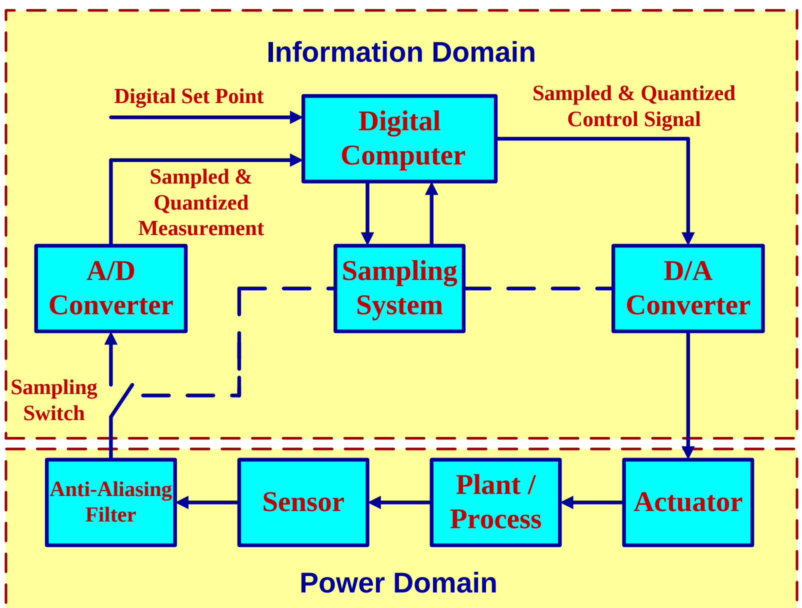
From The Real World to The Digital World

Digitization (Sampling and Quantization) is Universal and Essential in Engineering

When I wrote the April 2008 column entitled "Mama Don't Take My Kodachrome Away," I focused on how the image sensor of a digital camera was replacing film, never thinking that in 2011, even if you had a roll of that film, you could not get it developed anywhere in the world! Yet, that is what has happened. On December 30, 2010, at Dwayne's Photo in Parsons, Kansas, the last rolls of Kodachrome film in the entire world, with all those "nice bright colors," were processed. This is hard to believe, yet it is true, and it dramatically shows how digital the world has become. But how many people, engineers included, really understand the difference between the analog and digital worlds and the key issues involved in going from one to the other? For some it is just a curiosity, but for all engineers, it is an absolute necessity.

Why do wagon wheels in a movie sometimes appear to rotate backward while the wagon is actually moving forward? When you hear music in the background while on a cell phone, why does the music sound flat or distorted? The answers to questions like these are found in understanding the fundamental concepts of digitization – sampling, aliasing, and quantization.



The diagram shows a computer-controlled system and the interface between the analog power domain and the digital information domain. Digitization, or analog-to-digital (A/D) conversion, is the act of converting an analog signal – continuous in both time and amplitude – to a digital signal – discrete in both time and amplitude. Discrete values in time are the result of sampling an analog signal and discrete values in amplitude are the result of representing those values using a finite number of bits (quantization). There are a few fundamental concepts that every engineer needs to understand very well. Fourier showed that any waveform that exists in the real world can be generated by adding up sine waves of different amplitudes, frequencies, and phases, and that representation is unique. And Nyquist showed that a sampled signal can be converted back to its original analog signal without any error if the sampling rate is more than twice as large as the highest frequency of the signal. The digital-to-analog (D/A) converter accomplishes that task.

If this Nyquist Sampling Theorem is violated, an inevitable, irreversible effect called aliasing results. Aliasing cannot be completely eliminated, only reduced with an anti-aliasing analog filter before sampling takes place. The effect of aliasing is that frequencies above the Nyquist frequency (½ the sampling frequency, also called the folding frequency) are folded back into the useful frequency range and appear indistinguishable from the real signals. For example, a tone 1 KHz above the Nyquist frequency will fold back to 1 KHz below, while a tone 1 KHz below the sampling frequency will appear at 1 KHz. The control system will respond to both signals – real and fictitious. The anti-aliasing filter will limit performance because of time delay, but the effects of aliasing are much worse.

The accuracy achieved in a digital memory device depends on the number of bits used for storage of each sample. Quantization is the process of changing the sample values to discrete levels and results in errors called quantization noise, because the effect sounds like noise in a digitized music signal and looks like noise in a digital image. The measure of the relative size of quantization noise is called the signal-to-noise ratio (SNR) and it is given by a simple formula $SNR = 2^B$, where B is the number of bits used to store samples.

Yes, everything is going digital, but like Kodachrome film, I hope all these digital devices can "make you think all the world's a sunny day." We all need that!

Kevin Craig
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