BY HOWARD JOHNSON, PhD

Why reflections happen

Throw a rubber ball hard against a concrete wall. The ball bounces. You have just experienced a reflection. Reflections happen in propagating systems at those points where the conditions of propagation change.

The best way to understand reflections is to track the movement of energy. When the ball reaches the wall, it cannot continue on its original course. Neither can the ball simply stop, because the energy associated with its incoming path cannot just disappear; it must go somewhere.

Nature solves this problem by dividing the incoming energy among the available outgoing modes of propagation. Those modes include the ball's retreating along its incoming direction, an acoustic wave (bonk!) generated in the air, a slight movement of the concrete wall, and a residual thermal agitation of both rubber and concrete.

The proportions of energy contained in each outgoing mode are determined by the law of conservation of momentum in combination with the various properties, called boundary conditions, of each individual outgoing mode. The reflecting-ball problem is tricky, because the ball can arrive at any incident angle, it can carry spin, and there are multiple avenues for energy dissipation.

A transmission line supports only two modes of operation: A signal either goes straight down the line in one direction or comes back in the other. That's it. In a typical digital application, no other modes of operation are possible. When a traveling wave encounters a load at the end of a transmission structure, only three entities are involved: the incoming power, the fraction of that power that is dissipated in the load, and the remaining power, all of which reflects back toward the source.

The solution to the problem of allocating power among those three modes is the highly vaunted "reflection coefficient" formula, which is used to predict the size of a reflected signal:

$$\frac{V_R}{V_I}=\frac{Z_L-Z_C}{Z_L+Z_C}.$$

The reflection formula expresses the ratio of reflected voltage to incident voltage, as observed at the end of a transmission line, computed as a function of the load impedance at the end, Z_L, and the characteristic impedance of the transmission line, Z_C.

If the end of a transmission structure is left open-circuited, making an infinite load impedance, that load draws no current and therefore dissipates zero power. In that case, 100% of the incident power reflects, creating a reflected signal just as large as the incident waveform. If you imagine electrical current as being loosely analogous to physical velocity in the rubber-ball example, the concrete wall did the same thing. When struck, the wall hardly moved, absorbing very little energy, and thereby reflecting almost perfectly.

If you reduce the endpoint load impedance to successively lower values, the load begins to draw more current, dissipating more power and creating a progressively weaker reflected signal. In the physical world, you can test that idea by throwing your ball at three things: a wooden fence, a wall of hay bales, and a wet sheet hanging out to dry. When the mechanical impedance of the wall best matches the physical properties of the ball, the ball reflects least strongly.

Electrically, a load impedance that completely absorbs all incoming power creates zero reflection. That is the ideal arrangement for an end terminator. That particular impedance, if you can find it, is defined as the characteristic impedance of the transmission structure. There is no other definition. All formulas for characteristic impedance are merely approximations of this ultimate meaning. **EDN**

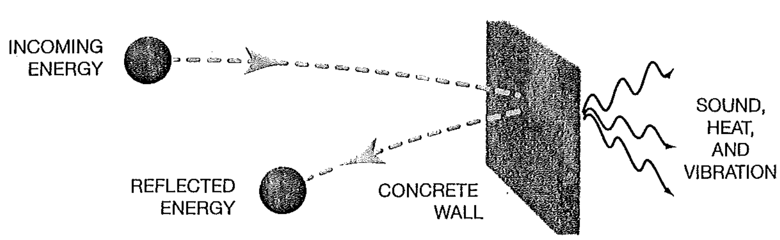

Figure 1 The wall converts a portion of the incoming energy into sound, heat, and vibration.

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