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Special Edition: Electrostatic Discharge (ESD) Testing Standards in Use for GaN Devices

Gallium nitride (GaN) semiconductor technology has been widely researched in the space electronics industry. GaN transistors provide fast switching with low gate voltage and low ON resistance. Their wide bandgap makes them ideal for high-power electronics, high-frequency RF devices, and optoelectronics. Popular applications of GaN include high-electron-mobility transistors (HEMTs), monolithic microwave integrated circuits (MMICs), and optocouplers. They are being used in small satellites, small platforms, medium-power and high-power systems, and more. The lattice structure and piezoelectric nature of GaN require unique testing standards. To characterize these new variables, one must assess the fabrication processes and electrostatic discharge (ESD) sensitivity of GaN. GaN devices are known to be more prone to ESD than are their silicon counterparts. This will be discussed in detail in a future bulletin.

The EEE Parts Bulletin has previously released five special issues on ESD [1–5]. 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 fifth issue, in 2020, assessed the effectiveness of the Human Body Model testing of two commonly used standards. In this issue, we will be exploring the ESD testing standards of various GaN space electronics manufacturers.

ESD Testing Models

There are three main tests used for industry ESD qualification: The Human Body Model (HBM), the Machine Model (MM), and the Charged-Device Model (CDM). HBM is a commonly used model that characterizes the ESD sensitivity (ESDS) of electronic devices and how they would react upon charged human contact. In this model, a resistor–capacitor circuit simulates a human pulse, and the probe results reveal the operational constraints of the tested device. For more information on this test method and its effectiveness, refer to EEE Parts Bulletin Volume 11, Issue 2 [5]. Both the MIL-STD and the JEDEC HBM standards discussed herein use a pulse-generation circuit with a 100 pf capacitor discharged through a switch and a 1500-ohm resistor into the device [6–9].

MM simulates the effects of a machine discharging through a device. This can occur when a device comes into contact with empty sockets or equipment. Its test setup is similar to that of HBM, using a pulse-generation circuit with a 200 pF capacitor discharged into a device with no resistor in series to produce ESD effects at lower voltages than those of the HBM [10].

CDM tests the reaction of a conductive device when it comes into contact with a charged device. This can happen in manufacturing environments, through direct contact, triboelectric effects, electrostatic induction, and more. It has been shown that CDM damage susceptibility correlates better to peak current levels than it does to charge voltage, and this test simulates a higher current than that of the HBM [11].

ESD Testing Standards

Charged-Device Model

JESD22-C101, Field-Induced Charged-Device Model Test Method for Electrostatic Discharge Withstand Thresholds of Microelectronic Components, was the JEDEC standard for ESD CDM [12]. Rescinded in February 2020, it has been superseded by JS-002-2018 [11].

JS-002-2018 [11] is intended to replace the CDM ESD standards JESD22-C101 [12] and ANSI/ESD S5.3.1 [13]. It contains the essential elements from both standards. This establishes ESD sensitivity evaluation procedures for "all packaged semiconductor devices, thin film circuits, surface acoustic wave (SAW) devices, opto-electronic devices, hybrid integrated circuits (HICs), and multi-chip modules (MCMs) containing any of these devices" [11].

Human Body Model

MIL-STD-750, Method 1020 establishes the procedure for classifying semiconductors according to their susceptibility to damage or degradation by exposure to ESD [6]. This classification is used to specify appropriate packaging and handling requirements in accordance with MIL-S-19500 and to provide classification data to meet the requirements of ESD S20.20, the multi-industry standard for the development of ESD control programs [14].

MIL-STD-883, TM3015 establishes the procedure for classifying microcircuits according to their susceptibility to damage or degradation by exposure to ESD [7]. This classification is used to specify appropriate packaging and handling requirements in accordance with MIL-PRF-38535 [15] and to provide classification data to meet the requirements of MIL-STD-1686 [16].

JESD22-A114 [9] was the JEDEC standard for ESD Sensitivity Testing HBM until it was superseded by JS-001-2010. The current revision of the latter, JS-001-2017 [8], applies specifically to microcircuits. It can be used to classify microcircuits' susceptibility to damage and degradation when exposed to charged human contact [8]. The calibration steps are outlined in its JEDEC documentation.

JS-001-2017 [8] is the HBM testing standard for all generic components. It replaces JS-001-2014, which superseded JESD22-A114F [9]. JS-001-2017 states, "Data previously generated with testers meeting all waveform criteria of ANSI/ESDA/JEDEC JS-001-2010 and subsequent versions, ANSI/ESD STM5.1-2007, or JESD22-A114F" are considered valid test data [8].

Machine Model

JESD22-A115 is the JEDEC standard for ESD Sensitivity Testing, Machine Model (MM). It is inactive as of September, 2016. JESD22-A115C [10] is a reference document and should not be used as a requirement for integrated circuit ESD qualification. This standard is specifically for microcircuits and is used to assess susceptibility to machinery discharges and to set up manufacturing handling practices. The testing method is similar to that of JESD22-A114 [9]; using an oscilloscope combined with an amplifier, a circuit simulates a pulse within a 350 MHz bandwidth. This model produces similar results to those of HBM and can help determine a microcircuit's failure mode.

GaN ESD Standards in the Industry

A survey was sent to several GaN manufacturers to assess their ESD test practices and to assess whether the companies follow a common standard. Additionally, a number of datasheets containing ESD test methods and ratings are publicly available online. A majority of the contacted companies follow the JEDEC ESD standards, although some follow the MIL-STD HBM. The survey responses are summarized in **Table 1**.

GaN Parts and Manufacturers

The information in this bulletin encompasses several devices, including the

- EPC800x from Efficient Power Conversion (EPC) Corp.
  - Entire product line of power and RF devices in GaN
- EPC2001, EPC2001C from EPC
  - Enhancement Mode Power Transistors
- GaN devices from EPC Space
- Entire product line from GaN Systems
- MAGX, MAGB, MAGE, MAMG, MAPC, NPT, and NPA Series from MACOM
  - GaN Amplifier
- NV6113, NV6115, NV6117 from Navitas Semiconductor
  - GaN Power IC

Table 1. Sample of ESD testing standards in use.

	HBM					CDM			MM
Manufacturer	JS-001-2017 Revision of ANSI/ESDA/JEDEC JS-001-2014[1]	JS-001-2014	JESD22A-114[2]	MIL-STD-750, Method 1020	MIL-STD-883 TM3015	JS-002-2018 Limited revision of ANSI/ESDA/JEDEC JS-002-2014[3]	JESD22C-101[4]	JS-002-2014	JESD22A-115[5]
Efficient Power Conversion (EPC) Corporation			x				x		x
EPC SPACE LLC			x	x					
GaN Systems	x					x			
MACOM	x					x			
Navitas Semiconductor		x						x	
Panasonic			x				x		x
Renesas					x		x	x	x
Solid State Devices				x					
Toshiba	x								
Transphorm	x					x			

[1] *JS-001-2017, May 2017: Joint JEDEC/ESDA Standard for Electrostatic Discharge Sensitivity Testing—Human Body Model (HBM)—Component Level [8].*
[2] *JESD22-A114F, Dec. 2008: Electrostatic Discharge (ESD) Sensitivity Testing Human Body Model (HBM) [9]. Superseded by ANSI/ESDA/JEDEC JS-001, April 2010.*
[3] *JS-002-2018, Dec 2018 [11]: Joint JEDEC/ESDA Standard for Electrostatic Discharge Sensitivity Testing—Charged-Device Model (CDM)—Device Level. This is intended to replace JESD22-C101 [12] and ANSI/ESD S5.3.1 [13].*
[4] *JESD22-C101F, Oct. 2013: Field-Induced Charged-Device Model Test Method for Electrostatic Discharge Withstand Thresholds of Microelectronic Components [12]. Rescinded February 2020. Superseded by JS-002-2018, published January 2019 [11].*
[5] *JESD22-A115C, Nov. 2010: Electrostatic Discharge (ESD) Sensitivity Testing, Machine Model (MM). Inactive as of Sep. 2016 [10].*

- GaN devices from Panasonic
- ISL70023SEH, ISL73023SEH from Renesas
  - GaN Power Transistor
- SGF48N10 from Solid State Devices
  - Power FET
- GaN devices from Toshiba
- TP65H035G4WS, TP65H035WSQA devices from Transphorm
  - GaN FET (automotive AEC-Q101–qualified device) [17]

Table 2. Summary of ESD ratings and test methods.

ESD Model	Charged-Device Model (CDM)	Human Body Model (HBM)	Machine Model (MM)
ESD Class/Range	1A, 1B, 1C, 2: 500 V to 2000 V	C3, C7: 250 V to >2000 V	>400 V
Test Methods	JS-002-2014 JS-002-2018 JESD22C-101	JS-001-2014 JS-001-2017 JESD22A-114 MIL-STD-883 TM3015 MIL-STD-750 Method 1020	JESD22A-115

The ESD ratings provided for these devices vary, and the trends are summarized in **Table 2**. The ESD sensitivity classification levels are provided in **Table 3** (CDM) and **Table 4** (HBM). The test method and voltage level data provided by manufacturers are shown in **Table 5**.

Conclusions

As GaN devices increase their presence in space applications, their physical and electrical properties continue to be researched and characterized. GaN technology has particular ESD sensitivity, and space GaN manufacturers use a variety of ESD testing standards to qualify their devices. ESD qualification testing is

Table 3. CDM ESDS device classification levels [11].

Classification Level	Classification Test Condition (V)
C0a	<125
C0b	125 to <250
C1	250 to <500
C2a	500 to <750
C2b	750 to <1000
C3	>1000

Table 4. HBM ESD component classification levels [6, 7, 8].[1]

Classification	Voltage Range (V)
0Z	<50
0A	50 to <125
0B	125 to <250
1A	250 to <500
1B	500 to <1000
1C	1000 to <2000
2	2000 to <4000
3A	4000 to <8000
3B	>8000

[1] *MIL-STD-750 Method 1020 Class 0: <250 V.*

specified in the listed JEDEC and MIL-STD testing models, and consists of the Human Body Model, the Charged-Device Model, and the Machine Model. These testing standards are not uniformly applied by all manufacturers, but all testing models are similar in circuit design. GaN semiconductor technology introduces better opportunities in high-power and RF design and new challenges in testing. In our subsequent bulletins we will continue to explore these new devices, their space applications, and their testing challenges.

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[2] NEPAG, "Second Special Edition on Electrostatic Discharge (ESD)," EEE Parts Bulletin, Volume 9,

Table 5. Device ESD class and voltage level.

Manufacturer	Part Number	MIL Spec or JEDEC	Test Method	Class/Voltage Level
Solid State Devices	SGF48N10	MIL Spec	MIL-STD-750, Method 1020	Initial testing shows parts passing at 2000 V (HBM Class 2)
MACOM	MAGX series MAGB series MAGE series MAMG series MAPC series NPT series NPA series	JEDEC	HBM CDM	HBM Class 1A: 250 V to <500 V CDM Class C3: >1000 V
Toshiba	—	JEDEC	JS-001-2017, HBM	Class 2: 2000 V to <4000 V
Efficient Power Conversion (EPC) Corporation	EPC2001	JEDEC	JESD22A-114, HBM, Pin to Pin G-S, G-D, D-S	Class 1A: (±) 400 V to 2000 V
			JESD22A-115, MM, Pin to Pin G-S, G-D, D-S	Class B: (±) 200 V to (±) 600 V
	EPC2001C	JEDEC	JESD22A-114, HBM, Pin to Pin G-S, G-D, D-S	Class 2: (±) 3000 V
				Class 2: (±) 2000 V
			JESD22C-101, CDM, All pins	Class C3: (±) 1000 V
	EPC800x	JEDEC	JESD22A-114, HBM, Pin to Pin G-S, G-D, D-S	Class 1A: (±) 350 V to (±) 500 V
			JESD22C-101, CDM, All pins	Class 1C: (±) 500 V
			JESD22A-115, MM, Pin to Pin G-S, G-D, D-S	Class A: (±) 25 V to (±) 100 V
EPC Space LLC	All	JEDEC or MIL Spec	JESD22A-114, MM or Mil-Std-750, Method 1020, HBM	Class 1A: 250 V to 499 V
GaN Systems	No specific part number provided	JEDEC	JS-001-2017, HBM JS-002-2018, CDM	For voltage levels, please contact manufacturer
Navitas Semiconductor	NV6115, NV6117, NV6113	JEDEC	JS-001-2014, HBM, Pin to Pin G-S, G-D, D-S	Class 1C: 1000 V to <2000 V
			JS-002-2014, CDM, Pin to Pin G-S, G-D, D-S	Class C3: >1000 V
Panasonic		JEDEC	JEDEC JESD22-A114, HBM JESD22-A115-A, MM JEDEC JESD22-C101, CDM	HBM Class 2: 2000 V to <4000 V MM Class C: >400 V CDM Class C3: >1000 V

Manufacturer	Part Number	MIL Spec or JEDEC	Test Method	Class/Voltage Level
Renesas	ISL70040SEH, ISL73040SEH	MIL-STD	MIL-STD-883, TM3015, HBM	Class 3A: 6000 V
		JEDEC	JESD22-A115C, MM	Class B: 200 V
			JS-002-2014, CDM	Class C3: 2000 V
	ISL70023SEH, ISL73023SEH	MIL-STD	MIL-STD-883, TM3015, HBM Pin to Pin G-S and D-S	Class 1B: 500 V to 2000 V
		JEDEC	JESD22-A115C, MM	Class B: 200 V
			JS-002-2014, CDM	Class C2b: 750 V
Transphorm	TP65H015G5WS	JEDEC	JS-001-2012, HBM	Class C7: ±2000 V
			JS-002-2018, CDM	Class 2: ±2000 V
	TP65H035G4WS		HBM Not Specified	Class 1B: ±900 V
		JEDEC	JS-002-2018, CDM	Class C7: ≥2000 V
	TP65H035G4WSQA	JEDEC	JS-001-2017, HBM	Class 1B: ±900 V
			JS-002-2018, CDM	Class C7: ≥2000 V
	TPH65H035WS	JEDEC	JS-001-2012, HBM	Class 1C: ±1000 V
			JESD22-A115B MM referenced	CDM Class C3: ±2000 V
	TP65H035WSQA		HBM Not Specified	Class 1C: ±1000 V
			CDM Not Specified	Class C3: ±2000 V
	TP65H050G4WS	JEDEC	JS-001-2012, HBM	Class 1B: ±700 V
			JESD22-A115B MM referenced	CDM Class C3: ±2000 V
	TP65H050G4BS	JEDEC	JS-001-2012, HBM	Class 1B: ±700 V
			JS-002-2018, CDM	Class C3: ±2000 V
	TP65H050WSQA		HBM Not Specified	Class 1B: ±700 V
			CDM Not Specified	Class C3: ±2000 V
	TP65H050WS	JEDEC	JS-001-2012, HBM	Class 1B: ±700 V
			JESD22-A115B MM referenced	CDM Class C3: ±2000 V
	TP65H070LSG	JEDEC	JS-001-2012, HBM	Class 1A: ±450 V
			JS-002-2018, CDM	Class C7: ≥2000 V
	TP65H070LDG	JEDEC	JS-001-2012, HBM	Class 1A: ±450 V
			JS-002-2018, CDM	Class C7: ≥2000 V
	TP65H150LSG	JEDEC	JS-001-2012, HBM	Class 1A: ±450 V
			JS-002-2018, CDM	Class C7: ≥2000 V
	TP65H300G4LSG	JEDEC	JS-001-2012, HBM	Class 1B: ±550 V
			JS-002-2018, CDM	Class C7: ≥2000 V
	TP65H480G4JSG	JEDEC	JS-001-2012, HBM	Class 1B: ±550 V
			JS-002-2018, CDM	Class C7: ≥2000 V
	TP90H050WS	JEDEC	JS-001-2012, HBM	Class 1B: ±700 V
			JS-002-2018, CDM	Class C7: ±2000 V

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