pass	Pass	Pass	Pass
17	Pass	Pass	Pass	Pass
18	Pass	Pass	Pass	Pass
19	Pass	Pass	Pass	Pass
20	Pass	Pass	Pass	Pass

3