

# Using Pre-Emphasis and Equalization with Stratix GX

## Introduction

New high speed serial interfaces provide a major benefit to designers looking to provide greater data bandwidth across the backplanes or when interfacing chip to chip. However high speed signaling techniques suffer from a number of issues not seen at normal digital signaling levels. One key problem, which applies to all transmission mediums, but particularly related to PCB layout, are frequency dependant transmission losses, caused primarily by skin effect and dielectric loss. This transmission loss can cause greater attenuation of the high frequency component of the signals than that of the lower frequency component, making it difficult for the receiver to interpret the signal, thereby greatly reducing drive length and increasing bit error rate. Two main techniques used to help overcome transmission losses are Pre-emphasis and Receiver Equalization. These methods require extra circuitry in the transmitter and receiver buffers to compensate for high frequency losses.

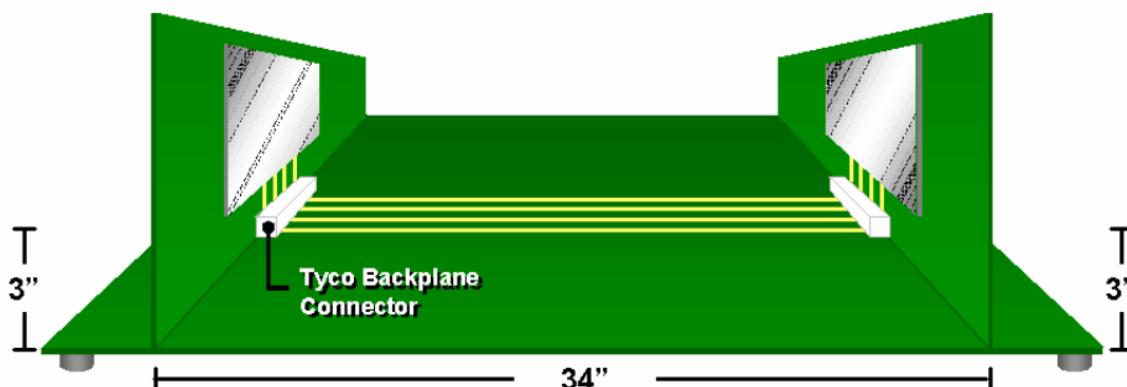
The high speed 3.125Gbps transceivers in the Stratix GX architecture incorporate pre-emphasis and equalization circuitry within the buffers; they are dynamically controllable to ensure the user can provide the optimum setting for their application.

This paper provides an overview of pre-emphasis and equalization and describes their operation within Stratix GX, including some guidelines on settings for various backplane applications.

## Overview of Pre-Emphasis and Equalization

High speed transceivers are now becoming common for backplane applications. A typical backplane will consist of a backplane trace, two backplane connectors and two traces on the card to the transceiver.

*Figure 1. Typical backplane example*



It is often necessary for the transceiver to successfully communicate over 40" of PCB trace and two backplane style connectors, e.g. HM-Zd connectors.

High speed signals transmitted along PCB tracks tend to suffer from high frequency attenuation, which makes it difficult for the receiver to interpret the information. The effect is similar to a low pass filter which decreases the gain of the high frequency signal. The main culprits are dielectric loss and skin effect, although crosstalk and stub reflections caused by poor termination can also cause issues. These issues are exaggerated when we consider a typical backplane application developed on FR4 PBC fabric. Fig 1 shows a typical backplane application. The interface consists of a backplane trace, two backplane connectors and two line cards or daughter cards.

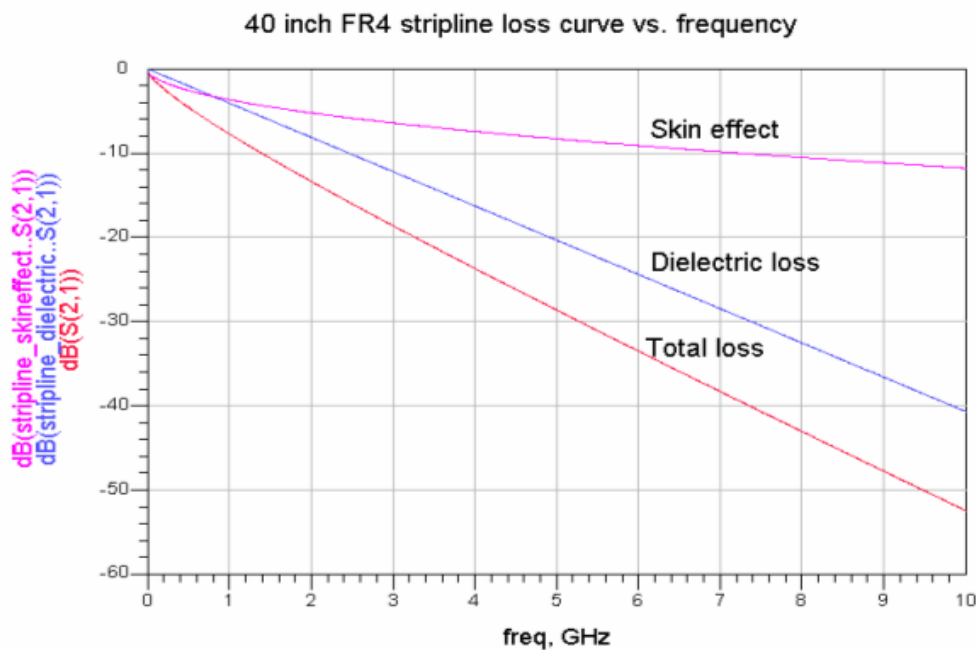
### Dielectric loss and Skin Effect

#### Skin Effect

The "Skin Effect" describes how high frequency currents tend to travel on the surface of the conductor, rather than the whole cross section of the conductor. This is caused by self inductance of the material, which increases the inductive reactance with frequency, forcing the current to travel on the surface of the material. This reduces the effective conductive area of the trace, increasing resistance which causes the signal to be attenuated.

As frequency increases, dielectric loss is the dominant factor in high frequency attenuation, since its effect is proportional to frequency, whereas skin effect is proportional to the square root of frequency. Figure 2 shows the stripline loss effects against frequency.

Figure 2. 40" Stripline loss effects.



*Dielectric loss*

All PCB laminate materials have a specific dielectric constant, which will affect the impedance of the transmission line. The value for dielectric constant can be determined by comparing its effect on the capacitance of a conductor pair to that of a conductive pair in a vacuum. A lower dielectric constant signifies that the material will support a longer transmission line before issues occur.

Some laminates such as FR4 will see conductivity vary with frequency. In this case dielectric loss can be defined as a ratio of conductivity to frequency. This is known as loss Tangent. Materials with a high loss tangent will see a deterioration of signal with frequency. FR-4 has high loss tangent, which results in a large attenuation of the signal at high frequency. Many materials are used as PCB laminates and have both better dielectric constraints and loss tangents; however, in volume, applications become prohibitive due to cost. Table 1 discusses dielectric performance of various laminates and relative material costs.

*Table 1 representative comparison of dielectric performance and cost*

<b>Material</b>	<b>Dielectric Constraint</b>	<b>Loss Tangent Value</b>	<b>Relative cost to FR-4</b>	<b>Comments</b>
FR-4	3.9 – 4.7	0.02 – 0.03	1 x	Standard process
GETEK	3.5 – 4.3	0.012	1.5 x	Standard Process
Polyimide	4.0 - 4.5	0.01	3 x	Hard to process
Speedboard N	3.0	0.02	5 x	Extra process
Rogers (RO3003)	3.0	0.0013	6.5x	Hard to Process

Both dielectric loss and skin effect can cause problems of Inter-Symbol-Interference (ISI), because the attenuation of the signal prevents it reaching full strength within its symbol time, causing it to spread into the next signal. The effect is pattern dependent and is known as “Pattern Dependent Jitter” (PDJ) or Data Dependent Jitter (DDJ). If a string of data remains at the same level, for example “000000” then the energy in the signal has time to reach its peak so will be transmitted correctly; however, for a quick switching signal such as “1010101”, full signal strength is not reached within the symbol causing a spread. “PDJ” causes smearing of the eye diagram, signal rounding and time displacement.

A further complication is caused by dispersion, where the losses in the medium cause the different frequency components of the signal to have different delays as they travel along the transmission line. This further reduces signal amplitude, and adds residual error from previous bit leading to increased inter symbol interference.

*Effects of increasing Drive signal*

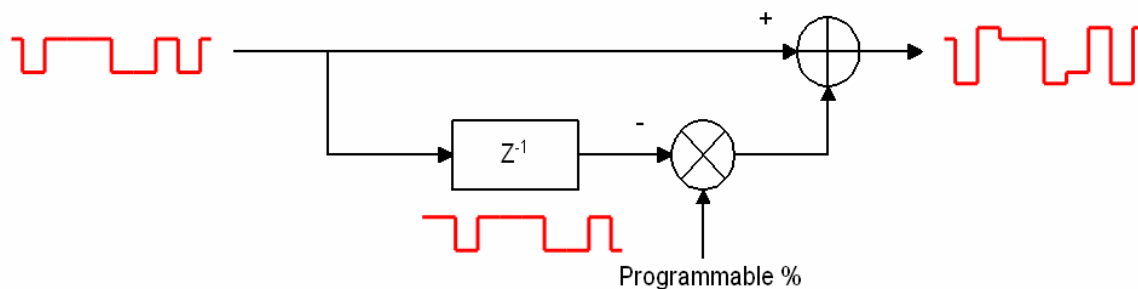
The simple resolution would seem to be to increase the signal strength to overcome the attenuation. For example, Stratix GX includes dynamically programmable drive strength which allows the user to select the drive strength most suitable for the application. Unfortunately, this does not solve the problem of high frequency roll off and the PDJ will worsen as the symbol will still not be able to achieve full strength within its slot, and may also spread further into the next slot as a result of the increased signal level. Signal strength also has an effect on proportional noise in the system, as the noise will increase with the signal. The overall Power Consumption of the transceiver will also increase as the buffer is required to drive more current.

### Pre-emphasis

The solution is to provide a method of boosting purely the high frequency components of the signal, while leaving the low frequency components in their original state. One way to achieve this is to use pre emphasis.

Pre-emphasis operates by boosting the high frequency energy every time there is a transition in the data, since this is when the most issues occur. The pre-emphasis circuitry within the Stratix GX interface acts like a two tap Finite Response filter (FIR). The circuitry works by comparing the previously transmitted data bit with the current data bit. If the two bits are the same level, then the current bit is transmitted at the normal level. If the two bits are different, then the current bit is transmitted at a higher magnitude. Figure 3 demonstrates the circuitry.

Figure 3. Block implementation of Pre-emphasis circuit.



Careful design of the pre-emphasis circuit can also help to overcome dispersion. Filters are carefully designed to ensure the frequency cutoff prevents the component of the signal spreading into the next symbol space.

### Pre-emphasis measurement

There are many different methods of measuring pre-emphasis. Although it is not important to follow a particular measurement, it is important for the user to understand the particular definition when modeling the system. Pre-emphasis in Stratix GX is defined as:

Figure 4: Waveform definition of pre-emphasis

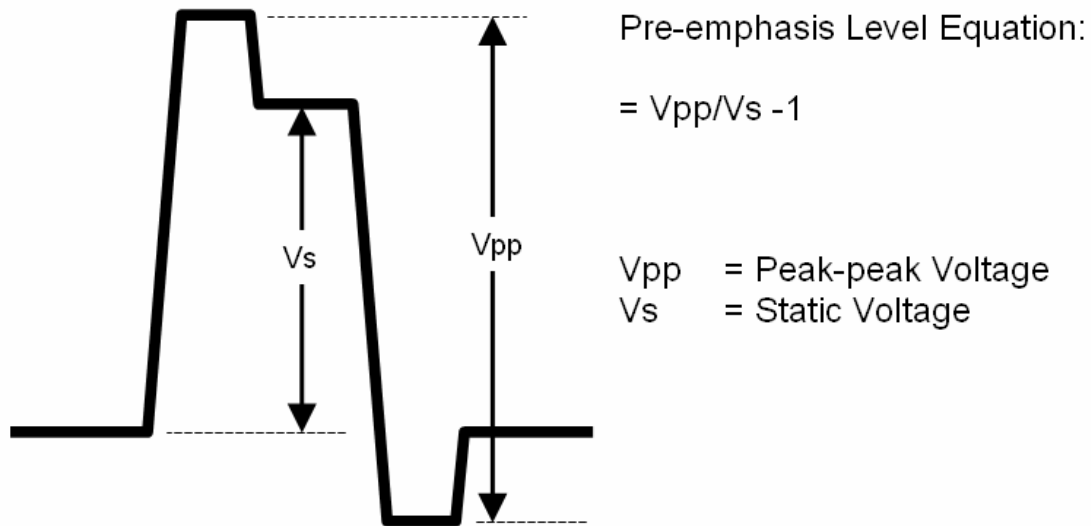


Figure 4 shows the Altera waveform definition of pre-emphasis. The waveform describes a Differential Signal.

The pre-emphasis circuitry within the Stratix GX architecture can be dynamically programmed to five different levels. It is not possible to put an exact % on these levels as this is dependent on the selected signal drive strength of the differential output. Table 2 shows example programmable pre-emphasis levels for Stratix GX. Levels show performance for a  $V_{OD}$  of 800mV, these values would change for alternative  $V_{OD}$  levels.

Table 2 Example Stratix GX Pre-emphasis levels for 800mV  $V_{OD}$

800mV $V_{OD}$	
Setting	Typical Pre-emphasis Levels
1	11%
2	36%
3	65%
4	100%
5	140%

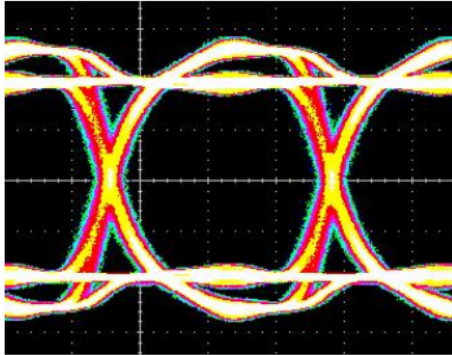
Note: Internal termination set to 100 Ohms

#### Sample Eye diagrams

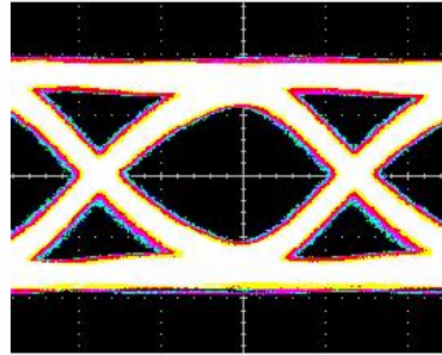
The eye diagram is an empirical measurement of quality of a transmitter signal. The wider the “eye” opening is, the better the signal quality. An eye diagram also contains abundant information about signal amplitude, rise and fall time, and jitter inter-symbol interference. Figure 5A shows an eye diagram from a Stratix GX transceiver with pre-emphasis fully on. It can be seen that eye opening is exaggerated with the high frequency signal and can be seen as overshoot and undershoot on the eye. Figure 5b shows the eye

diagram for same signal at the receiver. By the time the signal has traveled along the transmission line the attenuating effects have removed the exaggerations and the signal can be received correctly.

*Figure 5a 800mV signal with pre-emphasis, on operating at 3.125Gbps, taken at 0".*



*Figure 5b 800mV signal with pre-emphasis, on operating at 3.125Gbps. Taken at 20".*



### *Receiver Equalization*

Receiver equalization provides functionality in the receiver to help overcome high frequency signal losses of the transmission medium. Receiver equalization acts as a high pass filter and amplifier to the data as it enters into the receiver. This allows the receiver to rebuild the signal and interpret it successfully. External receiver equalization can be manufactured from external RC networks; however these require extra components and add track stubs into the system which can have adverse effects, and they are difficult to modify for different backplane conditions.

Stratix GX Architecture includes equalization within the receiver. The function is dynamically controllable and can be set to 0, 20" FR4 backplane or 40" FR4 backplane. The setting is dependent on application and environment. Receiver equalization adds up to 9db of gain at the 40" setting. Dispersion can also be overcome within the equalizer which can be designed to cut off the unwanted frequency components, thus stopping them from spreading into the next symbol.

### *Simulation Samples*

It is impossible to show exact results from the Stratix GX Receiver Equalizer because it is embedded within the device. However it is possible to simulate the results using SPICE modeling. Figure 6a shows a simulated eye diagram into the receiver after 40 inches without pre-emphasis. Figure 6b shows the same signal after it has passed through receiver equalization.

Figure 6a SPICE simulated input to Equalizer

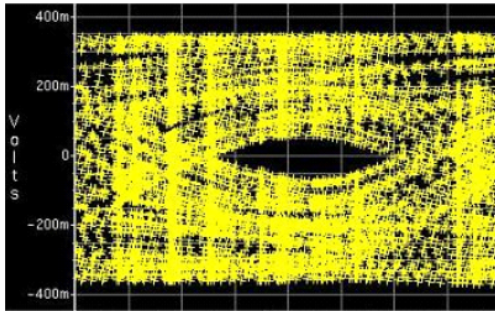
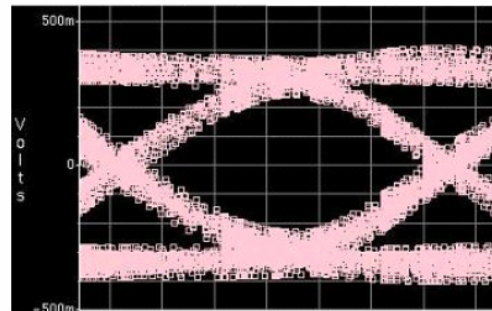


Fig 6b SPICE Simulated output from Equalizer



It is clear that the equalization circuitry greatly improves the quality of the eye.

### Using Pre-emphasis and Equalization

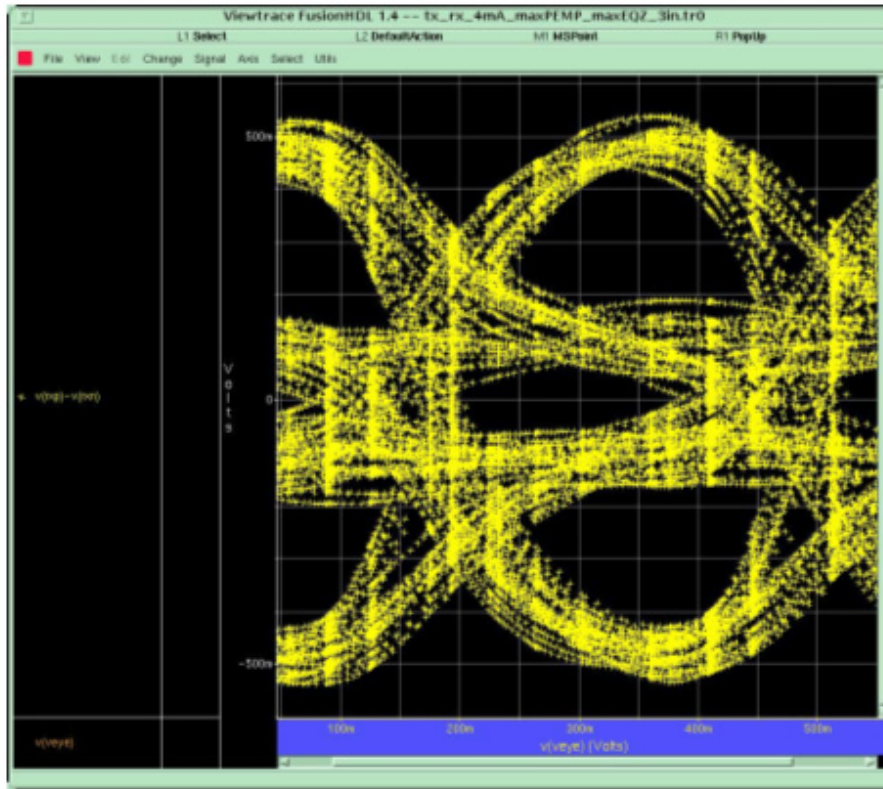
In many cases the system will require a combination of pre-emphasis and equalization. Functions are complementary and can help to overcome harsh operating environments. Both also have trade offs which need to be considered when configuring the system:

	Pre-Emphasis	Equalization
<b>Disadvantage</b>	1) If system is susceptible to crosstalk pre emphasis can emphasize system crosstalk as well as signal.	1) Equalization will amplify all the high frequency components of the signal. This can be an issue if the signal to noise ratio is poor
	2) Pre emphasis has higher power requirements due to the need to boost the switching part of the signal.	
	3) The faster edge rates, overshoot and undershoot associated with pre-emphasis contribute to increased Electro-Magnetic Interference (EMI)	

It is important to select the correct values for both pre-emphasis and equalization to ensure optimum performance. This can be achieved either via accurate system modeling using SPICE models or other link analysis tools, or even at the debug stage using demonstrator boards.

It is necessary to select the optimum settings for both pre-emphasis and equalization. Over compensation can cause additional issues within the system. It will add extra jitter which will close the eye making it impossible for the receiver to interpret the information. Fig 7 shows the simulated effect of adding too much pre-emphasis and equalization. The simulation shows a 3.125Gbps signal, after 3" FR4 PCB fabric ( $V_{OD} = 4mA$  max Pre Emphasis and Equalization)

Fig 7 Effects of over compensation.



### Overcoming issues in legacy systems

The explosion of high speed interfaces has led to some dilemmas because users still wish to use legacy backplanes to reduce the cost of replacing the entire infrastructure. This means that backplanes designed to operate at 1Gbps are now required to run at 2.5Gbps and beyond.

In some circumstances this may be possible with the combined use of pre-emphasis and equalization. Equalization can compensate for many of the issues of the legacy backplane such as narrow tracking, which suffers increased signal attenuation due to transmission losses. However, equalization is relatively new as an integral part of the receiver, so it is possible that legacy cards plugged into the system will not include equalization. This means that higher levels of pre-emphasis are required to ensure safe communications; it is not uncommon for pre-emphasis levels in excess of 100% to be used in legacy applications.

### Pre-emphasis and Equalization in Stratix GX

Stratix GX has been developed to operate in a number of differing systems and applications. Stratix GX provides a flexible buffer allowing the user to configure levels for pre-emphasis, equalization and drive strength. These levels may be programmed dynamically, making it simple to configure the transceiver for optimum performance.



Dynamic control allows the user to reconfigure the signal settings in a system. This is particularly useful in a large backplane application, where a Line Card in Slot 2 will need a completely different set of characteristics than a Line Card in slot 21, where both are accessing the same switch card in slot 1. Dynamic reconfiguration will allow the Line Card to reconfigure its transceiver setting, depending on the location in the backplane.

Pre-emphasis and Equalization functions in Stratix GX can be selected to be either set during configuration or dynamically via control pins once the device is on the board. Method of selection is made during design in the Quartus II software tool. All transceiver configurations are made via the Quartus II Megawizard, by using the ALTGXB Megafunction. The megafunction provides a simple interface to configure the entire transceiver. Full details of configuration can be found in the *Stratix GX Device Handbook*.

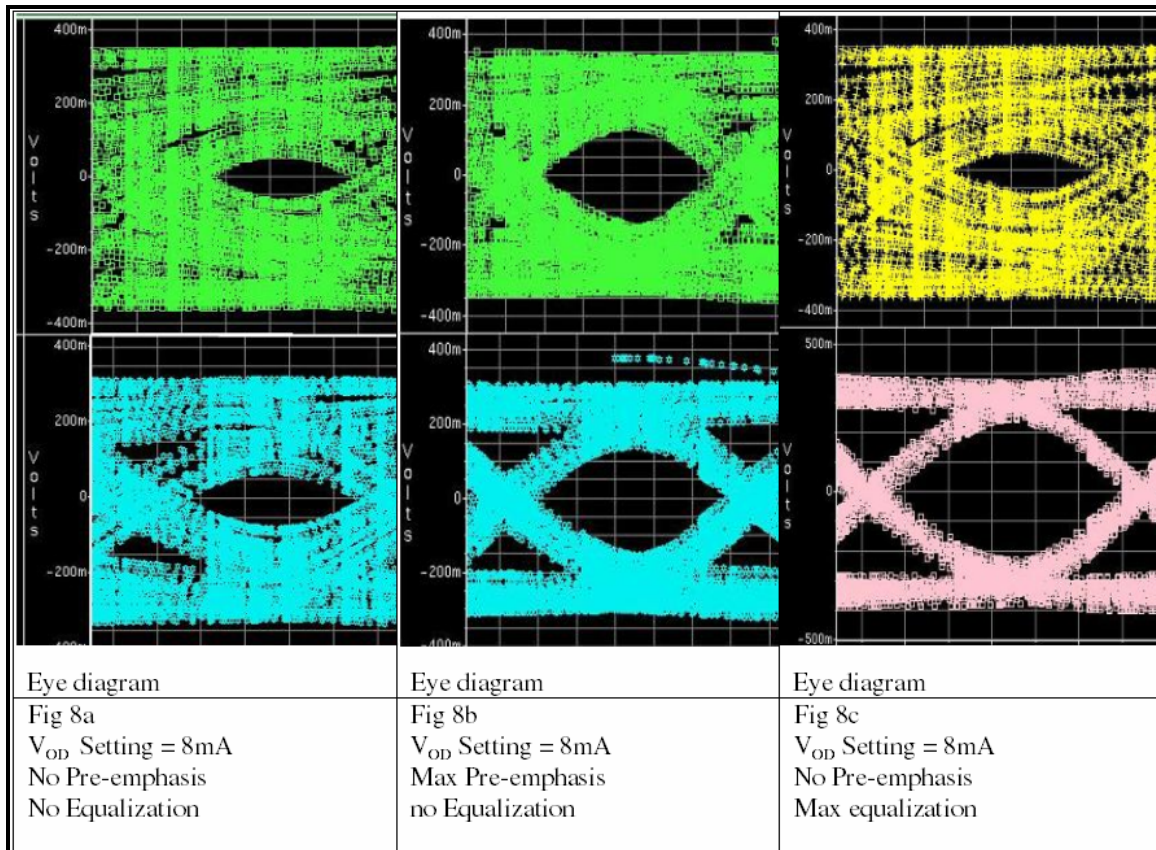
## Working Examples of Pre-Emphasis and Equalization with Stratix GX

Every system and application will require different setting for pre-emphasis, equalization and drive strength. It is therefore important to model the system environment, using accurate model for not only the transceiver interfaces, but also for interconnect and PCB traces to ensure the system is matched. The following table describes some results from Stratix GX characterization to show an example of the effects of pre-emphasis and equalization. The figures can be used as an indication for design, but settings should be based on measured and/or modeled results from the actual design.

Channel Topology			Stratix GX Setting	
Transceiver A	Backplane (Tyco)	Transceiver B	Pre-emphasis Setting	Equalization Setting
Stratix GX	20"	Stratix GX	0%	20"
Stratix GX	40"	Stratix GX	0%	40"
Stratix GX	40"	3 <sup>rd</sup> party device (with equalizer)	0%	40"
Stratix GX	40"	3 <sup>rd</sup> party device (without equalizer)	0 to max	40"

Characterization has shown receiver equalization to be an effective solution when interfacing between two Stratix GX devices, or with a third party device, (ASIC or ASSP) where the 3<sup>rd</sup> party products also provides equalization. The Fig 8 shows simulation based on a 40" Tyco backplane, using a PRBS 10 pattern. The simulation point is between the equalization circuitry and the receive buffer. Results are shown for various levels of pre-emphasis and equalization. Fig 8c shows the cleanest eye diagram, this was modeled without pre-emphasis, but with maximum equalization.

*Fig 8 40" Tyco backplane using a PRBS 10 pattern*



In most cases it has been found Equalization to be an effective solution to overcoming losses within the backplane. It has the advantage of being able to regenerate the symbol, without the need of increasing the power requirement within the system. This can be particularly important in backplane applications where power dissipation is difficult.

Pre-emphasis is at its most effective in systems where Stratix GX is to interface to a 3<sup>rd</sup> party device and the 3<sup>rd</sup> party product does not include receiver equalization. In this case pre-emphasis is the only weapon for overcoming high frequency losses.

## Conclusions

Skin effect and dielectric loss can cause major attenuation to high frequency signals, impacting the success of using high speed transceiver technology along conventional FR4 PCB fabric. The use of Pre-emphasis and Equalization can help to overcome these issues and with careful selection can enable high speed signal to operate in legacy systems designed to operate at much slower data rates.

The flexible transceivers in Stratix GX provide both pre-emphasis and receiver equalization, allowing them to drive in excess of 40" FR4 PCB fabric, making it ideal for backplane design. The equalization circuitry in particular has shown to be extremely effective in overcoming signal loss and in enabling the transceiver to operate over longer distances. It is also a major factor in enabling the transceiver to operate in legacy systems where the layout is being pushed to operate at higher transmission rates.

The transceiver implementation within Stratix GX can significantly help the designer to overcome signal integrity issues.



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