



## Equalization: It'll Open Your Eyes

### Abstract

Now, more than at any other time in recent memory, Digital System Designers are today facing a broad range of daunting challenges. A case in point is the dilemma associated with addressing the need to deliver more and faster data within enclosures and between cabinets over copper interconnects. As these data rates rise, the high frequency content of the signal also increases. In truth, it is exactly this high frequency content that gets attenuated most severely over dispersive transmission media channels such as cables and backplanes. A key challenge facing the Design Engineer is one of maintaining the integrity of the high frequency content of the transmitted signal, while at the same time, minimizing the loss characteristics of the channel that contribute to its degradation. One proposal for accomplishing this goal is the application of passive equalization to the signal. The intent of this paper is one of seeking to amplify the benefits of applying passive equalization to the transmitted signal along various typical transmission backplane and cable channels.

**Keywords:** High-speed; equalization; copper; interconnects; dispersive transmission media; insertion loss; high pass filter; signal integrity; eye pattern diagram; jitter; Gbps; impedance; loss tangent; transmission line.

1. **Introduction:** Measured against today's standards, the decades spanning across the 1950's to 1970's were indeed technology's dark ages, as in those days, analog signaling was, in fact, the only game in town. However, the veil lifted in the 1980's as that decade, and beyond, saw digital serial buses begin to proliferate to the point where today, they are virtually everywhere. Hertz gave way to bits per second (b/s), and b/s was only the tip of a swelling wave that led from Kb/s to Mb/s. It was a wave that washed over our system design like a data tsunami traveling at multi-Gb/s rates. Along with the increase in the data rates, came an associated miniaturization of the components of the electrical systems, which led to an increase in the number of electrical systems and a corresponding increase in the volume of wiring connecting them. All of these factors led to a vast array of effects that conspired against the designers and integrators at every turn. These effects of power delivery and grounding schemes, EMI, RFI, resistive losses, skin effect, dielectric losses and physical proximity all became everyday design considerations of system designers and the interconnect manufacturers. While the physical layer was handling

faster signals, the logical layer started standardizing on various protocols so that the systems could coherently communicate. One of the first protocols to be introduced in the Military arena was Mil-STD-1553 data bus (introduced at 1Mb/s). Soon thereafter, other faster commercial protocols began making their way into more and more systems (though with the appropriate redundant, latency and deterministic features addressed). Now we regularly see IEEE 1394 Fire wire (Introduced at 100, 200 and 400 Mb/s, now available in 800Mb/s and 1600Mb/s versions) and IEEE 802.3 family of Ethernet stds (10, 100, 1000 and 10000 Mb/s) Fibre Channel (256Mb/s, 512Mb/s, 1.025Gb/s and higher) more and more often.

The common thread that runs through these protocols is the transition from a parallel bus structure to serial point-to-point connectivity. In addition, the signal output drivers changed from being single-ended to differentially driven. Though the net effect increased the effective pin count of the interconnect (volume of wires) it also improved the reach; the actual length the wires could provide a clean more noise tolerant signal. A secondary effect also exhibited itself in that the separable interfaces and cables that worked just fine at slower data rates were less than ideal at the higher ones. These problems showed themselves in impedance discontinuities, reflective loss and high frequency attenuation (both real and imaginary components). However, as is often the case, designers develop design solutions that will keep the length and data rate of their Interconnects high. Equalization is one such design solution, and will be discussed following.

### 2. Technology Review

Over time, the transition from relatively slow data rates to much higher ones led to a key change in the way design engineers characterized the interconnects. From treating the interconnect path as a standard hook-up connection, to treating each part of the interconnect path as a transmission line. Impedance matching and stub length concerns (in MIL-STD-1553b) gave way to new design considerations examining smaller and smaller structures of the interconnect path all the way down to the launch geometry of the surface mount pad connecting the signal trace exiting the silicon driving the signal. These geometry considerations were not initially studied in isolation but were included with the big picture losses of the channel i.e. dielectric and copper losses. Slower edge rate TDR-only testing gave way to VNA characterization with signal generators, and BERT evaluation of the chip-to-chip channel on the same bench. Resistive DC loss gave way to



skin effect loss, and dielectric constant design parameter expanded to include both the real and imaginary parts as the loss tangent of the dielectric media began to dominate at data rates of 2Gb/s and higher. Microwave engineering vocabulary and design practices became more and more prevalent. Commercial industry design strategies and techniques started to be incorporated into the interconnect path.

Without treating all the aspects of high speed design at the board, connector and cable levels, this paper will concentrate on potential design solutions to overcome the linear dispersive loss associated with long FR4 traces and cable assemblies. Reflective losses will not be addressed simply because they should not be designed-in, in the first place. Typically, the longest part of a dispersive channel is the pcb trace in the board-to-board interconnect, or the wire and cable in the inter cabinet interconnect. Because both the pcb and the wire and cable manufacture today can be precisely controlled, the quality and consistency of the transmission path is extremely high. The development of low loss dielectrics and special conductors minimize the losses in order that a very consistent, repeatable characterization of the trace or cable can be constructed for use with the various simulation tools on the market. Indeed, a fairly recent design strategy being used in the commercial industry, and finding it's way into more and more Military designs, is to measure the S21 loss profile of a trace or a cable for a given length and frequency, and then construct a very simple, completely passive filter that will shape and flatten the channel response across the appropriate frequencies so that the received signal characteristics are maximized.

### 2.1 Eye Pattern Diagrams

Eye Pattern Diagrams (EPD's) are a good qualitative tool to evaluate the quality of the interconnect path as seen by the receiver. (See figure 1)

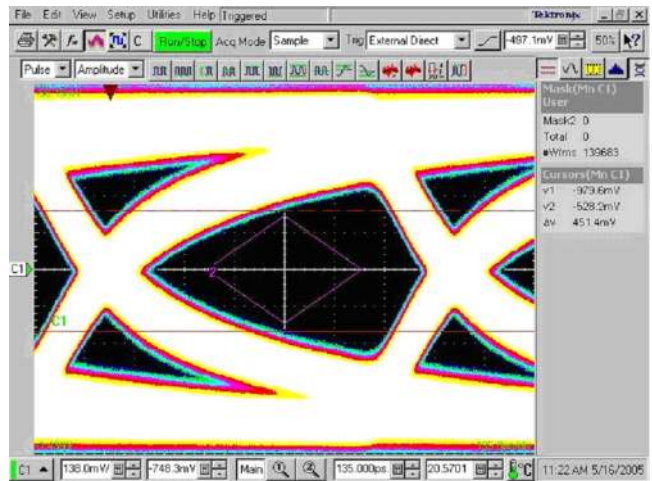


Figure 1 Typical Eye Pattern Diagram

The vertical scale defines the voltage level and the horizontal scale defines the time base or bit Unit Interval. EPD's are useful when evaluating predominantly linear, dispersive transmission channels. As you can tell from figure 1, the above screen shot of an EPD, the smearing of the signal indicates such a channel. At the zero crossing on the left hand side we have a visual indication of the total jitter (Random and Deterministic) inherent in this channel. The diamond overlay, in the center of the screen shot, is called a receiver mask. The receiver mask defines the boundaries for the minimum and maximum voltage levels required at the receiver, as well as the minimum and maximum unit interval time required to determine the allowable jitter to make a valid decision on the received signal.

### 2.2 Scattering Parameters

One way generate EPD's, is to capture the necessary broadband width frequency information of the interconnect path using scattering parameters, (S-parameter) of each segment. (figures 2 and 3)

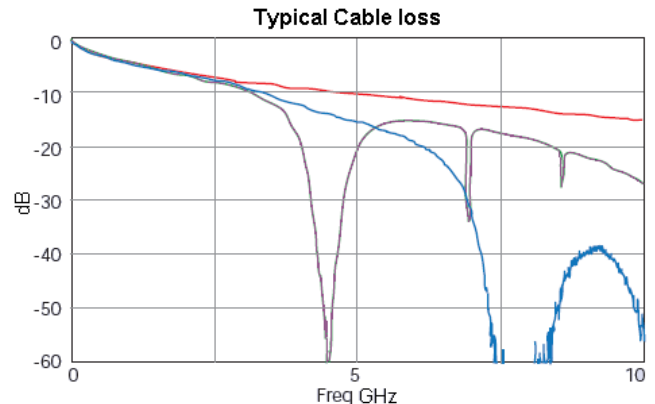


Figure 2 Typical Cable Insertion Loss

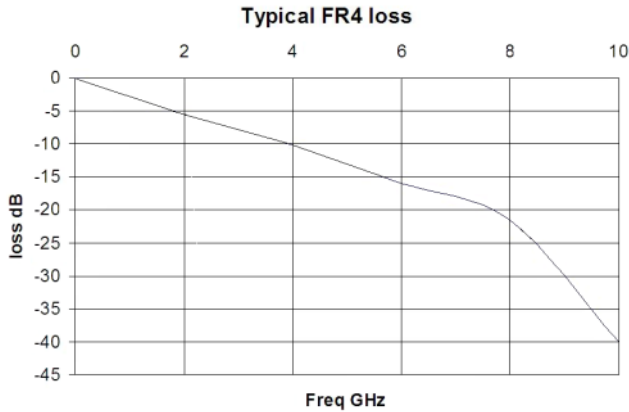


Figure 3 Typical FR4 Insertion Loss

To accomplish this, you can make use of either an expensive, 4 port VNA, or to save money in your test budget, use your current Time Domain Reflectometer (TDR). Most newer TDR's are fairly broadband ~10-14 GHz. Using Oculus, an intuitive software package optimized and refined by atSpeed Technologies, you capture broad bandwidth TDR data for a given length of cable and then it generates a scalable S21 model. The ideal aspect of having this full frequency, scalable S21 model is that, using Oculus software, you can manipulate both the length and data rates of your interconnect path, and then choose from one of the many options that will condition the signal to optimize the Driver-Transmission Path-Receiver characteristics. One of the easiest signal conditioning tools to consider is a basic equalization circuit whose parameters can be optimized in the software to determine the exact filter values to precisely tune your system performance.

### 2.3 Equalization

Knowing the electrical characteristics of the interconnect path along with the data rate and protocol of the signal you are driving over that path allows you to design the most cost-effective path in your system. For example, suppose you have a legacy wiring plant in your platform, and your company requests you retrofit new electronic LRU's as part of an upgrade to the system. Do you have to pull out and replace the old wiring harness? Can you stay with the current gauge of wire or can you go to a smaller one? Can adding a simple passive equalization network allow you to extend the reach of the signal to an area of the platform that you couldn't reach before? By knowing the characteristics of the interconnect path, you would be able to answer all these questions and then choose the most cost effective route to take.

So what is equalization, and why does adding it to the circuit path matter?

Equalization in its simplest form, is a high-pass filter designed to flatten the frequency response of the circuit for a given data rate and transmission media path length. Since the higher frequencies in digital signaling are attenuated most rapidly, by adding a 'high-pass filter,' you help preserve the rising and falling edges, thus optimizing the voltage at the center of the bit unit interval. Figures 4 and 5 below show EPD's of the received signal of a single-ended coax interconnect path of 36 feet, driven by a 1.5V, Fibre Channel 1.0625Gb/s transmit signal, with and without the addition an equalizer circuit to the path.

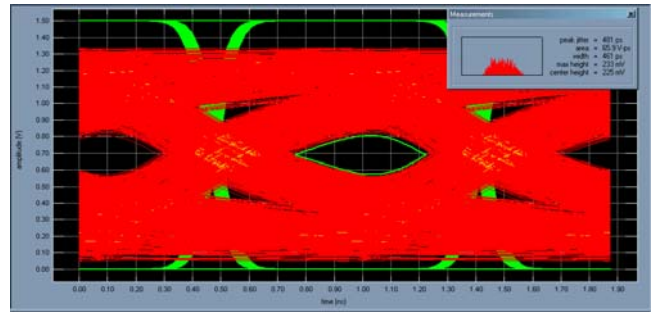


Figure 4 EPD without Equalization

The Eye height and total jitter of the above EPD (without Equalization) is .225V, 481pS respectively.

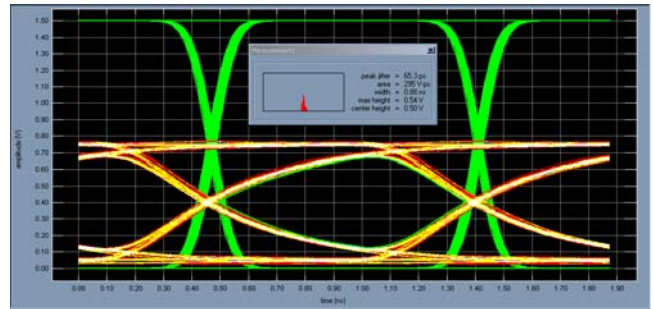


Figure 5 EPD With Equalization

The Eye height and total jitter on the above EPD (with Equalization) is .500V, 65pS jitter. N.B. An added benefit to maximizing the eye height parameter is that the deterministic jitter also gets significantly reduced, as shown.

### 2.4 Applied Design Strategy

What about those times when you are not able to measure the S21 characteristics? If, for whatever reason, the backplane is already designed and in your system or the cable is already in place? What about when you want to upgrade your systems performance with faster (higher data rate) boards or faster (higher data rate) I/O?

The question of paramount importance is, how can we, as engineers, apply this powerful tool without reducing valuable pcb real estate or kluge in a splice into our current cable systems? As it turns out, there are now on the market



commercial passive components that are broadband-robust enough to be used over a wide range of data rates, and can be incorporated into any point of the signal path that will provide compensation to the signal for the transmission medium. We have engineered into a Quadrax contact, that because of its small physical size and excellent electrical characteristics, is being incorporated into more and more high speed designs, just such as a passive equalizer that extends the length of the interconnect being used or increases the data rate for a given interconnect path. The benefits of this equalization strategy are shown below in figures 6 and 7, for various transmission paths and in the EPD's following for both FR4 based channels and twin-ax cable interconnects.

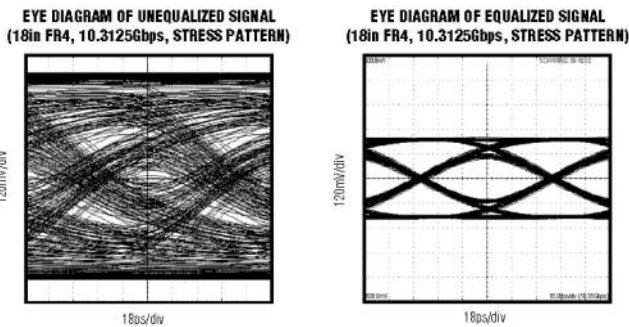


Figure 6 Before and After 18 inches FR4 at 10G bps

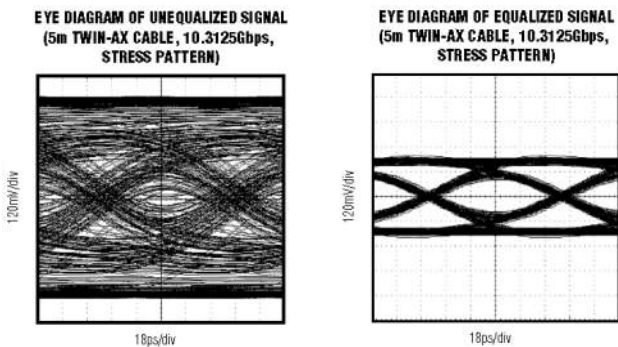


Figure 7 Before and After 5m Twin-ax 10 Gbps

### 3. Conclusions

The above before and after EPD's show clearly that a wide range of data rates may be used with our in-contact equalization technology. In the face of the resultant voltage level decreasing, the overall useful Eye Height is improved. As such, there is a higher the probability for the receiver to detect the proper logic level.

In conclusion, one can see that passive equalization is a very cost-effective way to realize many design improvements / upgrades to your system interconnects.

The benefit list includes, but is not limited to:

- Extending the reach of high bit rate FR4 connections
- Increasing the data rate of current 'lower speed' designs
- Extending the reach of new cabled interconnects
- Increasing the bit rate of current cabled interconnects
- Reducing ISI
- Designing in smaller gauge cables for a new interconnect design ( to save weight / volume )

### 4. References

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