The quarter-wave stub frequency: Rule of Thumb #17

Eric Bogatin - October 06, 2014

Spoiler summary: The quarter-wave stub resonant frequency, when built in FR4, is about: f[GHz] = 1.5/Len[inches] or f[GHz] = 3.8/Len[cm].

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 #16: The sheet inductance of a cavity

A uniform transmission line with roughly matched terminations on the ends will have an insertion loss that drops off monotonically. The drop off is due to the frequency dependent attenuation in the line, which was discussed in Rules of Thumb #9, #10 and #11.

In addition, if the routing topology of the circuit is not point-to-point, but includes a stub for whatever reason, the geometry of the stub will screw up the insertion loss, creating what looks like a large absorption dip in the insertion loss. An example of this behavior is shown in **Figure 1**.
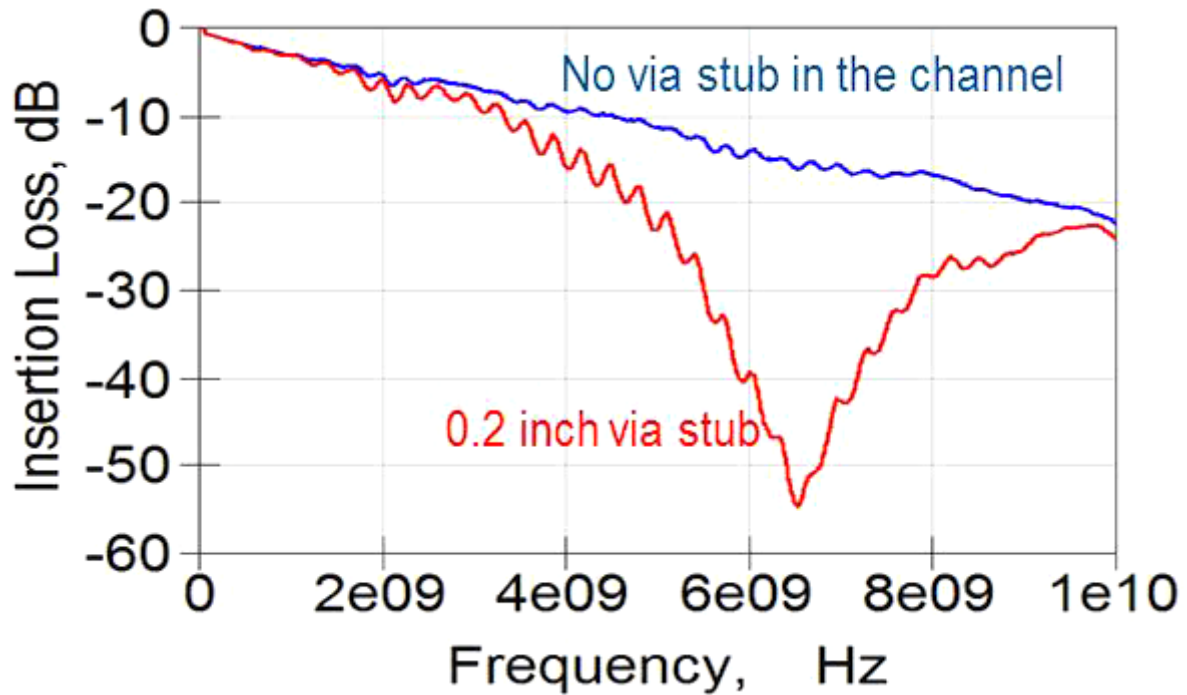
Figure 1 Measured insertion loss of two channels in a backplane. One channel has no via stub; the other channel has a 0.2 inch long via stub.

If this frequency happens to occur where there is substantial signal energy, it will distort the signal and result in bit errors.

Knowing this dip frequency and engineering it to higher frequency, beyond the bandwidth of the signal, is very important, especially in high speed serial links.

The cause of this dip in the received signal is due to the interference of the incident signal to the receiver (Rx) and the part of the signal that split, went to the bottom of the stub, reflected, and then ended up at the Rx. This path is illustrated in **Figure 2**.
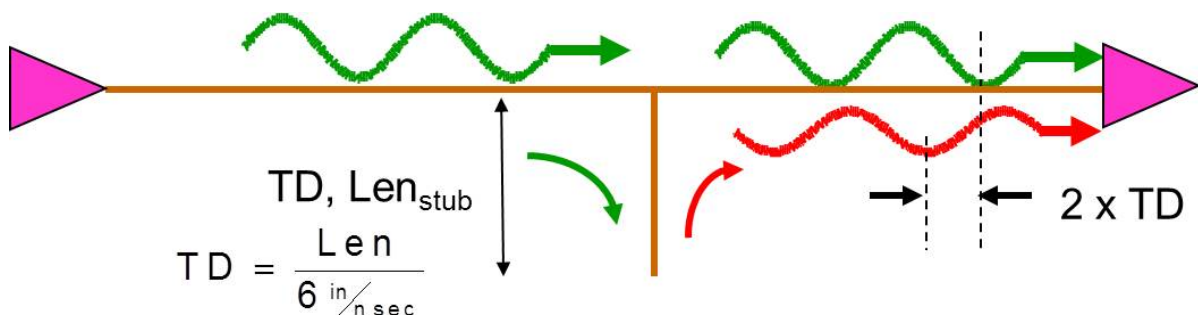

$$TD = \frac{Len}{6\ ^{in}/_{n\,sec}}$$

Figure 2 The signal at the Rx comprises the incident signal and the reflected signal from the bottom of the stub. When these are 180° out of phase, they cancel out, and the Rx sees a minimum.

The part of the signal that detoured to the bottom of the stub traveled an extra distance to get to the Rx. When this round trip time down and back from the bottom of the stub is half a wavelength, the

two parts of the signal at the Rx subtract and we have a minimum.

The condition for the round trip distance to be half a wavelength is for the one-way length of the stub to be a quarter wavelength. This is why we call the frequency of the minimum – when the stub is a quarter wavelength – the quarter-wave stub resonance frequency.

The condition is that the time delay (TD) of the stub equals: ¼ (1/f_{res}). In FR4 material, with a Dk of about 4, this corresponds to:

$$f_{res}[GHz] = \frac{1}{4} \frac{1}{TD[ns]} = \frac{6}{4 \times Len[in]} = \frac{1.5}{Len[in]} = \frac{3.8}{Len[cm]}$$

If the stub is 0.5 inches or 1.3 cm, the quarter-wave stub resonance frequency will be about 3 GHz.

We see in this rule of thumb that if we want to engineer a higher dip frequency, we must make the stub length shorter. This is why, if we want to run at about 2 Gbps and higher, we cannot tolerate any routing stub length, and must use a point-to-point architecture.

Now you try it:

1. What is the quarter-wave stub resonant frequency for a via stub that is 50 mils long?
2. What is the longest stub you can tolerate if you want the quarter-wave stub resonant frequency to be higher than 5 GHz?

As an added puzzler, what happened to the energy at the quarter-wave stub resonant frequency? If it left the Tx but did not make it to the Rx, where did it go? For a bonus point, how would you test your theory?

Next rule of thumb #18: How long a stub is too long?

Also see:

- [Bogatin's Rules of Thumb](#)
- [Loss in a channel: Rule of Thumb #9](#)
- [How much attenuation is too much?: Rule of Thumb #10](#)
- [What is the bandwidth of a high speed serial-link signal?: Rule of Thumb #11](#)

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