Introduction

The push for increased system bandwidth and data rates in telecom and datacom backplane systems has led to two general technical solution paths. The first solution is to simply increase the density of moderate speed parallel bus structures while the second solution focuses on relatively less dense, high data rate differential pair channels which, in the extreme, yields a third solution - the all cable backplanes used in some datacom applications. Each of these three backplane technologies requires a distinctly different approach to the design of the connectors used to tie the backplane system to the system daughter cards. The purpose of this paper is to examine the general bandwidth-density performance characteristics of backplane systems and how best to set the connector design requirements and goals to yield a match between the performance of the interconnects and the backplane system.

For any given system data transmission protocol there is usually a linear relationship between the desired system data rate in Gigabits/sec and the required system 3db bandwidth in GigaHz. For example, using the fiber channel protocol, the available data rate is approximately four times the 3 db system bandwidth. Therefore, all
bandwidth considerations are referenced to the 3db bandwidth. The following analysis considers only differential pair data channels, but a similar analysis is also possible for single ended data channels.

**Broadside Coupled Differential Pair PCB Backplane Systems**

The backplane data channels can use either edge coupled or broadside coupled differential pairs. However, since the edge coupled pairs can have a higher conductor-loss attenuation than a comparable broadside coupled pair, and because the bandwidth of the backplane system is limited by the data channel attenuation arising from conductor and dielectric losses, only broadside coupled pair data channels are considered in the following analysis. The attenuation of a data channel has two components, a square root of frequency term due to conductor losses and a linear term in frequency arising from dielectric losses.

\[
A1 = (\pi \mu \omega p)^{0.5} \frac{(w/p)p^2}{Zo}
\]

(1)

The pitch of the data channels is p, w is the trace width, \( \mu \) is the resistivity of the PCB traces, and \( \omega \) and DF are respectively the permittivity and dissipation factor of the PCB dielectric. For scaling, w/p is held constant at ~0.5 or less and Zo is held constant by making the layer spacing between traces, h, proportional to p where h/p = 0.2. The solution of (1) for A=3 db yields the 3db bandwidth of the data channel for a specific backplane length, L.

The bandwidth per channel for a 0.75m Speedboard™ backplane is shown in Figure 1. As the data channel pitch, p, decreases, the channel bandwidth decreases due to increasing conductor losses relative to the dielectric losses. For a highly parallel backplane, the bandwidth density per channel layer, BW/p, is of primary concern in that as the density of the parallel channels is increased, one would hope that the increase in the density occurs faster than the drop in the channel bandwidth and that the total system bandwidth increases. However, as can be seen from the plot of bandwidth density vs. channel pitch for the Speedboard™ backplane shown in Figure 2, the bandwidth density reaches a maximum at a channel pitch of approximately 1.2 mm. Any further decrease in the channel pitch actually results in a decrease in bandwidth density and a decrease in system performance! This maximum in bandwidth density occurs when the conductor and dielectric losses are approximately equal.
The bandwidth of a connector is determined primarily by the extent of reflections between internal geometrical and impedance discontinuities, and modal dispersion, not attenuation. Therefore, the "channel bandwidth" is to first order a constant and relatively independent of the connector signal to ground ratio which in typical pin and socket connectors determines the "data channel" density, i.e., the lower the signal-ground ratio the lower the channel density. The bandwidth density is then a linear function of the data channel density. A plot of connector bandwidth as a function of bandwidth density yields a rectangular area bounded by the channel bandwidth and the maximum bandwidth density.

Since the backplane connector performance can be characterized in terms of the bandwidth vs. bandwidth density plane, it is a natural extension to characterize the backplane systems in terms of this "phase plane" representation.
Plots of bandwidth vs. bandwidth density /layer for a 0.5m FR-4 backplane, and 1m and 0.75m Speedboard™ backplanes are shown in Figure 3 where the channel pitch is the independent variable. It is clearly evident that, for a given bandwidth density, there are two possible solutions for channel bandwidth, i.e., a dense low bandwidth "parallel" solution and a high bandwidth "serial" solution.

The bandwidth vs. bandwidth density plots for the Metral® family of 4 row pin and socket, High Speed, HS, and the High Bandwidth, HB, connectors are also shown in Figure 3. How well the plot of each connector overlaps that of a backplane system is an indication of how well the connector is "matched" to that particular backplane system.

**The Metral® High Bandwidth Differential Pair Connector**

The preceding analysis illustrates that backplane interconnects must have not only high bandwidth but also a high bandwidth density of routable data channels per backplane signal layer. Since bandwidth is largely determined by the magnitude of the reflections between internal impedance discontinuities, the number and degree of the discontinuities along the data channel must be minimized. Also, for a differential pair connector, the function of the grounding structures is to minimize the effects of modal dispersion by reducing the number of modes to only local even-odd modes by strongly reducing the inter pair coupling. An important side benefit of this decoupling is reduced crosstalk. The intra pair coupling needs to be relatively large to maximize the difference between the differential (odd) and common (even) mode impedances. These design guidelines set the basis for the design of the Metral® High Bandwidth, HB, connector.

In contrast to current "high performance" backplane connector designs which consist of a multitude of strip line shielding variations, the Metral® HB design incorporates a unique twinax shielding construction along the entire differential signal path, providing superior decoupling and crosstalk isolation between signal pairs. Additionally, the differential signal pairs are coupled in a row based orientation which minimizes intra pair skew concerns and enables the routing of two differential channels (edge or broadside coupled) per signal layer on a channel pitch of 2 mm, closely matching the maximum bandwidth density point of high performance backplanes.
A head on view of the Metral® HB connector receptacle is shown in Figure 4, which shows the row based orientation of the signal pairs.

The ground structures of the twinax structures of the receptacle contact assembly use double inverted “L” ground shields. The header also incorporates inverted “L” shaped ground pieces to form a continuation of the twinax structure.

A summary of preliminary Metral® HB data is presented below in Table I.

<p>| | |</p>
<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Differential Characteristic Impedance</td>
<td>110-120 Ohms</td>
</tr>
<tr>
<td>Step Response Risetime</td>
<td>32 psec.</td>
</tr>
<tr>
<td>3 db Bandwidth</td>
<td>&gt; 6 Ghz.</td>
</tr>
<tr>
<td>Bandwidth Density/ Signal Layer</td>
<td>&gt; 3 Ghz /mm</td>
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<tr>
<td>Single Active Pair NEXT @ 100 psec.</td>
<td>&lt; 0,5 %</td>
</tr>
<tr>
<td>Multiple Active Pair NEXT @ 100 psec.</td>
<td>&lt; 2 %</td>
</tr>
<tr>
<td>Backplane and Daughter Card Cable Plug-Ups are Available.</td>
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<tr>
<td>Metral® Compatible Modular Form Factor.</td>
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</tbody>
</table>

The Metral® HB connector provides a match to the bandwidth and bandwidth density requirements of the present and next generation high performance backplanes. In addition, it provides mechanically reliable double contact beams on both the signal and ground contacts, as well as a conventional press fit termination to the PCB, thus minimizing some of the processing issues related to the transition to higher performance backplane systems.

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