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Predicting Field Failure From Small Environmental Stresses

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Abstract

Applying repetitive small stresses to circuits can help predict circuit failure in the field at both the IC and PCB level. Accumulating damage has been demonstrated from thousands of very small ESD events resulting in system failure. In addition, application of small electrical stresses can also be used to find areas of a design that can lead to soft errors. Background of this topic will be discussed and a field example will be presented.

Author(s) Biography

Mr. Smith has worked over five decades specializing in high frequency measurements, circuit/system design and verification, switching power supply noise, EMC/ESD, and immunity to transient noise. He continues to provide consulting services in these areas. He has lectured at many universities and delivers public and private seminars. Mr. Smith holds the title of "University of Oxford Course Tutor" in the Department of Continuing Education at Oxford University in the UK and is author of the book *High Frequency Measurements and Noise in Electronic Circuits.* His very popular website is located at http://emcesd.com/http://www.dsmith.org.

Introduction and Background

Currently, ESD standards-based testing subjects an IC or system to a relatively few large pulses, and then checks for damage or improper operation are conducted. There are, however, instances in the field where thousands of small ESD event applied to a system or IC can cause accumulating damage resulting in an eventual failure, even if standards based ESD testing shows no problems.

The probability of the occurrence of an ESD event in the environment decreases as the voltage of the discharge increases. However, small ESD events, on the order of a few hundreds of Volts, occur almost every time a human comes in to contact with a conductive object. These events are too small to feel and go unnoticed. For Human Body Model (1500 Ohm, 100 pF) the threshold of feeling is between 2000 and 3000 Volts.[1]

But these small events, of both HBM and Human Metal Model, HMM (330 Ohm, 150 pF as per IEC 61000-4-2), can cause accumulating damage and ultimate failures in the field.[2]

Conditions conducive to accumulating damage.

There are several instances that can result in accumulating damage from repetitive small ESD. Some of these include:

- Ports on equipment that are connected many times, such as a USB port.
- Devices that include physical movement as part of their operation, such as printers and medical equipment.
- Protected ports on equipment that include protection devices. Such devices shunt the energy from an ESD event from sensitive devices. However, there is always a small portion of the energy that gets by these protective devices.
- Protected ports on equipment where the main protector is not sized correctly
- Protected ports on equipment where PCB layout issues compromise the effectiveness of the protection device, such as parasitic inductance in series with the protection device or where the protection device is returned to a different "ground" than the device being protected.[3,4]

An Example

One example of these effects was observed on a printer. The media was slightly conductive, referred to as ESD dissipative. During operation, the media would become charged and generated small ESD events, essentially micro lightning, that, over time, could damage the print head. The first job was to characterize the event.

Characterizing the stress and its current waveform

Figure 1 shows measurement of the approximate charge voltage placed on the media via a KeyTek Mini-Zap and Figure 2 shows measurement setup to measure media discharge current. Figure 3 shows one discharge from the print media and Figure 4 a second one. There was quite a bit of variation in the discharge waveforms as one would expect in air discharges.

In general, the media was charged to a known voltage similar to what was measured in real operation (up to 10 kV) and then dropped onto the target shown in Figure 2. The target was made from plastic plumbing pieces and holds a Fischer Custom Communications F-65 current probe. This probe has a one Ohm transfer impedance (1 Volt/Amp) and a flat frequency response from 1 MHz to 1000 MHz, ideal for ESD measurements. It is well shielded to E-field induced errors, common in ESD current measurements.

Figure 1. Measuring the Approximate Charge Voltage on the Print Media


Figure 2. Measuring the Discharge Current from the Print Media

An Agilent DSO5054a, 500 MHz oscilloscope was used for these measurements. Once the discharge was characterized, the next step was to apply similar discharges to the printhead. Since much of the testing was done at higher voltages, a 500 MHz bandwidth scope was adequate for the purpose.

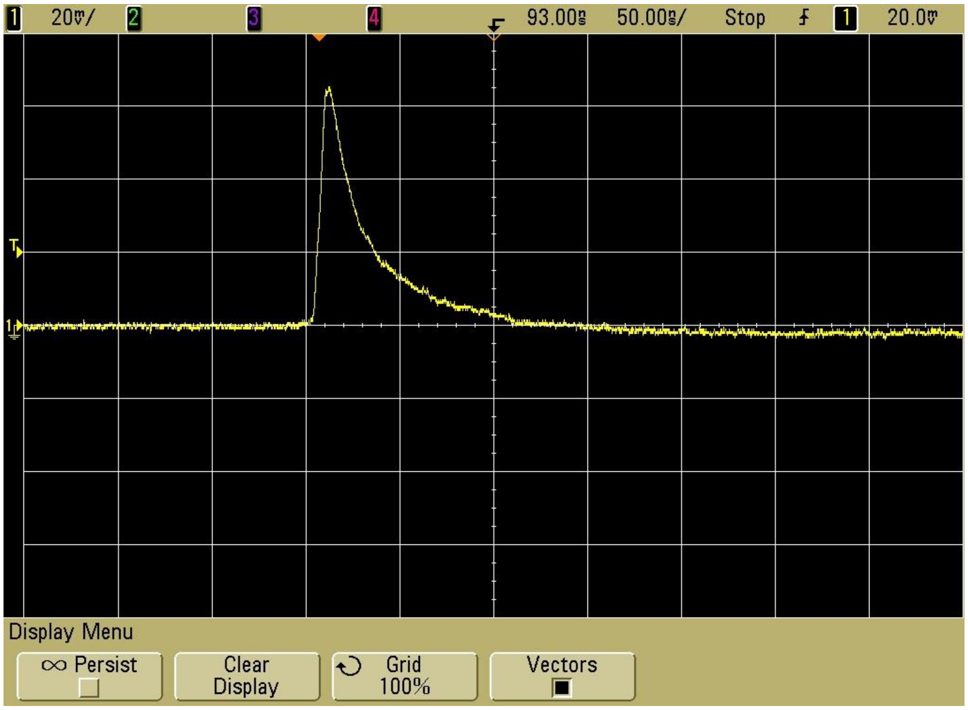

Figure 3. One Example of Media Discharge
Vertical scale = 20 mA/div, Horizontal scale -= 50 ns/div

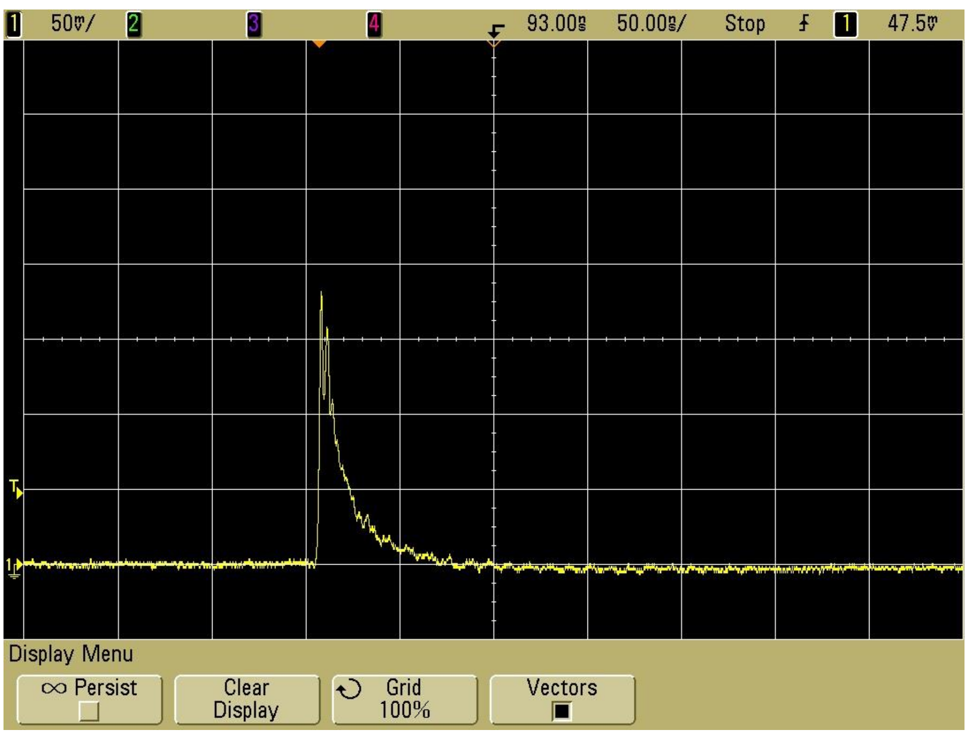

Figure 4. Another Example of Media Discharge
Vertical scale = 50 mA/div, Horizontal scale -= 50 ns/div

Applying the stress

To apply the stress, I designed an ESD simulator for the purpose. It generated pulses of small peak currents of about 100 mA, a tiny fraction of the Amperes of current delivered by normal ESD simulators, both IEC and HBM. The simulator also was adjusted to deliver discharges at about once per second. Since the simulator had no moving parts (such as the relay ESD simulators normally use) it can pulse indefinitely. The discharge was an air discharge from the end of the resistor lead in Figure 5 to the printhead. On the right side of the picture, one can see the F-65 current probe used to monitor the current. The simulator circuit itself is not shown in the picture. Three versions are currently commercially available based on my original design for this project. Each delivers a different waveform (HBM, HMM, shortened EFT).[1][2][5]

The simulator was run for three hours, about 10,000 ESD events. At that point, the printhead showed degradation similar to what was happening in real operation during a life test in a lab environment.

Figure 5. Applying a Discharge to the Printhead

Another Use for the Simulator

I have described previously at DesignCon in 2009 a troubleshooting method for finding the cause of soft errors due to ESD and other impulse sources. That paper, titled “Noise Injection for Design Analysis and Debugging,” described a method of injecting controlled amounts of impulse noise in circuits to find weak spots in the design. In the past, I have used several pulse generators for the test including IEC6000-4-4 EFT Burst generators and a TG-EFT pulse generator from Fischer Custom Communications.[5][6]

It seemed like a variation of the simulator I used for the low level ESD investigation above might be useful for troubleshooting but at a much lower cost and much more portable (EFT generators can cost upwards of US$20,000 and weigh 20+ kg.

Data on the new simulator

Figure shows the measurement of the short circuit current on the modified simulator using the F-65 current probe.

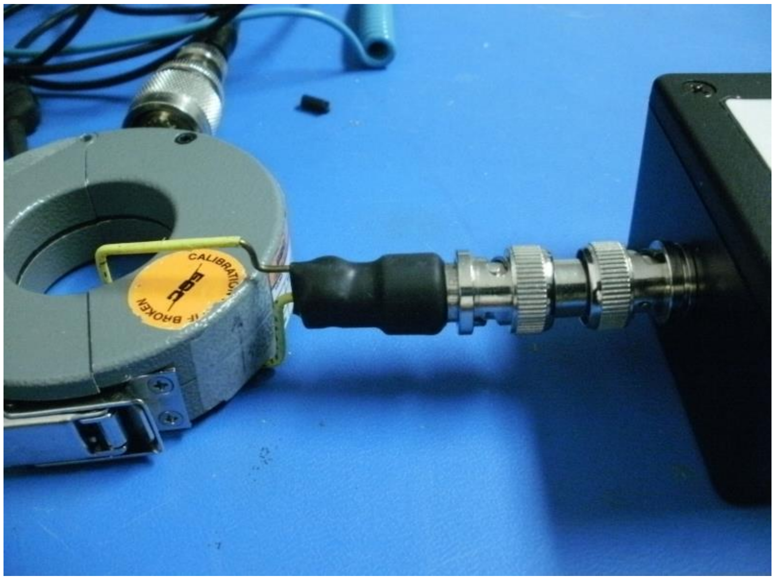

Figure 6. Measuring the Short Circuit Current from Generator

Figure 7 shows the measured current on a Tektronics MDO4104B-6, 1 GHz. oscilloscope/spectrum analyzer. The 10 Ampere peak output corresponds to a 500 Volt setting of an EFT generator, adequate for debug purposes. The waveshape has been modified to reduce energy content while still preserving a good fall time to rise time ratio as described in the 2009 DesignCon paper referenced above.

Figure 8 shows the overall test setup for measuring the short circuit current. Note the "USB" battery to provide power for the generator. The generator is an order of magnitude smaller and two orders of magnitude lighter than an EFT generator and is battery powered.

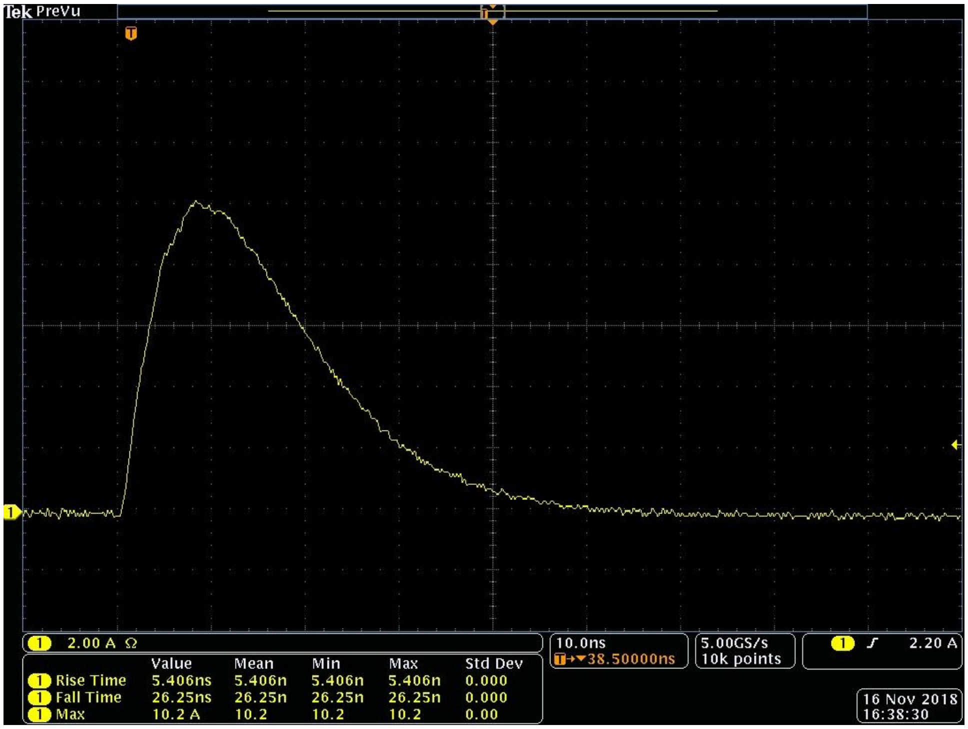

Figure 7. Short Circuit Current from Generator
Vertical scale = 2 A/div, Horizontal scale -= 10 ns/div

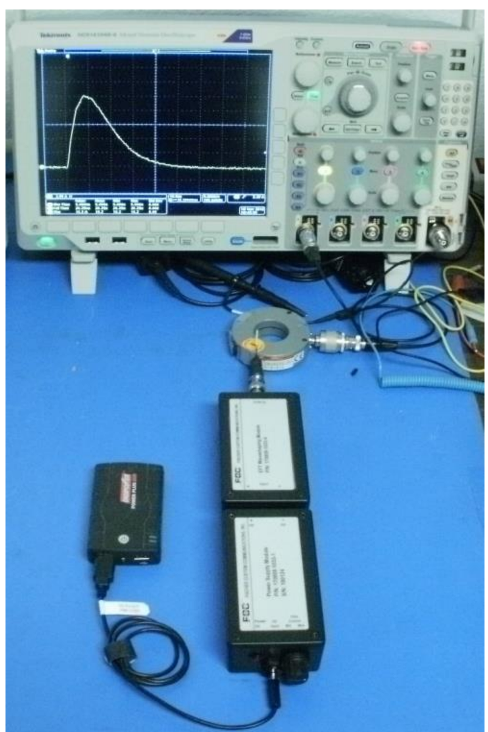

Figure 8. Overall Test Setup for Measuring the Short Circuit Current from Generator

This generator design has now been used in many troubleshooting investigations with good results.

More Detail on the Current Target Used

The current target shown in Figure 2, is shown in more detail in Figure 9. It may have use for other types of ESD and other measurements, especially those involving very high voltages where directly sparking to the current probe is possible. The structure is built of plastic plumbing components and serves to hold the current probe off the ground plane and to provide high voltage insulation between the current probe and other conductors.

A #12 screw passes through the structure and connects to the ground plane. It is inserted in a smooth brass tube to lower the inductance to the ground plane. The brass tube is covered in four layers of heat shrink tubing.

Target Construction

- Insulates the probe from the brass tube
- Provides a low inductance path to the plate for HF current
- Centers the brass tube in the (F-65) current probe to minimize capacitance to the current probe from the brass tube.

Figure 9. Close-up of Current Target

Summary and Conclusions

Thousands of small ESD events have been shown in the field to cause cumulative damage and eventual failures in the field. After characterizing one type of event for printheads, it was shown that application of thousands of small ESD events could reproduce an observed failure mode.

A design based on the simulator that was constructed for this investigation has been shown useful for troubleshooting operations described in a DesignCon 2009 paper titled “Noise Injection for Design Analysis and Debugging,”

A final word

There is precedent for smaller ESD events possibly being a problem. In IEC 61000-4-2, to declare passing the test at a specific voltage level, testing must be done at all lower levels as well. There are many reasons that smaller ESD events can be more problematic than large ones. One reason is the design of protective circuits that leave a band of voltages between when the protector fires and a lower level than may damage the circuit.

A high voltage event fires the protector causing it to fold back to a short circuit, sparing the circuit, whereas a voltage just below the protector firing voltage can still damage the circuit.

The proposed testing described in this paper can be viewed as an extension to the concept of testing to all lower voltages in standards based testing.

References

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