

TABLE OF CONTENTS

1.0 BACKGROUND AND INTRODUCTION	1
1.1 SCOPE.....	1
1.2 TECHNICAL REPORT #1	1
1.3 ANSI/ESD SP5.4.....	1
2.0 REPLICATING REAL-WORLD LATCH-UP THREATS	2
2.1 SOURCE DRIVEN TRANSIENT.....	2
2.2 STORED CHARGE TRANSIENT (POWERED ESD THREATS).....	3
2.3 RF COUPLED OR CAPACITIVELY COUPLED TRANSIENTS	3
3.0 DEVELOPMENT OF THE PRESENT STANDARD PRACTICE SP TLU-1	4
3.1 ELECTRON FLOOD THEORY (PROPOSED TRIGGER MECHANISM).....	4
3.2 DEFUNCT PROCEDURE A	5
3.3 NEGATIVE-GOING SQUARE PULSE	6
3.4 EFFECT OF RISE-TIME OR SLEW RATE ON LATCH-UP SENSITIVITY	7
3.5 EXPERIMENTING WITH OTHER WAVEFORMS.....	8
3.6 ADVANTAGES AND DISADVANTAGES TO THE METHOD IN ANSI/ESD SP5.4.....	8
4.0 TEST HARDWARE.....	9
4.1 TLU1–TLU5 EQUIPMENT	9
4.2 TLU BROADBAND AMPLIFIER SPECIFICATIONS.....	10
4.3 INFINEON’S SETUP.....	10
4.4 EXPERIMENTAL SETUP FROM FRAUNHOFER FHG IZM–M MUNICH USING TLP	13
4.4.1 Wafer-level TLU.....	14
4.4.2 Package-level TLU	15
5.0 EXPERIMENTS PERFORMED USING THE TLU AMPLIFIER.....	16
5.1 EXPERIMENTS EMPLOYING SINE OR PARTIAL SINE TRANSIENT PULSES.....	16
5.1.1 Results from TLU-1 amplifier.....	16
5.1.2 Transient Latch-up test results from TLU-2 amplifier	21
5.2 EXPERIMENTS DEFINING PULSE WIDTH	31
5.3 EXPERIMENTS DEFINING RISE-TIME.....	34
5.3.1 Preliminary Round Robin.....	34
5.3.2 Agere Systems Experiments	37
5.3.3 UltraTest International Experiments	40
5.3.4 Infineon’s Initial Slew Rate Experiments	45
5.3.5 Data From Fraunhofer FhG IZM–M Munich	46
6.0 TEST METHODS SIMILAR TO TLU	48
6.1 EOS TEST DATA	48
6.2 LOW SPEED ESD STRUCTURE CHARACTERIZATION	48
7.0 SUMMARY: TODAY’S STATUS AND APPLICABILITY OF TLU TESTING.....	49

7.1 BENCH TEST FOR SPECIAL CHARACTERIZATION 49

7.2 DEVICE RELIABILITY SCREENING TOOL 50

7.3 CORRELATION WITH SYSTEM LEVEL ESD TESTING FAILURES 50

8.0 FUTURE CONSIDERATIONS FOR TLU RESEARCH – RECOMMENDATIONS FOR FURTHER STATISTICAL ANALYSIS AND DATA GATHERING 51

8.1 OVERALL THREAT ASSESSMENT FOR TLU IN RANDOMLY SELECTED DEVICES 51

8.2 SLEW RATE OR RISE-TIME CHARACTERIZATION ON KNOWN SUSCEPTIBLE DEVICES..... 52

8.3 ROUND ROBIN TESTING 52

8.4 CORRELATION OF FIELD FAILURES WITH TESTING RESULTS 52

8.5 TRIGGERING OF I/O PINS..... 52

9.0 REFERENCES..... 53

FIGURES

Figure 1: Basic Implementation of Broadband Amplifier for Creating TLU Events 2

Figure 2: Oscilloscope waveform showing TLU failure using Method in ANSI/ESD SP5.4 4

Figure 3: Basic hardware configuration for Procedure A 5

Figure 4: Typical I_{DD} waveform produced by “Procedure A” Apparatus with No Load, also known as a Damped Bipolar Sine Wave 6

Figure 5: Actual I_{DD} waveform from Procedure A with DUT connected 6

Figure 6: Slew rate dependency of latch-up sensitivity using the procedure in ANSI/ESD SP5.4 and a 74HCT00 device with known latch-up sensitivity 8

Figure 7: Bench setup for TLU testing. Note the TLU amplifier at the top center of the photo. On the right is a photo of a typical manual switch box used to bias simple devices..... 9

Figure 8: Left: TLU-2 Hardware; right: TLU-5 Hardware front panel 10

Figure 9: Basic TLU setup for “internal” latch-up investigations. The baseline of the pulse generator provides the power supply. A relay enables discharge of the DUT after TLU stress in order to avoid charging effects..... 11

Figure 10: Oscilloscope diagram of pulse (amplitude approx. 100 mA), TLU event with shortcut between the two supplies and the following “clear pulse” to reset the device 12

Figure 11: Basic TLU setup for “external” latch-up investigations. Power supply and exciting pulse require different pulse sources 13

Figure 12: Test setup schematics of the TLU-Module 14

Figure 13: The TLU-Module 14

Figure 14: Setup for testing the TLU-Module..... 14

Figure 15: TLU-Module response to a load transient 14

Figure 16: TLU-Module current limiting behavior..... 14

Figure 17: Test setup schematic for wafer-level TLU. 15

Figure 18: Test setup picture of wafer-level TLU 15

Figure 19: Test setup schematic for package-level TLU 16

Figure 20: T7296 TLU Results 17

Figure 21: Typical Latch-up event* using half sine wave on 74HCT30E..... 19

Figure 22: Typical trigger event using the full sine wave 20

Figure 23: Scope plot shows that the device accepts the negative sine transient and returns to normal operation levels.	21
Figure 24: Trace shows the device accepting a large positive overshoot ($V_{DD} + 13\text{ V}$)	21
Figure 25: Triggering of latch-up at $V_{DD}+14\text{ V}$ without (top) and with (bottom) current limiting (500 mA/div)	22
Figure 26: Stressing a Harris 74HCT30 device with -1.1 V.	23
Figure 27: Stressing a Harris 74HCT30 device with -1.8 V	23
Figure 28: Stressing a T7288 device with 40 μs pulse width without (left) and with (right) triggering latch-up	24
Figure 29: Stressing a T7288 device with a failure threshold of 8 V	25
Figure 30: Stressing a T7288 device with a failure threshold of 6 V with positive half sine trigger	25
Figure 31: Stressing a T7288 device with a failure threshold of -9 V with negative half sine trigger	25
Figure 32: Triggering of latch-up of T7296 at -3 V without latch-up (500 mA/div)	26
Figure 33: T7296 latch-up to 275 mA after a -3.24 V trigger	26
Figure 34: Negative-going rectangular pulse – AC coupling	28
Figure 35: Negative-going rectangular pulse – DC coupling	28
Figure 36: Negative-going rectangular pulse – AC coupling	28
Figure 37: Negative-going half sine – AC coupling	29
Figure 38: Negative-going full sine – AC coupling	29
Figure 39: Negative-going full sine – DC coupling	29
Figure 40: Negative-going rectangular pulse – DC coupling	29
Figure 41: Device 1039A, TLU failure oscillographs showing an increase in I_{DD} as a result of a positive transient pulse at 2 μs and 5 μs	31
Figure 42: Device 1135BGA, TLU failure oscillographs showing an increase in I_{DD} as a result of a Negative transient pulse at 10 μs	32
Figure 43: Device T7296, TLU failure oscillographs showing an increase in I_{DD} as a result of a Negative transient pulse at 70 μs	33
Figure 44: A comparison of TLU sensitivity for various devices as a function of the waveform period	34
Figure 45: 74HCT00 Sample # 1	36
Figure 46: T7288 Sample # 1	36
Figure 47: LC1135 Sample # 1	36
Figure 48: Device Response with 20 μs fall-time on leading pulse edge	38
Figure 49: Device Response with 20 μs fall-time on trailing edge	39
Figure 50: 493ns rise-time with $R=500\ \Omega$, $C=0\ \text{nF}$	41
Figure 51: 1.34 μs rise-time with $R=500\ \Omega$, $C=1\ \text{nF}$	41
Figure 52: 2.23 μs rise-time with $R=500\ \Omega$, $C=2\ \text{nF}$	41
Figure 53: 3.21 μs rise-time with $R=500\ \Omega$, $C=3\ \text{nF}$	41
Figure 54: 4.36 μs rise-time with $R=500\ \Omega$, $C=4\ \text{nF}$	41
Figure 55: 5.14 μs rise-time with $R=500\ \Omega$, $C=5\ \text{nF}$	41
Figure 56: $R=500\ \Omega$, $C=0\ \text{nF}$ For all graphs: top trace is V_{DD} (5 V/div); bottom trace is I_{DD} (500 mA/div)	43
Figure 57: $R=500\ \Omega$, $C=1\ \text{nF}$	43

Figure 58: R=500 Ω, C=2 nF..... 43

Figure 59: R=500 Ω, C=3 nF..... 43

Figure 60: R=500 Ω, C=4 nF..... 43

Figure 61: R=500 Ω, C=5 nF..... 43

Figure 62: Device sensitivity to slew rate..... 44

Figure 63: Dependence of the TLU robustness on the pulse width (left) and the rise-time (right) of a 0.13 μm CMOS product..... 45

Figure 64: Dependence of the TLU robustness on the pulse width of a product in a 0.5 μm CMOS technology 46

Figure 65: Testing bare dies with wafer-level TLU setup..... 47

Figure 66: TLU of a CMOS NOR IC, ACT02, wafer-level..... 47

TABLES

Table 1: Target Specification for a TLU Amplifier 10

Table 2: Trigger Voltage Threshold Levels versus Pulse Widths on the T7296 Devices..... 17

Table 3: Trigger Voltage Threshold Levels versus Pulse Widths on the Harris 74HCT300E Devices 18

Table 4: Trigger Voltage Threshold Levels versus Pulse Widths on the 74HCT30 Devices..... 24

Table 5: Trigger Voltage Threshold Levels versus Pulse Widths on the T7296 Devices..... 27

Table 6: Latch-up Sensitivity versus Wave Shapes..... 30

Table 7: Dev# 1039C-A with DC Rectangular Pulse 31

Table 8: 1135BG-E TLU Pulse Width Dependence..... 32

Table 9: T7296 TLU Pulse Width Dependence 33

Table 10: Round Robin Data when Different Rise-times were used 35

Table 11: Differences in Device Failure Thresholds using the TLU-1 and TLU-3 and TLU-4 Amplifiers 37

Table 12: Typical Failure Thresholds using the TLU-3 and TLU-4 Amplifiers..... 37

Table 13: Pulse Trailing Edge Dependence: Dev #96, -D, 70 μs, DC Pulse..... 37

Table 14: Pulse Trailing Edge Dependence: Dev #96, -D, 70 μs with DC Pulse Step-Stressing..... 38

Table 15: RC Filter Networks and their Corresponding Rise-times which were used during Slew Rate Sensitivity Testing 40

Table 16: Device Date Code 9623-1 Test Results 42

Table 17: Device Date Code 9623-2 Test Results 42

Table 18: Device Date Code 9623 Test Results..... 42

Table 19: Device Date Code 9727 Test Results..... 42