 By Howard Johnson, PhD

Differential U-turn

Q: *What is the effect of a split in a solid plane on the impedance of a coplanar differential pair? The differential pair passes over a solid plane (logic return) and then crosses a 50-mil void into an I/O area that has a solid plane of its own that is tied to the chassis.—Boris Shusterman*

A: Significant current flows on the solid reference planes beneath your differential traces. Cutting the plane interrupts these currents.

Consider first a single-ended pc-board trace. When a changing voltage propagates down a *single-ended* transmission structure, currents flow through the distributed capacitance of the trace to all nearby objects, especially the big, solid plane underneath the trace. This capacitive effect generates a returning (reverse) flow of current on the solid reference plane. The return current flows all the way back to the source along the reference plane, staying underneath the signal trace the whole way, making a complete circuit. (Current always makes a loop.)

Now, consider a differential-pc-board-trace pair. Differential structures have capacitance from each trace individually to the reference plane and also *between* the traces. The between-trace, or "mutual," capacitance of the differential pair induces returning current on the other trace, as well as on the solid reference plane. In a differential pc-board pair, most of the returning current from each trace still flows on the solid plane, not the other trace, because each differential trace couples much more strongly to the big, solid nearby plane than it does to its little, skinny differential buddy.

Try to visualize the propagation of a differential signal as a quad of four currents: two currents, i+ and i−, on the two signal traces and, the returning currents, r+ and r−, on the reference plane underneath the traces (**Figure 1**). In most cases, the currents are almost as big as i+ and i−.

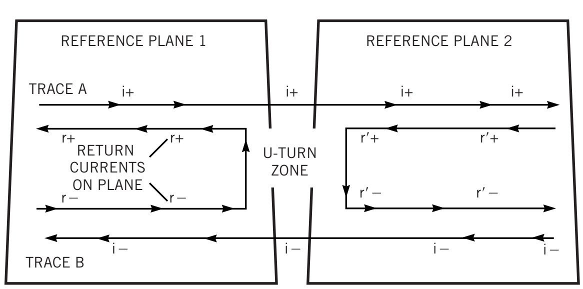
When a differential signal encounters the gap between reference planes, the two signal currents continue across the gap on the signal wires, but the gap blocks the two return currents, r+ and r−. This situation forces the return currents to execute a U-turn maneuver, whereby each return current U-turns into the other position. On the new reference plane, a similar effect takes place with a second U-turn formation creating a pair of currents r′+ and r′− to complete the quad.

At the boundary between reference planes, the U-turn zone separates the return currents from their primary signal currents. Electromagnetically speaking, the U-turn zone forms a small current-loop antenna, which generates a substantial, fast-changing magnetic field near the U-turn zone. The magnetic-field makes the circuit behave as if an inductor were in series with the signal path. The length and width of the U-turn zone determine the inductance. For example, a trace-to-trace separation of 0.100 in. and a plane-to-plane separation of 0.100 in. would generate an inductance of about 10 nH, which, in a 100Ω differential system, would introduce a lowpass-filter response with a time constant of 100 psec. If rise time exceeds 1 nsec, you probably won't even notice the effect. On the other hand, at very high speeds, a 100-psec rise time could mess up your signals.

The U-turn zone is more than merely a region of increased impedance due to the absence of the reference planes. It is an effect whose physical dimensions span both the gap between planes and the spacing between traces. You eliminate the U-turn problem by shrinking *both* the reference-plane gap and the spacing between traces.

The magnetic fields from the U-turn zone also induce crosstalk and EMI. The crosstalk couples all the differential pairs that pass over the same gap. The EMI varies, like problems with crosstalk and inductance, in proportion to the size of the U-turn zone. The presence of any common-mode signals that might result from a poorly balanced or highly skewed driver greatly magnify all problems associated with reference-plane gaps.□

Figure 1



The U-turn zone at a reference-plane gap separates the return currents from the primary signal currents on traces A and B.

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