Understanding Pre-pulse and Ramp-up Voltages in HBM Testers

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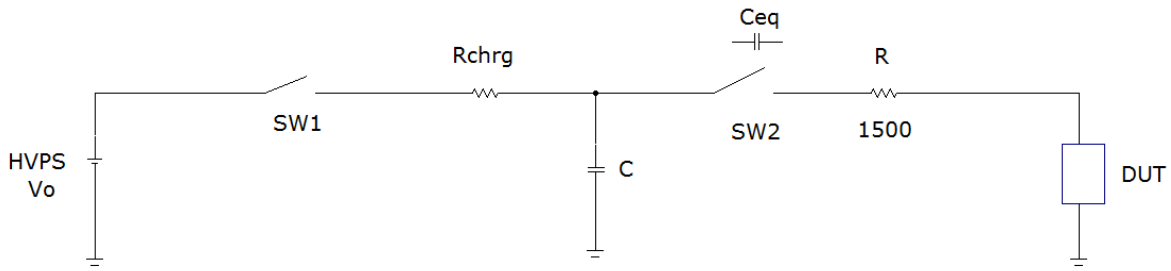
There is a class of ESD protection devices used in semiconductors that could be very sensitive to normal phenomena produced by an ESD simulator. Two of these phenomena are the pre-pulse and ramp-up events. These two events are produced by the relays used to produce the simulated HBM pulse. In this application note, we will review the math and physics behind the pre-pulse and ramp-up events; look at what types of ESD protection devices are susceptible to these events, and describe how to prevent these devices from lower voltage threshold failure.

Let's first take a look at the steps that happen during an HBM ESD waveform generation

1. The charge relay SW1 closes. This causes a current to flow to the charge capacitor through the charge resistor (Rchrg).



2. After the charge relay SW1 is closed, the charge capacitor (C) and the capacitor formed by the open contacts of the ESD discharge relay SW2 both charge as determined by the following equations:

$$V_c(t) = V_0\left(1 - e^{\frac{-t}{(R_{chrg})C}}\right)$$

Equation 1

$$V_{ceq}(t) = V_0\left(1 - e^{\frac{-t}{(R_{chrg}+R)Ceq}}\right)$$

Equation 2

Where:
Vc(t) = Voltage across the charge capacitor C as a function of time
Vo = Voltage at power supply
t = time in seconds
Rchrg = value of charge resistor
C = value of capacitor C in Farads

3. As the capacitor Ceq charges, there is current flow given by the equation:

$$i_{Ceq}(t) = \frac{V_0}{R_{chrg} + R} e^{\frac{-t}{(R_{chrg}+R)C_{eq}}}$$

Equation 3

4. It is i_{Ceq} in Equation 3 that produces the pre-pulse in a HBM simulator.

5. After C is charged, the charge relay SW1 opens.

6. With C fully charged and SW1 open, the discharge relay SW2 starts to close:

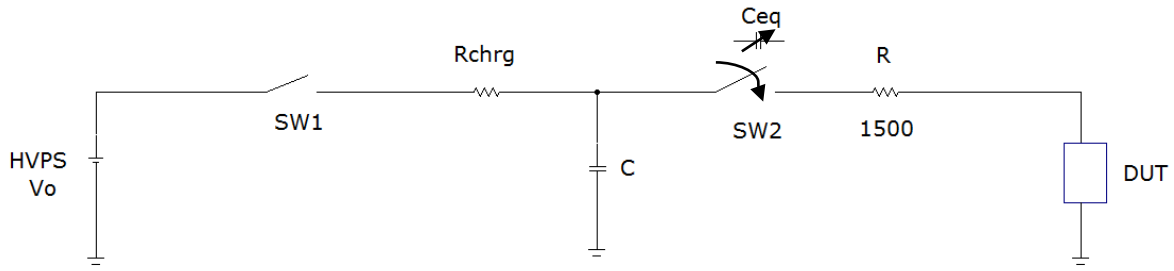


Figure 1 HBM simulator circuit

7. As SW2 closes, the capacitance of Ceq changes as the gap between the contacts decreases. This produces a variable capacitor and a current given by the equation:

$$i_{Ceq} = V_0 \frac{dC_{eq}}{dt}$$

Equation 4

Where:

$\frac{dC_{eq}}{dt}$ = rate of change of relay contact capacitance with time

8. The current produced by Equation 4 is known as Ramp-up.

9. The currents of Equation 3 and Equation 4 cause a voltage drop across the DUT that depends on its impedance.

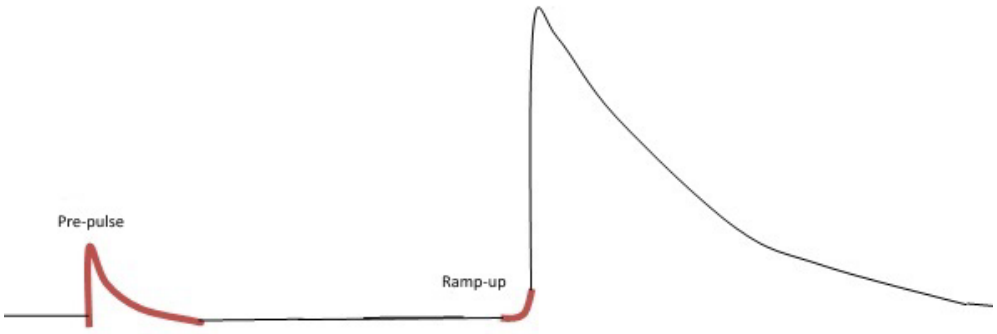


Figure 2 Pre-pulse and ramp-up events (not to scale)

Effects of pre-pulse and ramp-up events on an ESD protection structure

Some protection structures used to protect devices against ESD events are not sensitive to either the pre-pulse or ramp-up events. In general, ESD protection structures that operate as voltage level detectors are not affected by pre-pulse or ramp-up events.

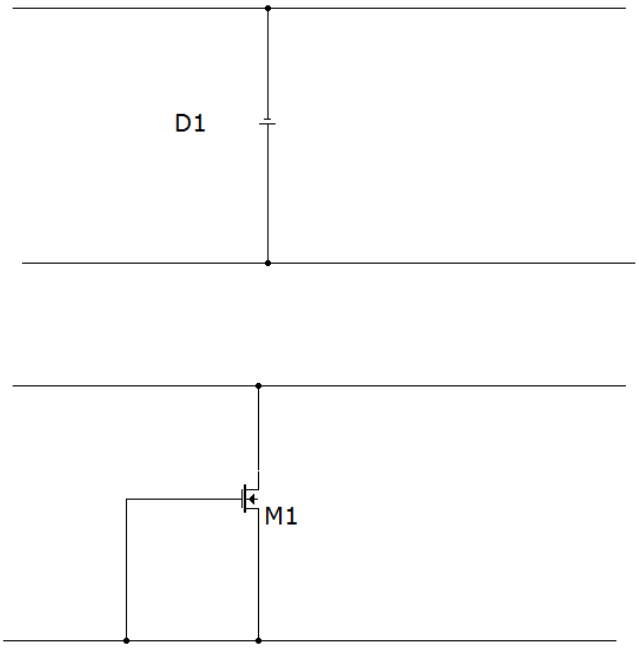


Figure 3 Examples of level detector ESD protection devices

Level detector ESD protection devices are designed to trigger after a certain voltage level is reached for any event. If the pre-pulse or ramp-up event exceeds the voltage limit of the level detector, the protection device turns on and safely shunts the event to the ground or power rails.

One of the most common ESD protection devices used today is a rise time triggered clamp. These protection devices turn on only when the rise time and amplitude of an event match its design specifications. The typical clamp consists of an NMOS transistor with a high pass filter connected to its gate.

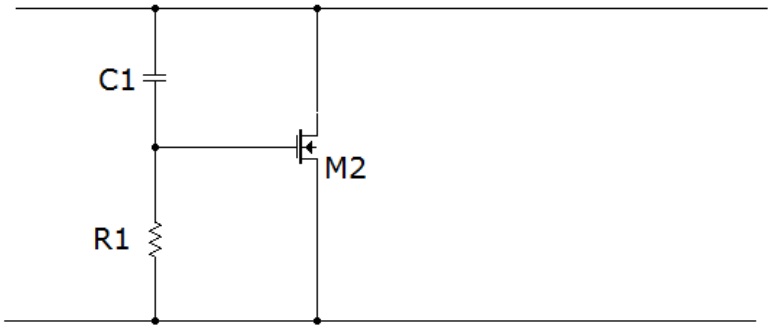


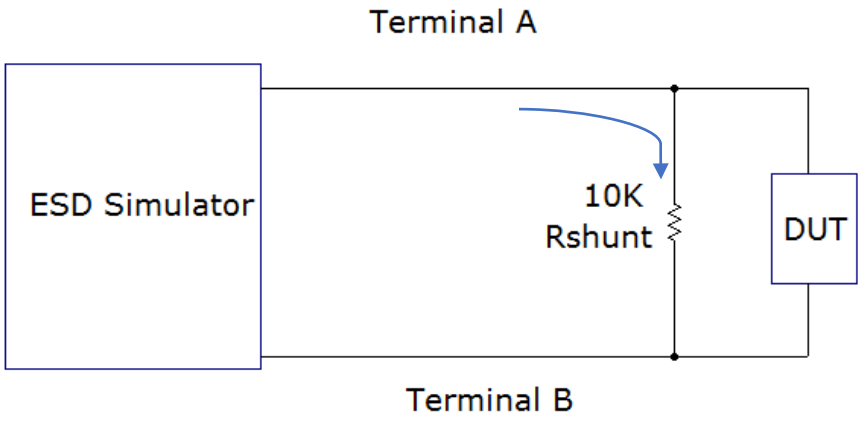
Figure 4 Rise Time triggered ESD protection clamp

As the rise time triggered clamp is exposed to a pre-pulse, depending on its design, the rise time of the pre-pulse (Equation 3) or ramp-up (Equation 4), may not be enough to turn on the clamp, rendering the clamp ineffective for these types of events. The result is an earlier DUT failure not due to the ESD event, but rather the pre-pulse and / or ramp-up events.

While pre-pulse is not a natural event (there is no charge relay in the real world for HBM), the ramp-up event occurs as a human approaches an integrated circuit, just as when SW2 closes, but at a much slower speed $\frac{dC_{eq}}{dt}$ causing a lower current as described in Equation 4.

Figure 5 Real World ramp-up effect caused by a human

Since pre-pulse and ramp-up events may not accurately represent real world events, it is prudent to test devices sensitive to these two events in a test environment that eliminates or minimizes pre-pulse and ramp-up. The joint JEDEC / ESDA test standard JS-001 describes an option to eliminate the effects of pre-pulse and ramp-up. This option consists of adding a 10KΩ resistor across the DUT during the actual event. This option is typically called the “10K Shunt”, and ESD simulators should offer this shunt as an option that can be enabled or disabled.



The shunt resistor provides a DC path for the relatively slow signal (compared to the ESD event) of the pre-pulse and ramp-up events, preventing early damage to the DUT. Because of the large value of Rshunt, compared to the DUT Ron (typically < 1Ω), the protection structure is still fully active during the ESD event, providing a more accurate real world ESD protection performance.

FAQs

1. Q: How do I know if the DUT I am testing is susceptible to pre-pulse or ramp-up events?

   A: Test the DUT with and without the 10K shunt option, if the results are different, then the DUT is susceptible to pre-pulse or ramp-up.

2. Q: When should I use the 10K shunt option?

   A: You should enable this option any time you test a DUT that is susceptible to pre-pulse or ramp-up. When in doubt, always use the 10K shunt option. There is no harm in using the shunt, and it does not interfere with any of the specifications of the standards.

3. Q: Since the 10K shunt is an option, should I use it?

   A: Every time a device using a rise time triggered ESD protection structure (Figure 4), the 10K option must be used to ensure proper performance evaluation. Because it has no adverse effects on any type of simulated ESD waveforms, there is no case where the 10K shunt should intentionally be avoided.

4. Q: If my device fails at a particular voltage, and then I use the 10K shunt option and see the threshold level increase, should I report the higher stress value as my device threshold level?

   A: Yes. JS-001 allows for and in fact recommends the use of the 10K shunt. Therefore, in this type of test results scenario, the higher threshold level should be reported.