Techniques for Investigating the Effects of ESD on Electronic Equipment

Douglas C. Smith

Address: P. O. Box 60941, Boulder City, NV 89006
TEL: 800-323-3956/702-570-6108
FAX: 702-570-6013
Mobile: 408-858-4528
URL: www.dsmith.org
Email: doug@dsmith.org

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D C Smith

University of Oxford, Department for Continuing Education, Course Tutor
Rewley House, 1 Wellington Square, Oxford, Oxfordshire, OX1 2JA, UK
US address: 1305 Arizona St. #101, Boulder City, NV, USA 89005

Email: doug@dsmith.org

Abstract. During of course of determining the mechanism by which electrostatic discharge affects electronic equipment, the process is complicated by the fact that the energy of the ESD event is dispersed across the whole of the electronic system and its connections. A collection of methods is presented whereby the effects of ESD on electronic equipment and potentially other objects can be determined. These methods narrow down the parts of the system affected by applying E and H field stresses locally in the system. Although the stresses are not necessarily ESD, they model the local effects of ESD within the system and allow determination of which parts of the system are affected by ESD so the specific design fixes can be applied to the appropriate parts of the system.

1. Introduction

When trying to determine the mechanisms whereby ESD affects electronic equipment, the results of the ESD test itself may not be useful. This is because the ESD illuminates the whole system, making it difficult to determine the mechanism(s) by which the ESD affects the system. One would like to determine the specific way ESD gets into the circuitry. There are several quick techniques that can be used right on the lab bench to illuminate specific parts of the system in order to determine how ESD is causing problems. One of these techniques uses capacitive coupling.

2. Capacitive Coupling

Figure 1 shows an ESD simulator fitted with an air discharge tip that is insulated to insure that no direct discharge is made to the PCB. A contact discharge is made and capacitance between the insulated tip and PCB couples high frequency energy to the area of the PCB closest to the simulator tip. The tip is then moved around the board and additional contact discharges are made to test areas of the PCB for sensitivity to the electric fields produced by the simulator tip.

Generally, contact discharge levels up to about two to four kilovolts are used. The charge on the tip must be bled off after each firing of the ESD simulator. This can be done using a one megohm resistor between the tip of the simulator and its ground lead. The simulator shown provides a discharge path back into the simulator, but many simulators do not.

Figure 2 shows an ESD simulator with an air discharge tip that is covered with copper tape applied over insulation to prevent a direct discharge from the tip to the copper tape.[1] A contact discharge is applied and the capacitance between the tip and the copper tape forms a high pass filter that only allows the high frequency portions of the ESD to be injected into a system at the point of contact with

the copper tape. As before, one must insure the tip of the ESD simulator is allowed to bleed off charge before the next simulator discharge.

Figure 1. Coupling ESD energy to a PCB.

Figure 2. High pass filter on ESD simulator.

Figure 3 shows the discharge current into a ground plane measured with a current probe. The resulting waveform is displayed in Figure 4. Only the high frequency components of ESD are able to pass though the copper tape high pass filter and appear as a single pulse about two nanoseconds wide. If a system responds to this, when the peak is adjusted to be the same amplitude as the peak of a normal contact discharge at the desired voltage, then the system is responding to the high frequency components of ESD. If the system responds to a normal contact discharge but not after the high pass filter is added, then the system is responding to the lower frequency components of the applied ESD. The circuit mechanisms are quite different for the two cases and knowing whether high or low frequency components are dominating the system response is valuable information.

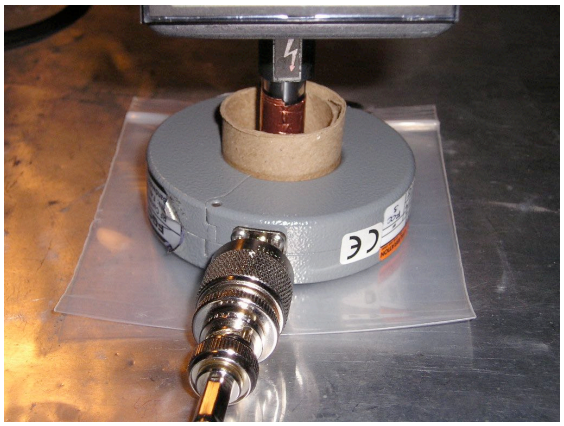

Figure 3. Measuring the filtered discharge current.

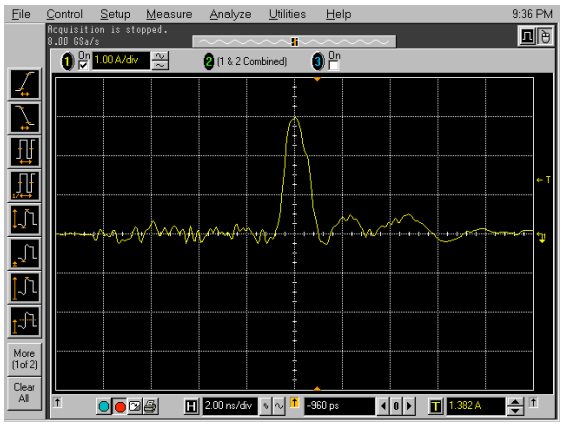

Figure 4. Measured discharge current. Scale factors are 1 A/div and 2 ns/div.

In a system with many cables, one question arises in cases of problems caused by ESD. Which cable or cables are involved? Figure 5 shows one technique for injecting ESD “noise” into a system cable.[2] A contact discharge is delivered to a length of foil wrapped around the cable in question. About 10 cm is an adequate length of foil to get most of the high frequency energy of the ESD into the cable and some of the lower frequency components as well. It is a good idea to monitor the injected current with a current probe on the cable as it enters the system.

Capacitive coupling, as in Figure 5, results in a current injection and this current splits in two directions, entering the system and traveling in the opposite direction away from the system. Both to force more of the current into the system and make that current less dependent of external cable arrangements, a ferrite core can be added as shown in Figure 5 to increase the cable common mode impedance for currents traveling away from the system.

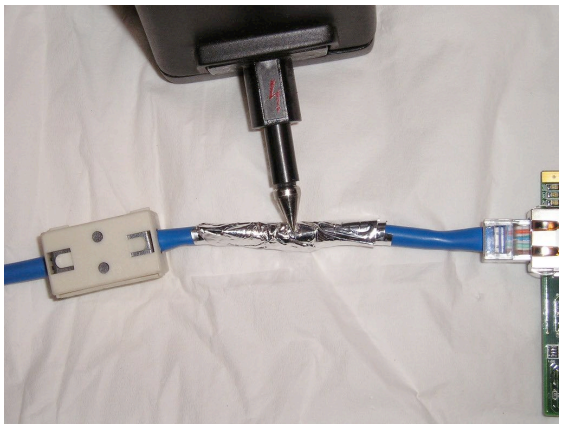

Figure 5. Injecting ESD energy into a cable.

Be sure to discharge the foil between contact discharges if the ESD simulator does not do this. As before, a one megohm resistor can be used, connected between the foil and ground. Or one can simply touch the foil with a finger while wearing a wrist strap. The foil will not store enough charge to be a problem.

The ESD simulator should be set at a low enough voltage so as not to punch through the cable insulation, 2 kV is generally safe. ESD current gets distributed throughout a system, its cables, and through displacement current to other objects, so only a fraction of the energy ends up on a single cable. Thus applying 2 kV on one cable this way is a reasonable stress.

3. Inductive Coupling

Inductive coupling can also be used to find ESD sensitivities in a system and can be used with much more spatial resolution than capacitive coupling. In this case, the stress is not derived from an ESD simulator but from an Electrical Fast Transient, EFT, simulator (IEC 61000-4-4 generator or any pulse generator that can furnish a high open circuit voltage, high current pulse with a fast rise time and slow fall time).

Figure 6 shows a current probe (Fischer Custom Communications F-65 with a flat frequency response from 1 MHz to 1000 MHz) used to measure the current flowing in a square 2.5 cm loop being fed an EFT like pulse. The current waveform is shown in Figure 7 along with its time derivative as calculated by the oscilloscope.

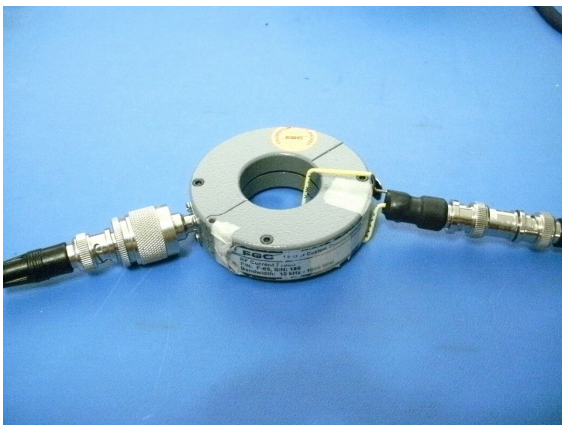

Figure 6. Measuring loop probe current.

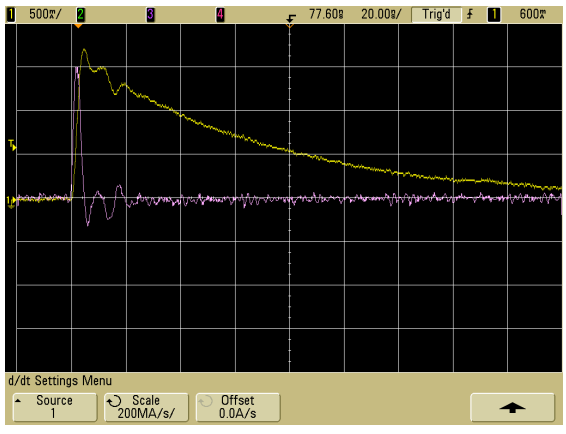

Figure 7. Loop probe current and its di/dt. Scale Factors are 0.5 Amp (Current), 0.2 A/ns (di/dt), and 20 ns/div.

Note the current rises to 1.5 Amperes in a few nanoseconds and falls over a period of over 100 ns. This results in a di/dt consisting of a single positive pulse as the current falls so slowly that it cannot be seen in the di/dt plot. Since the induced voltage in a circuit adjacent to the loop is Mdi/dt, where M is the mutual inductance between the circuit and the loop, the induced voltage will have the same wave shape as the di/dt plot in Figure 7, different only by a constant. If this loop is then held up to a path on a PCB or a wire in the system, a controlled positive or negative (by reversing the loop) pulse can be injected into the circuit.

Figure 8 shows the loop positioned over a PCB trace and the resulting induced voltage is shown in Figure 9. The induced voltage is very similar in shape to the di/dt waveform in Figure 7 as expected.

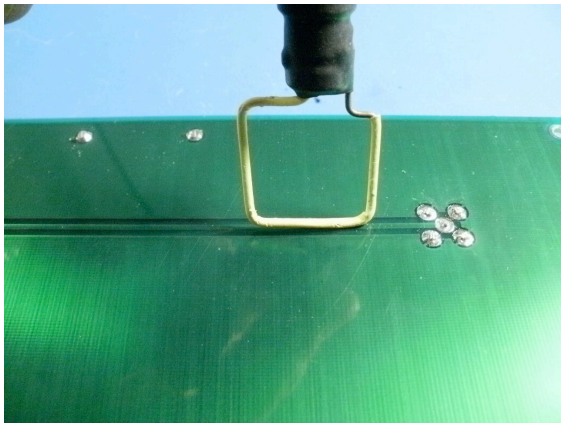

Figure 8. Injecting pulses into a PCB trace.

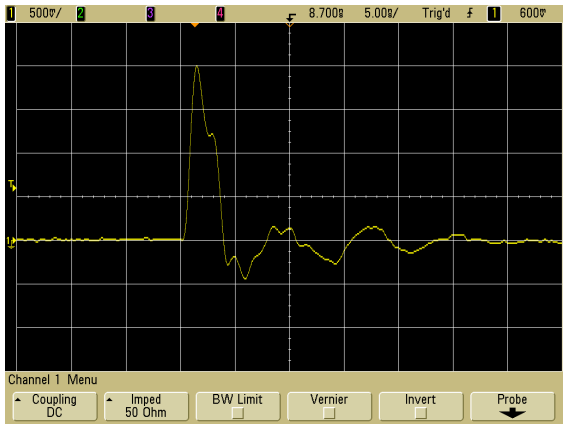

Figure 9. PCB induced voltage. Scale factors are 0.5 Volt and 5 ns/div.

Applying this technique to a PCB is demonstrated in a YouTube video by the author.[3] Another treatment of this inductively coupled method is given in a paper published by the author in 2009.[4] Generally the amplitude of the injected pulse is slowly increased as the board is scanned by the loop. If the first symptom to appear is the same as an observed symptom in response to ESD, that part of the circuit is likely involved. In the above figures, a 100 Volt open circuit pulse was applied to the loop from an EFT pulse source.

4. Summary and Conclusions

By applying stresses locally within a system, ESD induced problems can generally be tracked to their cause in the system design. Both capacitively and inductively coupled stresses are useful. Inductive coupling has the better spatial resolution, but electric field sensitivities are also important in system design.

Application of the methods described here to otherwise intractable ESD problems have found the root causes of those problems in hours after weeks and months of traditional ESD troubleshooting methods, basically trial and error methods in an ESD test area, had failed.

References

[1] "Filtering Contact Discharges - Part 2, High Pass Filtering," Douglas C. Smith, http://www.emcesd.com/tt2006/tt100106.htm

[2] "Injection of ESD Current Into Cables Using Capacitance," Douglas C. Smith, http://www.emcesd.com/tt2009/tt010109.htm

[3] Demonstration video at: http://youtu.be/CdJuaNlUTqE

[4] "Noise Injection for Design Analysis and Debugging, Douglas C. Smith, 2009 Design Con paper, available at: http://emcesd.com/pdf/DC09_DCSmith.pdf