When Signal Integrity Matters

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I recently served on a panel where I was asked, "At what point does signal integrity become a problem?" The intent of the question was to ask at what **frequency** did signal integrity become an issue for board designers, but as stated, the question was more general. And that got me thinking about how broad the term "signal integrity" really is, even though we have come to think of it terms of more narrowly defined high-speed issue.

A not-really-facetious answer to the question is that we have a signal integrity problem whenever the signal begins to lose its integrity! And this is not related to frequency. Two of the more obvious and common ways a signal can lose integrity are when it becomes distorted or when the signal-to-noise ratio (S/N) begins to degrade.

Signal distortion typically means that the waveform of interest begins to change shape. The degree that this can happen before it becomes a problem depends very much on the application. Digital signals, which we typically think of as being rectangularly shaped pulses, usually carry one bit of information per clock cycle. They can often withstand a fair amount of distortion without obscuring the bit-state they are in. Analog signals, on the other hand, such as we find in video and audio systems, can be very sensitive to distortion. A change in the waveform will often be seen or heard. Your home hifi system, for example, probably has a spec for harmonic distortion, which relates to the "purity" of the audio signal as it is processed.

I my lifetime, home entertainment harmonic distortion specs have improved greatly, and today's hifi and home entertainment systems are, for all practical purposes, distortion free. The most common way to make a distortion-free system is to design it so that the gain is absolutely linear over the frequency range of interest.

S/N issues come into play whenever an unwanted noise becomes detectable and/or interferes with the signal we are concerned with. For example, if you hear a 60 Hz hum (which is, of course, a very low frequency) from your home hifi system, you have a S/N or a signal integrity problem! And signal integrity issues and solutions are not new. People who have spent part of their careers designing power or electromagnetic switching systems have understood the importance of decoupling and separation of power supply and grounding systems for decades. Problems associated with reflections, and their transmission line solutions, have also been around for years. Radio frequency engineers (even with "low" AM transmitting frequencies below one MHz) have needed to understand transmission line techniques since the broadcasting industry began. Signal integrity issues at the circuit design level have been around for a long, long time.

In our industry, (circuit board design) we have come to equate "signal integrity" with "high speed" only in recent years. That is because up until now the circuit board has been a purely passive device with virtually no circuit impact (unless you were among the very few designers putting RF or microwave circuits on the board.) But in recent years, the board itself has begun to cause S/N degradation. Here's why.

Frequency components (as opposed to the frequencies themselves) have steadily increased through the years. Consider what we typically view as a square-wave clock or data signal **(Figure 1)**. If we "disassemble" a square wave we find that it really is the complex sum of an infinite series of sine (really cosine) waveforms. The formula for this series is given in the caption to the figure. Each term in the series represents a higher frequency (harmonic). To **perfectly** represent a square wave, our circuit must faithfully pass all these frequency components (harmonics) without any additional distortion or phase shift. **Figure 2** shows the degree of degradation caused by limiting the system bandwidth to just the first few harmonics.

Clock and signal "square waves" are never "perfect." They are really characterized by a rise time. (Footnote 1) It can be shown that the highest frequency component we usually need to be concerned with (in a practical sense) on our board can be approximated by $1/(3*T_r)$, where T_r is the rise time of the pulse. Thus, to reproduce a one nanosec-

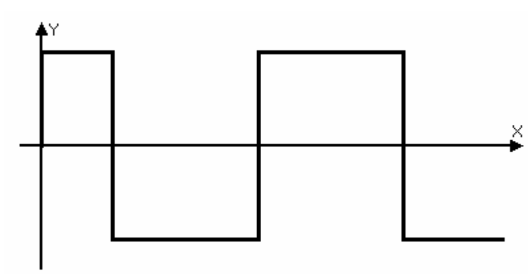

Figure 1
The formula for a square wave is given by the infinite series Y=cos(wt)-cos(3wt)/3+cos(5wt)/5-cos(7wt)/7 … (etc.) where w = 2*Pi*f, f is the cyclical frequency, t is time, and Pi is the constant 3.14159

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ond rise time pulse typically requires a system bandwidth of something over 300 MHz.

Back to our boards. Let's use inductance for our illustration. Traces have **always** had inductance. That is important for new board designers to understand. The fact that there is inductance associated with the trace is not new. The voltage generated across an inductor can be approximated by $V = L*di/ T_r$, where L is, in this case, the inductance of the trace, di is the change in current being switched, and T_r is the rise (fall) time associated with the switching current. V gets larger as (among other things) T_r gets smaller. V can be considered a noise voltage. Thus, the S/N ratio gets worse as V gets bigger (or, as T_r gets smaller!). Therefore, signal integrity gets worse (because the S/N ratio degrades) as T_r gets smaller (i.e. rise time gets faster.)

This illustration used inductance. We can use stray trace capacitance to illustrate exactly the same point. There is stray (parasitic) inductance and capacitance all over our boards.

So, back to the initial question: "At what point does signal integrity become a problem." For board designers, the answer is: When the rise time decreases to the point where the parasitic inductances and capacitances on the board begin to result in noise signals that become troublesome. And when is that? Well, it depends, of course, on the circuit specifics, so it is very difficult to generalize on a specific value. But for the most part, this can happen in the range of 2 nanoseconds or so, and faster. These rise times are sometimes (but not always) associated with high frequencies. Therefore, signal integrity issues on our boards have become associated with high frequency signals on our boards. But it is important to recognize, first, that signal integrity issues are not necessarily related to frequencies and rise times, and secondly, when they are it is usually rise time that is the culprit, not frequency.

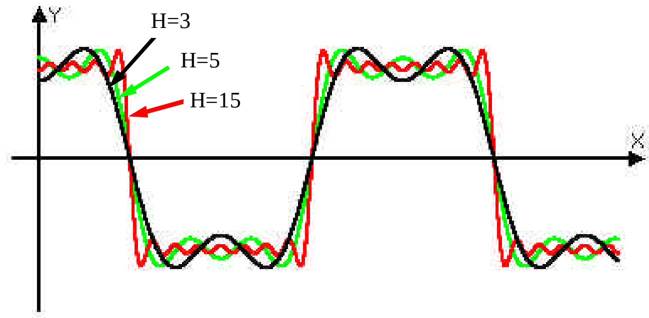

Figure 2
The curves look more like square waves as the number of harmonics in the series (H) increases.

Footnotes:

1. Rise time is usually defined as the time required to transition between the 10% and 90%, or sometimes 20% and 80%, amplitude points on the waveform. Fall time is similarly defined, and is equally as important.