How much attenuation is too much?: Rule of Thumb #10

Eric Bogatin - April 17, 2014

This rule of thumb enables us to estimate how much attenuation would be in the loss budget of a serial channel.

Spoiler summary: With no equalization, about -10 dB at the Nyquist. With just CTLE, about -15 dB. And with best practices CTLE, FFE, and DFE, about -25 dB.

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

Previous: Loss in a channel: Rule of Thumb #9.

When we do everything right in the design of a high speed serial link channel, we will still have the frequency dependent attenuation due to the conductor loss and dielectric loss. This will cause the rise time to increase because the high frequencies are attenuated more than the low frequencies.

Unfortunately, with the roughly linear drop off in the insertion loss with frequency, it is difficult to calculate an analytical expression for the shape of the rising edge of a signal. The shape of the edge is not linear, it is not Gaussian, it is… complicated. It will have a fast rise and a long tail.

This makes estimating the resulting single bit response, ISI, and impact on the vertical and horizontal collapse of the eye, very difficult. One approach is to just run a few simulations and look for generalizations.

If we take a typical low loss channel, 36 inches long, we can calculate the insertion loss and the step response to a 10ps rise time signal. The figure below shows the result.

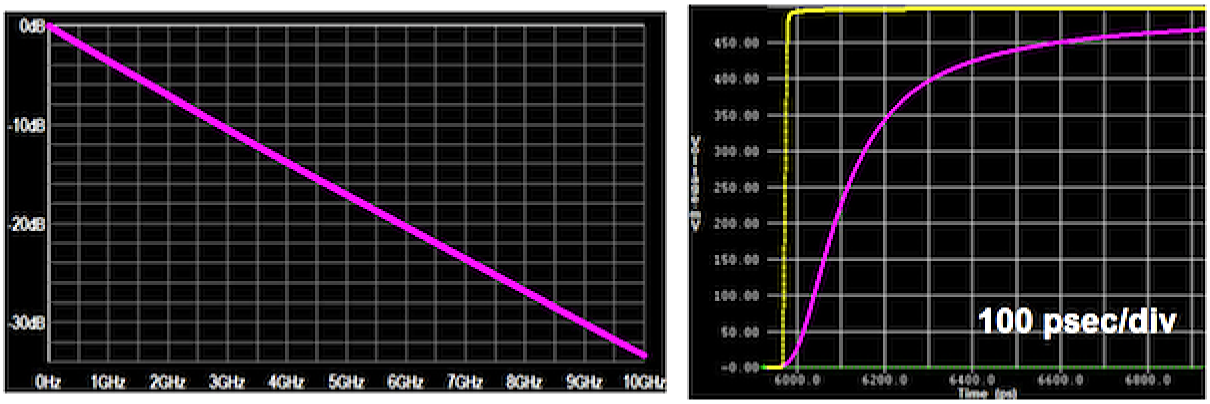

Figure 1 Channel response in the frequency domain and the step response for 36 inch low loss channel. Note, the FOM is about -34 dB/10 GHz/36 inches = 0.1 dB/in/GHz.

The shorter the unit interval is compared to the rising edge of the step response, the less signal level we achieve at the end of a single bit, and the more sensitive we are to the prior data pattern. The result is more ISI and more collapse of the eye in the horizontal and vertical directions.

We can explore, as the data rate increases, and the unit interval decreases, what the connection is between the collapse of the eye and the attenuation at the Nyquist. The following figure shows three examples of different data rate PRBS patterns through this channel and the resulting collapse compared with the attenuation at the Nyquist.

Figure 2 Eye diagrams for three different PRBS data rates and the attenuation at the Nyquist

When the attenuation at the Nyquist is only -4 dB, there is little impact on the eye from the attenuation. When the attenuation is -8 dB at the Nyquist, the eye is still open enough to meet virtually all mask specs. But when the attenuation at the Nyquist is -12 dB, the eye is way too collapsed.

This is the origin of the rule of thumb:

> *With no equalization, the maximum attenuation at the Nyquist for an eye opening that is still acceptable is about -10 dB.*
>
> *Using just CTLE equalization, an acceptable eye can still be recovered if the attenuation at the Nyquist is -15 dB.*
>
> *Using the 10GBASE-KR spec as a guide, if the attenuation at the Nyquist is as much as -25 dB, the eye can be opened enough to be acceptable using best practices for FFE, DFE, and CTLE equalization.*

For example, in a lossy channel operating at 8 Gbps, using CTLE, what is the maximum channel length possible?

The attenuation is about 0.2 dB/in/GHz, and the maximum attenuation we can tolerate at 4 GHz is -15 dB with CTLE equalization. This means, the maximum channel length is given from:

-15 dB = -0.2 dB/inch/GHz x 4 GHz x Len and Len = 15/(0.2 x 4) = 19 inches.

Don't expect to be able to go much more than about 20 inches at 8 Gbps in this channel.

Now you try it:

1. What is the maximum data rate for a lossy channel with no equalization that is 20 inches long?
2. What is the maximum channel length for a 10 Gbps system, in a low loss system using the best equalization?

Next rule of thumb: RoT #11: What is the bandwidth of a high speed serial link?

Also see:

- Selecting PCB materials for high-frequency applications
- What you lose from a lossy line
- Characteristic impedance of lossy line
- Mixtures of skin-effect and dielectric loss
- Rule of Thumb #4: Skin depth of copper
- Loss in a channel: Rule of Thumb #9