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How to Handle the Dreaded Danglers, Part 1

by Barry Olney
IN-CIRCUIT DESIGN PTY LTD / AUSTRALIA

Dangling via stubs can distort signals passing through your interconnect, and decrease the usable bandwidth of the signal. A via stub acts as a transmission line antenna, and has a resonant frequency determined by the quarter wavelength of the structure. At this frequency, the transmitted signal is greatly attenuated, by up to 3dB. For low-frequency signals, this is not much of an issue because these signals are significantly lower than the resonant frequency of the via stub.

However, for higher-frequency signals (>1GHz), which are becoming more common as performance specifications are increased, this issue becomes a problem because the signals are transmitted at frequencies near or at the resonant frequency of the via stub. Harmonic components that are odd multiples of the fundamental frequency can also be highly attenuated.

The conventional solution to this problem is to back-drill (or control-depth drill) the vias to bore out the via stub barrels, so that the via stubs are reduced in length, if not completely removed (Figure 1).

If the via is short, compared to the signal rise time, then it acts mostly as excess shunt capacitance. The entire length of the via contributes to the capacitance, while only the section where the signal current actually flows makes up the inductance. However, a long via stub can develop resonance that exacerbates the effects of its capacitance. I should point out that it is fine to have a plated through-hole (PTH) via, providing the signal goes in at one end and out at the other, using the entire length of the barrel.

When a via's stub length is equal to a quarter wavelength of the signal frequency, the signal travels from the trace to the end of the stub and

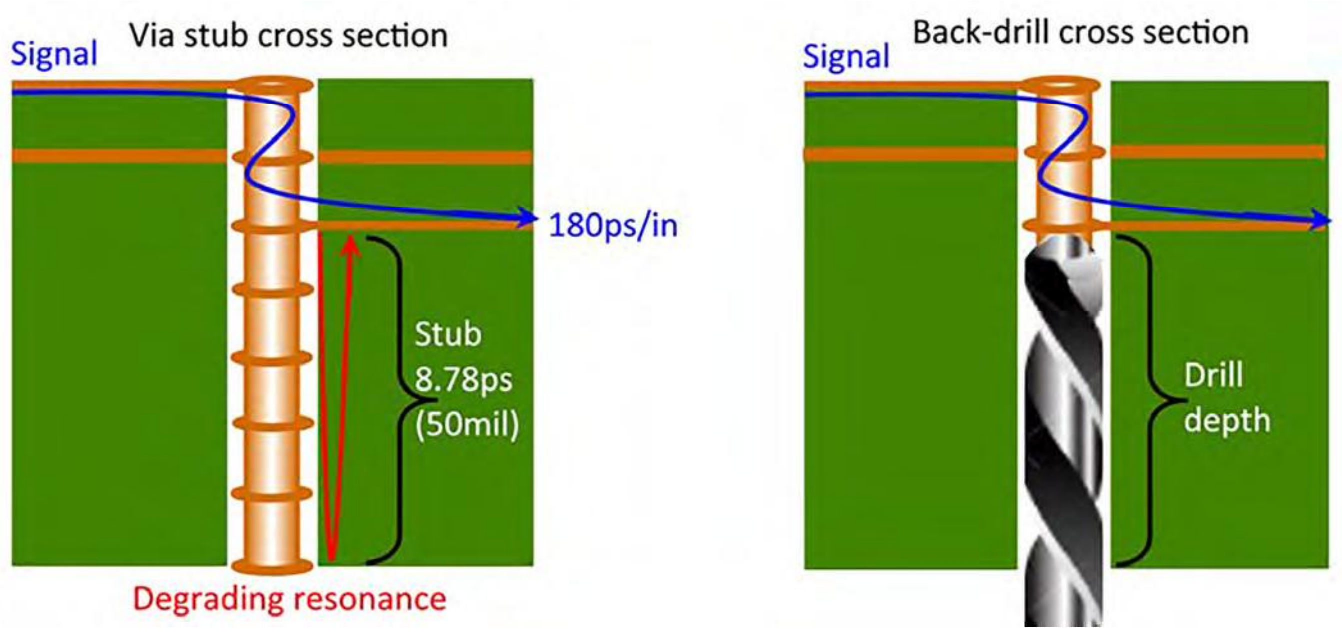

Figure 1: The unterminated via stub (left) and a back-drilled via stub (right).

then bounces off the open circuit end-point and back to the trace for a total distance of a half wavelength. This half wavelength travel has the effect of shifting the phase of the signal by 180 degrees, creating resonance in the via stub. The phase-shifted, reflected signal has a maximum value at a time when the signal has a minimum value, and vice-versa.

The Nyquist frequency of a discrete signal is defined as a half of the sampling rate of the signal and will have a strong frequency component at this frequency. In addition, the signal can have strong power spectrum harmonic components at frequencies greater than the Nyquist frequency typically up to the 5th harmonic. The resonant frequency of the via stub is inversely proportional to the dielectric constant of the material, surrounding the via, with a wavelength of four times the length of the unused portion of the via. This relationship is given by the following equations:

$$Tvia = l\,\frac{\sqrt{Er}}{c}$$

$$Fres = \frac{1}{4.l.Tvia}$$

Where is the time for the signal to propagate in a stub (~180ps/in for FR4), is the length of the via stub, Er is the dielectric constant, c is the speed-of-light and is the resonant frequency of the via stub.

When the resonant frequency is approximately equal to the Nyquist frequency, one or more frequency components, of a signal transmitted through the via, can be strongly attenuated which causes the impedance of the via drop. And although, it seems high enough to be outside consideration for most designs, the affects actually start to come into play above

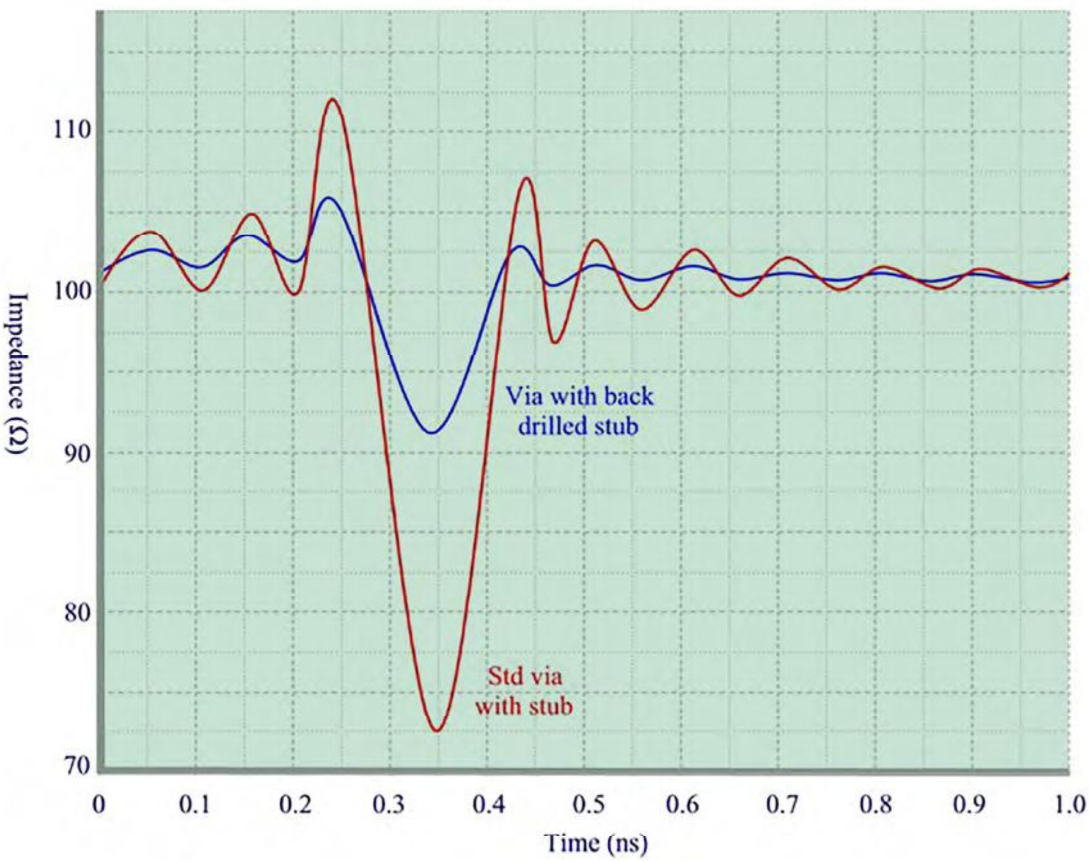

Figure 2: Differential 100Ω via with stub (red) vs. via with back-drilled stub (blue).

1GHz and become an issue at around 4–5GHz in most cases. This attenuation limits bandwidth. Figure 2, illustrates the impedance of a standard PTH via compared to a back-drilled via stub as displayed on a Time Domain Reflectometer (TDR). In the case of a high-speed backplane, the effects are even more dramatic as the Nyquist frequency can be in the order of 5GHz, for a 250-mil substrate, and the impact can be evident at 1GHz.

As mentioned, vias can appear as capacitive and/or inductive discontinuities. These parasitics contribute to the degradation of the signal as it passes through the via. One approach is to break each segment of the via into small discrete inductance and capacitance elements corresponding to each section of the barrel interacting with the planes and with each other. With this method, it is difficult to achieve an accurate result because the fields are inherently fringe field dominated. Also, matching discrete elements to overlapping fringe fields is difficult.

Figure 3 shows a simplified lumped LC π model (without non-function pads) to illustrate via capacitance and inductance affects. Although this model is only applicable if the delay of the via is less than 1/10th of the signal rise time, it is still useful for understanding the capacitance and inductance affects. The attenuated phase-shifted signal (red) shows the degradation effects of the via stub, whereas the back-drilled via (blue) has an undistorted, broader signal.

Channel discontinuities can emanate from several sources and each of these must be carefully considered. One commonly overlooked cause is the signal via. Vias can add jitter and reduce eye openings that can cause data to be misinterpreted by the receiver. Length is the primary factor that influences the inductance of the via, which depends on the design complexity, the number of layers, and hence the overall PCB thickness. The length of the PTH via is the same as the overall thickness of the PCB. A typical high-speed PCB design ranges from 1.0 mm to 1.8 mm. For more complex designs, backplanes and military rugged applications, the PCB thickness can go above 3 mm. Given the increasing complexity of high-speed digital design, PCB thickness is expected to increase due to higher layer count. In order to mitigate the effects of the via stub, we need to:

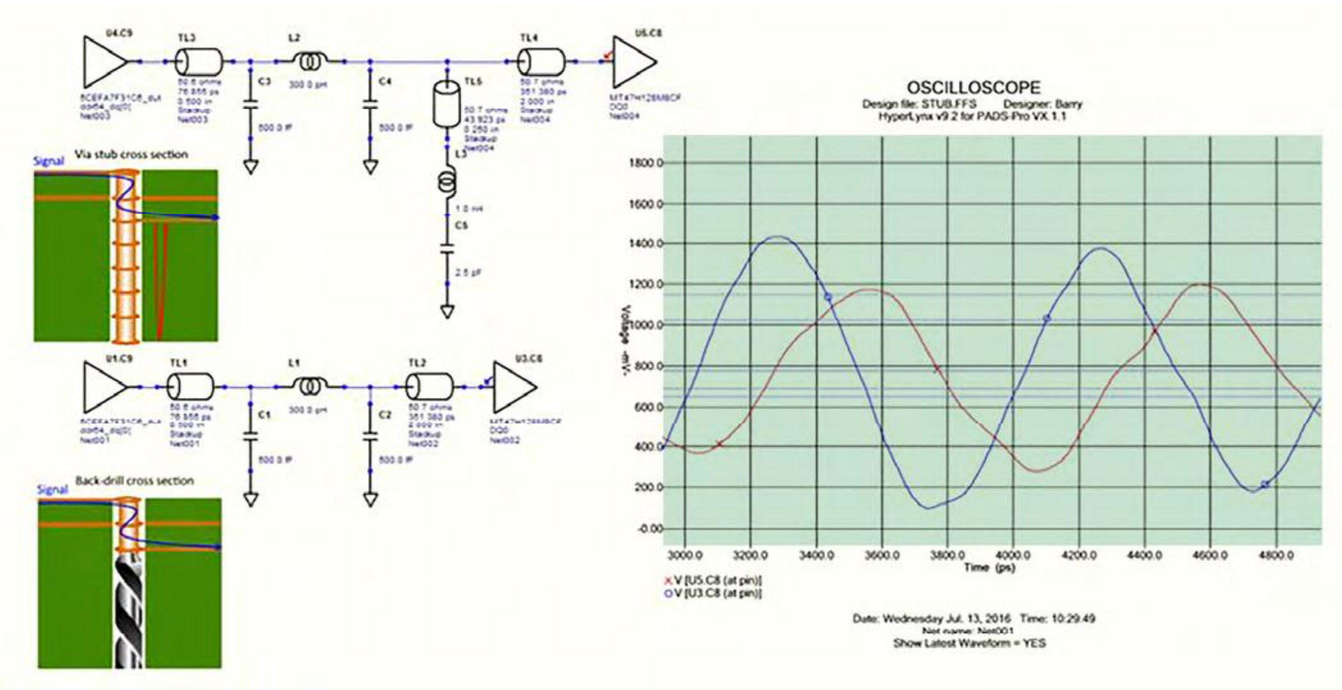

Figure 3: Simplified LC Pi model of via with and without the stub simulated in HyperLynx.

Minimize the via inductance by
• Eliminating or reducing stubs
• Reducing the via barrel length

Minimize the via capacitance by
• Reducing the pad size
• Removing non-functional pads
• Increasing the antipad size

There have been a number of solutions put forward to alleviate this issue including:

• Back-drilling the stub
• Using blind vias
• Removing non-functional pads
• Increasing the antipad diameter
• Terminating the stub
• Lowering the surrounding dielectric constant
• Plating the via barrel with a lossy material

Next month, in Part 2 of this series, I will look into the possible solutions to alleviate this issue, including tuning methods to make the vias more transparent to faster edge rates are evaluated. Via trade-offs are also examined because of manufacturability concerns of higher oven temperatures associated with the recent switch to restriction of hazardous substances (RoHS) processes. Finally, general guidelines and recommendations will be made to show how to design an optimized the vias for better high edge-rate signal transmission will be discussed.

Points to Remember

• Dangling via stubs distort signals passing through an interconnect and also decrease the usable bandwidth of the signal.

• A via stub acts as a transmission line antenna, and has a resonant frequency determined by the quarter wavelength of the structure.

• It is fine to have a plated through-hole (PTH) via providing the signal goes in at one end and out at the other using the entire length of the barrel.

• The Nyquist frequency of a discrete signal is defined as one-half of the sampling rate of the signal. The impedance of the via stub drops at this frequency.

• The resonant frequency of the via stub is inversely proportional to the dielectric constant of the material surrounding the via with a wavelength of four times the length of the unused portion of the via. **PCBDESIGN**

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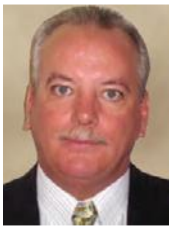

Barry Olney is managing director of In-Circuit Design Pty Ltd (ICD) Australia. The company is a PCB design service bureau that specializes in board-level simulation. ICD has developed the ICD Stackup Planner and ICD PDN Planner software, which is available here.

Chemical Sensing at Telecom Wavelengths

Lasers operating at the wavelength of 1,550 nanometers power high-speed fiber-optic Internet communications. MIT Microphotonics Center Principal Research Scientist Anuradha Agarwal is developing chemical sensors based on this wavelength using a new materials system built of silicon carbide on silicon dioxide on silicon.

Ashley Del Valle Morales, a junior at the University of Puerto Rico at Mayaguez, will test the silicon carbide-based sensor before and after it is exposed to gamma rays.

Del Valle says, "I know it's really important to select a project you like and you're interested in. I also liked the enthusiasm and the interest that the grad students and the principal research scientist showed."