



BY HOWARD JOHNSON, PhD

## Driving-point impedance

In **Figure 1**, cut the PCB (printed-circuit-board) trace at its left end, disconnecting it from resistor  $R_0$ . Measure impedance  $Z_1$ , the impedance looking from your cut to the left back toward the driver. If the resistor is sufficiently close to the driver and there are no other impairments, you should see just the natural output resistance of the driver,  $R_S$ , plus the external series resistor,  $R_0$ .

In the terminology of circuit theory, you just measured the driving-point impedance of the circuit to the left of the cut. The circuit to the right is the circuit load.

In this example, assume  $R_S + R_0$  equals the characteristic impedance,  $Z_0$ , of the perfect, lossless transmission line. That arrangement forms a perfect termination at the driver location. The perfect termination at the driver will absorb any signals reflected from the right end of the net, traveling back to the left. Such a circuit is known as a series-terminated net.

On the same PCB trace, repair your first cut and then make a second mea-

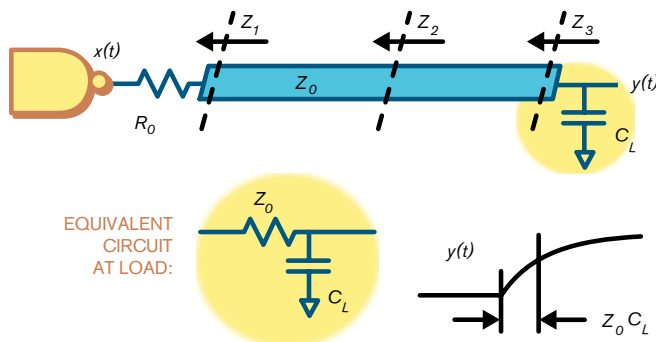
### The endpoint effect delays the received signal in a predictable way.

surement of driving-point impedance, this time cutting the circuit in the middle. Do you suppose that  $Z_2$  differs from  $Z_1$ ? How could it? When making this measurement, every signal you inject travels to the left only to meet its death at the driver termination. Nothing reflects. No experiment reveals any information about the distance to the driver. In other words, because

of the perfect source termination, the distance to the driver does not and cannot affect your driving-point impedance measurement. In a perfect series-terminated architecture, you can measure the driving-point impedance at the driver, in the middle of the line, or 100 miles away—assuming a perfectly lossless transmission line; the measurement always returns the same number,  $Z_0$ .

I raise this topic because the driving-point impedance at the end of the line predictably distorts the received signal at the endpoint. Knowing that the driving-point impedance,  $Z_3$ , equals  $Z_0$ , a nearly pure resistance, you may recognize that the driving-point impedance, working in conjunction with the load capacitance, forms a simple RC lowpass filter. That filter disperses each rising and falling edge, imposing an additional delay on the circuit. The group delay of the endpoint filter for a series-terminated line equals  $Z_0 C_L$ . For the special case of a series-terminated line, the same group-delay calculation applies regardless of transmission-line length.

The overall time of flight for a series-terminated net equals the raw, unloaded propagation delay of the transmission line plus the group delay of the RC endpoint effect. That simple calculation estimates the time of flight from the signal midpoint at the driver to the signal midpoint at the receiver. **EDN**



**Figure 1** Cut the trace at any point to measure its driving-point impedance.

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