New high-speed architectures require a closer look at the complete signal path

By Ralf Möller, Mihai Savu, and Frank Weiser

Bus structures like PCI (Peripheral Component Interconnect) or VME (VERSA module Eurocard) were developed over the last few decades. The Data transfer of these multipoint bus structures is limited by the CPU clock frequency, bus protocol (e.g. VME handshake), or the number of data lines. The bandwidth of a CompactPCI backplane, for example, is limited to 533 Mbytes/sec (64 Bit @ 66 MHz). The needs of today's applications are orders of magnitudes greater than this. Higher bandwidth requires other solutions, not only for the chipsets on the cards and the protocols, but also for connectors and the backplane topology.

As a result, groups like PICMG (PCI Industrial Computer Manufacturers Group) and VITA (VMEbus International Trade Association) are defining new specifications that support the newest technologies and architectures in high-speed data transfer and bandwidth requirements:

- PICMG 2.16 Compact PCI Packet Switching Backplane
- PICMG 2.17 StarFabric
- PICMG 2.20 CompactPCI Serial Mesh Backplane
- PICMG 3.x AdvancedTCA
- VITA 31 Gigabit Ethernet on VME64x
- VITA 34 APS Advanced Packaging System
- VITA 41 VXS VMEbus Switched Serial Standard

Some of these new specifications have already been released while others are still in progress.

Most of these new specifications use a common way of increasing the bandwidth for applications that need high data transfer rates. The solution is to use point-to-point connections transferring packet switched data via differential pairs with speeds up to 3.125 Gbits/sec. In the near future, data transmission will achieve 5 Gbits/sec, and 10 Gbits/sec will come soon after.

At such speeds the quality of the signal is negatively affected by several factors on its way from transmitter to its receiver. Therefore, the design of high-speed backplanes requires new thinking. To guarantee functionality and reliability, it is necessary to see the complete signal path (card, connectors, backplane, connectors, card) as one entity.

To investigate this new approach, Elma Trenew designed a high-speed test system comprising backplane and cards (435mm x 520mm, FR4, 10 layer, impedance controlled) to determine the influence of such interconnection elements as: connectors, materials, trace width and length (dielectrical losses and skin effect), backplane thickness and vias (stub effect), and connector-based cross talk (see Figure 1).

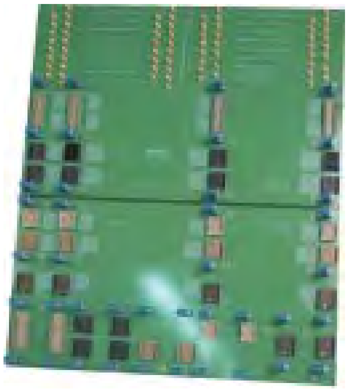

Figure 1

All these parameters are essential for signal integrity and have to be controlled by the designer of the backplane. Furthermore, all parameters are interrelated. Thus, at high speeds a change of only one of these elements implies a new adjustment of all the others.

To determine the influence of each interconnection element, the test backplane was divided into three different sections:

- **Reference area (SMA coaxial contacts, 50 Ohm):** Allows determination of the influence of backplane traces without the influence of the high-speed connectors. Differential lines – edge coupled/broadside coupled, and single ended lines are implemented with different trace widths in different layers.
- **Link area:** Consists of real interconnection paths. Edge coupled, broadside coupled differential lines and single ended lines with different trace widths and trace lengths situated in different layers can be investigated. Four high-speed differential connectors (the most representative in the market) are present, plus the HM 2.0mm connector (standard CompactPCI).
- **X-talk area:** Allows investigation of the amount of cross talk introduced by the connectors.

A total number of 555 differential links and 80 single ended lines are implemented in the backplane, allowing various measurements to be performed in order to see the influence of only one interconnection element or the influence of combinations of these elements.

Comparing traces with the identical topology situated in the same layer but with different lengths allows observation of only the influence of the trace length. In a similar manner, comparing traces situated in the same layer with identical lengths but routed with different widths, allows observation of the influence of skin effect only. The stub effect can be analyzed by measuring similar links located in different layers.

For completion of the signal path, test cards (passive) were designed for all connector types used on that backplane. All these cards were made in FR4, impedance controlled, and with all the traces routed with the same width and length to have the same influence on the signal. SMA coaxial contacts, about 1000 for all cards, allow measurements for various topologies.

Two measurement methods were performed, one using real drivers (up to 3.125

Gbits/sec), the other using a data pattern generator (up to 10 Gbits/sec) on the transmitting side, and a signal analyzer to investigate the received signal.

Overview

Below is a short overview showing the influence of each interconnection element:

The signal speed or data rate is the most important factor because the losses and also the cross talk increase with the frequency, but in a different manner (for example, dielectric losses are related directly to the frequency, and skin effect to the square root of frequency).

The drivers or chipsets used to transmit data have a significant impact on the signal quality. Many drivers on the market are intended for different speeds and behaviors, with or without built-in terminations, with or without selectable pre-emphasis levels, or that need to be AC or DC coupled and so on. However, a backplane should be driver agnostic. To achieve that it is very important to know the behaviors of different drivers. Simulations were made to analyze the signal integrity on the backplane with different types of drivers.

Trace width is an important factor for high-speed signals. It is commonly believed that the wider the traces, the better the signal integrity because wider traces result in lower skin-effect losses. This is correct. However, a few factors need to be considered when using wide lines:

- Wider traces result in lower signal-routing density, which can lead to more signal layers. Wider traces also require thicker cores and prepregs in order to achieve the desired impedance, resulting in thicker PCBs. So, the desire for wider traces to reduce skin-effect losses can result in thicker boards with more layers, which will increase the critical stub effect.
- Trace length is another important parameter besides trace width and board thickness for finding the best design compromise. This is because the losses due to skin effect and also the losses in dielectric material increase with trace length.

So, it is possible that the best compromise between trace width and backplane thickness for a certain length may not be the best solution for the longer trace (because the stub influence remains constant while the skin effect is increased). It is possible to find another compromise, increasing the stub effect a little and minimizing the skin effect, while getting smaller total losses. Therefore, measurements and simulations were performed for different trace widths and trace lengths to determine at which frequency and data rate the trace width starts to make enough of a difference.

To highlight the described behavior of different trace widths and lengths there are two pairs of eye diagrams in Figure 2. This figure shows the results for two links routed with different trace widths: 5mm (A) and 8mm (B). The measurement was made at 10 Gbits/sec.

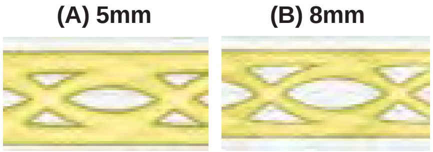
(A) 5mm
(B) 8mm

Figure 2

The 8mm case means an improved eye opening of 37 percent compared to the 5mm case.

The results for two traces with identical widths (8mm), but lengths of 150mm (A) and 400mm (B) at a speed of 3.125 Gbits/sec are shown in Figure 3.

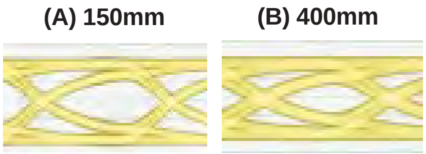
(A) 150mm
(B) 400mm

Figure 3

The figures show very clearly a dramatic reduction of the eye opening (due to increased losses) at a speed of only 3.125 Gbits/sec.

The stub effect is the resonant effect created when the signal trace enters a hole on a top layer of the board and exits the hole on an internal layer, leaving an "unused rest" of the plated through hole (see Figure 4). The Figure shows two plated through holes with a stub difference of 1mm. This acts like a high frequency filter and creates an effective decrease in the impedance. Therefore, the backplane thickness is important because it determines the amount of the plated-through-hole stub that remains between the signal inner layer and the external bottom layer of the PCB.

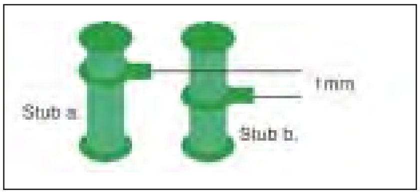

Figure 4

The stub length relative to the optimized thickness of the backplane is a very important design parameter that, if ignored, can have an adverse effect on signal performance. This can be observed in Figure 5, showing the eye diagrams for two 10 Gbits/sec links, identical from the topology point of view, but situated in different layers, with only 1mm difference in their stub length.

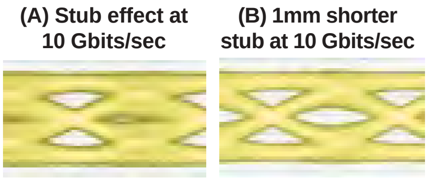
(A) Stub effect at 10 Gbits/sec
(B) 1mm shorter stub at 10 Gbits/sec

Figure 5

It can be observed that only 1mm less of stub copper means a significant positive impact on the transmitted signal.

Cross talk: Beside dielectric losses, skin, and stub effect, higher frequencies also increase the cross talk sensitivity. To define the global solution (backplane thickness, trace width, trace length, and connector type), the cross talk should be considered, too. Cross talk can be minimized using thinner cores and prepregs to reduce the distance of signal-to-ground (positive impact on backplane thickness) or by increasing the separation between differential pairs. However, this is possible in many cases by adding more signal layers (increased backplane thickness) or reducing the trace width (increased skin effect).

The connector type has a significant influence on the cross talk level for two reasons. First, cross talk exists inside the connector and must be considered when calculating the total cross talk. Second, in many cases the distance between differential pairs is imposed by the distance between the connector pins. Therefore, it is very important to know the specific connector influence. A special cross talk section was implemented in the test backplane to verify only the cross talk influence for all implemented connector types.

Conclusion

The design of backplanes for the new high-speed architectures requires considerable technical experience and expertise to find the best design compromises for stub effect, skin effect, dielectric losses, cross talk, differential pair routing, and matching of impedances. Before specifying the final requirements of a high-speed backplane (application), close cooperation between customer and backplane designer is necessary to guarantee the signal integrity and the successful performance of the application. Only cooperation with an experienced partner familiar with simulation, design, production, and measurement leads to good quality of the complete signal path.

Finally, Figure 6 shows an example of an Elma backplane for such new high-speed architectures, compliant with PICMG 3.0 (draft) AdvancedTCA, having 14 slots with 12 Node slots, and two fabrics centered in the middle. This configuration:

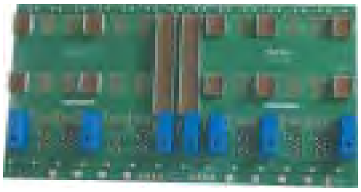

Figure 6

- Reduces the trace length to decrease the dielectrical and skin effect losses dramatically (up to 50 percent).
- Applies an optimized routing strategy with a layer number of 12.

12 layers means a considerable positive impact on the signal performance (thin PCB for minimized stub effect) and cost savings. Clearly, design experience leads to increased performance and lower costs for the customer.

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