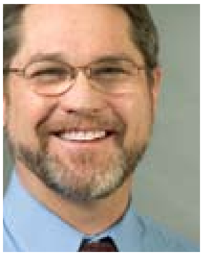

BY HOWARD JOHNSON, PhD

Uncertainty principle

The uncertainty principle that German physicist Werner Heisenberg made famous in 1927 asserts the improbability of knowing with complete precision the position and momentum of any subatomic particle. According to Heisenberg, you may in some cases know the position quite well, or, in other cases, know the momentum—that is, the velocity—quite well, but there are limits to the accuracy of simultaneously knowing these two independent properties. Heisenberg's principle slammed shut the door on older, particle-oriented, deterministic interpretations of physics, making way for a new generation of quantum-mechanical understanding.

In the language of quantum-mechanical-wave functions, author Enrico Persico puts the principle like this: "The smaller the extent of a wave packet in space, the wider must be the distribution of propagation vectors of the wave trains composing it" (**Reference 1**). In that form, you may recognize the uncertainty principle as a relation between the time domain (physical length) and the frequency domain (spectral width) of a wave packet.

The proof of the uncertainty principle rests on properties of the Fourier transform that apply just as well to electrical engineers as to physicists. In the high-speed-digital world, the uncertainty principle translates as, "The shorter the duration of an event in time, the wider must be the spread of frequencies associated with it."

The principle stipulates an inescapable relation between time and frequency, but the large number of ways to define the terms "signal duration" and "signal bandwidth" makes that relation somewhat fuzzy.

Regarding measures of rising-edge duration, you might define the rise time of a digital signal at its 20 to 80% points, whereas your buddy uses the 10 to 90% points. Other persons might draw a line tangent to the rising edge at some point (the midpoint?) and interpret the rise time from that measurement. A mathematically inclined individual might differentiate the signal (turning each step edge into a brief pulse) and then compute the rms duration of each pulse amplitude. A physicist would square her signal, forming a power waveform, and then use the rms duration of the power waveform.

Regarding bandwidth, you can choose between the −3-dB and the −6-dB point, or perhaps you can choose the "equivalent noise-power bandwidth," which is the bandwidth required to pass a specified amount of white-noise power. A physicist computes the Fourier transform of her signal, squares it (making a power spectrum), and then evaluates the rms width of the squared power spectrum.

Each of these definitions—and this is not a complete list by any means—was created to solve a specific problem. For example, the combination of the rms duration of a power waveform and the rms width of the associated squared-power spectrum forms the basis of Heisenberg's principle.

Each measure is slightly different, yet they all exhibit a common behavior: Regardless of the model, shrinking the signal duration in time always increases its bandwidth.

If I could, I would give you an easy means of translating from one measurement standard to another. Unfortunately, a precise translation exists only if you precisely specify the signal shape. For gaussian shapes, the translations between forms of measurements all just involve simple scaling constants. (For example, the product of 10 to 90% rise time and 3-dB bandwidth is 0.338 Hz.) That simplicity explains, in part, why mathematicians love gaussian shapes; the math works out so neatly. For other signal shapes, the translations differ, sometimes markedly (**Reference 2**).

Small details of measurement technique can influence the result. If your data sheet calls out a 20 to 80% rise/fall time, does that mean 20 to 80% of full-scale or just 20 to 80% of the effective signal swing under loaded conditions? What are the loaded conditions? With what bandwidth probe was the signal measured?

With attention to details of measurement technique, I hope you can improve the consistency and reduce the uncertainty in your design process. EDN

REFERENCES

1. Persico, Enrico, *Fundamentals of Quantum Mechanics*, Prentice-Hall, 1950, pg 118.
2. Johnson, Howard, *High-Speed Digital Design: A Handbook of Black Magic*, Prentice-Hall, 1993, pg 399.

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