Crosstalk: How much is too much?: Rule of Thumb #19

Eric Bogatin - November 19, 2014

Crosstalk is one of the three important sources of noise that can distort the received signal and cause bit errors from voltage noise. Just how much is *too* much obviously depends on the application. But if you need a rough number to shoot for, this rule of thumb will help.

Spoiler summary: In single-ended systems, the maximum amount of crosstalk to design for, from all sources, should be less than about 5% of the signal swing. In high speed serial links, a safe value for the maximum crosstalk to design for should be less than -50dB, or 0.3%.

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

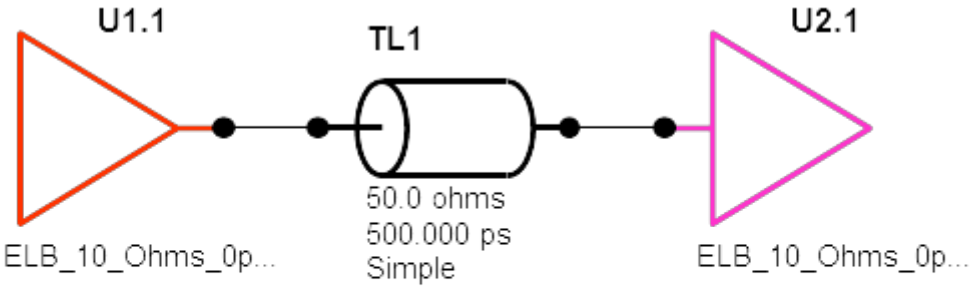
Previous: Rule of Thumb #18: How long a stub is too long?

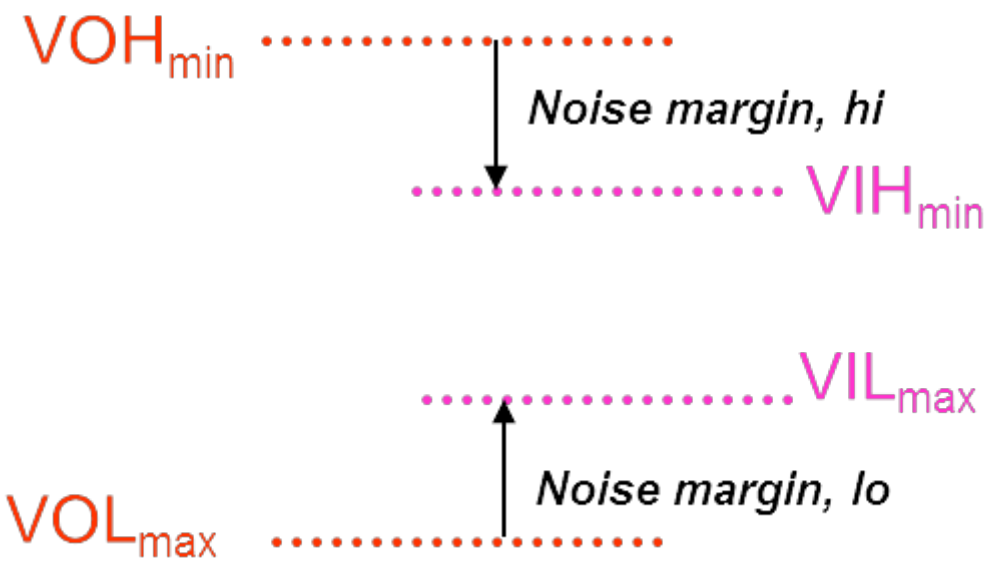
There are two general problems which will cause a bit error at the receiver: noise in the vertical direction, we call voltage noise, and noise in the horizontal direction, which we call jitter.

We often divide the voltage noise sources into the general root causes of losses, reflection noise, crosstalk, power noise and in the special case of differential pairs, mode conversion. These also contribute to jitter, which we lump into the general category of deterministic jitter, as distinct from random jitter.

In single-ended systems where loss is generally not important, the dominant impact of voltage noise is collapse of the eye in the vertical direction. How much voltage noise from reflections, crosstalk, and power noise is acceptable? As with almost all signal integrity questions, the answer is, it depends.

Coming out of the Tx we can expect a minimum voltage for a 1 and a maximum voltage for a 0. To be read correctly at the Rx, it needs to see a minimum voltage for a 1 and a maximum voltage for a 0. These levels are illustrated below.





The difference between the worst voltage from the Tx and the worst at the Rx is the amount of "wiggle" room available. It is the amount of noise that can be tolerated before the Rx signal exceeds the limits to an accurately received 1 or 0. We call this difference the "noise margin."

It varies depending on the technology. For 2.5V CMOS technology, it is about 15% of the signal swing. For 1.8V CMOS, it is about 18%.

Of course, this acceptable voltage level must also be present around the real or recovered clock edge – within the setup time before the edge, and the hold time after the edge. It's these boundaries that define an acceptable eye.

For robust operation, all the noise at the Rx, from all the noise sources mentioned above, have to add up to less than the noise margin. This allocation of noise amplitude to each source is the noise budget.

If the overall noise budget is 15% of the signal swing, and everyone on the design team is a good negotiator, and there is no compelling reason otherwise, one way of allocating the noise budget is by splitting it evenly between reflection noise, crosstalk, and power noise.

This is the origin of the rule of thumb that, as a rough starting point, keep the crosstalk from all sources to less than 5% the signal swing.

In high speed serial links, in the presence of a lot of loss, the Rx signal amplitude at the Nyquist frequency can be as low as -25dB, and still be opened with equalization. Some specs, like the 10Gbase-KR, recommend a signal to noise ratio (SNR) at the Nyquist of better than 23dB. If the

signal could be as low as -25dB, this means the total noise should be below -25dB - 23dB, or -48dB. This is about 0.3%.

In the worst case configuration of interleaved architecture, the near-end crosstalk should be kept below about -50dB of the signal to maintain acceptable SNR. Of course, if the signal at the Rx is larger than -25dB, the maximum allowable crosstalk could be larger.

Now you try it:

1. In a CMOS system, if the signal swing is 2.5V, what is the maximum amount of crosstalk voltage to design for?
2. In a PCIe gen II Tx, the minimum output voltage level is 600mV. For a SNR of 23dB, and a maximum acceptable attenuation of -13dB, what is the maximum acceptable crosstalk at the Rx?

Next rule of thumb #20: How far apart should signal lines be spaced for near-end crosstalk to be acceptable?

Also see:
- Bogatin's Rules of Thumb
- See the crosstalk in 100GbE
- Crosstalk problems are back
- Receiver Tolerance Testing – with crosstalk!

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