Keywords: lightning, integrated circuits, electrical overstress, EOS, electrostatic discharge, ESD, reliability, spark, triboelectric voltage, short rise time, HBM, human body model, Schottky diodes, Zener diode, transient suppression, TVS, MOV

APPLICATION NOTE 4491

Damage from a Lightning Bolt or a Spark—It Depends on How Tall You Are!

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Sep 12, 2012

Abstract: Large steel buildings, automobiles, mountains, even people survive real atmospheric lightning. Humans can also create their own miniature lightning bolts (sparks) and survive. When those sparks reach an IC, however, major trouble results. In this tutorial, we will discuss ways to protect printed circuit boards (PCBs) against ESD destruction. We will show that analog parts with bigger geometries are the best to use to protect a field-programmable gate array (FPGA) with their small geometries. By taking these measures, the ICs in an FPGA remain more reliable and deliver consistent quality performance.

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Introduction

Lightning can be fun and entertaining, or dangerous and destructive. Maybe all these things at once—it just depends on where you are, what you are doing, and your height. For an IC, lightning is never good.

A few years ago we were in a 10-story, steel-frame hotel building. An afternoon lightning storm approached across a large open field. Because of the building's steel frame, we felt comfortably safe. Our computers were not plugged in, so that was no concern. It was a spectacular show for about 10 minutes as the storm passed.

Large steel buildings, automobiles, mountains, even people survive real atmospheric lightning. Humans can also create their own miniature lightning bolts (sparks) and survive. When those sparks reach an IC, however, major trouble results. Nanometer-tall transistors need protection to survive even human sparks. In this tutorial, we will discuss ways to protect printed circuit boards (PCBs) against ESD destruction. We will show that analog parts with bigger geometries are the best to use to protect a field-programmable gate array (FPGA) with their small geometries. By taking these measures, the ICs in an FPGA remain more reliable and deliver consistent quality performance.

A Spark from Two Perspectives

Where do human-generated sparks come from? They are caused by a triboelectric charge. That is a big word. This happens when two materials come into contact (rubbing helps) and are then separated. Some electrons will transfer to one of the items. How many electrons move and to which surface depends on the material's composition. This is a common phenomenon because almost all materials, insulators, and conductors exhibit triboelectric properties. We are familiar with many common sources. Petting the cat's fur, rubbing a balloon on one's hair, and walking across a rug can all exhibit the triboelectric effect.

A tutorial on the fundamentals of electrostatic discharge[1] illustrates the voltages that humans produce during various activities. **Table 1** lists those voltages versus relative humidity (RH).

Table 1. Human Activity and the Static Charge Generated

Typical Voltage Levels		
Means of Generation	**10% to 25% RH**	**65% to 90% RH**
Walking across a carpet	35,000V	1,500V
Walking across vinyl tile	12,000V	250V
Working at an ungrounded bench	6,000V	100V
Picking up a polybag from a bench	20,000V	1,200V
Sitting in a chair with urethane foam	18,000V	1,500V

No wonder it hurts when we walk across a rug and touch a door knob! A general rule is that 5,000V can jump about one centimeter (0.4 inches) in 50% RH air. For someone five- or six-feet tall, this is a spark; it is painful, but we survive. Now change your perspective. What havoc would that spark cause to something a few micro-inches tall, like a transistor in an integrated circuit (IC)? In this situation, a centimeter spark is a massive, frightening, lightning display.

Now, we can turn to ICs. Microprocessors have long led the density improvements of digital semiconductors. Fabrication technology has resulted in smaller and smaller transistors. In 1971, the Intel® 4004 computer processing unit (CPU) was introduced in a 10µm geometry. In the 1980s and 1990s, the process made parts smaller than a bacterium. In 2012, ICs are approaching densities 1,000 times smaller than the 1971 technology and the features on the chip are smaller than a virus. In 2012 one can buy FPGAs with 28nm features and 6.8 billion transistors in one package[2] and the future promises to double that density in the next few years. The small transistors are closely packed together and need to operate on low voltages (typically 1V and below) to control the heat generated.

To put 28nm in perspective, note the zeros: it is 28 billionths of a meter (0.000000028). Let the distance between San Francisco and New York City represent one meter (about 4000 kilometers or 2500 miles). Now 28nm (one part in 36 million) is 0.11 meters or 4.4 inches. How big must a lightning bolt be to damage such small geometry devices and how does one protect such necessary and useful FPGAs?

The easy answer is to use the very I/O interface devices that bridge the digital and analog worlds. Analog mixed-signal ICs are made in comparatively large geometries (10 to 100 times larger than digital) and with higher voltage (typically 20V to 80V and higher), which makes them more robust than the tiny digital transistors. Though today's analog mixed-signal devices are generally tolerant of ESD, they do benefit from discrete ESD devices.[3]

Understanding the Damage from a Spark

Semiconductor manufacturers take electrical overstress (EOS) and electrostatic discharge (ESD) very seriously. First, for the obvious reason, that EOS and ESD can destroy parts during fabrication, package assembly, and test. But more importantly, these negative forces directly impact the quality and lifetime of the circuit in the customer's hands.

At first a part that is electrically overstressed may appear to function properly. It might even function in a slightly degraded manner but still pass the automatic test equipment's (ATE) examination, only to fail later in the field. EOS and ESD failures are preventable and are, without doubt, critical quality-control issues.

Building an IC in manufacturing is the first place where EOS and ESD damage can occur. **Figure 1A** shows a schematic diagram of the PCB. We might think that the IC is protected by the series capacitor. This is not the case. The second opportunity for damage is when the customer mounts the IC on a PCB to build a product. Looking closer at **Figure 1B** we see that the capacitor has a 50V working voltage, but the distance between the two metallic end connections is only 0.28 inches (7mm). Since the spark just jumped 0.4 inches (1cm), the small gap around the capacitor is easily compromised. The result may be that the IC pays with its life (**Figure 1C**). Finally, the EOS or ESD damage can occur when the customer operates the product in their environment.

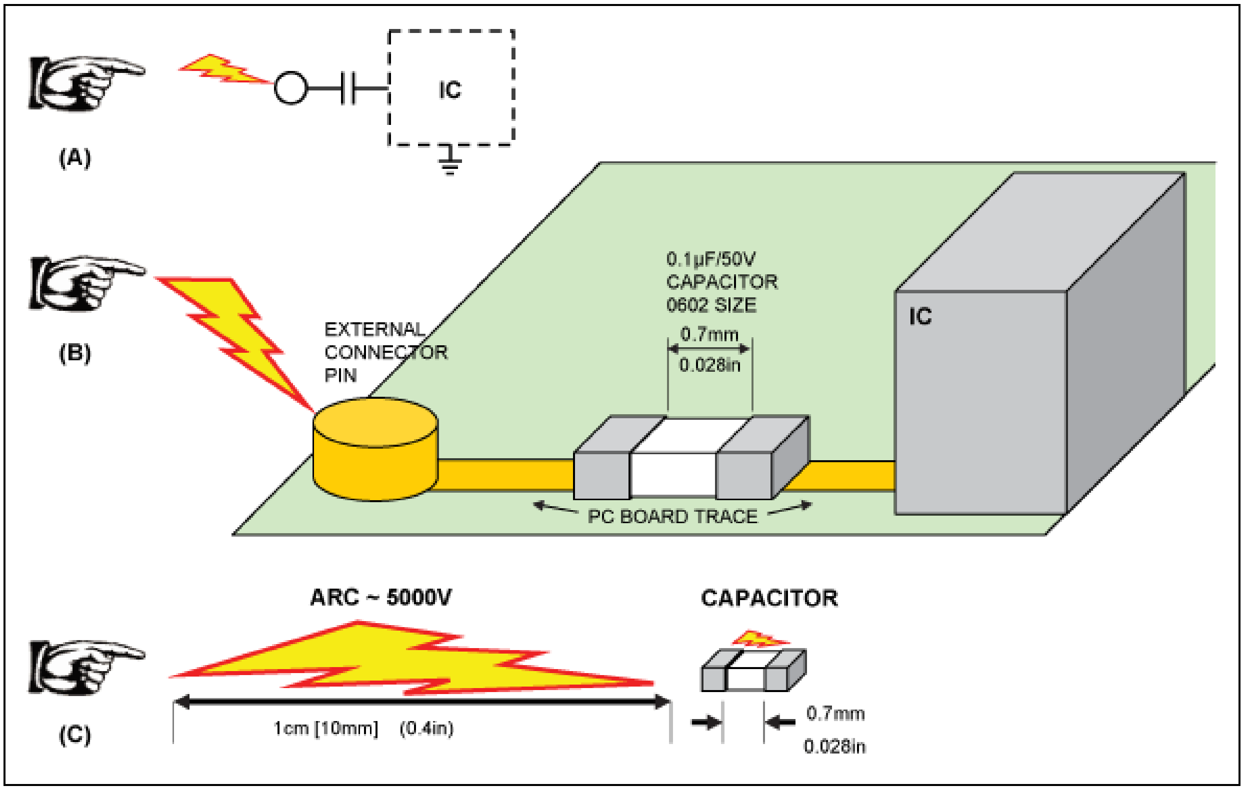

Figure 1. Sources of board-level EOS and ESD problems.

There certainly are many opportunities for considerable damage. We can actually see the result of EOS and ESD destruction inside an IC. To do this, the package epoxy material must be removed. This is usually done with hot acids in a double-glove isolation box. This process is incredibly dangerous. The fumes are deadly. One breath will cause a painful death; one drop of acid on human skin would result in, at best, the amputation of a hand or arm, or at worst death.

Microphotograph **Figure 2A** shows no apparent damage. The bond wire and pad labeled REF is provided so we can orient ourselves and compare photos. The liquid crystal material is painted on the die (pink color) and is similar to the liquid crystal used in mood rings and children's forehead thermometers. It changes color with small changes in temperature. When power is applied to the IC, the area drawing excess current, marked here with a yellow box, heats and changes color. It is a hot spot. This is interesting, but what caused the problem?

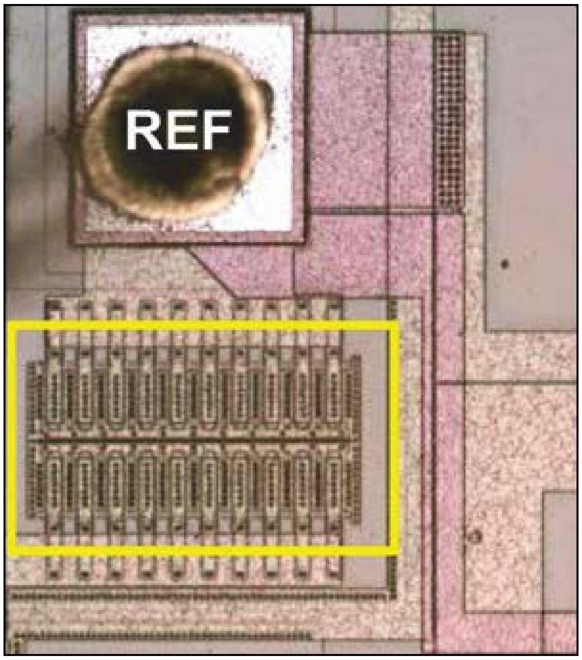

Figure 2A. A circuit in visible light shows no apparent damage from EOS or ESD. The liquid crystal area (marked in yellow) of the circuit is damaged by heat.

The REF bond wire (**Figure 2B**) indicates that this image is rotated 45 degrees. As we progressively zoom in, we see electromigration. The EOS has caused a short circuit as the damage grew under the influence of the electrical stress. This process can happen over time and progress during many short stresses until, suddenly, the part fails.

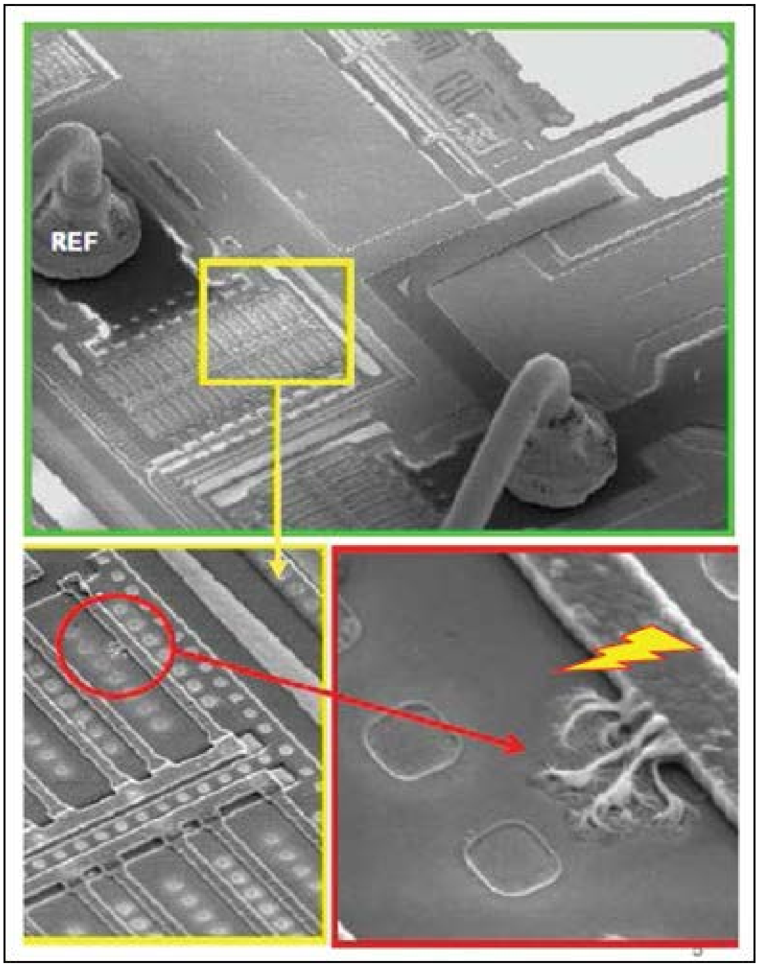

Figure 2B. Scanning electron microscope photos of the circuit in Figure 2A.

For comparison, now we examine another IC where a lightning bolt caused quick destruction (**Figure 3**).

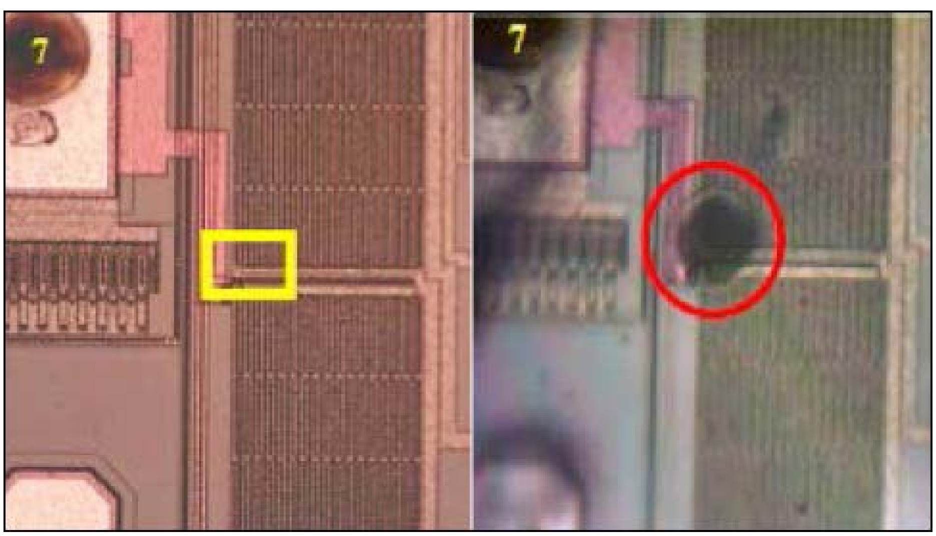

Figure 3. A circuit (left) under visible light shows no apparent damage from the lightning bolt. The same circuit (right) under a microscope shows a hot spot with damage.

The "7" in the upper left corner of each image in Figure 3 is for orientation. There is not much to see under visible light, but under magnification the liquid crystal shows the temperature rise and resulting EOS.

Figure 4 plots the data from the circuit in Figure 3 and we see that the known good part exhibits a clean, repeatable plot. The current increases in the vertical axis with 4.5V applied. When the current approaches 250µA, a knee is formed; as the voltage increases, the current stays at 250µA. Figure 4 also shows that the defective part continues to draw more current above the knee.

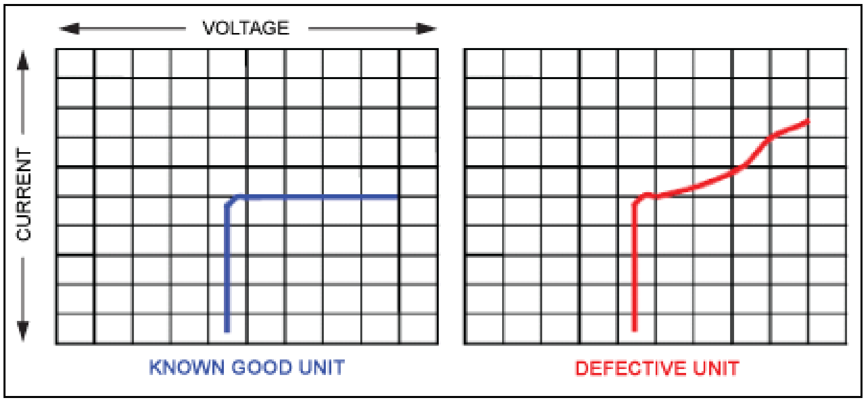

Figure 4. Semiconductor curve tracer plots for the circuit in Figure 3. Curve tracer current/div.is 50µA; voltage/div. is 1V.

Under closer scrutiny, part serial number 1 (SN1) shows a hole in the gate oxide (**Figure 5**). The lightning bolt shorted the gate to the substrate, causing excess current to flow. Of course, the transistor paid with its life. Typical gate oxide is 5nm to 15nm in thickness, depending on the fabrication process. In dense digital microprocessor parts, the oxide may be 1.2nm to 3nm thick. To illustrate how thin that is, in silicon 1.2nm is ~5 or 6 atoms thick. Thus, to a gate that is a few nanometers tall, almost any spark is a giant lightning bolt.

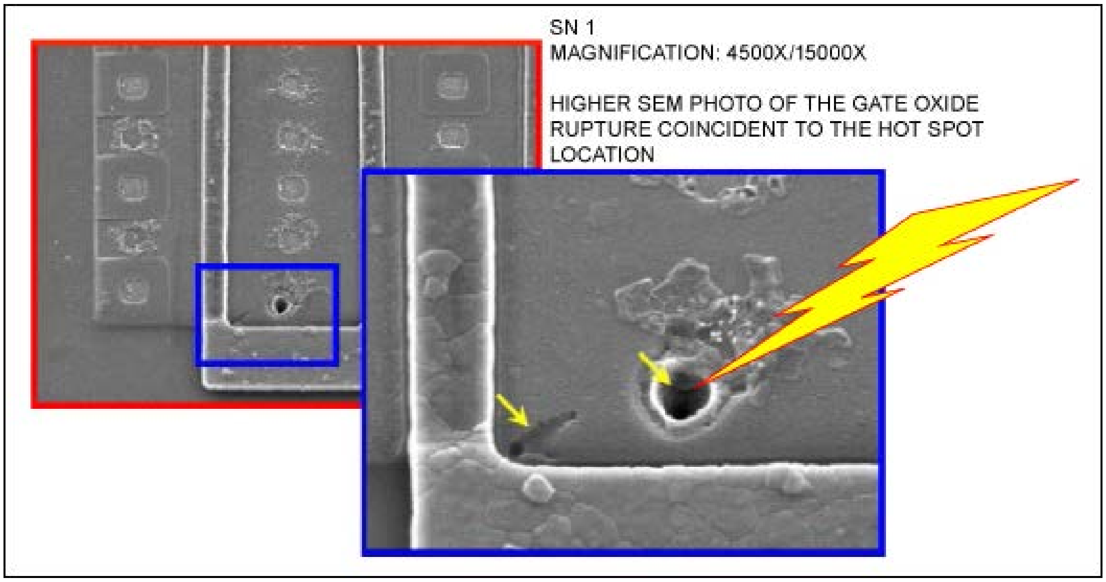

Figure 5. Scanning electron microscope photos of the circuit in Figure 3. The lightning bolt caused a hole in the gate oxide, which shorted the circuit.

Combat the Spark and Protect the Circuit

We will quickly discuss how to protect the ICs and the PCB from a spark and EOS/ESD.

The risetime of a spark is very fast, so any way that we can slow it down will reduce the peak voltage. ESD structures (**Figures 6** and **7**) are typically used in two places in a system: at the board level inputs and outputs with series resistors; and inductors along with capacitors to ground that can act as a lowpass filter. PCBs are thus protected from EOS/ESD by a combination of discrete silicon (small signal or reference) Schottky diodes, avalanche (Zener) diodes, transient voltage suppression (TVS) diodes, gas-tube discharge devices, resistors, inductors, and metal oxide varistors (MOVs).

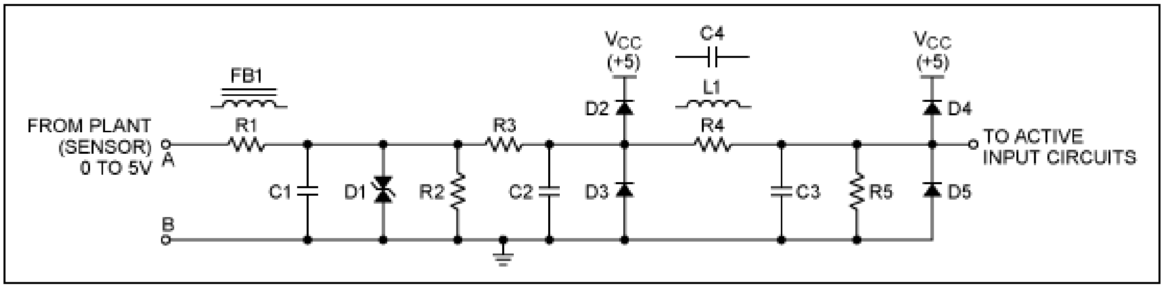

Figure 6. An inventory of suggested discrete components which can protect against unwanted electrical vulnerabilities.

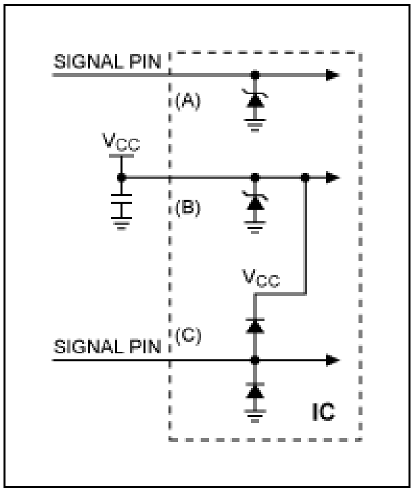

Figure 7. Simplified ESD structures.

The ESD structures of Figure 7A through C are internal to the ICs. External discrete components used for EOS/ESD protection tend to be physically larger and carry larger currents. In addition to the ESD protection built into many products, specialized ESD protection devices like the MAX14541 and MAX3203 are available to designers.

It is important to note that many circuits have built-in EOS/ESD protection, even though that is not their primary function. Consider for a moment the MAX5481 family of 10-bit nonvolatile (NV) potentiometers, the MAX5134 quad 16-bit DAC, and the MAX6001 family of low-power, low-cost voltage references. A close look at the data sheets shows that ESD is not mentioned. But the ESD specification depends on the IC fabrication process and is stated on the reliability reports for each part. You can find the ESD information by starting at the QuickView page for each part on Maxim's website. Near the bottom of the page is the technical documents area and the reliability report.[4] A click here brings up the reliability report page. If the reliability report is not online, it can be requested.

Summary

Whether large or small, steel buildings, automobiles, mountains, and even people survive real atmospheric lightning. Five- to six-foot tall humans can, and regularly do, create their own miniature lightning bolts (sparks) and barely even notice. That is never the case with nanometer-tall transistors. They need protection to survive even human sparks. As we have seen, protection against EOS and ESD destruction of the board circuits and ICs is critical for reliable, quality product performance. Circuit designers should be vigilant to employ EOS/ESD protection circuitry in their designs or to ensure that they are using circuits with built-in ESD protection from the outset. It is a serious oversight to ignore any seemingly trivial spark...no matter how tall you are...or are not.

References

1. ESD Association, **ESD Fundamentals**, *An Introduction to ESD Part 1*, © 2001, Rome, NY at https://www.esda.org/about-esd/esd-fundamentals/part-1-an-introduction-to-esd/.
2. Xilinx, **Device Reliability Report**," Table 1-7: Wafer Process Technology Family," Fourth Quarter 2011 Page 15, www.xilinx.com/support/documentation/user_guides/ug116.pdf.
3. Tutorial 4991, "Oops...Practical ESD Protection vs. Foolhardy Placebos" and Tutorial 1167, "Practical Aspects of EMI Protection."
4. Here are some example excerpts of EOS/ESD protection from those reliability reports:
   - Reliability Report for MAX5482EUD+[2] (MAX5481, MAX5483, MAX5484). "Item C.) E.S.D. and Latch-Up Testing; The DP22-1 die type has been found to have all pins able to withstand a HBM (human Body Model) transient pulse of 2500 V per JEDEC JESD22-A114-D." For the complete report, go to www.maximintegrated.com/reliability/product/MAX5482.pdf.
   - Reliability Report for MAX5134AGTG+[3], "Item C.) E.S.D. and Latch-Up Testing; The DB34 die type has been found to have all pins able to withstand a HBM transient pulse of +/-1500 V per JEDEC JESD22-A114-D." For the complete report, go to www.maximintegrated.com/reliability/product/MAX5134A.pdf.
   - Reliability Report for MAX6001EUR+[4] (MAX6002, MAX6003, MAX6004). "Item C.) E.S.D. and Latch-Up Testing; The RF23-6 die type has been found to have all pins able to withstand a HBM transient pulse of 2500 V." For the complete report, go to www.maximintegrated.com/reliability/product/MAX6001.pdf.

Related Parts		
MAX501	Voltage-Output, 12-Bit Multiplying DACs	Free Samples
MAX502	Voltage-Output, 12-Bit Multiplying DACs	Free Samples
MAX507	Voltage-Output, 12-Bit DAC with Internal Reference and 12-Bit Interface	Free Samples
MAX508	Voltage-Output, 12-Bit DAC with Internal Reference and 12-Bit Interface	Free Samples

MAX5104	Low-Power, Dual, Voltage-Output, 12-Bit DAC with Serial Interface	Free Samples
MAX5120	+3V/+5V, 12-Bit, Serial, Voltage-Output DACs with Internal Reference	Free Samples
MAX5121	+3V/+5V, 12-Bit, Serial, Voltage-Output DACs with Internal Reference	Free Samples
MAX5122	+5V/+3V, 12-Bit, Serial, Force/Sense DACs with 10ppm/°C Internal Reference	Free Samples
MAX5123	+5V/+3V, 12-Bit, Serial, Force/Sense DACs with 10ppm/°C Internal Reference	Free Samples
MAX5130	+3V/+5V, 13-Bit, Serial, Voltage-Output DACs with Internal Reference	Free Samples
MAX5131	+3V/+5V, 13-Bit, Serial, Voltage-Output DACs with Internal Reference	Free Samples
MAX5132	+5V/+3V, 13-Bit, Serial, Force/Sense DACs with 10ppm/°C Internal Reference	Free Samples
MAX5133	+5V/+3V, 13-Bit, Serial, Force/Sense DACs with 10ppm/°C Internal Reference	Free Samples
MAX5134	Pin-/Software-Compatible, 16-/12-Bit, Voltage-Output DACs	Free Samples
MAX5135	Pin-/Software-Compatible, 16-/12-Bit, Voltage-Output DACs	Free Samples
MAX5136	Pin-/Software-Compatible, 16-/12-Bit, Voltage-Output DACs	Free Samples
MAX5137	Pin-/Software-Compatible, 16-/12-Bit, Voltage-Output DACs	Free Samples
MAX5138	Low-Power, Single, 16-/12-Bit, Buffered Voltage-Output DACs	Free Samples
MAX5139	Low-Power, Single, 16-/12-Bit, Buffered Voltage-Output DACs	Free Samples
MAX514	CMOS Quad, 12-Bit, Serial-Input Multiplying DAC	Free Samples
MAX5141	+3V/+5V, Serial-Input, Voltage-Output, 14-Bit DACs	Free Samples
MAX5142	+3V/+5V, Serial-Input, Voltage-Output, 14-Bit DACs	Free Samples
MAX5143	+3V/+5V, Serial-Input, Voltage-Output, 14-Bit DACs	Free Samples
MAX5144	+3V/+5V, Serial-Input, Voltage-Output, 14-Bit DACs	Free Samples
MAX5150	Low-Power, Dual, 13-Bit Voltage-Output DACs with Serial Interface	Free Samples
MAX5151	Low-Power, Dual, 13-Bit Voltage-Output DACs with Serial Interface	
MAX5152	Low-Power, Dual, 13-Bit Voltage-Output DACs with Configurable Outputs	Free Samples
MAX5153	Low-Power, Dual, 13-Bit Voltage-Output DACs with	Free Samples

	Configurable Outputs	
MAX5154	Low-Power, Dual, 12-Bit Voltage-Output DACs with Serial Interface	Free Samples
MAX5155	Low-Power, Dual, 12-Bit Voltage-Output DACs with Serial Interface	Free Samples
MAX5156	Low-Power, Dual, 12-Bit Voltage-Output DACs with Configurable Outputs	Free Samples
MAX5157	Low-Power, Dual, 12-Bit Voltage-Output DACs with Configurable Outputs	Free Samples
MAX5170	Low-Power, Serial, 14-Bit DACs with Voltage-Output	Free Samples
MAX5171	Low-Power, Serial, 14-Bit DACs with Force-Sense Voltage-Output	Free Samples
MAX5172	Low-Power, Serial, 14-Bit DACs with Voltage-Output	Free Samples
MAX5173	Low-Power, Serial, 14-Bit DACs with Force-Sense Voltage-Output	Free Samples
MAX5174	Low-Power, Serial, 12-Bit DACs with Voltage-Output	Free Samples
MAX5175	Low-Power, Serial, 12-Bit DACs with Force-Sense Voltage-Output	Free Samples
MAX5176	Low-Power, Serial, 12-Bit DACs with Voltage-Output	Free Samples
MAX5177	Low-Power, Serial, 12-Bit DACs with Force-Sense Voltage-Output	Free Samples
MAX5200	Low-Cost, Voltage-Output, 16-Bit DACs with Internal Reference in µMAX	Free Samples
MAX5201	Low-Cost, Voltage-Output, 16-Bit DACs with Internal Reference in µMAX	Free Samples
MAX5202	Low-Cost, Voltage-Output, 16-Bit DACs with Internal Reference in µMAX	Free Samples
MAX5203	Low-Cost, Voltage-Output, 16-Bit DACs with Internal Reference in µMAX	Free Samples
MAX5204	Low-Cost, Voltage-Output, 16-Bit DACs in µMAX	Free Samples
MAX5205	Low-Cost, Voltage-Output, 16-Bit DACs in µMAX	Free Samples
MAX5206	Low-Cost, Voltage-Output, 16-Bit DACs in µMAX	Free Samples
MAX5207	Low-Cost, Voltage-Output, 16-Bit DACs in µMAX	Free Samples
MAX5230	3V/5V, 12-Bit, Serial Voltage-Output Dual DACs with Internal Reference	Free Samples
MAX5231	3V/5V, 12-Bit, Serial Voltage-Output Dual DACs with Internal Reference	Free Samples
MAX5234	Single-Supply 3V/5V, Voltage-Output, Dual, Precision 12-Bit DACs	Free Samples

MAX5235	Single-Supply 3V/5V, Voltage-Output, Dual, Precision 12-Bit DACs	Free Samples
MAX525	Low-Power, Quad, 12-Bit Voltage-Output DAC with Serial Interface	Free Samples
MAX5253	+3V, Quad, 12-Bit Voltage-Output DAC with Serial Interface	Free Samples
MAX526	Calibrated, Quad, Voltage-Output, 12-Bit DAC	Free Samples
MAX5264	Octal, 14-Bit, Voltage-Output DAC with Parallel Interface for ATE	
MAX527	Calibrated, Quad, Voltage-Output, 12-Bit DAC	Free Samples
MAX5270	Octal, 13-Bit Voltage-Output DAC with Parallel Interface	
MAX5290	Buffered, Fast-Settling, Dual, 12-/10-/8-Bit, Voltage-Output DACs	Free Samples
MAX5291	Buffered, Fast-Settling, Dual, 12-/10-/8-Bit, Voltage-Output DACs	Free Samples
MAX530	+5V, Low-Power, Parallel-Input, Voltage-Output, 12-Bit DAC	Free Samples
MAX5302	Low-Power, 12-Bit Voltage-Output DAC with Serial Interface	Free Samples
MAX5306	Low-Power, Low-Glitch, Octal 12-Bit Voltage-Output DACs with Serial Interface	Free Samples
MAX5307	Low-Power, Low-Glitch, Octal 12-Bit Voltage-Output DACs with Serial Interface	Free Samples
MAX531	+5V, Low-Power, Voltage-Output, Serial 12-Bit DACs	Free Samples
MAX5312	±10V, 12-Bit, Serial, Voltage-Output DAC	Free Samples
MAX532	Dual, Serial Input, Voltage-Output, Multiplying, 12-Bit DAC	Free Samples
MAX5322	±10V, Dual, 12-Bit, Serial, Voltage-Output DAC	Free Samples
MAX535	Low-Power, 13-Bit Voltage-Output DACs with Serial Interface	Free Samples
MAX5351	Low-Power, 13-Bit Voltage-Output DACs with Serial Interface	Free Samples
MAX5352	Low-Power, 12-Bit Voltage-Output DACs with Serial Interface	Free Samples
MAX5353	Low-Power, 12-Bit Voltage-Output DACs with Serial Interface	Free Samples
MAX536	Calibrated, Quad, 12-Bit Voltage-Output DACs with Serial Interface	Free Samples
MAX537	Calibrated, Quad, 12-Bit Voltage-Output DACs with Serial Interface	Free Samples
MAX538	+5V, Low-Power, Voltage-Output, Serial 12-Bit DACs	Free Samples

MAX539	+5V, Low-Power, Voltage-Output, Serial 12-Bit DACs	Free Samples
MAX541	+5V, Serial-Input, Voltage-Output 16-Bit DACs	Free Samples
MAX542	+5V, Serial-Input, Voltage-Output 16-Bit DACs	Free Samples
MAX543	Serial, CMOS, Multiplying, 12-Bit DAC in 8-Pin Package	Free Samples
MAX544	+5V, Serial Input, Voltage-Output 14-Bit DACs	Free Samples
MAX5441	+3V/+5V, Serial-Input, Voltage-Output, 16-Bit DACs	Free Samples
MAX5442	+3V/+5V, Serial-Input, Voltage-Output, 16-Bit DACs	Free Samples
MAX5443	+3V/+5V, Serial-Input, Voltage-Output, 16-Bit DACs	Free Samples
MAX5444	+3V/+5V, Serial-Input, Voltage-Output, 16-Bit DACs	Free Samples
MAX545	+5V, Serial Input, Voltage-Output 14-Bit DACs	Free Samples
MAX547	Octal, 13-Bit Voltage-Output DAC with Parallel Interface	Free Samples
MAX5481	10-Bit, Nonvolatile, Linear-Taper Digital Potentiometers	Free Samples
MAX5482	10-Bit, Nonvolatile, Linear-Taper Digital Potentiometers	Free Samples
MAX5483	10-Bit, Nonvolatile, Linear-Taper Digital Potentiometers	Free Samples
MAX5484	10-Bit, Nonvolatile, Linear-Taper Digital Potentiometers	Free Samples
MAX5500	Low-Power, Quad, 12-Bit Voltage-Output DACs with Serial Interface	Free Samples
MAX5501	Low-Power, Quad, 12-Bit Voltage-Output DACs with Serial Interface	Free Samples
MAX551	+3V/+5V, 12-Bit, Serial, Multiplying DACs in 10-Pin µMAX Package	Free Samples
MAX552	+3V/+5V, 12-Bit, Serial, Multiplying DACs in 10-Pin µMAX Package	Free Samples
MAX5530	Ultra-Low-Power, 12-Bit, Voltage-Output DACs	Free Samples
MAX5531	Ultra-Low-Power, 12-Bit, Voltage-Output DACs	Free Samples
MAX5532	Dual, Ultra-Low-Power, 12-Bit, Voltage-Output DACs	Free Samples
MAX5533	Dual, Ultra-Low-Power, 12-Bit, Voltage-Output DACs	Free Samples
MAX5534	Dual, Ultra-Low-Power, 12-Bit, Voltage-Output DACs	Free Samples
MAX5535	Dual, Ultra-Low-Power, 12-Bit, Voltage-Output DACs	Free Samples
MAX5541	Low-Cost, +5V, Serial-Input, Voltage-Output, 16-Bit DAC	Free Samples
MAX5544	Low-Cost, +5V, Serial-Input, Voltage-Output, 14-Bit DAC	Free Samples
MAX5580	Buffered, Fast-Settling, Quad, 12-/10-/8-Bit, Voltage-Output DACs	Free Samples
MAX5581	Buffered, Fast-Settling, Quad, 12-/10-/8-Bit, Voltage-Output DACs	Free Samples

MAX5590	Buffered, Fast-Settling, Octal, 12/10/8-Bit, Voltage-Output DACs	Free Samples
MAX5591	Buffered, Fast-Settling, Octal, 12/10/8-Bit, Voltage-Output DACs	Free Samples
MAX5621	16-Bit DACs with 16-Channel Sample-and-Hold Outputs	Free Samples
MAX5631	16-Bit DACs with 32-Channel Sample-and-Hold Outputs	
MAX5632	16-Bit DACs with 32-Channel Sample-and-Hold Outputs	Free Samples
MAX5633	16-Bit DACs with 32-Channel Sample-and-Hold Outputs	
MAX5661	Single 16-Bit DAC with Current and Voltage Outputs for Industrial Analog Output Modules	Free Samples
MAX5712	12-Bit, Low-Power, Rail-to-Rail Voltage-Output Serial DAC in SOT23	Free Samples
MAX5722	12-Bit, Low-Power, Dual, Voltage-Output DAC with Serial Interface	Free Samples
MAX5732	32-Channel, 16-Bit, Voltage-Output DACs with Serial Interface	Free Samples
MAX5733	32-Channel, 16-Bit, Voltage-Output DACs with Serial Interface	Free Samples
MAX5734	32-Channel, 16-Bit, Voltage-Output DACs with Serial Interface	Free Samples
MAX5735	32-Channel, 16-Bit, Voltage-Output DACs with Serial Interface	Free Samples
MAX5742	12-Bit, Low-Power, Quad, Voltage-Output DAC with Serial Interface	Free Samples
MAX5762	32-Channel, 16-Bit, Voltage-Output DACs with Serial Interface	
MAX5764	32-Channel, 16-Bit, Voltage-Output DACs with Serial Interface	
MAX5773	32-Channel, 14-Bit, Voltage-Output DACs with Serial Interface	
MAX5774	32-Channel, 14-Bit, Voltage-Output DACs with Serial Interface	Free Samples
MAX5775	32-Channel, 14-Bit, Voltage-Output DACs with Serial Interface	
MAX5812	12-Bit Low-Power, 2-Wire, Serial Voltage-Output DAC	Free Samples
MAX5822	Dual, 12-Bit, Low-Power, 2-Wire, Serial Voltage-Output DAC	Free Samples
MAX5839	Octal, 13-Bit Voltage-Output DAC with Parallel Interface	
MAX5842	Quad, 12-Bit, Low-Power, 2-Wire, Serial Voltage-Output	Free Samples

	DAC	
MAX6001	Low-Cost, Low-Power, Low-Dropout, SOT23-3 Voltage References	Free Samples
MAX6002	Low-Cost, Low-Power, Low-Dropout, SOT23-3 Voltage References	Free Samples
MAX6003	Low-Cost, Low-Power, Low-Dropout, SOT23-3 Voltage References	Free Samples
MAX6004	Low-Cost, Low-Power, Low-Dropout, SOT23-3 Voltage References	Free Samples
MAX7645	CMOS 12-Bit Buffered Multiplying DACs	
MX7245	Complete, 12-Bit, Voltage-Output Multiplying DAC	
MX7248	Complete, 12-Bit, Voltage-Output Multiplying DAC	
MX7521	CMOS, 14- and 12-Bit Multiplying DACs	Free Samples
MX7531	CMOS, 10-Bit Multiplying DAC	Free Samples
MX7534	Microprocessor-Compatible, 14-Bit DACs	Free Samples
MX7535	Microprocessor-Compatible, 14-Bit DACs	Free Samples
MX7536	µP-Compatible, 14-Bit DAC	Free Samples
MX7537	CMOS, Parallel Loading, Dual, 12-Bit Multiplying DAC	
MX7538	CMOS, µP-Compatible, 14-Bit DAC	Free Samples
MX7541	CMOS, 12-Bit Multiplying DAC	
MX7541A	CMOS, 12 Bit Multiplying D/A Converter	Free Samples
MX7542	CMOS, 12-Bit, µP-Compatible DAC	Free Samples
MX7543	CMOS, 12-Bit, Serial-Input DAC	Free Samples
MX7545	CMOS, Buffered, 12-Bit Multiplying DAC	Free Samples
MX7547	CMOS, Parallel Loading, Dual, 12-Bit Multiplying DAC	Free Samples
MX7548	CMOS, 8-Bit-Compatible, 12-Bit DAC	Free Samples
MX7837	Complete, Dual, 12-Bit Multiplying DAC with 8-Bit Bus Interface	Free Samples
MX7839	Octal, 13-Bit Voltage-Output DAC with Parallel Interface	
MX7841	Octal, 14-Bit Voltage-Output DAC with Parallel Interface	
MX7845	Complete, 12-Bit Multiplying DAC	Free Samples
MX7847	Complete, Dual, 12-Bit Multiplying DAC with 8-Bit Bus Interface	Free Samples

More Information

For Technical Support: http://www.maximintegrated.com/support
For Samples: http://www.maximintegrated.com/samples
Other Questions and Comments: http://www.maximintegrated.com/contact

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Application Note 4491: http://www.maximintegrated.com/an4491
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