Keysight Technologies

Using a Wideband AWG to Optimize Data Throughput with Multi-Level Signaling Techniques

Application Brief

KEYSIGHT TECHNOLOGIES

Overview and motivation

Increasing the data throughput on high-speed digital interfaces can be accomplished in at least three ways:

1. Using multiple parallel signals
2. Increasing the symbol rate
3. Using higher order modulation schemes that carry more than 1 bit per symbol (such as NRZ)

Traditionally, #1 and #2 are used because NRZ data transmission is very well understood and can be realized in a cost-effective way, both on the transmit side as well as the receive side. However, there are limitations.

Using a large number of parallel signals requires a higher pin-count on chips and more traces on backplanes, cables and boards, which makes the overall solution more expensive and eventually impractical.

Increasing the symbol rate works well up to a certain point. But board traces have significant attenuation at higher frequencies. Depending on the length of the trace, increasing the symbol rate beyond ~32 Gbaud is very difficult. For technologies such as chip-on-glass used in smart-phone displays, the threshold is at even lower symbol rates of 1 to 2 GBaud.

Using a higher order modulation scheme has the advantage that more than 1 bit per symbol can be transmitted without increasing the bandwidth requirement. The spectrum plots below show that the data rate can be doubled without increasing the occupied bandwidth.

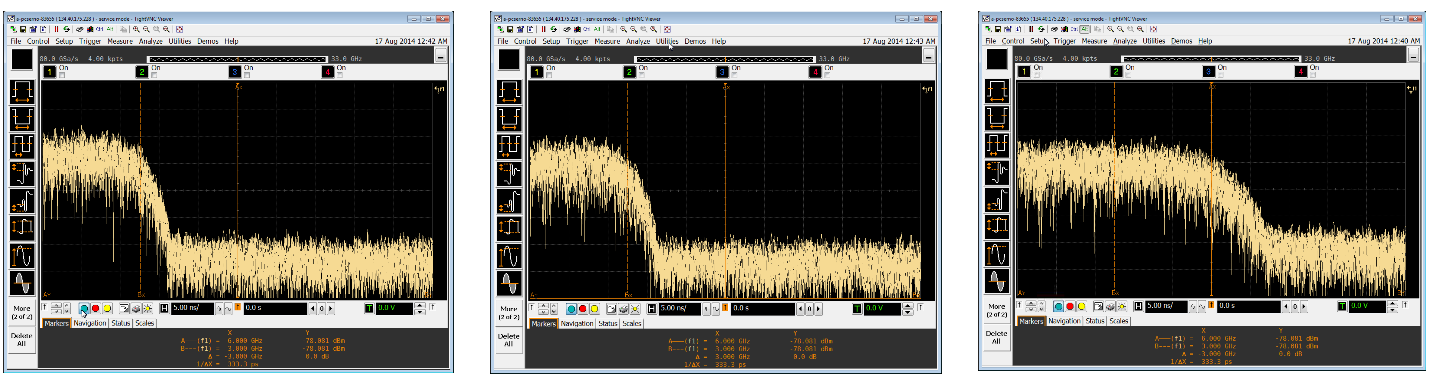

Figure 1: Spectrum of 6 Gbit/s NRZ, 6 Gbaud PAM4 (=12 Gbit/s), 12 Gbit/s NRZ

(all three data signals are raise cosine filtered with alpha = 0.35 in order to limit the bandwidth)

Effect of transition times in PAM4

Unlike NRZ, where the transition time of the data signal does not generate significant horizontal eye closure, this is very different in PAM4. Therefore, even with “clean” signals (i.e. no jitter), there is a certain amount of **switching jitter** dependent on the rise and fall time of the signal. The two figures below illustrate the effect. The rise and fall times are normalized to 1 and assumed to be cosine shape, i.e. with minimum bandwidth. The dashed lines indicate the decision thresholds; the dotted lines indicate the amount of switching jitter.

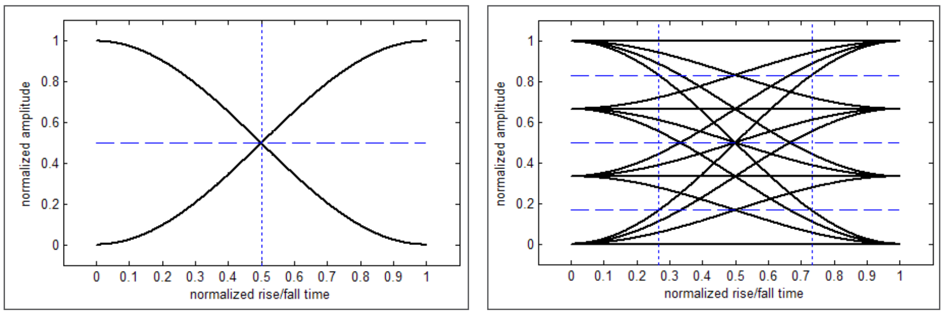

Figure 2: transitions of NRZ and PAM4 signals showing the amount of switching jitter

The PAM4 graph shows that the **switching jitter affects the outer two eyes more than the center eye** – assuming that the decision thresholds are centered within the eye. The PAM4 diagram also shows that the **switching jitter is approximately equal to the 20/80 rise time of the signal**.

The following two screen shots with real signals confirm this rule-of-thumb. They show a 6 GBaud PAM4 signal with transition times of 22 picoseconds (ps) and 52 ps respectively. The red lines with the arrows show the amount of switching jitter. As shown in the scope measurements, the switching jitter matches quite well with the transition times.

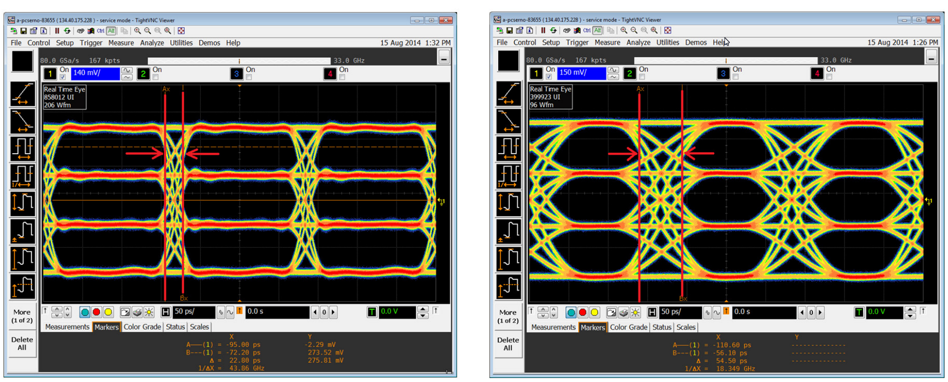

Figure 3: Two PAM4 signals at 6 GBaud with different transition times

Dealing with bandwidth limited channels

Switching from NRZ to PAM4 is often motivated by a bandwidth limitation of the channel (and/or the transmitter and receiver).

In the radio frequency (RF) world this is a very common problem because using excess bandwidth in a frequency division multiplex environment causes distortions in a neighboring channel. In order to limit the bandwidth of a digitally modulated signal, a pulse-shaping filter is applied to the baseband signal. Typical pulse shaping filters include raised-cosine or root-raised-cosine. The trade-off between occupied bandwidth and wide eye-opening of the time-domain signal can be controlled using the roll-off coefficient of the filter. The two plots below show the frequency response on a linear scale and the step response with different roll-off coefficients.

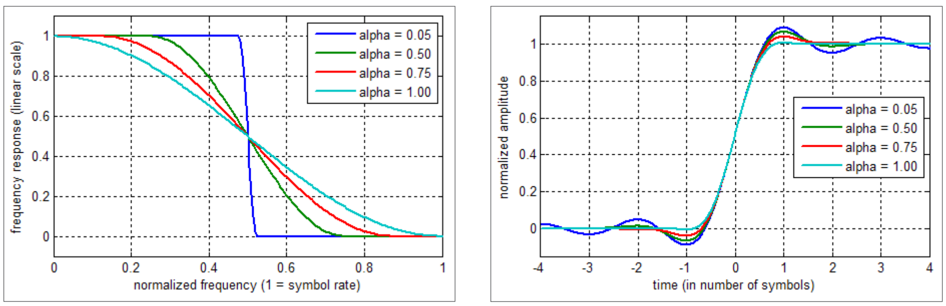

Figure 4: frequency response and step response of a raised cosine filter

With alpha = 0.05, the occupied bandwidth is the most narrow (“brickwall filter”), but the step response shows significant ringing. With alpha = 1, the occupied bandwidth is larger (still less than 2x the symbol rate), but the step response has almost no overshoot. The following two examples show 32 GBaud PAM4 signals with two different raised cosine filter coefficients: 0.1 and 1.0.

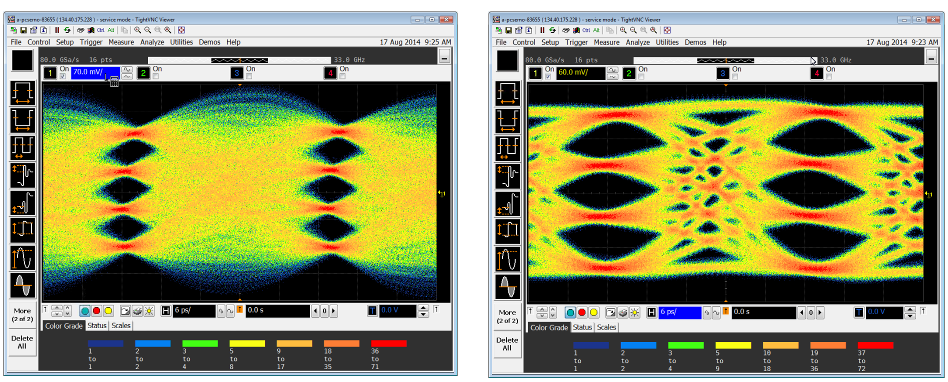

Figure 5: 32 GBaud PAM4 signal, raised cosine filtered with alpha = 0.1 and alpha = 1.0 respectively

Both signals can be decoded with similar error vector magnitude (EVM), but the occupied bandwidth is very different between the two, as shown in the following spectrum plots:

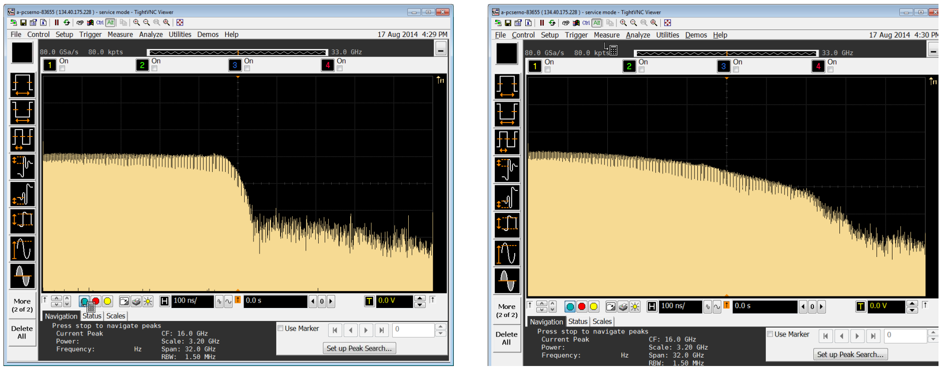

Figure 6: Spectrum of 32 GBaud PAM4 signal, raised cosine filtered with alpha = 0.1 and 1.0, respectively

Channel embedding and de-embedding

Another benefit of using a high-speed AWG for generating PAM4 signals is the possibility to embed or de-embed the behavior of a channel. The characteristic of the channel can either be supplied by providing its S-parameters or it can be measured in-system. In the AWG, the waveform is digitally pre-distorted to include the frequency and phase response of the channel or its inverse.

The following screenshots show a clean PAM4 signal as well as the same signal with the S-parameters of a 522 mm long trace embedded and de-embedded.

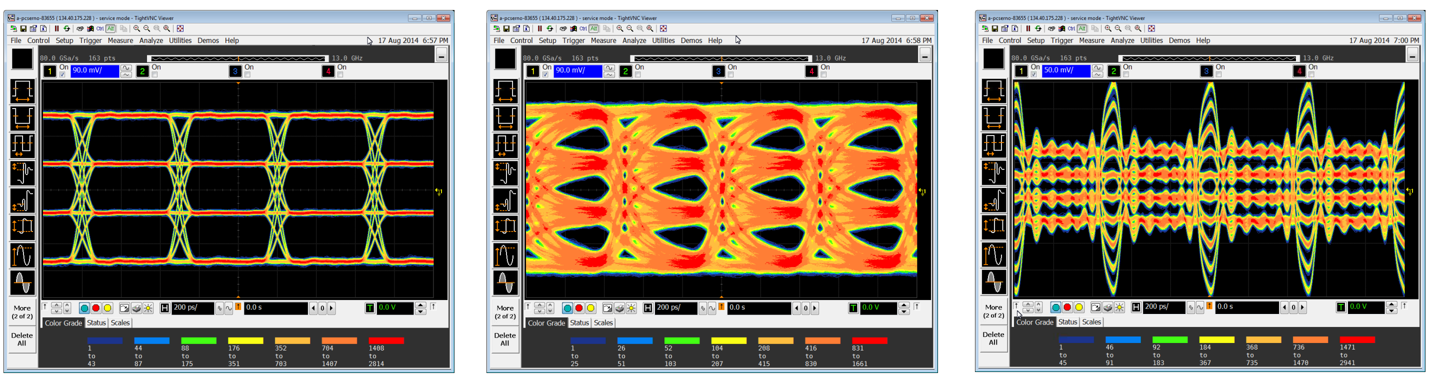

Figure 7: Clean 2 GBaud PAM4 signal, with channel embedded, with channel embedded

Non-equidistant voltage levels

For optical applications, it is often necessary to generate PAM4 signals with non-equidistant voltage levels if the external amplifier and the Mach-Zehnder modulator is used beyond their linear operating range.

The traditional method of generating a PAM4 signal is to passively combine two NRZ signals with an amplitude ratio of 2:1 to generate equidistant voltage levels. By changing the amplitude ratio, the height of the middle eye can be altered, but the height of the upper and lower eye always remain the same.

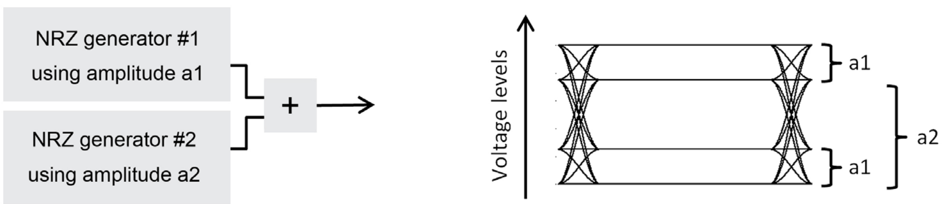

Figure 8: Generating PAM4 signals using two NRZ generators

When generating a PAM4 signal with a high-speed AWG, there is no such limitation – an arbitrary relationship of the four voltage levels can be realized. An example is shown in the following screenshot.

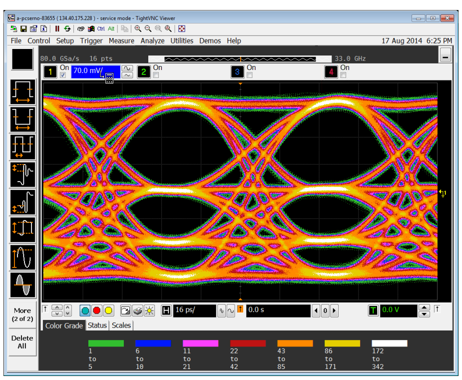

Figure 9: 16 GBaud PAM4 signal with non-equidistant voltage levels

Higher order PAM modulations

Generating more than 4 discrete levels (e.g. PAM8, PAM16, etc.) is of course possible as well, but in order to gain an additional bit per symbol, the number of discrete levels has to be doubled, which requires significantly larger signal-to-noise ratio. Therefore, a significantly larger number of levels are rarely used.

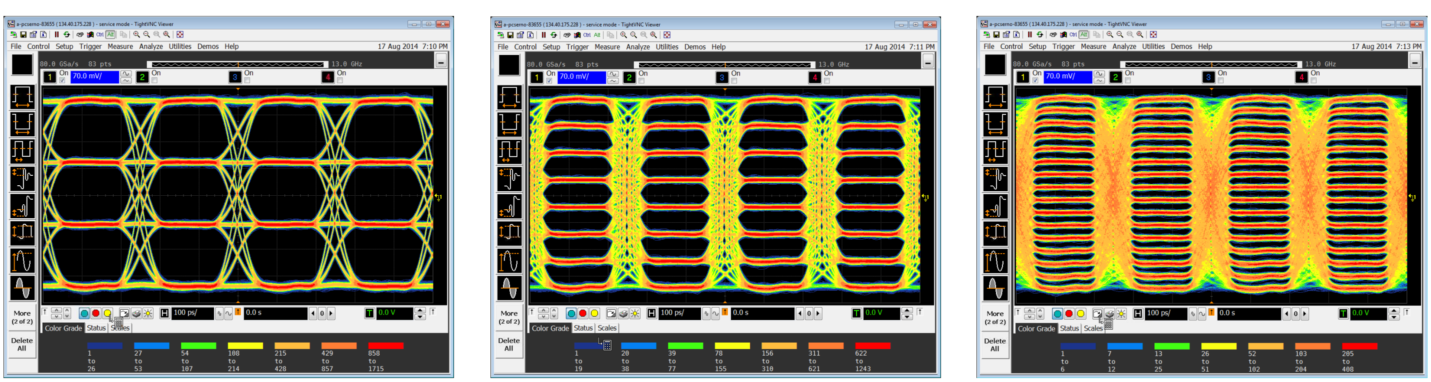

Figure 10: 4 GBaud PAM4, PAM8 and PAM16 signals

Adding distortions

Testing the margins of a receiver requires that the generator can add distortions to the signal, such as variable transition times, jitter, noise, inter-symbol interference (ISI) and duty cycle distortion (DCD). High-speed AWGs can add all of these distortions without any additional hardware such as ISI traces. Below are a few examples of distortions added to PAM4 signals:

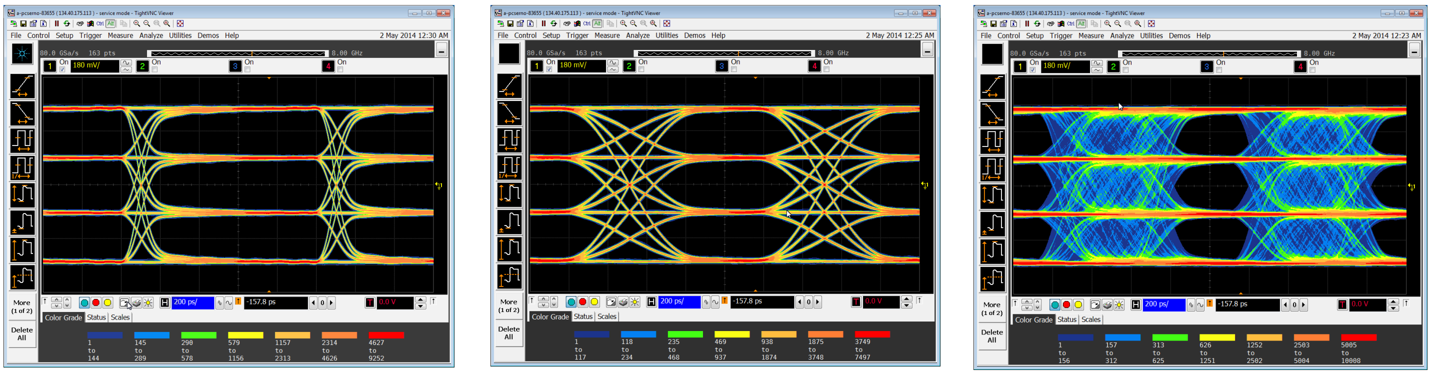

Figure 11: PAM4 signal – clean, with slow transition times, with added jitter

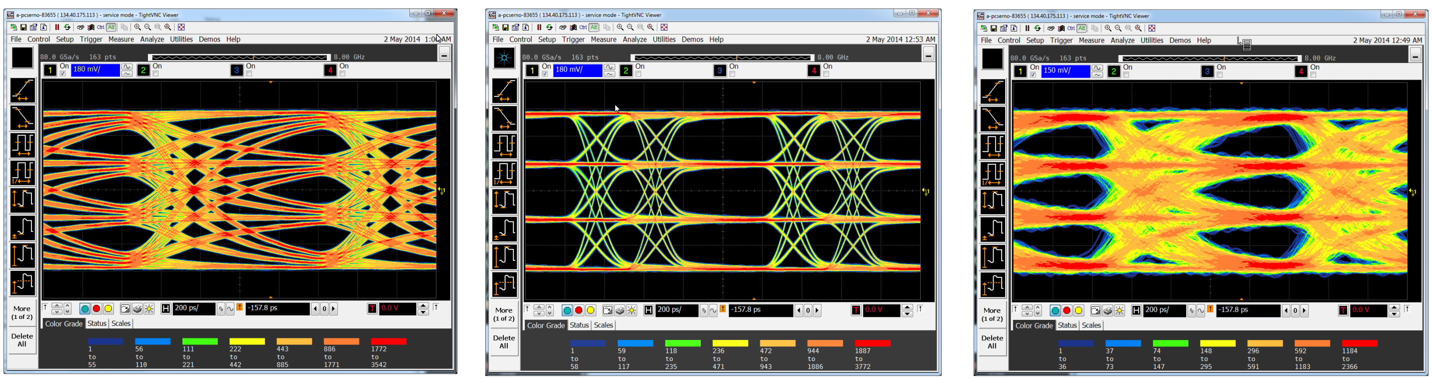

Figure 12: ...with added ISI, with DCD, with jitter, ISI and noise

Conclusion

High speed AWGs, such as the new Keysight M8195A are very well suited to generate PAM4 signals up to 32 GBaud including the necessary parameter changes, such as:

- Variable transition times
- Various pulse shaping filters
- Adding distortions, including:
  - Jitter
  - Noise
  - DCD
  - ISI
- Embedding and de-embedding S-parameters
- Generating PAMx signals with non-equidistant voltage levels

Using an AWG for signal generation provides greater flexibility than traditional NRZ generators – independent of which direction the technology goes.

myKeysight

www.keysight.com/find/mykeysight
A personalized view into the information most relevant to you.

www.axiestandard.org
AdvancedTCA® Extensions for Instrumentation and Test (AXIe) is an open standard that extends the AdvancedTCA for general purpose and semiconductor test. Keysight is a founding member of the AXIe consortium. ATCA®, AdvancedTCA®, and the ATCA logo are registered US trademarks of the PCI Industrial Computer Manufacturers Group.

Three-Year Warranty

www.keysight.com/find/ThreeYearWarranty
Keysight's commitment to superior product quality and lower total cost of ownership. The only test and measurement company with three-year warranty standard on all instruments, worldwide.

www.keysight.com/quality
Keysight Technologies, Inc.
DEKRA Certified ISO 9001:2008
Quality Management System

Keysight Channel Partners
www.keysight.com/find/channelpartners
Get the best of both worlds: Keysight's measurement expertise and product breadth, combined with channel partner convenience.

Keysight Solution Partners
www.keysight.com/find/solutionpartners
Get the best of both worlds: Keysight's measurement expertise and product breadth, combined with solution partner convenience.

www.keysight.com/find/M8195A

More information:
M8195A 65 GSa/s AWG datasheet - 5992-0014EN

For more information on Keysight Technologies' products, applications or services, please contact your local Keysight office. The complete list is available at:
www.keysight.com/find/contactus

Americas	
Canada	(877) 894 4414
Brazil	55 11 3351 7010
Mexico	001 800 254 2440
United States	(800) 829 4444
Asia Pacific	
Australia	1 800 629 485
China	800 810 0189
Hong Kong	800 938 693
India	1 800 112 929
Japan	0120 (421) 345
Korea	080 769 0800
Malaysia	1 800 888 848
Singapore	1 800 375 8100
Taiwan	0800 047 866
Other AP Countries	(65) 6375 8100
Europe & Middle East	
Austria	0800 001122
Belgium	0800 58580
Finland	0800 523252
France	0805 980333
Germany	0800 6270999
Ireland	1800 832700
Israel	1 809 343051
Italy	800 599100
Luxembourg	+32 800 58580
Netherlands	0800 0233200
Russia	8800 5009286
Spain	0800 000154
Sweden	0200 882255
Switzerland	0800 805353
	Opt. 1 (DE)
	Opt. 2 (FR)
	Opt. 3 (IT)
United Kingdom	0800 0260637

For other unlisted countries:
www.keysight.com/find/contactus
(BP-07-10-14)

KEYSIGHT TECHNOLOGIES

Published in USA, September 5, 2014
5992-0020EN
www.keysight.com