CONNECTOR
SPECIFIER

Forms of shielding take sides: air vs. plastic

There are two different types of shielding technology in backplane connector design: those with plastic and those without.

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Is a high-frequency backplane connector without shields possible? Can virtual grounds do the job of real grounds? Is air or plastic a better insulator? What performance trade-offs are involved in these design choices?

Connector design is a complicated balancing act. Each decision about the various pieces of metal and plastic that make up a connector system simultaneously affects such aspects of performance as mechanical strength, reliability, signal integrity, packaging density, ease of use, ability to upgrade, component cost, system cost, and long-term cost of ownership. Connector designs, which try to improve performance in one area by sacrificing elsewhere (reliability, for example), are often out of balance in practice. Taking an overly narrow component view rather than a system view of connector design requirements can also lead to imbalance.

Air versus plastic

Consider the difference between air and plastic as the principal insulating material within a connector. Signals traveling in air experience lower dielectric loss and delay than signals traveling in plastic, but this is relatively insignificant for a connector that represents a short portion of the overall signal path. In fact, a certain amount of loss within a connector can actually smooth the overall amplitude and phase response of high-frequency-interconnect channels by reducing the effects of multiple reflections.

In RF and microwave measurement, attenuators inserted at various points in a test setup smooth the frequency response of a complex interconnection path. In a digital system, such reflections typically result from via stubs, signal path transitions in plated through-holes, SMT pads, and vias at either end of a connector, and from differences in characteristic impedance between the two different boards. Careful connector design can reduce reflections from these sources, but never entirely eliminate it, due to printed-circuit-board manufacturing tolerances and various conflicting design requirements.

A desire for lower signal attenuation and delay in the connector portion of the overall system signal path should be balanced with the need for mechanical strength and robustness of design. Because air does not add mechanical strength, using air as the primary insulator can result in a more fragile connector. A weaker connector may not cause problems in a laboratory environment, where it is handled with care. However, the real-world backplane application environment is a tough one, and requires a connector that can consistently handle mismating, dust, board deflection, and other challenges to reliable, repeatable performance.

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Because air has a lower dielectric constant than plastic, an air-based design may require closer spacing of adjacent uninsulated signal and ground conductors than a comparable plastic-based design in order to achieve the desired characteristic impedance values of 50-Ω single-ended or 100-Ω differential. The lack of solid insulation between different electrical conductors over substantial lengths in a connec-

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tor can increase the chances of shorting, due either to contamination with dust or to contact bending under conditions of stress encountered during handling of loose connectors, connectorized module cards, pressing of connectors into boards, solder reflow, thermal cycling, or mating of connectors under worst-case misalignment conditions. The additional costs of requiring tighter tolerances on card-cage hardware and board deflection to prevent damage to a more fragile connector can be significant.

In the 1970s and early 1980s, the typical board-to-board connector consisted simply of multiple rows of signal pins. In these open pin-field connectors, various signal pins served as ground returns to control electrical crosstalk and voltage reflections within a certain range. The grounded pins served as electrical shields by isolating signals and differential signal pairs from each other. Starting with a typical 0.100" pitch four-row and assigning 20% to 50% of the pins to ground yielded a density of 20 to 32 signals per linear inch.

In 1983, the industry saw the launch of the first backplane connectors with specialized external ground/power-shield conductors designed to lower simultaneous switching noise and improve signal integrity in the form of the HD-Plus platform. Various manufacturers introduced internally shielded connectors in the 1980s and early-to-mid 1990s, such as the Z-Pack SL100, HDM Plus, and HM shielded. (see Fig. 1)

During the late 1990s, dramatic system-driven changes in backplane data-transmission architectures involved greater use of differential-pair signals and point-to-point interconnections, which together enabled much higher data rates. In response, new generations of internally shielded backplane connectors were introduced that incorporated various patented internal-shield configurations.

Virtual versus real grounds

In the course of ongoing competitive efforts among connector vendors, the older unshielded configurations (in which the physical ground shields are signal-type contacts assigned to function as ground returns) were examined for ways of extending their original levels of performance. Besides the grounding of signal pins, the more widespread use of differential signals effectively added virtual grounds to various levels of system interconnection.

The general idea of virtual grounds is not new. Any symmetrical and oppositely driven conductor pair acts as if there is a virtual ground plane located midway between them, according to the theory of electrical images. For this reason, a differential pair of signals effectively carries its own virtual ground plane. The presence of this virtual ground "shield" is due to field cancellation.

FIGURE 1. The Ventura connector features an internally shielded surface-mount design with up to 1400 shielded single-ended signals, or 700 differential pairs in 222 mm of length, including guidance features.

A second type of cancellation can occur at the differential receiver input when crosstalk noise is picked up by a differential pair in a symmetrical fashion, with each half of the pair picking up the same amplitude and sign of noise. Benefits due to cancellation effects, however, rely on maintaining sufficiently tight tolerances in silicon, packaging, and system design and construction. Such requirements are necessary to provide adequate symmetry and balance of the timing and amplitude of the two "halves" of each transmitted differential signal, electrical balance of each pair of signal lines, including differential delay, and adequate noise-canceling or common-mode rejection characteristics at the receiving device.

Neither aspect of virtual grounds or noise cancellation will work for single-ended (or ground-referenced) signals, and only the perfectly balanced part or odd-mode component of differential signals will benefit from this approach. Real-world differential signal pairs include an unavoidable unbalanced, "even-mode," or "common-mode" component which acts like a single-ended signal, because it depends upon physical ground return paths, and does not benefit from virtual ground. Certain arrangements of conductors that reduce differential-pair to differential-pair crosstalk through cancellation effects may actually increase common-mode crosstalk coupling, as well as increase various kinds of mode-to-mode conversion.

For this reason, connector and system designers should not rely on cancellation effects alone. Even from a theoretical viewpoint, the cost of requiring sufficiently tight tolerances on silicon and interconnect to guarantee lower in-pair skew can be substantial. Moreover, as data rates continue to rise, the challenge and cost of maintaining perfectly balanced silicon and interconnect in a large system will increase.

Real-world examples

Connectors with physical shields also benefit from virtual ground effects when used with differential signals, but can be designed to provide enhanced margins for real-world system tolerances by taking advantage of both real grounds, as well as the cancellation effects possible with differential pair signals. As an example, consider a surface-mount connector designed with integrated internal physical shielding. A 14-row version of this connector accommodates 1400 shielded single-ended signals, or 700 differential signal pairs, with wide-band performance to 10 GHz in either case.

The electrical benefits provided by internal physical shields are born out in laboratory measurements of the connector. Including the effects of this connector plus the real-world contributions of SMT pad footprints on 0.080"-thick FR-4 test boards, and of 12-mil diameter through-vias with 0.020" signal stubs, measured single-ended transmission is smooth and resonance-free out to 10 GHz. Single-ended attenuation is less than 2 dB out to 6 GHz, which is the mid-band frequency for 12 Gbit/s transmission. Single-ended, multi-line forward crosstalk is more than 13 dB lower, and multi-line backward crosstalk is more than 16 dB lower

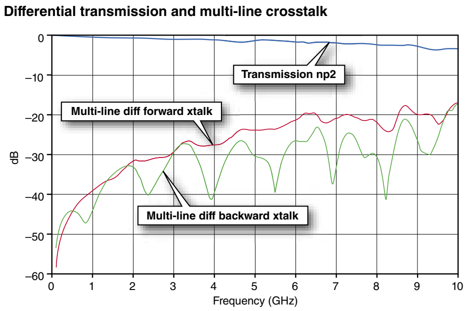

FIGURE 2. Measured single-ended transmission and multi-line crosstalk (forward and backward, 0 to 10 GHz) of the longest row signal path in a 14-signal-row Ventura connector includes the effects of SMT pads and 12-mil through-vias.

than the transmission over the same frequency range (see Fig. 2).

When the same connector and test boards are measured with differential pair signals, signal-to-noise is improved by the added benefits of virtual grounding and differential cancellation. The result is differential multi-line forward crosstalk 20-dB lower, and multi-line backward crosstalk 25-dB lower than transmission up to 6 GHz (see Fig. 3).

Taking the system view for connector design requirements results in a more balanced design where superior performance in one area does not come as the expense of other important elements. As part of a well-balanced connector design, physical shields provide the electrical performance needed to support emerging requirements of higher bandwidth systems and the mechanical robustness required for real-world applications. **CS**

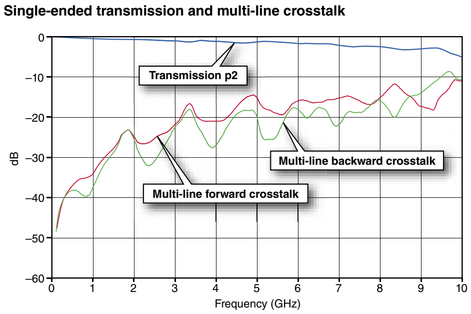

FIGURE 3. Measured differential transmission and multi-pair crosstalk (forward and backward, 0 to 10 GHz) of the longest signal pair in a 14 signal-row Ventura connector includes the effects of SMT pads and 12-mil through-vias.

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