BY HOWARD JOHNSON, PhD

The shot heard 'round the world

Professor Wallace Clement Sabine removed a cheap, nickel-plated pistol from his waistcoat, raised the weapon above his head, and pulled the trigger. An earsplitting crack washed over the auditorium, penetrating every crevice. The sound reverberated wildly for eight full seconds, passing back and forth across the room some 50 times or more. As the echo slowly died out, the professor turned to face his audience. Wiggling a finger finger in one ear, he began to lecture, "There we have the impulse response of a Gothic cathedral."

The year was 1898, and Sabine was just developing his theory of acoustics—a theory that has since influenced the design of every great symphonic-performance hall. Sabine asserted that the most significant parameter is the reverberation time. He further stated that, with only two constants, you can predict in advance of construction the expected reverberation time.

The two constants you need are, first, the average fraction of acoustic power reflected at the boundaries of the room. Next, you must know the mean time required for acoustic waves to transit the structure.

For example, if the average attenuation coefficient for waves bouncing off the walls, ceiling, and floor is 2 dB, then it probably takes on average about 30 bounces for the sound to die down to a level 60 dB below the source. If the mean time between bounces (the mean transit time) is *T*, then the 60-dB reverberation time, RT_{60}, equals 30*T*. In general, given a reflection coefficient, *r*, expressed in decibels, the 60-dB reverberation time equals $(60/r)T$. The remainder of Sabine's theory refines that basic idea with a little algebra.

The most significant parameter (in performance-hall design) is the reverberation time.

Let's apply Sabine's theory to a digital problem. Assume a simple, unilinear transmission path. Sabine would define the time required for reverberant signals to damp down to a level *x* dB below the source signal level as $RT_x=(x/r)T$, where *T* is the round-trip delay, *x* is the required level of damping in units of decibels, and *r* is the round-trip attenuation coefficient in decibels. Coefficient *r* includes the sum of attenuation coefficients at either end of the transmission line plus the round-trip attenuation of the transmission line itself. In a highly reverberant system, the formula RT_x predicts how long you must wait after each data edge before the line settles to an acceptable degree.

In a hairball network with many interconnected nodes, the same theory applies but with a slightly different interpretation. Coefficient *r* represents the average attenuation at each discontinuity, and *T* becomes the average transit time between discontinuities.

Regardless of the topology, the expression for RT_x, because it contains three terms, supplies three basic ideas for improving signal quality:

- Reduce *x*. Single-ended logic with widely spaced V_{IH}/V_{IL} (high-input-voltage/low-input-voltage) thresholds typically requires damping of at least $x \geq 20$ dB. Differential logic, because it has tighter input-threshold specifications and thus larger percentage-voltage margins, can work with less damping. By analogy to the acoustic world, it is easy to design a building for listeners who do not require perfect acoustics, such as rock 'n' roll fans who don't mind massive reverberation.
- Increase *r*. Intentional terminations at one or both ends of a transmission line dramatically increase the round-trip attenuation. Sabine would advocate draping a large room with heavy curtains and using well-padded seats to damp reflections. Nowadays, large buildings incorporate acoustic ceiling tiles and thick carpet.
- Decrease *T*. Shrink the line length or change the dielectric constant. Lowering the dielectric constant slightly speeds signal propagation, decreasing *T*. Both ideas help. Acoustically, Sabine's equation teaches that large rooms are more difficult to control and that a large room constructed at the top of Mount Everest would be the most difficult of all due to the low temperatures and thus relatively low speed of acoustic propagation.

Come to think of it, if I decide to build a symphony hall at the top of Mount Everest, just shoot me. **EDN**

Howard Johnson, PhD, of Signal Consulting, frequently conducts technical workshops for digital engineers at Oxford University and other sites worldwide. Visit his Web site at www.sigcon.com or e-mail him at howie03@sigcon.com.

⊞ **www.edn.com/signalintegrity**