De-emphasized Signal Generation with the Agilent N4916A De-Emphasis Signal Converter

Application Note

Agilent Technologies

Overview

De-emphasis is a commonly used technique when transmitting electrical signals at gigabit data rates. It compensates for signal integrity issues caused by the channel on printed circuit boards and backplanes.

The most popular high-speed electrical standards require transmitter de-emphasis. These standards are: PCI EXPRESS®, SATA 3 Gb/s, fully buffered DIMM, Hypertransport, CEI, and 10 Gb Ethernet.

Figure 2: The channel model with embedded loss: the TX output uses de-emphasis, the RX input uses equalization to improve signal integrity

Topics:
* The definition of de-emphasis
* Correlating time and frequency domains

Using de-emphasis for:
* Characterization of receivers and media
* Compliance testing according to a standard
* De-embedding a test setup
* De-emphasis implementation with three taps
* IEEE802.3ap
* Combining two N4916A
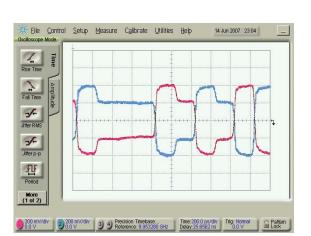* The benefits of a three-tap solution

Figure 1: The normal and complement waveform of a de-emphasized signal and its data content

Signal integrity issues on printed circuits, motherboards and connectors arise from loss in the transmission channel that decreases signal performance.
Using de-emphasis at a transmitter (TX) output and equalization at a receiver (RX) input can compensate for the channel and optimize the transmission
(see figure 2).

Figure 1 shows the waveform of a de-emphasized signal. Sometimes this is called pre-emphasis, as one could see it as boosting the first cycle after a transition. However, usually the signal's amplitude is reduced after a delay of one unit interval (UI), if the data content does not change, so the method is called de-emphasis.

This product note deals with implementing de-emphasis with the Agilent N4916A De-emphasis Signal Converter. It describes how this can be used for characterization and compliance testing according to various standards. It covers a de-embedding technique to improve the signal integrity in a bench-type test setup, and it covers a sophisticated example of combining two N4916A units for the IEEE802.3ap standard.

De-emphasis improves signal integrity

The signal integrity issues on printed circuits, motherboards and connectors arise from loss in the transmission channel. The loss has many causes. It depends on the conductivity of the signal line, especially the skin effect, which concentrates the current at the edge of the conductor. Another source of loss is the dielectric material, where the storage of humidity has a large influence. Bandwidth issues can affect the loss. And last but not least, the radiation of signal energy contributes to the loss.

Loss can be compensated for at the transmitting and the receiving end. At the transmitter the loss can be compensated either by boosting the high frequency content (pre-emphasis) or by decreasing the low frequency content (de-emphasis).
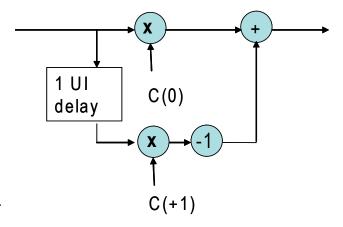
Figure 4: Block diagram of a two-tap de-emphasis

On the receiving end, there is the choice of using analog techniques, by applying high pass filters to reverse the channel effect, or digital techniques, using Decision Feedback Equalization. Analog filters may have the disadvantage of collecting unwanted noise.

A description for loss is: it performs like a low pass filter applied to a data signal. However, the reality is more complex than a simple, 1st order, low pass filter. There is no roll-off, nor a constant decrease after the roll-off. The loss curve is proportional to the data rate^1.5.

Another large area of signal integrity issues are reflections. Reflections occur because of impedance mismatches. But reflections cannot be compensated for by de-emphasis.

Figure 3: Agilent N4903A high-performance serial BERT (Bit Error Ratio Tester) and the N4916A De-Emphasis Signal Converter

The definition of de-emphasis

The Agilent N4916A De-Emphasis Signal Converter, as shown in figure 3 with the N4903A J-BERT, provides a two-tap de-emphasis, as shown in figure 4.
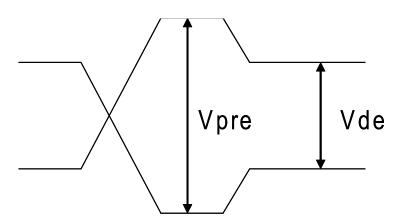
The first tap is the main signal while the second tap inverts and delays the signal by 1 UI, before the two signals are added together.

The output parameters are defined by C(0), which is controlled by the level programming of the N4903A and C(+1) which is defined by the de-emphasis value.

The de-emphasis is the ratio of the differential amplitude after the transition and the amplitude after 1 UI. It is a unit-less figure, which may also expressed in dB, as shown in figure 5.

The de-emphasis value is positive, even though the signal is subtracted after the delay. An example of the waveform is shown in figure 7.

The signal shown in figure 4 may also be called "post-cursor", but this name can have different meanings in different standards, and may be applied to more complex signal conditioning. Because of this possible naming conflict, the expressions pre– and post-cursor are not used in this document.

$$R = V_{pre} / V_{de}, \text{ in dB: } R = 20 * \log (V_{pre} / V_{de})$$

Figure 5: Definition of the amplitude parameters of a two-tap de-emphasis

Using the Agilent N4916A De-Emphasis Signal Converter with negative de-emphasis values

The Agilent N4916A allows de-emphasis to be programmed as a negative value, as shown in figure 8. As shown in figure 6, the un-delayed tap is inverted. C(+1) is controlled by the N4903A levels and C(0) is controlled by the de-emphasis value.
The main signal is subtracted from the pre-shoot after 1 UI. This is the same as inverting the data signal. As shown in the resulting waveform, in figure 9, the de-emphasis behaves like a pre-shoot.

Please note that the absolute delay through the N4916A is the same for the first transition whether using positive or negative de-emphasis.

This means, when combining two Agilent N4916A to create a signal with three taps (one tap for a pre-shoot and one tap for the de-emphasis), it is necessary to delay one N4916A 1 UI against the other.
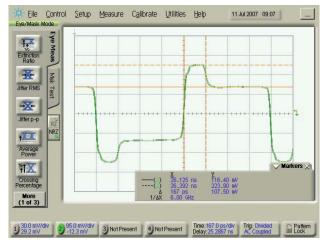This is discussed later in this document.

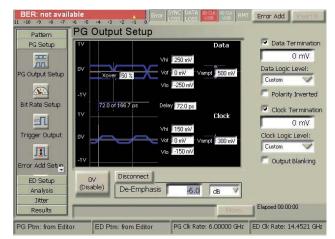**Figure 7: N4916A waveform obtained with a positive de-emphasis value**

Figure 8: Negative programming value for the de-emphasis (-6dB)
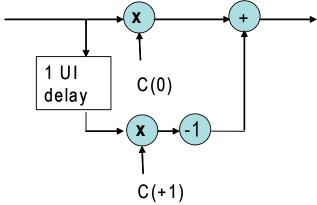

Figure 6: Diagram of the N4916A two-tap de-emphasis when programming a negative de-emphasis value
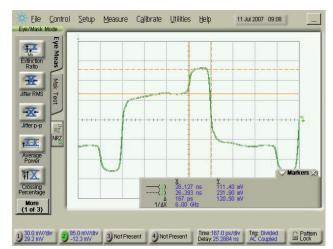

Figure 9: N4916A waveform obtained with a negative de-emphasis value

ISI and de-emphasis in the time and frequency domains

This experiment visualizes and correlates effects in the time and frequency domains. The experiment uses a long twisted pair cable (length 20 m), operating at a data rate of 50 Mb/s. Due to the low data rate, we do not use the N4916A; but the principle applies at higher data rates.

The experiment is set up as shown in figure 10. For the screen shots shown here, we used an Agilent 81104A Pulse Pattern Generator (PPG) with two channels as the stimulus, though another PPG, such as the Agilent 81110A could also have been used.

Custom signal conditioning circuitry was used to generate the de-emphasized signals, as shown in figure 15. The receiver end of the twisted pair cable is connected with both wires to two scope channels, with the inputs switched to 50 Ohm termination.

We used an Agilent Infiniium scope to look at the digital signal in the frequency domain, we used a 86100C DCAj to look at the signal in time domain. The scope can calculate the Fourier transformation (FFT), which shows the harmonics corresponding to the edge speed of the digital signal.

The edge speed is responsible for the odd harmonics in the frequency domain, so the energy of the digital signal appears as peaks at $n \times f$, where f = data rate/2, and $(n = 1, 3, 5, \ldots..)$

The faster the edges, the higher the peak, and the more peaks we see before the signal disappears in the noise. In this example we look at the 9th harmonic at 225 MHz. The diagrams show that there is still reasonable energy in the 19th harmonic at 475 MHz.
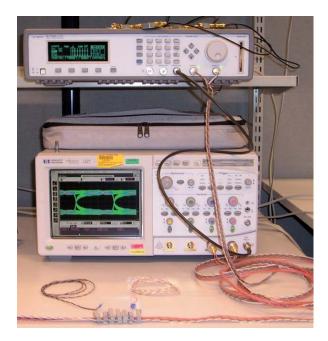
Figure 10: Setup for ISI measurements to correlate results in the time and frequency domains

The figures shown here are grouped as follows:

(figures 11/13/15/17): Eye diagrams from an Agilent 86100C DCAJ

(figure 12/14/16/18): Frequency diagram (FFT). The ratio of harmonic k9 to the base is circled

(figures 11 to 14): Signals without de-emphasis

(figures 15 to18): Signals with de-emphasis

(figures 11/12/15/16): Signal at the cable input, single ended

(figures 13/14/17/18): Signal from cable output, single ended measured

Conclusions

Looking at the results in the time domain (top row of pictures), the cable loss causes signal droop, slower transition times and eye closure (jitter). Though it does not restore it completely, the de-emphasis of 4 dB improves the signal, and in particular it reopens the eye, removing the effect caused by ISI jitter.

De-emphasis restores energy to the harmonics, which improves signal integrity by compensating for the degradation caused by the loss in the cable. The nice thing about de-emphasis is that it boosts the harmonics and not the noise, which is what a linear filter or amplifier would do.

Figure 11: Input signal eye diagram, without de-emphasis

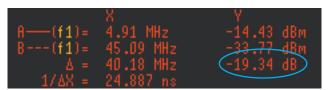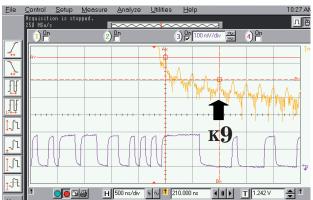**Figure 13: Output signal eye diagram, without de-emphasis**

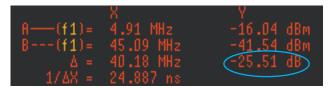**Figure 12: Input signal without de-emphasis, FFT mode measurement**

Figure 14: Output signal without de-emphasis, FFT mode measurement

In the frequency domain (bottom row of pictures) the loss attenuates the harmonics. It reduces harmonic k9 by 6.2 dB (figures 12 and 14). De-emphasis boosts harmonic k9 by 0.7 dB (compare figures 12 and 16 with figures 14 and 18). De-emphasis restores energy to the harmonics, which improves signal integrity by compensating for the degradation caused by the loss in the cable.

The nice thing about de-emphasis is that it boosts the harmonics and not the noise, which is what a linear filter or amplifier would do.
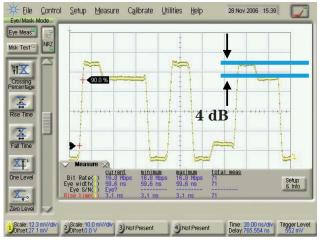

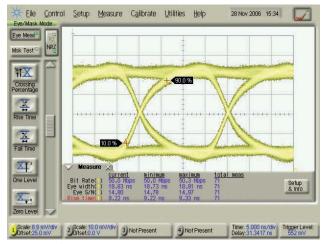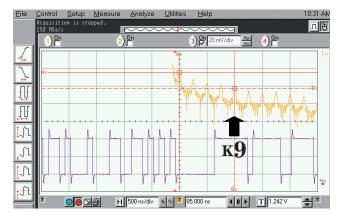**Figure 15: Input signal eye diagram, with de-emphasis**

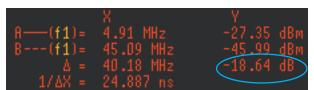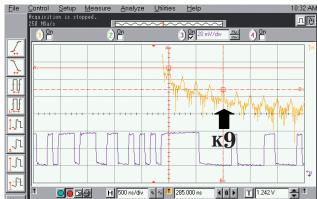**Figure 17: Output signal eye diagram, with de-emphasis**

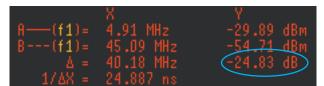**Figure 16: Input signal with de-emphasis, FFT mode measurement**

Figure 18: Output signal from the cable with de-emphasis, FFT mode measurement

Using the E4916A De-Emphasis Signal Converter to Compensate for a Backplane at 5 Gb/s

This example shows the waveforms of the input and output signals obtained on a 20" backplane without and with de-emphasis.

This could be used as base for compliance testing of a PCIe™ 2nd generation receiver, for example.

The screen shots shown here from the scope are grouped as follows:
This page: Test setup (figure 19), and input (figure 20) and output (figure 21) signals without de-emphasis
Next page: Test setup (figure 22), and input (figure 23) and output (figure 24) signals with de-emphasis
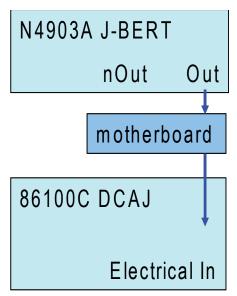

Figure 20:Input signal to the motherboard @ 5 Gb/s without de-emphasis

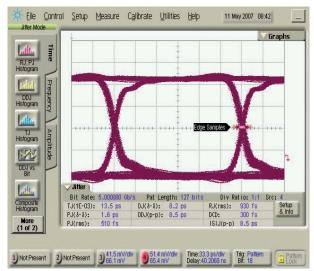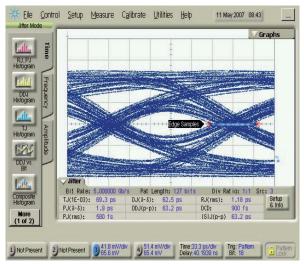**Figure 19: Setup for the reference measurements on the motherboard without de-emphasis**

Figure 21:Output signal from the motherboard @ 5 Gb/s with the input signal from figure 20

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Conclusions

The motherboard causes an eye closure of roughly 0.3 UI. A de-emphasis of around 6 dB compensates adequately for the ISI jitter: the remaining eye closure due to ISI is less than 0.1 UI.

Varying de-emphasis makes characterization measurements possible, by sweeping the de-emphasis and logging the resulting ISI jitter. This makes it possible to optimize a specific setup. The de-emphasis can be programmed according to specific standards and the remaining eye opening can be checked for compliance.
Another application is to connect the motherboard to a receiver. Sweeping the de-emphasis while measuring BER characterizes the proper range of operation.
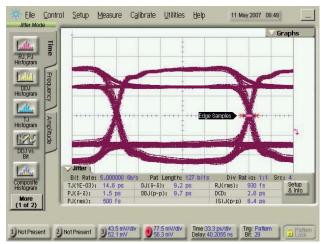
Figure 23: Input signal to the motherboard @ 5 Gb/s, with de-emphasis

Again, by setting a de-emphasis according to a specific standard, the BER measurement can verify compliance.
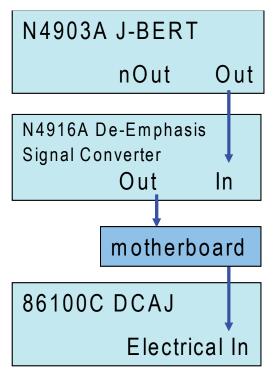
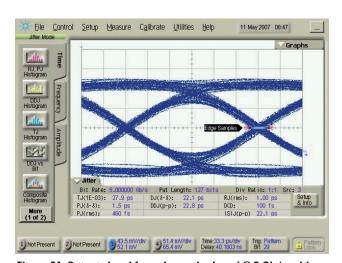**Figure 22: Setup for the measurement on the motherboard with de-emphasis**

Figure 24: Output signal from the motherboard @ 5 Gb/s with the input signal from figure 23

Using the E4916A De-Emphasis Signal Converter to Compensate for an E/O Converter at a Data Rate of 10 Gb/s

This example provides the waveforms of the input and output signals obtained from an e/o converter without and with de-emphasis at the data rate of 10 Gb/s.
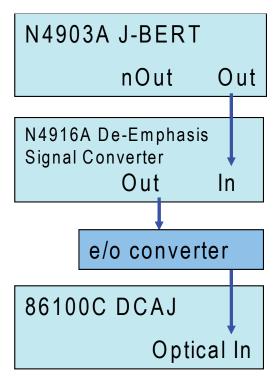This can be used to de-embed a bench-type test setup for testing the receiver of 10 Gb/s optical transceivers.

Figure 26:Input signal without de-emphasis 10Gb/s

Figure 25: Setup for the reference measurements of an e/o converter without de-emphasis

Figure 27: Output signal from the e/o converter with the input signal from figure 26

The screen shots shown here from the scope are grouped as follows:
This page: Test setup (figure 25), and input (figure 26) and output (figure 27) signals without de-emphasis
Next page: Test setup (figure 28), and input (figure 29) and output (figure 30) signals with de-emphasis
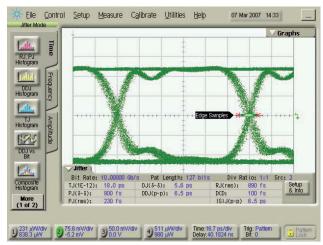
Conclusions

The e/o converter causes an eye closure of around 0.15 UI. A de-emphasis of around 6 dB reduces the ISI jitter to close to 0.1 UI. This may sound marginal, but bearing the various 10Gb/s standards in mind, this can be the key to de-embedding a bench setup to create a precisely defined stressed eye by adding the various sources of jitter.

By varying the de-emphasis, the eye opening and the signal shape can be optimized.

As a next step, the specific jitter sources of the N4903A can be used to close the eye, according to the stress condition of a specific standard.

This signal can be fed to the receiver of the optical transceiver, to perform characterization and conformance measurements with the BER. For characterization measurements, the jitter sources can be swept over frequency and magnitude, while for conformance tests the jitter sources can be set to the corner cases defined in the standards.

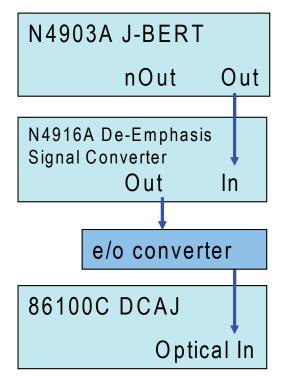**Figure 28: Setup for the measurements with de-emphasis applied to the input of the e/o converter**
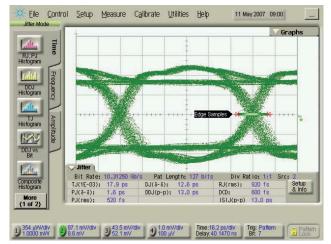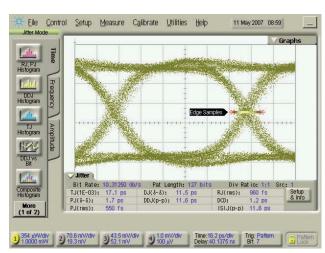
Figure 29: De-emphasized input signal

Figure 30: Output signal from the e/o converter with the de-emphasized input signal from figure 29

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A Three-tap Solution for the IEEE802.3ap 10GBASE-KR

The 10GBASE-KR transmitter includes programmable de-emphasis to compensate for frequency-dependent loss in the backplane channel, and to facilitate data recovery at the receiver. This de-emphasis uses a three-tap finite impulse response (FIR) configuration as shown in figure 31.

The actual implementation of the transmitter de-emphasis, including the incorporation of additional taps, is beyond the scope of the IEEE802.3ap standard.

Transmitter de-emphasis performance is specified in terms of Vpre, Vpst, Vss, Rpre, and Rpst, as defined in figure 32.

It should be noted that the valid ranges of $c(1)$ and $c(-1)$ coefficients may have positive or negative values. A value of zero is used to turn off equalization for the tap.
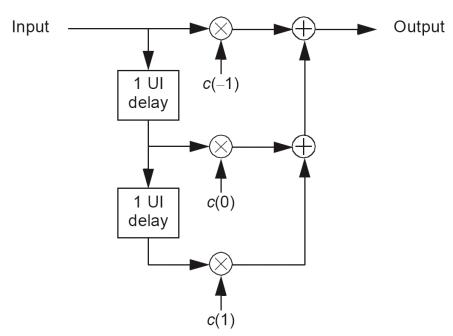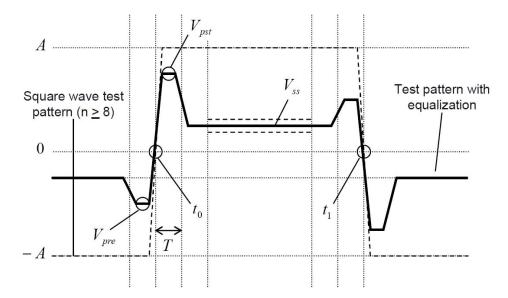
Figure 31: Block diagram of the IEEE802.3ap three-tap finite impulse response (FIR) configuration

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Figure 32

Definition of the pre and post tap ratio:

$$R_{pre} = -\frac{V_{pre}}{V_{ss}}$$

$$R_{pst} = \frac{V_{pst}}{V_{ss}}$$

A   =   peak differential transmit output amplitude

T   =   symbol period

t_0 =   zero-crossing point of the rising edge of the AC-coupled signal

t_1 =   zero-crossing point of the falling edge of the AC-coupled signal

Vpre =   minimum voltage measure in the interval t_0- T to t_0

Vpst =   maximum voltage measured in the interval t_0 to t_0 + T

Vss   =   steady-state voltage measured as the average voltage in the interval t_0 + 2T to t_1 - 2T

Figure 32: IEEE802.3ap transmitter waveform definition, based on the block diagram shown in figure 31

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The setup uses an Agilent N4903A J-BERT, two Agilent N4916A De-Emphasized Signal Converters and an Agilent 86100C DCAJ for calibration and measurements.
The setup is connected as shown in figure 35. The N4916A responsible for Vpst is connected through a 1 UI delay to the normal data output of the J-BERT.

The N4916A responsible for Vpre is connected to the inverted data output of the J-BERT. There are inversions of the data and the negative de-emphasis, so altogether both N4916A are in phase.

As can be seen in figure 33 the delay of 1 UI is achieved using variable phase shifters in both data lanes. The phase shifters will be adjusted for a 1 UI delay between the two paths. The output signals of both N4916A are combined using an Agilent 11636B power divider.
This adjustment is performed using the Agilent 86100C DCAJ to monitor the combined signal. For the adjustment, the N4916A responsible for Vpst is set for 0.1 dB the other N4916A is set for -.0.1 dB de-emphasis. A repeating pattern of ,1111111100000000' is recommended. The DCAj is triggered with a sub rate clock divided by 16 from the N4903A sub rate clock out.

The N4916A outputs are alternately replaced by a termination at the power divider. The phase shifters are adjusted until a positive edge of both N4916A outputs are at the same position (+/- 1 ps) on the screen of the DCAJ.

After completing the adjustments, both N4916A outputs are connected to the power divider and the de-emphasis values are set to: 12 dB for Vpst and - 4 dB for Vpre, resulting in a signal as shown in figure 34.
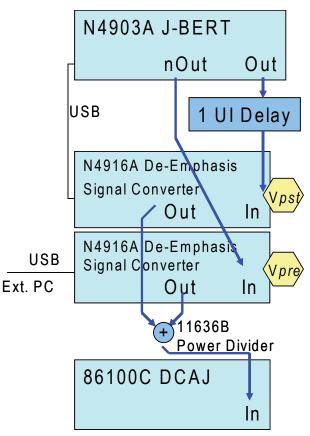

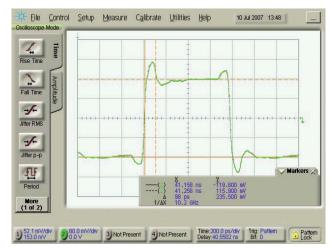Figure 33: Block diagram of the combination of two N4916A for the three-tap solution

Figure 34: Three-tap waveform generated with the setup in figure 33

Actual setup

The N4916A responsible for Vde is connect-
ed to the Data Output; the unit responsible
for Vpre is connected to the complement
Data Output

Two phase shifters are used to adjust the 1
UI delay between both N4916A

N4916A for Vpst

N4916A for Vpre

The top trace is the de-emphasized input
signal.
The bottom trace is the motherboard out-
put signal

Motherboard with a 12" trace

Two power dividers are cascaded to first
add the signals from the two N4916A and
then split this signal for scope and mother-
board input

Not shown is the programming of the two
4916A units: the upper unit is connected
over USB to the N4903A and the value for
the de-emphasis is set from the graphi-
cal user interface there. (Controlling the
N4916A from the N4903A requires a
software revision 4.8 or higher.)

The second N4916A is controlled over USB
from an external PC, where an offline ver-
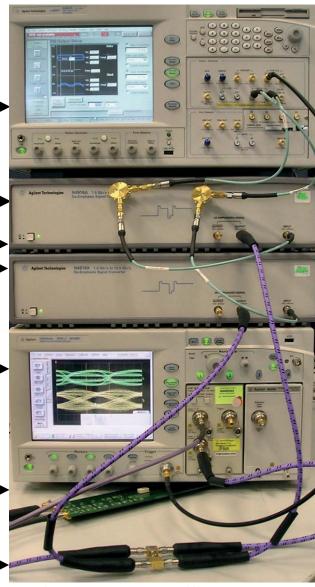sion of the N4903A software is installed.

**Figure 35: Actual setup including N4903A BERT with two
N4916A and a DCAJ for the motherboard measurements**

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The need for de-emphasis with
a three-tap implementation

Figure 36 to 38 show the measurements over a backplane with a 12" trace, using a 2^7-1 PRBS pattern. The measurements use the setup from figure 35. The Agilent 86100C DCAJ is used in eye mode, the trigger is set at the data rate. The top trace is the input signal, the bottom trace is the motherboard output signal.

Figure 36: Both de-emphasis values are set to a minimum: 0.1 dB for the ratio Vpst/Vss and –0.1 dB for the ratio Vpre/Vss.

Figure 37: The ratio Vpst/Vss is set to 12 dB, the ratio Vpre/Vss is kept at - 0.1 dB (a similar result is obtained if Vpst/Vss is set to 0.1 dB and Vpre/Vss is set to 12 dB)

Figure 38: The optimum eye opening is obtained for Vpst/Vss set to 12 dB and Vpre/Vss set to -6.0 dB. This achieves an eye opening of around 0.55 UI. A signal transmitted over a 12" backplane at a data rate of 10.3125 Gb/s needs three taps for the de-emphasis to achieve a reasonable eye opening.
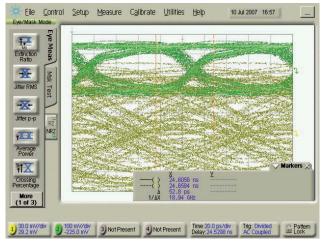

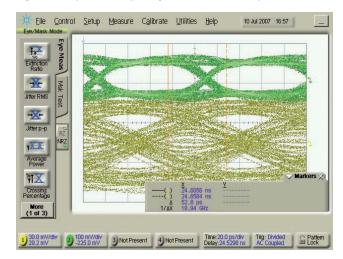**Figure 36: Input and output signals without de-emphasis**

Figure 37: Input and output signal with a two-tap de-emphasis

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Conclusion

A two-tap implementation is not sufficient to open the eye at all.

The combination of two Agilent N4916A De-Emphasized Signal Converters together with an Agilent N4903A J-BERT provides a solution for characterization measurements and compliance testing according to IEEE802.3ap 10GBASE-KR. This solution is more economic and convenient than a solution using multiple generator channels added together.
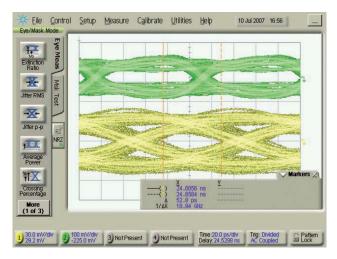

Figure 38: Input and output signal with an optimized three-tap de-emphasis

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