ESD TR23.0-01-20

ESD Association Technical Report

ESD TR23.0-01-20

For the Protection of EOS/ESD Susceptible Items -

Electrical Overstress in Manufacturing and Test

Authors:

Working Group 23.0,
EOS Best Practices
EOS/ESD Association, Inc.

Electrostatic Discharge Association
7900 Turin Rd., Bldg. 3
Rome, NY 13440

CAUTION NOTICE

Electrostatic Discharge Association (ESDA) standards and publications are designed to serve the public interest by eliminating misunderstandings between manufacturers and purchasers, facilitating the interchangeability and improvement of products, and assisting the purchaser in selecting and obtaining the proper product for his particular needs. The existence of such standards and publications shall not, in any respect, preclude any member or non-member of the Association from manufacturing or selling products not conforming to such standards and publications. Nor shall the fact that a standard or publication is published by the Association preclude its voluntary use by non-members of the Association, whether the document is to be used domestically or internationally. Recommended standards and publications are adopted by the ESDA in accordance with the ANSI Patent policy.

Interpretation of ESDA Standards: The interpretation of standards, in-so-far as it may relate to a specific product or manufacturer, is a proper matter for the individual company concerned and cannot be undertaken by any person acting for the ESDA. The ESDA Standards Chairman may make comments limited to an explanation or clarification of the technical language or provisions in a standard, but not related to its application to specific products and manufacturers. No other person is authorized to comment on behalf of the ESDA on any ESDA Standard.

DISCLAIMER OF WARRANTIES

THE CONTENTS OF ESDA'S STANDARDS AND PUBLICATIONS ARE PROVIDED "AS-IS," AND ESDA MAKES NO REPRESENTATIONS OR WARRANTIES, EXPRESSED OR IMPLIED, OF ANY KIND WITH RESPECT TO SUCH CONTENTS. ESDA DISCLAIMS ALL REPRESENTATIONS AND WARRANTIES, INCLUDING WITHOUT LIMITATION, WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR USE, TITLE, AND NON-INFRINGEMENT.

DISCLAIMER OF GUARANTY

ESDA STANDARDS AND PUBLICATIONS ARE CONSIDERED TECHNICALLY SOUND AT THE TIME THEY ARE APPROVED FOR PUBLICATION. THEY ARE NOT A SUBSTITUTE FOR A PRODUCT SELLER'S OR USER'S OWN JUDGEMENT WITH RESPECT TO ANY PARTICULAR PRODUCT DISCUSSED, AND ESDA DOES NOT UNDERTAKE TO GUARANTEE THE PERFORMANCE OF ANY INDIVIDUAL MANUFACTURERS' PRODUCTS BY VIRTUE OF SUCH STANDARDS OR PUBLICATIONS. THUS, ESDA EXPRESSLY DISCLAIMS ANY RESPONSIBILITY FOR DAMAGES ARISING FROM THE USE, APPLICATION, OR RELIANCE BY OTHERS ON THE INFORMATION CONTAINED IN THESE STANDARDS OR PUBLICATIONS.

LIMITATION ON ESDA's LIABILITY

NEITHER ESDA, NOR ITS MEMBERS, OFFICERS, EMPLOYEES, OR OTHER REPRESENTATIVES WILL BE LIABLE FOR DAMAGES ARISING OUT OF, OR IN CONNECTION WITH, THE USE OR MISUSE OF ESDA STANDARDS OR PUBLICATIONS, EVEN IF ADVISED OF THE POSSIBILITY THEREOF. THIS IS A COMPREHENSIVE LIMITATION OF LIABILITY THAT APPLIES TO ALL DAMAGES OF ANY KIND, INCLUDING WITHOUT LIMITATION, LOSS OF DATA, INCOME, OR PROFIT, LOSS OF OR DAMAGE TO PROPERTY AND CLAIMS OF THIRD PARTIES.

Published by:

Electrostatic Discharge Association
7900 Turin Road, Bldg. 3
Rome, NY 13440

Copyright © 2020 by EOS/ESD Association, Inc.
All rights reserved

No part of this publication may be reproduced in any form, in an electronic retrieval system or otherwise, without the prior written permission of the publisher.

Printed in the United States of America

FOREWORD

The term, electrical overstress (EOS), is assigned to most of the electrical failures of devices that occur in factories and the field. EOS has many root causes. One EOS root cause, electrostatic discharge (ESD), has received much attention in technical literature, standards bodies and educational workshops and tutorials. The approach has been in a systematic manner which has resulted in relatively successful practice for design of robust devices and control procedures for the factory. However, the same is not true for the effects of the broader categories of electrical stresses that can be the root cause of EOS. These other root causes (over-voltage, over-current, over-power), when grouped, are more prevalent causes of failure (damage) than ESD by a wide margin because of the lack of a coherent design and mitigation (control) strategy.

The focus of this technical report[1] is the group of EOS root causes that can cause device damage in manufacturing and test. The working group anticipates frequently updating the document as additional information on the many root causes of EOS becomes available. This initial version describes the scope of possible damage root causes. Since there is more detailed information currently available on EMI sources, and IC and board-level test, these are described in greater detail. The document will be revised as best practices in use in the industry are shared and evaluated by the working group.

At the time ESD TR23.0-01-20 was prepared, the 23.0 EOS Best Practices subcommittee had the following members:

Terry Welsher, Chair
Dangelmayer Associates LLC

John Anderson
NASA – Dryden Flight Research Center

Robert Ashton
Minotaur Labs

Andrea Boroni
STMicroelectronics

Brett Carn
Intel Corporation

Yorgos Christoforou

Kevin Duncan
Seagate Technology

Melissa Feeney-Jolliff
The Aerospace Corporation

Rita Fung
Cisco

Reinhold Gaertner
Infineon Technologies AG

David Girard
Static Control Consulting

Fatjon (Toni) Gurga
Reliant ESD

Chris Jones
Semtech Corporation

John Kinnear
IBM

Peter Koeppen
ESD Unlimited LLC

Vladimir Kraz
OnFILTER, Inc.

Charles McClain
Micron Technology, Inc.

Thomas Meuse
Thermo Fisher Scientific

Nathaniel Peachey
Qorvo

Wolfgang Reinprecht
ams AG

Alan Righter
Analog Devices, Inc.

Jim Roberts
Stoneridge, Inc.

Wolfgang Stadler
Intel Deutschland GmbH

Matt Strickland
Boeing, Inc.

Scott Ward
Texas Instruments

Joshua Yoo
Core Insight, Inc.

---

[1] **ESD Association Technical Report (TR):** A collection of technical data or test results published as an informational reference on a specific material, product, system or process.

TABLE OF CONTENTS

1.0 PUrpose 1
2.0 Scope 1
3.0 DEFINITIONS 1
4.0 SOURCES (ROOT CAUSES) OF EOS DAMAGE DURING THE ASSEMBLY PROCESS...2
4.1 When is a Possible Root Cause a Significant Risk for EOS Damage? 2
4.2 Categories of EOS Exposure 3
4.2.1 Unpowered Devices 3
4.2.2 Powered Devices 4
4.3 AC and DC EOS Sources and Inadequate Grounding 4
4.4 EMI-Induced Root Causes of EIPD 5
4.5 Basics of EMI Diagnostics 5
4.6 EMI Instrumentation 8
4.6.1 Time Domain Measurements 8
4.6.2 Frequency Domain Measurements 9
4.6.3 Broadband Measurements 9
4.6.4 Power Line EMI Adapters 10
4.7 Voltage or Current? 10
4.8 Sources of EMI in a Manufacturing Environment 11
4.8.1 Commutation of Power 11
4.8.2 Dimmers/Gradual Heat Control 12
4.8.3 Switched Mode Power Supplies (SMPS) 12
4.8.4 Uninterruptable Power Supplies (UPS) 13
4.8.5 Servo and Variable Frequency Motors 13
4.8.6 CFL and LED Lighting 14
4.8.7 Power Line Surges 15
4.9 Propagation of EMI 15
4.10 How EMI Can Cause Damage 15
4.10.1 EMI on Power and Signal Lines 15
4.10.2 EMI on Ground 16
4.11 Mitigation of EMI in Electronic Assembly 18
4.11.1 Reduction of AC Noise 18
4.11.2 Soldering 19
4.11.3 Servo Motors and Variable Frequency Drives 20
4.11.4 Ground 21
4.11.5 Power Line Spikes 21
4.11.6 DC Power 22
4.12 Conclusion – EOS in Assembly 22
5.0 EOS Concerns during automated TESTING 22

5.1 Introduction – Scope of Testing Environment 22
5.2 Power and Signal Integrity Evaluation 22
5.3 Testing for Latent or Wounded Products 23

5.3.1 Order of Test Routines ... 24
5.3.2 Testing at PCBA Level ... 24
5.3.3 Testing at Strip Level ... 27
5.4 TEST CONDITIONS – BEST PRACTICE ... 27
5.4.1 Test Board Design Best Practice ... 29
5.5 SUMMARY ... 31
6.0 REFERENCES ... 31

FIGURES

Figure 1: Voltage on Ground Caused by Return Current in Ground ... 5
Figure 2a: Individual Transient on Power Line ... 6
Figure 2b: Composite EMI Signal on Power Line ... 6
Figure 3: Peak Versus Root Mean Square (RMS) Values ... 7
Figure 4: Measuring Repetition Rate of Pulses ... 7
Figure 5a: Portable Oscilloscope ... 8
Figure 5b: Power Line EMI Adapter ... 8
Figure 5c: Portable Spectrum Analyzer ... 9
Figure 5d: Measuring Broadband EMI ... 9
Figure 5e: High-Frequency Current Probe ... 10
Figure 6: Miniature Current Probe ... 11
Figure 7: Power Line Transient from Turning on Heat Gun ... 11
Figure 8: Noise from a Light Dimmer ... 12
Figure 9: Noise on AC Mains Generated by Several Switched Mode Power Supplies ... 12
Figure 10: Waveform Shape of Typical Noise from Uninterruptable Power Supplies ... 13
Figure 11: Effect of Servo Motor Pulse on Ground Noise ... 14
Figure 12: LED Lighting as Source of EMI ... 14
Figure 13a: High-Frequency Signal Between USB Ground and Equipment Ground ... 16
Figure 13b: Resulting Voltage Between USB Data Line versus Ground ... 16
Figure 14: High-Frequency Voltage Between Robotic Arm and a Tool Frame in an IC Handler . 17
Figure 15: Transient on Power Line from a Periodic Signal and Resulting Current from the Tip of a Soldering Iron ... 17
Figure 16a: Connection of Equipment via Power Line EMI Filter ... 18
Figure 16b: EMI Before and After the Filter ... 19
Figure 17a: Connection of Soldering Iron via Specialized EMI Filter ... 19
Figure 17b: Current from the Tip with Filter ... 20
Figure 18: Servo Filter Reduces Ground Currents in the Tool ... 20
Figure 19: Ground Filter Blocks Noise Propagation Throughout Facility Ground ... 21
Figure 20: Using Small Ground Filter in Line with ESD Ground in Equipment ... 21
Figure 21: Special EMI Filter Transient Surge Suppression Performance ... 22
Figure 22: Recommended Retesting of Opens and Shorts after Functional Testing ... 23
Figure 23: Example of Hot Swapping with Incorrect Order of Connection - IC on System Board with I/O 1 and I/O 2 Connecting Pins in First and Second Followed by VDD and GND ... 25
Figure 24: Correct Order and Alignment of GND, VDD, and I/O to Prevent Mis-Biasing EOS Conditions ... 26
Figure 25: First Mate Last Break Example ... 26
Figure 26: Ground Bounce Solution ... 27
Figure 27: Optical Micrograph Depicting Electrically-Induced Physical Damage in the Metal Connected to the VS Pin ... 28
Figure 28: Simplified Schematic of Test Pins with Corresponding Bypass Capacitors Depicting Current Discharge Path from VOUTPUT to VS ... 28

Figure 29: TVS and Schottky Diode Protection Between Supply and Ground to Protect Against Positive and Negative Going Transients on Supply and Ground 29
Figure 30: Random Fuse Block and Latch-up Like Failures in an Accelerometer IC 30
Figure 31: Root Cause and Fix for Supply Capacitor Switching Failure 31

ESD Association Technical Report for the Protection of EOS/ESD Susceptible Items – Electrical Overstress in Manufacturing and Test

1.0 PURPOSE

This document is the first in a series of documents intended to provide information that will promote the reduction of electrical overstress (EOS) damage in manufacturing and test, and provide the knowledge base for on-going mitigation and monitoring for possibly damaging electrical stresses. This document will be revised and expanded as others in the industry come forward with additional best practices used in their facilities. The content in this version represents best practices that have been shared and reviewed up to the time of its submission for publication.

2.0 SCOPE

This document covers certain aspects of the control, mitigation, and monitoring of electrical stresses which may cause EOS damage. These stresses may occur during the processing, assembly, installation, or testing, of electrical or electronic parts, assemblies, and equipment. In general, this includes sources of excessive voltage, current or power.

NOTE: Electrostatic discharge (ESD) is one possible root cause of EOS damage. However, several other ESDA documents [1] cover ESD control and event mitigation.

NOTE: This document does not apply to electrically-initiated explosive devices, flammable liquids or powders.

3.0 DEFINITIONS

The ESD Association Glossary of Terms, ESD ADV1.0, defines many terms related to this document. The following terms or acronyms may not be familiar to the reader. Recently revised definitions of EOS and related terms from the Industry Council White Paper on EOS [2] are used in this document. In some cases, this may depart from previous common usage of these terms.

The changes in the definitions related to EOS proposed by the Industry Council were made to provide a common terminology related to EOS. Common terminology is needed between suppliers of integrated circuits, system manufacturers, system designers, and users to assist in the determination of root cause when damage from EOS is suspected. The term EOS has had many definitions, but the most common have fallen into two categories:

- A violation of an electrical component’s voltage, current, or power specifications.
- The physical damage to an electrical component due to excess current or voltage.

The most common example of this is the failure analysis (FA) diagnosis of EOS or EOS/ESD.

The Industry Council’s EOS definition, shown below, is clearly within the first category above. This definition has the advantage of delineating responsibility when damage occurs. (If electrical damage has occurred, but there is no violation of electrical specifications, the device’s manufacturer has responsibility. If a device specification is violated, the user can be said to have caused the damage.) If EOS is a violation of a device specification, there is a need for a term to describe damage seen in a component that appears to be due to excess current or voltage. From looking at failure, we cannot tell the root cause. Physical damage can occur from sources other than EOS including normal stress to a weak device. The term electrically induced physical damage (EIPD) was introduced to describe any damage from electrical stress and is a preferred term for use in FA reports since it does not presuppose the cause of the damage. The Industry Council defined a third term, absolute maximum rating (AMR), to define the device specification which when violated constitutes an EOS event.

absolute maximum rating (AMR). The values of voltage, current, temperature, power dissipation, etc., which should not be exceeded at any time.

NOTE: More information on AMR is available in Industry Council White Paper 4 [2].

automated test equipment (ATE). Computer-controlled equipment that tests electronic devices for functionality and performance. ATE also conducts stress testing with minimal human interaction.