[What is the ringing period on an unterminated line?: Rule of Thumb #26]

[Eric Bogatin] - March 13, 2015

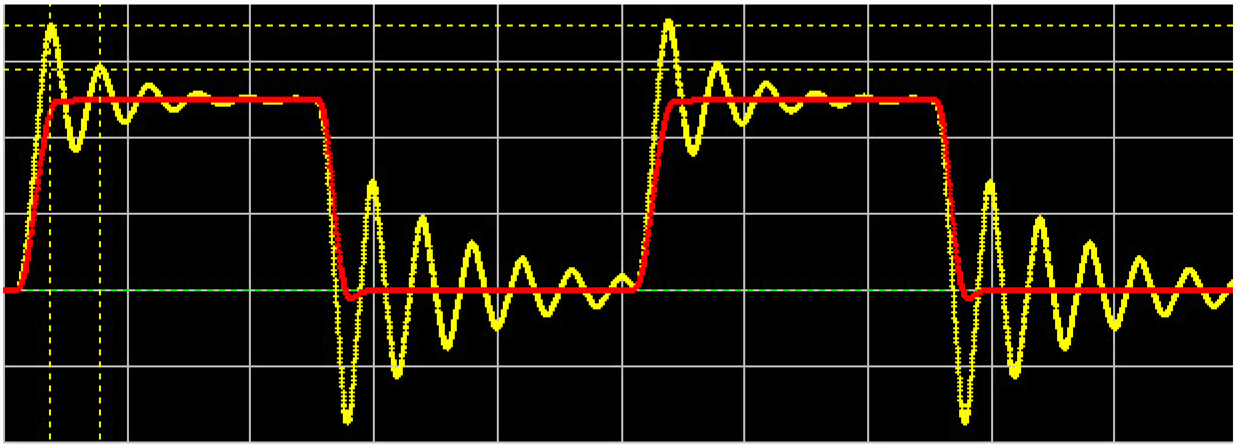
The most common source of signal integrity problems, and the easiest to fix, is ringing at the RX from unterminated lines. This is an issue on circuit boards as well as when measuring signals with a scope. The fastest way to check if this is your problem is to look at the period of the ringing. If it matches the estimate from this rule of thumb, check your line termination.

Spoiler summary: The period of successive peaks in the ringing, if due to unterminated transmission lines, is: Period[ns] = 2/3 × Len[inches].

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

Previous: Rule of Thumb #25: How much is impedance affected by an adjacent trace?

The poster child for signal integrity problems is ringing at the RX end due to reflections on an unterminated transmission line. A great example is shown in the figure below. In yellow is the signal at the RX with no termination, and in red, the same, with a terminated line.



This also illustrates two general features of output signals. When the n-channel output FET turns on, and the signal switches from high to low, it often (but not always) has a faster turn-on time and a lower impedance than when the p-channel transistor turns on and the signal goes from low to high.

Both of these features contribute to higher ringing amplitude on the falling edge when due to unterminated lines.

The root cause of the ringing is reflections from the mismatch at the RX between the impedance of the line and the high input impedance of the RX, and the mismatch when the reflected signal makes its way back to the low output impedance of the TX.

The reflection coefficient is close to 1 at the RX, but is a negative value at the TX. Let’s trace the signal path on its journey. When it first reaches the RX, it reflects. The initial voltage at the RX is high. The reflected signal makes its way back to the TX, where it sees a high to low impedance and reflects. But the reflected voltage is negative.

This negative reflected signal makes its way back to the RX, where it again reflects, but since it is negative, pulls the signal at the RX down. When it reflects from the RX, it is still negative, makes its way back to the TX, changes sign when it reflects, and travels back to the RX as a positive signal.

From the initial positive signal at the RX, the signal takes one TD (time delay) to make it back to the TX, another TD to reflect back to the RX (that’s 2 × TD from a peak to a valley at the RX), another TD to get to the TX again, and another TD for the reflected signal to make it to the RX as a positive signal.

This is a rather surprising result: four time delays between successive peaks due to reflections in an unterminated line.

If the interconnect is in FR4, the speed of the signal should be about 6 inches/ns (see RoT #3). This means the time between successive peaks – the period of the oscillations – is:

$$\text{Period}[\text{ns}] = 4 \times \text{TD}[\text{ns}] = 4 \times \frac{\text{Len}[\text{inch}]}{6\,{}^{\text{in}}\!/_{\text{ns}}} = \frac{2}{3}\,\text{Len}[\text{inch}]$$

and

$$\text{Len}[\text{inch}] = 1.5 \times \text{Period}[\text{ns}]$$

For example, if you see a period of 1ns in the ringing, expect an unterminated interconnect length to be on the order of 1.5 inches. Of course, to see this ringing would require a rise time of the signal significantly less than the ringing period, but that’s another rule of thumb.

Now you try it:

1. You are measuring the low impedance of a power supply with a 6 foot long coax cable and the scope is set for high impedance. What is the period of the ringing you expect to see?
2. The board trace is 12 inches long and unterminated. What period do you expect to see for the ringing at the RX?

Also see:

- Bogatin's Rules of Thumb

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