

ESD Machine Model Transient Analysis

[http://www.leapcad.com/Other_Tech/ESD Machine Model Analysis.mcd](http://www.leapcad.com/Other_Tech/ESD_Machine_Model_Analysis.mcd)

MM 400V Test: A 200pF cap is charged to 400V. At time $t = 0$ we close the switch to short the capacitor, $v_c(0+) = 400V$. The MM ESD test specifies the following current waveform.

MM Specification (Q-100-003): The initial peak current must be 6.0 - 8.1A. The second + current peak must be 67 to 90% of the first. The major period must be 66 - 90 ns.

Hidden Parameters?: The MM spec is for a finite current and requires oscillatory behavior. There must be a resistance and an inductance, LCR, with parasitic inductance, L and cap ESR, R.

Find required R and L for $i_c(R,L,C,t)$: $v_{c0} := 400 \cdot \text{volt}$ $C := 200 \cdot 10^{-12} \cdot \text{F}$ $L := 500 \cdot 10^{-9} \cdot \text{henry}$ $R := 7 \cdot \text{ohm}$

Summing the voltages across C, R, L: $v_c + v_r + v_l = 0$ $v_c + R \cdot i + L \cdot \frac{d}{dt} i = 0$

Solve for Voltage, $v_c(t)$:

Now $i = dq/dt$ and $q = C V$. Substitute for the loop current, $i = C dv_c/dt$.

$$v_c + R \cdot C \cdot \frac{d}{dt} v_c + L \cdot C \cdot \frac{d^2}{dt^2} v_c = 0$$

Take the LaPlace Transform of the above, where $V_c = \text{LaPlace transform of } v_c(t)$:

$$V_c + R \cdot C \cdot (s \cdot V_c - v_{c0}) + L \cdot C \cdot \left(s^2 \cdot V_c - s \cdot v_{c0} - \frac{dv_{c0}}{dt} \right) = 0$$

$$V_c + R \cdot C \cdot (s \cdot V_c - v_{c0}) + L \cdot C \cdot (s^2 \cdot V_c - s \cdot v_{c0}) = 0$$

Cap Energy:

$$E := \frac{1}{2} \cdot C \cdot v_{c0}^2$$

$$E = 16 \mu\text{J}$$

Solve for V_c and then take inverse transform.

$$V_c = \frac{v_{c0} \cdot (L \cdot C \cdot s + R \cdot C)}{L \cdot C \cdot s^2 + R \cdot C \cdot s + 1}$$

$$\text{nH} \equiv 10^{-9} \cdot \text{henry}$$

$$\text{nsec} \equiv 10^{-9} \cdot \text{sec}$$

$$\mu\text{J} \equiv 10^{-6} \cdot \text{J}$$

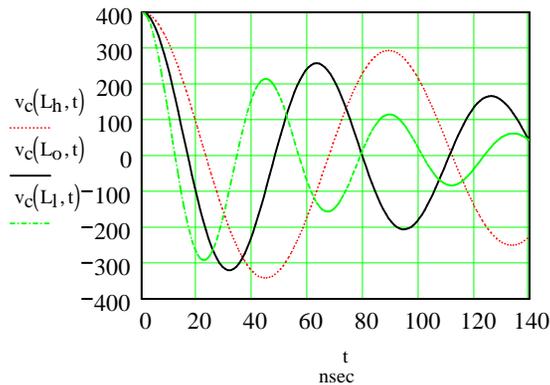
$$v_c(L,t) := v_{c0} \cdot C \cdot \left[\frac{\exp\left(\frac{-1}{2} \cdot \frac{R}{L} \cdot t \cdot \text{nsec}\right)}{(-4L + R^2 \cdot C)} \cdot R^2 \cdot \cos\left[\frac{1}{2} \cdot \left[\frac{-(-4L + R^2 \cdot C)}{(L^2 \cdot C)}\right] \cdot t \cdot \text{nsec}\right] \cdot \left(\frac{1}{2}\right) - \frac{\exp\left(\frac{-1}{2} \cdot \frac{R}{L} \cdot t \cdot \text{nsec}\right)}{(-4L + R^2 \cdot C)} \cdot L \cdot \left[\frac{-(-4L + R^2 \cdot C)}{(L^2 \cdot C)}\right] \cdot R \cdot \sin\left[\frac{1}{2} \cdot \left[\frac{-(-4L + R^2 \cdot C)}{(L^2 \cdot C)}\right] \cdot t \cdot \text{nsec}\right] - 4 \cdot \frac{\exp\left(\frac{-1}{2} \cdot \frac{R}{L} \cdot t \cdot \text{nsec}\right)}{[(-4L + R^2 \cdot C) \cdot C]} \cdot L \cdot \cos\left[\frac{1}{2} \cdot \left[\frac{-(-4L + R^2 \cdot C)}{(L^2 \cdot C)}\right] \cdot t \cdot \text{nsec}\right] \cdot \left(\frac{1}{2}\right) \right]$$

The graphs below verify that our choice of parameters, Lo, match the machine model plots.

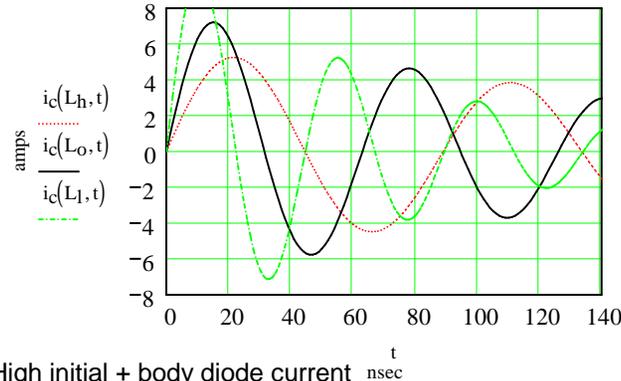
$$t := 0..200 \quad L_h := 1000 \cdot 10^{-9} \cdot \text{henry} \quad L_o := 500 \cdot 10^{-9} \cdot \text{henry} \quad L_1 := 250 \cdot 10^{-9} \cdot \text{henry}$$

$$i_c(L, t) := \frac{-C}{\text{nsec}} \cdot \frac{d}{dt} v_c(L, t) \quad i_c(L_h, 13) = 4.299 \text{ A} \quad i_c(L_o, 13) = 7.049 \text{ A} \quad i_c(L_1, 13) = 9.162 \text{ A}$$

CAPACITOR VOLTAGE AND CURRENT



MM ASPS Current ~ ic * vco/400V



High initial + body diode current can result in destructive high power =Vds x -peak current.

The difference in potential between adjacent Drain pads at the +Vds Current Peak for the ASPS 200V MM Test is 1V.

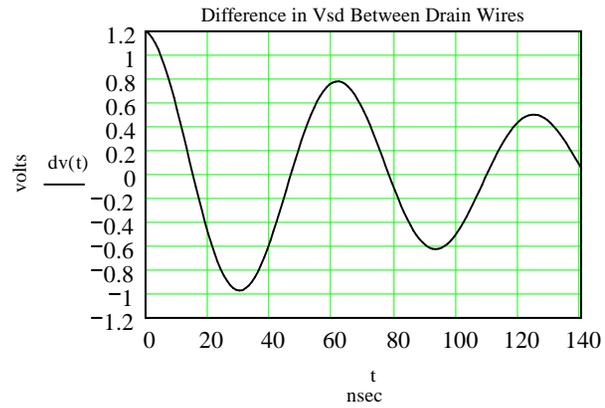
Difference in position of D or S bump pads ~ 7mm.
 Difference in location of wire bonds to terminal ~ 5mm.
 Assume a wire inductance of 1nH per mm of length.
 Difference in length of wire bond, ΔLw ~ 12 mm.
 Assume that ΔLw causes only a slight perturbation in currents in each wire and that the resistances in the wire paths is equal. The currents then divide approximately equally between the 4 sections of the half ASPS output tested during the MM ESD tests and the bond wire current, iw during ASPS MM testing is ic/4. Then the voltage difference

between adjacent pads, $dv(t)$, is $\sim \Delta Lw \times diw/dt$. The voltage in the wire with the least inductance will crest first.

For 200V and 4 sections the wire current can be obtained from the nominal 400V current above with a factor of 1/8.

Voltage Difference between ASPS MM Test wires at 200V, $dv(t)$

$$dv(t) := \frac{12 \cdot \text{nH}}{8 \cdot \text{nsec}} \cdot \frac{d}{dt} i_c(L_0, t)$$



$$dv(30) = -0.972 \text{ volt}$$

