Loss in a channel: Rule of Thumb #9

Eric Bogatin - April 04, 2014

This rule of thumb enables us to estimate the attenuation at the Nyquist for a lossy, uniform channel.

Attenuation figure of merit: 0.2 dB/inch/GHz, for a lossy channel, 0.1 dB/inch/GHz for a low loss channel.

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 #8: Ground bounce in a connector.

There are four important effects which contribute to inter-symbol interference (ISI) in high speed serial link channels: attenuation, reflection noise, crosstalk, and mode conversion.

If everything is done right in the interconnect design, the attenuation will still be left as a fundamental limit imposed by the choice of materials in the interconnect. It is the frequency dependent attenuation that causes the rise time to increase. When the rise time is long compared to the unit interval, ISI is the result.

Many channel specifications have a budget for how much attenuation is acceptable for the channel. With PCIe gen II, for example, the attenuation at the Nyquist for PC applications must be less than 13.5 dB. If we can estimate the expected attenuation at the Nyquist for the channel, we can estimate whether the channel may be acceptable.

The frequency dependent attenuation arises from two root causes, the conductor loss and the dielectric loss. When all the other problems are reduced, these two loss mechanism will always be left.

To a pretty good approximation, the attenuation, at a frequency, f, is:

$$\text{atten}[\text{dB/in}] \sim \frac{1}{w[\text{mils}]}\sqrt{f[\text{GHz}]} + 2.3 \times f[\text{GHz}] \times Df \times \sqrt{Dk}$$

where:

w = the line width in mils

f = the sine wave frequency in GHz, equivalent to the Nyquist

Df = the dissipation factor

Dk = the dielectric constant

This model assumes skin depth limited current in microstrip or stripline, the series resistance in the return path, and a factor of 2 increase in resistance from surface roughness and a 100 Ohm impedance line.

Let's put in the numbers for a PCIe III channel, at 8 Gbps or 4 GHz Nyquist, for the case of a 5 mil wide trace in FR4. This is a relatively lossy channel.

$$\text{atten}\left[\text{dB/in}\right] \sim \frac{1}{5}\sqrt{4} + 2.3 \times 4 \times 0.02 \times \sqrt{4.3} =$$
$$0.4\text{dB/in} + 0.38\text{dB/in} = 0.78\text{dB/in}$$

We see that the attenuation is comparable between the conductor and the dielectric loss. It is not strictly linear with frequency, but as a rough approximation, around 4 GHz, the attenuation is about 0.78 dB/in/4 GHz = 0.2 dB/in/GHz.

In a Megtron6 channel, we'd expect to see:

$$\text{atten}\left[\text{dB/in}\right] \sim \frac{1}{5}\sqrt{4} + 2.3 \times 4 \times 0.002 \times \sqrt{3.6} =$$
$$0.4\text{dB/in} + 0.035\text{dB/in} = 0.44\text{dB/in}$$

Here, we see how much larger the conductor loss is from the dielectric loss. This is why Megtron 6 is not the savior for very high data rate channels. The attenuation in the channel will be dominated by the conductor loss.

For a low loss channel, the figure of merit is about 0.44 dB/in/4 GHz = 0.1 dB/in/GHz. This is the origin of our rule of thumb:

For a lossy channel, we expect to see an attenuation of about 0.2 dB/inch/GHz. For a low loss channel, we expect to see an attenuation of about 0.1 dB/inch/GHz.

As an example, here is the measured attenuation, as S21, in dB/in for an FR4 and Megtron6 interconnect each about 16 inches long.

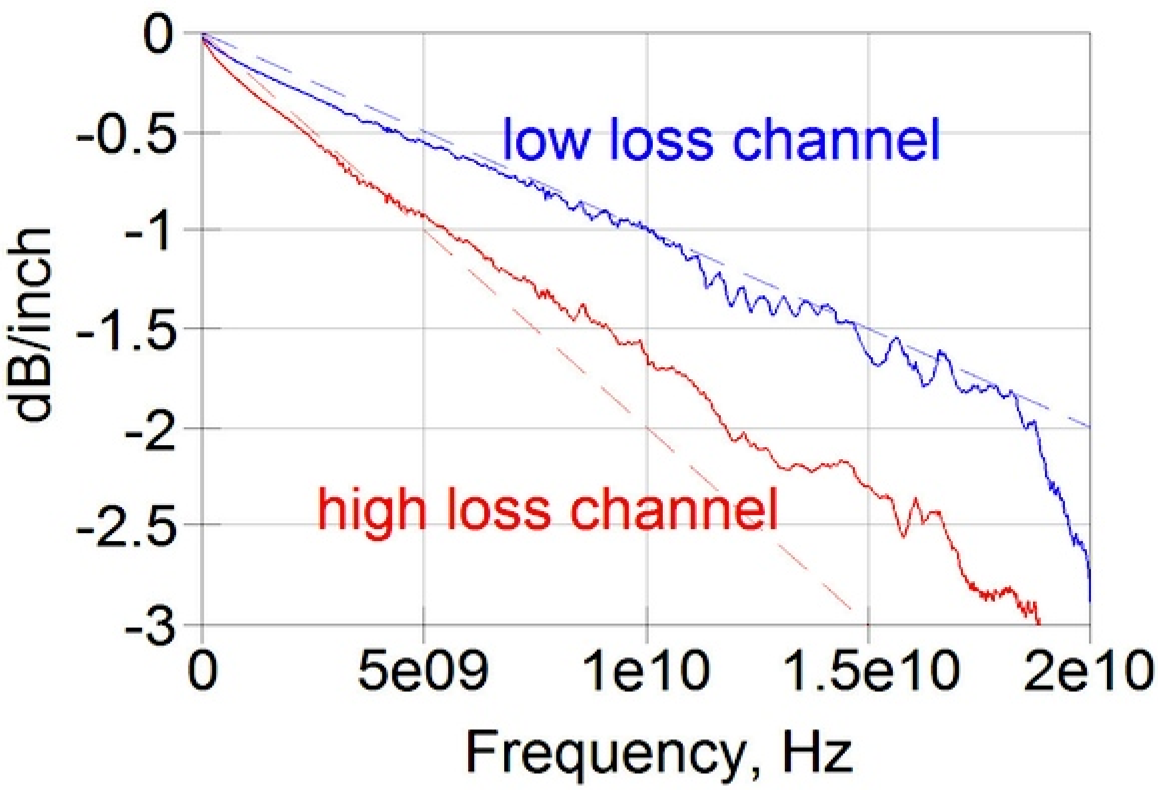

Figure 1 Solid lines: measured insertion losses, and dashed lines: our simple figure of merit

These are not perfect interconnects, and the line width was a little wider than 5 mils, and the FR4 was an FR408HR, with a slightly lower dissipation factor than cheap FR4.

Even so, we see our estimates from this simple rule of thumb are not so far off.

Now you try it:

1. An FR4 channel is 10 inches long. How much attenuation would be expected for a 5 Gbps signal?
2. A low loss channel operates at 10 Gbps. How much attenuation is expected if the channel is 40 inches long?

Next rule of thumb: RoT #10: How much attenuation is too much?

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