When to worry about a capacitive discontinuity: Rule of Thumb #23

Eric Bogatin - January 21, 2015

Spoiler summary: When the capacitance (in femtofarads) of your discontinuity is greater than 10 × risetime (in ps), the discontinuity will affect the signal.

Remember: before you start using rules of thumb, be sure to read the Rule of Thumb #0: Use rules of thumb wisely.

Previous: Rule of Thumb #22: The dip frequency in S21 of coupled microstrips

A signal will propagate down a uniform, lossless interconnect with exactly the same rise time at each step along the way. If a 1ps rise time goes in, a 1ps rise time will come out. Except in two important cases.

Two common interconnect features screw up the rise time: losses, and discontinuities. The losses will filter out the higher frequency components by absorbing them, reducing the signal bandwidth and increasing the signal rise time.

The capacitive discontinuities will act as RC filters with the impedance of the line, introducing single-pole filters, decreasing the signal bandwidth, and increasing the rise time of the signal.

We can estimate the impact from the capacitive discontinuities in a very simple way. When a discrete capacitor is added to an otherwise lossless, uniform line with a characteristic impedance, Z0, the signal will be filtered with an RC time constant of:

$$t = RC = \frac{1}{2}\, Z0 \times C$$

The "½" comes from the in-and-out transmission lines to/from the capacitance acting in parallel. In any RC filter, the 10%-90% rise time is 2.2× the RC time constant. The modified rise time coming out of an RC filter in the special case of a 50Ω line is:

$$RT[ps] = 2.2 \times \frac{1}{2} \times Z0 \times C \approx 50 \times C[pF]$$

For example, if the excess capacitance of a via pad is 0.1pF, the intrinsic 10%-90% rise time of the RC filter is 50 × 0.1 = 5ps.

How much intrinsic rise time filtering has to occur before it becomes a problem?

The composite rise time of a signal, RT_out, coming out of a filter with rise time RT_filter, when the rise time going into the filter is RT_in, is roughly:

$$RT\_out = \sqrt{RT\_in^2 + RT\_filter^2}$$

As a rough estimate, if the filter rise time is half the input signal rise time, the output signal rise time is only 10% longer. At a first pass, we need to worry about the filter rise time when it is longer than about half the signal rise time. That's when it will start to have a noticeable effect.

This suggests a criterion on when to worry about a capacitive discontinuity in a 50Ω environment; namely, when:

$$50 \times C[pF] > \frac{1}{2} RT[ps] \quad \text{or} \quad C[pF] > \frac{1}{100} RT[ps] \quad \text{or} \quad C[fF] > 10 \times RT[ps]$$

For example, if the signal rise time is 50ps, a capacitive discontinuity smaller than about 0.5pF may not be a problem.

Now you try it:

1. Suppose the rise time is 10ps. How much capacitive discontinuity could be tolerated?
2. Suppose the capacitive discontinuity is 20fF. At what rise time should you worry?

Also see:

- Bogatin's Rules of Thumb
- Designing controlled-impedance vias

Additional information on this and other signal integrity topics can be found at the Signal Integrity Academy, www.beTheSignal.com.