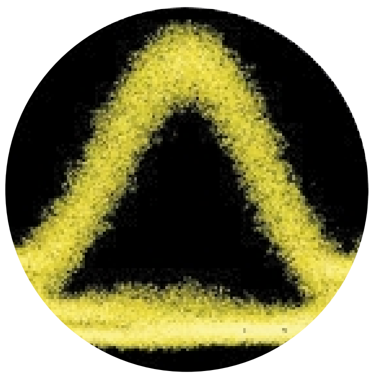
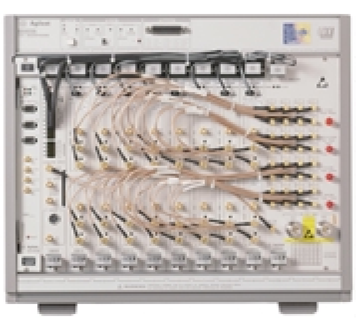
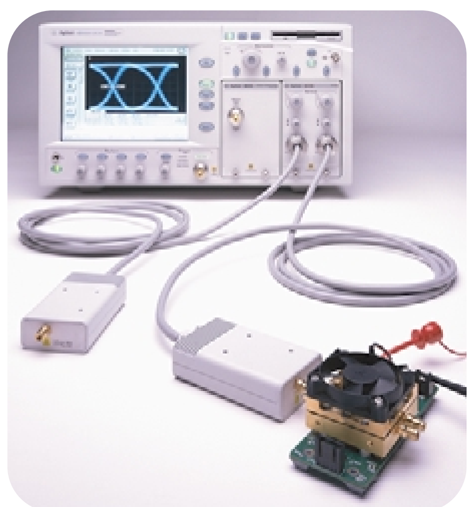
The Art of Measuring 40G Eye Patterns

Application Note







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1. Introduction

The measurement of the signal performance in a transmission system may strongly depend upon each individual part used in the measurement chain, e.g. attenuators, adapters and cables. The bandwidth and transfer function of oscilloscopes may also have a direct impact on the measurement result, e.g. the signal waveform.

While this is true in general, measurements at 40 Gbit/s continue to be a particular challenge. This is due to the fact that 40G measurements are still relatively uncommon. Adequate bit error ratio testers (BERTs), like the Agilent Technologies ParBERT 81250, are now available commercially. However, using such testers in conjunction with inappropriate accessories and instruments, e.g. attenuators, adapters, cables or oscilloscopes that may happen to be available in a typical lab environment, is very likely to impact the measurement result significantly, e.g. the 40G eye pattern. Therefore, all elements of the measurement chain need to be selected carefully.

The real eye pattern performance and fast transition times < 10 ps of leading-edge 40G signals can only be fully revealed with an optimized measurement setup. Effects such as ringing, overshoot and droop can be caused by bandwidth limitations of individual parts in the measurement chain and will alter the eye pattern measured. An example is given in figure 1.

Most of these effects can be related to the frequency response of cables, adapters, attenuators and oscilloscopes.

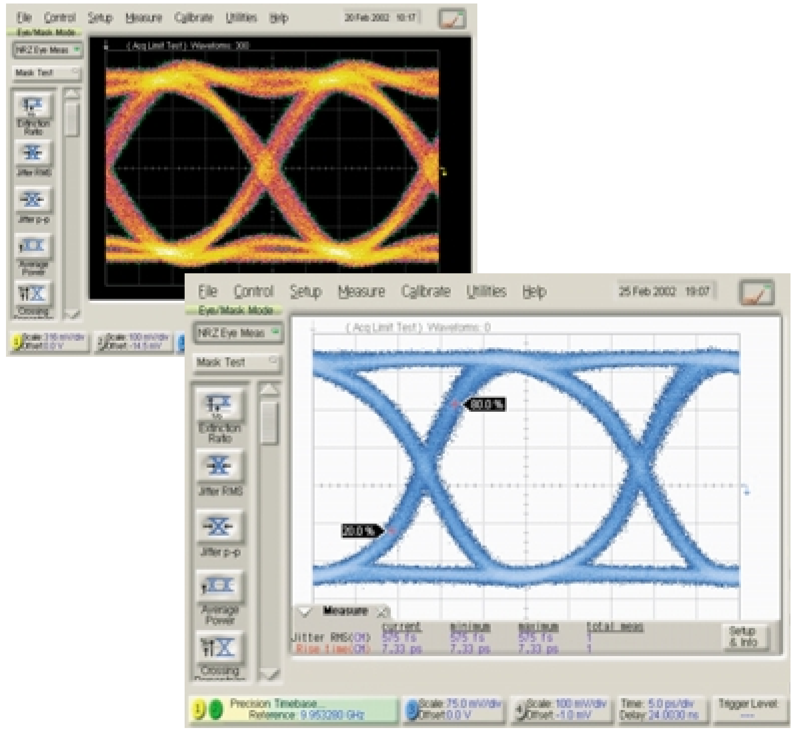


Figure 1: 40G eye pattern measured with a scope with insufficient bandwidth (back) and appropriate bandwidth (front) - same input signal

This application note will discuss how bandwidth effects will impact a waveform and how 40G pulse shapes can be measured with minimal distortion. After a brief review of the theory, the results of several measurements will be analyzed and compared.

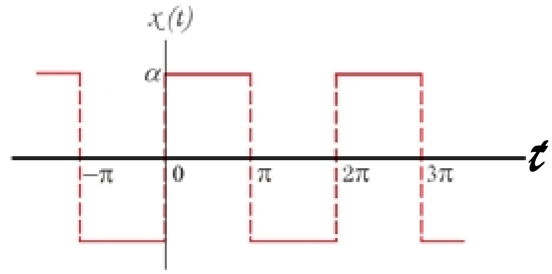
2. Back to Basics

2.1 Principles of Fourier Series

In time domain, signals can be constructed by superimposing individual waveforms. The individual waveforms are defined by distinct frequencies in the Fourier series.

Figure 2 gives the Fourier series of a square wave.

For function $x(t) = \begin{cases} \alpha & \text{for } 0 < t < \pi \\ -\alpha & \text{for } -\pi < t < 0 \end{cases}$



the **Fourier Series** is:

$$x(t) = \frac{4a}{\pi}\left(\frac{\sin t}{1} + \frac{\sin 3t}{3} + \frac{\sin 5t}{5} + \dots\right)$$

Figure 2: The Fourier Series of a Square Wave

2.2 Time and Frequency Domain

The Fourier-Transformation translates a signal from time domain to frequency domain, i.e.

$$x(t) \longrightarrow x(f)$$

Formulae (1) and (2) also apply to a single pulse as given in figure 3. In the frequency domain, the amplitude of the distinct frequencies of the series above are easily detectable as discrete lines in the signal's magnitude-spectrum, see e.g. figure 3.

As indicated by (1), the full "construction" of a square wave or pulse requires an infinite number of sine waves with distinct frequencies. In this particular case, all frequencies are odd harmonics of the fundamental frequency f_0.

The pulse can be approximated by neglecting higher order harmonics. Taking only the fundamental frequency (a) and the third harmonic (b) into account results in a rough approximation (c).

The quality of a waveform is defined by its risetime, falltime, overshoot and ringing. These parameters depend on the bandwidth of the signal. As seen in figure 1, a high quality, high bandwidth signal will be significantly distorted if the bandwidth of the input filter of the oscilloscope used for the visual representation is insufficient. Band limitations may also be caused by cables, attenuators and adapters.

Band limitations supress higher order harmonics significantly. This is demonstrated with curve (d) by arbitrarily reducing the contribution of the harmonic (b). In comparison with a sinusoidal waveform, the resulting waveform is wider.

The impact of the band limitation of individual components is discussed in chapter 3 with measured and simulated data.

An ideal input signal is simulated by two ideal waveforms m3 and m4, representing the normal and complementary waveform for the simulation of an ideal eye pattern, see figure 4

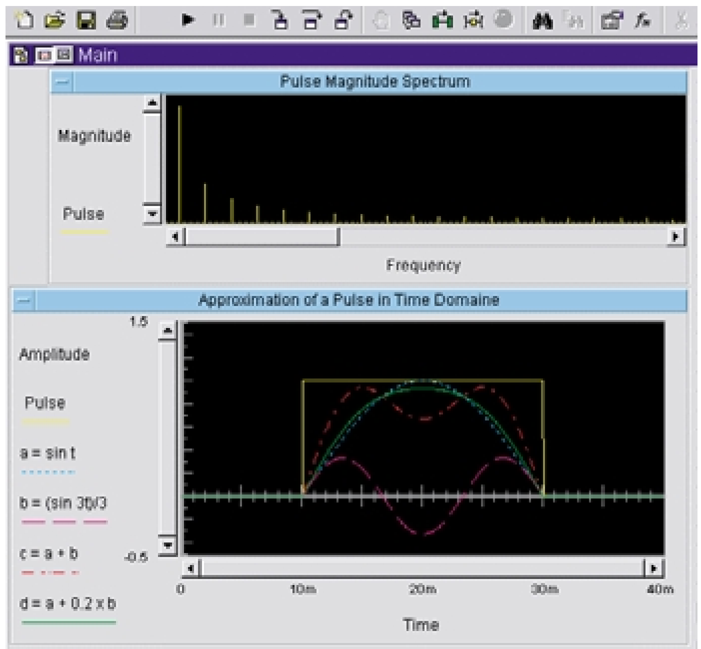


Figure 3: Frequency and time domain representation of a pulse

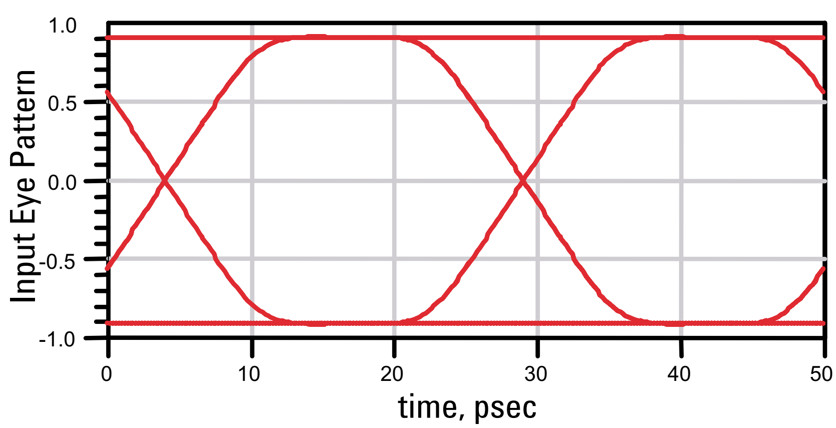


Figure 4: Simulation of an ideal eye pattern

3. Impact of Individual Components

3.1 Equipment Used

In order to show the impact on the eye pattern, the following equipment has been used:

- Agilent Technologies ParBERT 81250A 40G Pattern Generator
- Agilent Technologies 50 GHz oscilloscope with Chebyshev filter, 2.4 mm connector input
- Agilent Technologies 40 GHz oscilloscope with Thompson-Bessel filter
- Agilent Technologies Digital Communication Analyzer 86100B with precision time base and 70 GHz+ remote head Plug-In, 1.85mm female connector

All measurements were taken with:

- 20-80% rise time
- rms jitter

3.2 Impact of a Chebyshev Input Filter

The impact of a Chebyshev input filter is demonstrated by a simulation and a scope measurement with 50 GHz bandwidth.
The main characteristic of the frequency response of a Chebyshev filter is the fast roll-off after the cut-off frequency. For the simulation, a filter with cut-off frequency at 50 GHz (see figure 5) is applied to the eye pattern.

The filter causes ringing, overshoot and a bimodal behavior on the ideal signal, as shown in figure 6.

A 40G eye pattern measured with an oscilloscope with 50 GHz input bandwidth and Chebyshev filter characteristic is given in figure 7. The similarity with the result of the simulation above is striking.

In this waveform, overshoot and ringing are mainly caused by the interaction of the high frequency content of the 40G signal (fast transition times) and the Chebyshev input filter.

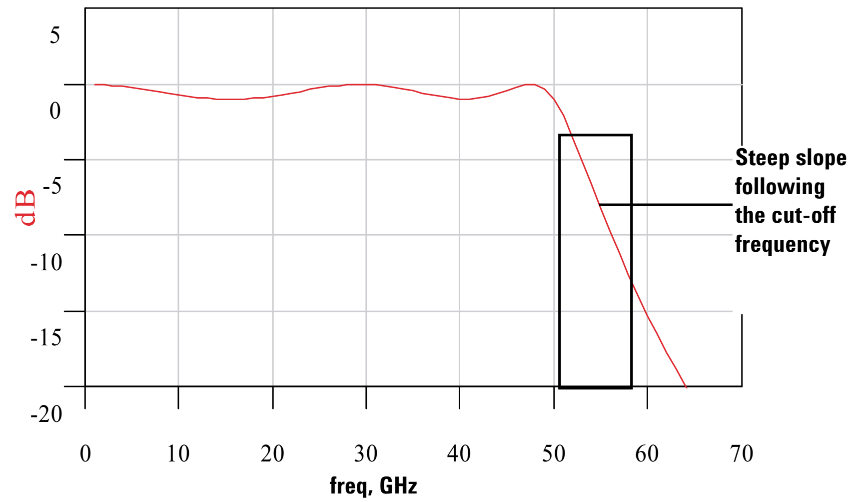


Figure 5: Chebyshev filter frequency response

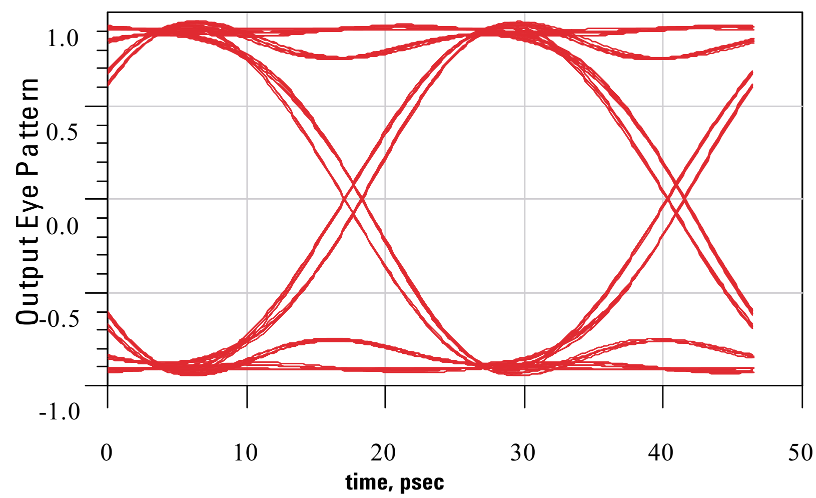


Figure 6: Simulated impact of a Chebyshev input filter on an ideal eye pattern

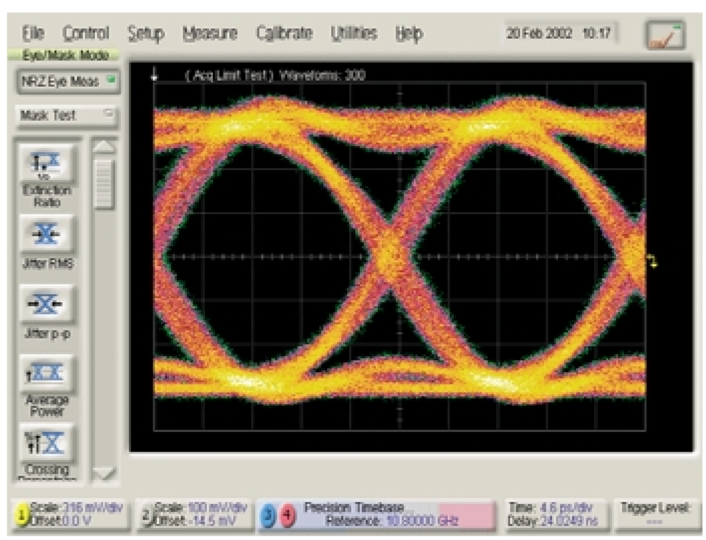


Figure 7: 40G Eye pattern measured with a 50GHz Chebyshev input filter

3.2 Impact of a Bessel-Thompson Input Filter

Again, the ideal signal given in figure 4 is used for a simulation.

A Bessel-Thompson filter is characterized by a very gentle roll-off after the -3 dB cut-off frequency. This characteristic is similar to a Gaussian filter response. A much wider frequency range can pass this Bessel-Thompson filter beyond its cut-off frequency at 40GHz (see figure 8).

The characteristic of the Bessel-Thompson filter results in a much cleaner eye pattern without ringing or overshoot. The simulation (figure 9) shows the effect clearly. The reason for the "improved" eye pattern compared to figure 6 is that more of the signal's high-frequency content is left after the filtering.

This simulation is also in line with measurements (figure 10). Note that the 40G input signal used to generate figures 7 and 10 was identical!

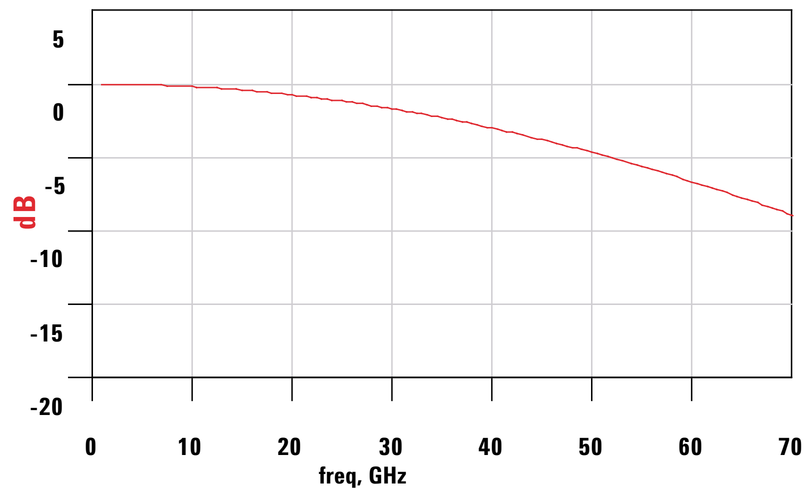


Figure 8: Frequency response of a Bessel-Thompson filter

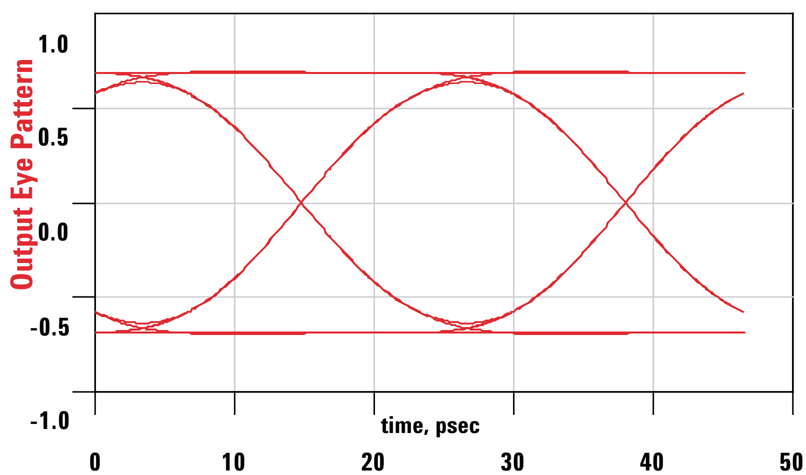


Figure 9: Bessel-Thompson filter applied to an ideal eye pattern

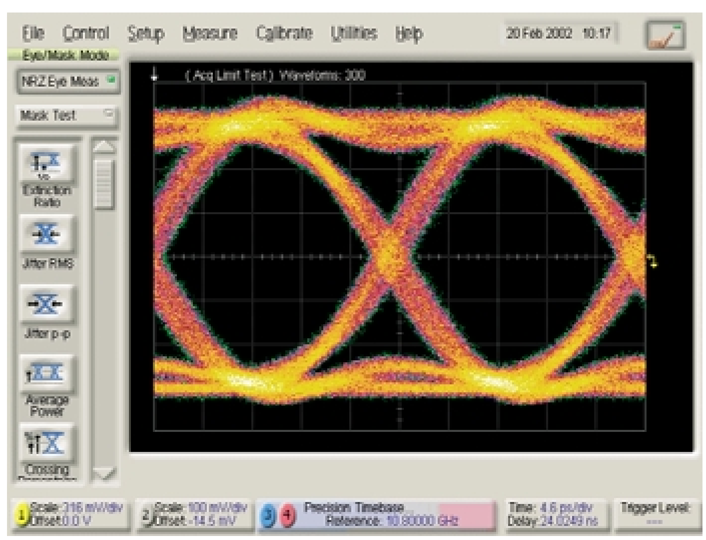


Figure 10: 40G eye pattern after Bessel-Thompson filtering

3.3 Impact of Attenuators

A source for ringing at 60-70 GHz are 50 GHz attenuators.

The impact of attenuators is simulated for four different types, given in figure 11. The following values have been used for the simulations:

 : 20 dB

 : 10 dB

 : 6 dB

 : 3 dB

 : 0 dB attenuation (no attenuator used)

Above 50 GHz, the frequency response of all attenuators show regions of gain reduction as well as resonance.

Applying the simulated frequency response functions to the simulated ideal waveform (figure 4) leads to the results shown as an example in figure 12.

Four simulated eye patterns reveal the dependency of the ringing at 10 dB attenuation on the signal's transition time.

The faster the transition time, the higher the frequency content of the spectrum of the 40G signal. The higher the frequency content of the spectrum, the higher the overshoot due to the resonances of frequencies > 50 GHz. This will cause increased ringing.

The simulated results again match the measured data. Note however that in order to conduct such measurements, the input bandwidth of the scope used needs to be adequate.

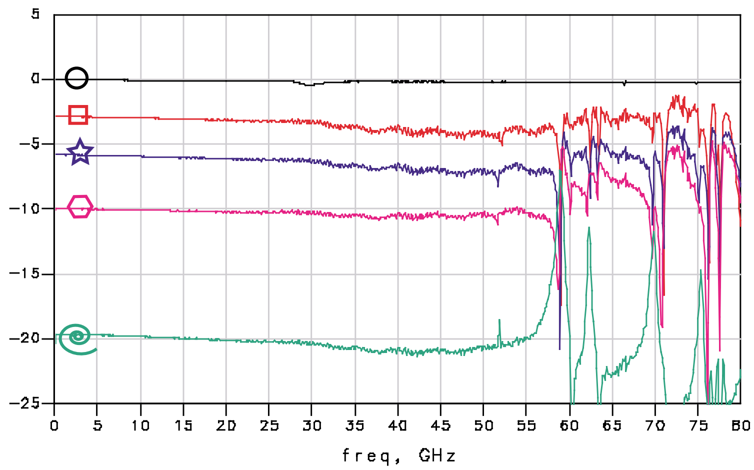
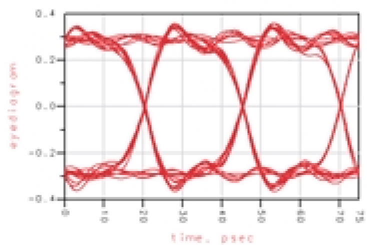
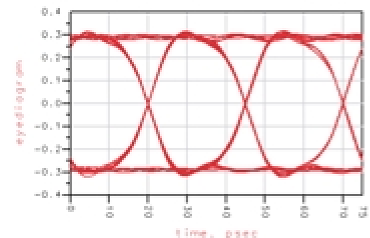


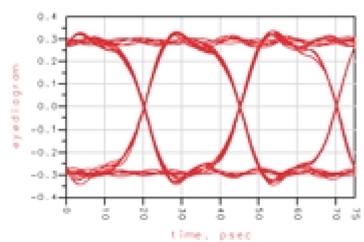
Figure 11: Simulated frequency response of attenuators



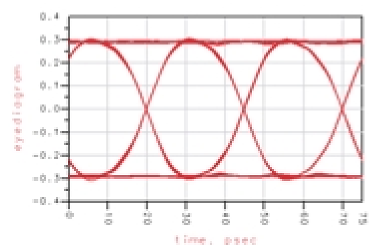
1) Transition time 8.5 ps



2) Transition time 10 ps



3) Transition time 8.5 ps



4) Transition time 11.5 ps

Figure 12: Simulated impact of the trasition time for -10 dB attenuation

The screenshot of the eye pattern in figure 13 was taken with the Agilent Technologies 86116A 65 GHz Sampler and a 50 GHz 10 dB attenuator.

The transition time of the signal applied to the scope was about 9 ps. Although the impact of the attenuator is clearly seen, the measured data does not match the simulated data as closely as in the previous examples. This is due to the scope's 65 GHz bandwidth, which is still not sufficient to measure such effects adequately.

Ringing caused by attenuator

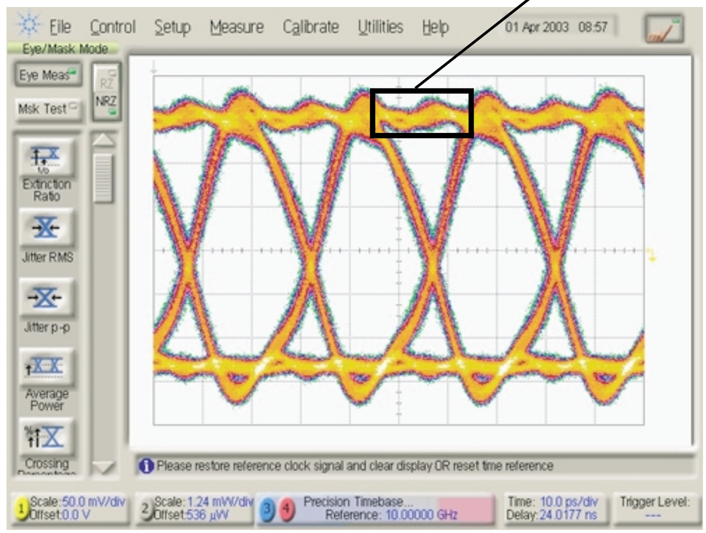


Figure 13: Measured impact of a 10 dB attenuator

3.4 Impact of Cables

As before, the ideal eye pattern of figure 4 is used for this simulation.

Figure 14 shows the residual frequency response of a 20” cable and the Agilent 86116A scope. The frequency response continuously decreases to 75 GHz, then falls steeply with approximately -7 dB slope to 90 GHz.

The simulated result of the ideal eye pattern, filtered by the cable and the scope input, reveals droop in the signal level as depicted in figure 15.

Again, the measurement with an Agilent Technologies 86116A 65GHz Sampler and a 20" cable matches the simulated data perfectly and clearly show droop effects (figure 16).

Note that the same input signal has been used as in Figures 7 and 10!

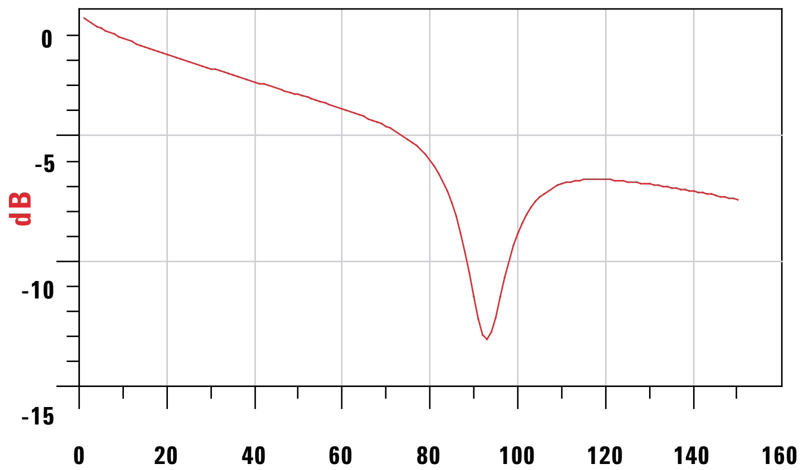


Figure 14: Frequency response of a scope with Bessel-Thompson filter and 20” cable

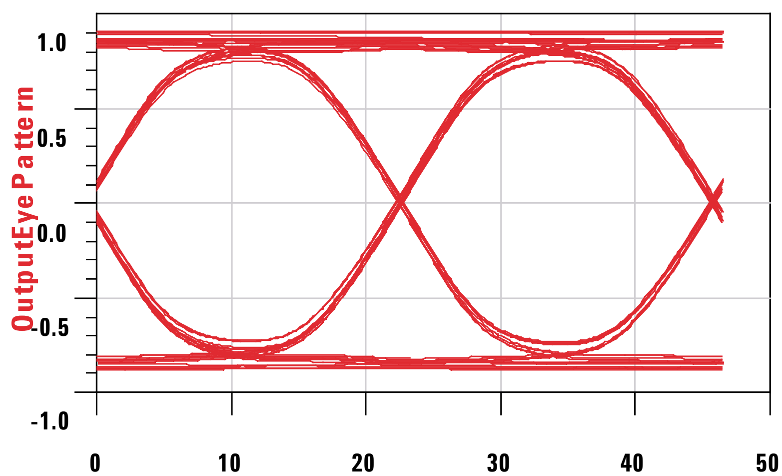


Figure 15: Simulated input of cable and scope

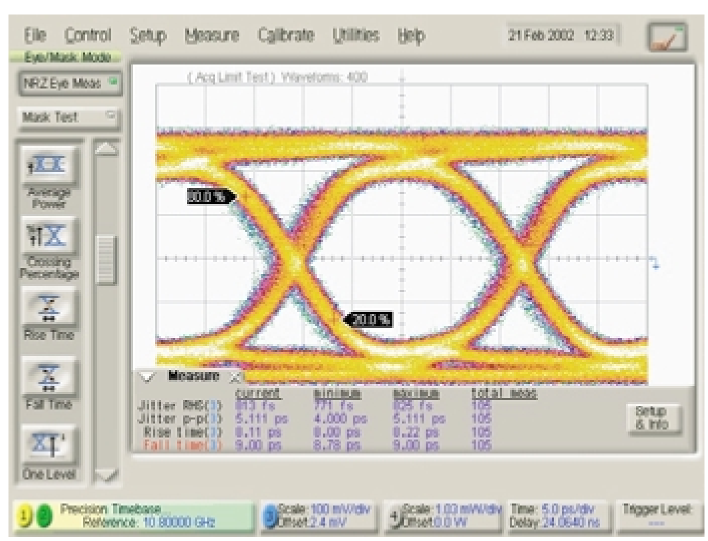


Figure 16: 40G eye pattern after Bessel-Thompson filtering and 20” cable

4. 40G Eye Pattern measured with the remote sampling head DCA 86118A

In chapter 3, the impact of individual components of the measurement chain, such as the scope input filter characteristic, attenuators and cables were shown by using simulated and measured data. Other accessories that were not discussed, but which show similar effects, are adapters.

The conclusion of this discussion is that for high-quality 40G measurements the scope input filter function needs to be selected carefully. Also, as few accessories as possible should be used. Furthermore, the cable length should be minimized.

Attenuators can be omitted if the Pattern Generator provides a variable output voltage. Cable lengths can be minimized or avoided completely by using new oscilloscope modules with remote sampling heads. Figure 17 shows the Agilent Technologies DCA plug-in 86118A with two remote heads. The heads contain the high-speed electronics for data-processing.

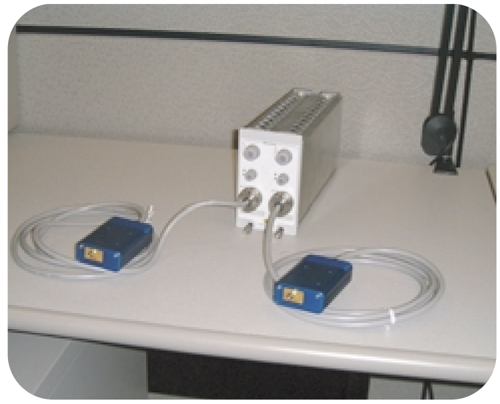


Figure 17: DCA remote sampling head plug-in 86118A

This new architecture allows the user to connect the remote head directly to the generator output without using additional cables. Attenuators can also be omitted, if the Pattern Generator offers variable amplitude.

The frequency response of the remote head has a linear slope in the frequency domain to 60 GHz (-1.25 dB at 40 GHz) followed by a -3 dB cut-off frequency at 65 GHz.

Data Output **Data complementary Output**

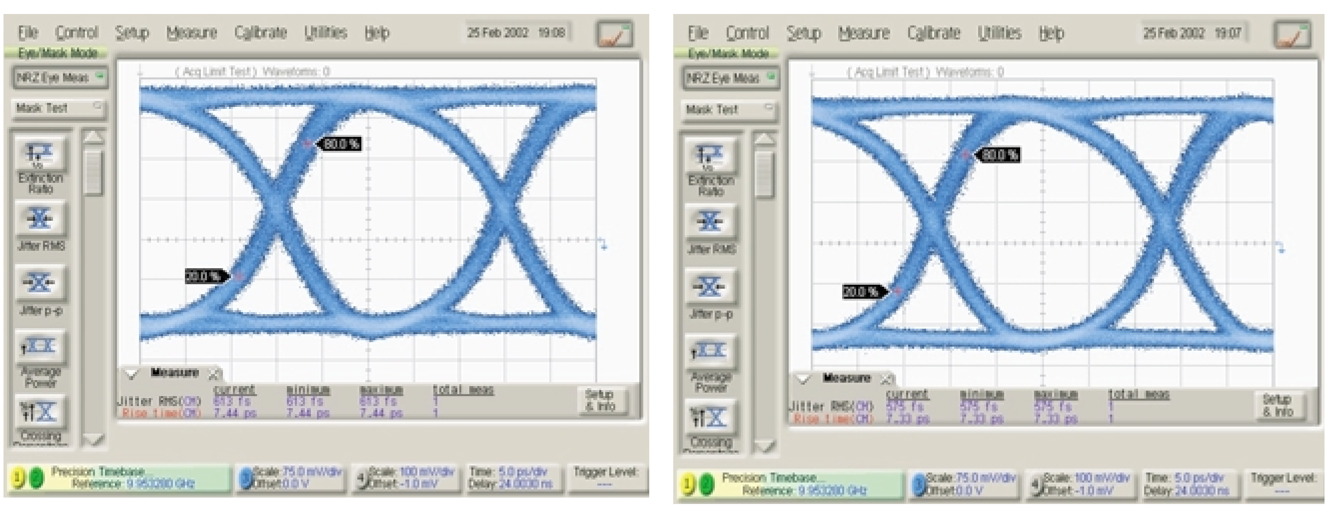


Figure 18: Normal and Complementary 40G signal measured with remote sampling heads

The screenshoots given in figure 18 were taken with remote head and Precision Time Base (option 86107A). The symmetry of the normal and complementary output signal of the ParBERT 40G Pattern Generator is apparent.

5. Summary

This application note has discussed the importance of the higher-order harmonics for the generation of 40G signals with fast transition times. Typically, fast transition times are required to stress test devices, under realistic conditions, e.g. for applications in telecommunications.

This note has also discussed how individual components of a typical traditional measurement chain e.g. attenuators, cables and the scope input filter, bandlimit a 40G signal. The band-limitation in turn causes effects like overshoot, ringing, multi-modal behavior and droop. In addition to these effects, the signal's transition times can be slowed down significantly.

Finally, it was demonstrated how most of the components leading to the band-limitations can be avoided by using an oscilloscope with a remote head and Bessel-Thompson-type input filter frequency response. With this advanced instrument, the true performance of a ParBERT 40G Pattern Generator can be measured. Other conventional instruments and accessories were proven to be insufficient.

Related Literature	Pub. No.
Need to Test BER?, Brochure	5968-9250E
Agilent ParBERT 81250, Mux/Demux Application, Application Note	5968-9695E
Agilent ParBERT 81250 Parallel Bit Error Ratio Tester, Photo Card	5980-0830E
Agilent Productivity Assistance	5980-2160E
Agilent ParBERT 81250 43.2G Product Overview	5988-3020EN
Agilent ParBERT 81250 Parallel Bit Error Ratio Test Platform	5988-5901EN
Agilent 81250 ParBERT Product Note (The influence of Generator Transition times on Characterization Measurements)	5988-5948EN
Agilent ParBERT 81250 Automatic Phase Margin Measurements at 43.2 Gb/s	5988-5654EN
Agilent ParBERT 81250 Product Overview	5968-9188E

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Printed in Germany May 21st, 2003
5988-6625EN

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