Peak-to-peak output measurement results and proposal

Comments #82, #93, #94

Adee Ran, Cisco

Existing differential peak-to-peak specification (focusing on C2M, but it's the same everywhere)

Table 176D–1—Summary of host output specifications at TP1a

Parameter	Reference	Value	Units
Signaling rate (range)		106.25 ± 50 ppm	GBd
Differential peak-to-peak voltage (max)[a] Output disabled Output enabled	176D.7.1	 0.03 1.2	 V V

[a] Measurement uses the method described in 93.8.1.3 with the exception that the PRBS13Q test pattern is used.

93.8.1.3 Signal levels

The differential output voltage v_{di} is defined to be SL*i*<p> minus SL*i*<n>. The common-mode output voltage v_{cmi} is defined to be one half of the sum of SL*i*<p> and SL*i*<n>. These definitions are illustrated by Figure 93–6.

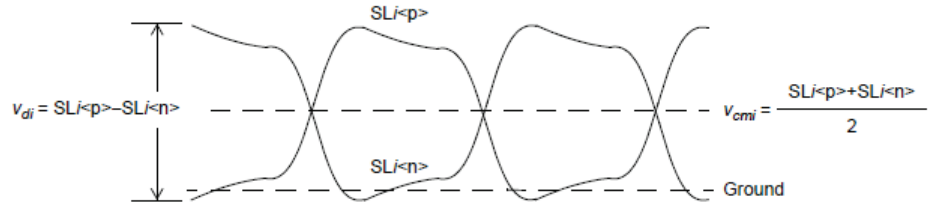

Figure 93–6—Transmitter output voltage definitions

<...>

Unless otherwise noted, differential and common-mode signal levels are measured with a PRBS9 test pattern.

Neither this diagram nor the text around it define the peak-to-peak voltage. The diagram does not resemble a PAM4 signal after IL of >30 dB

Contrary to the footnote, 93.8.1.3 does not describe a measurement method. The only relevant information is the test pattern, which is overridden by the footnote.

The origins of the text

10GBASE-KR

Table 72–6—Transmitter characteristics for 10GBASE-KR

Parameter	Subclause reference	Value	Units
Signaling speed	72.7.1.3	10.3125 ± 100 ppm	GBd
Differential peak-to-peak output voltage (max.)	72.7.1.4	1200	mV

72.7.1.4 Output amplitude

The differential output voltage is constrained via the transmitter output waveform requirements specified in 72.7.1.10. For a 1010 pattern, the peak-to-peak differential output voltage shall be less than 1200 mV, regardless of equalization setting. The transmitter output voltage shall be less than 30 mV peak-to-peak when disabled. The differential output voltage test pattern shall consist of no fewer than eight symbols of alternating polarity.

NOTE 2—See Figure 72–8 for an illustration of the definition of differential peak-to-peak output voltage.

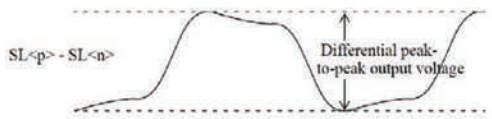

Figure 72–8—Transmitter differential peak-to-peak output voltage definition

- The term “peak-to-peak” is only “defined” by the Figure (which is not a very useful definition)
- There is no explicit definition of a test pattern for measurement of this parameter, but the definition says “no fewer than eight symbols of alternating polarity”
  - It isn’t clear that the maximum applies to any pattern; with no equalization, lower frequencies might reach higher voltages.
  - However, with measurement at TP0 after low loss from the source, it is likely that the measured voltage is close to the real peak-to-peak.
- This spec can be interpreted as “the maximum launch voltage is 1.2 Vdpp” (on a 100 Ohm load)
  - Component designers (Tx and Rx) understand it this way (ignoring possible loss in the package or test fixture).
- **The differential peak-to-peak limits the launch voltage; it is not the signal seen by the receiver!**
  - The receiver gets a signal attenuated by the channel and by the Tx equalization; its range is dependent on equalization setting.

As presented in ran_3dj_02a_2409, the original definition of peak-to-peak is in clause 72, with a 1010 pattern measured after negligible insertion loss. The diagram there is an illustration, not a definition.

Previous discussion on this topic

Cl 176E *SC* 176E.4.3 *P*698 *L*28 # 416

Ran, Adee Cisco Systems, Inc.

Comment Type TR *Comment Status* R *Tx diff PtP, vf*

The specification of "Differential peak-to-peak voltage (max)" points to 176E.6.1 but has a footnote saying that the measurement uses the method in 93.8.1.3 except that PRBS13Q test pattern is used.
It should be noted that 93.8.1.3 is a KR specification at TP0a (very close to the transmitter) and it does not describe a measurement method in detail.

With an insertion loss of ~30 dB to from the transmitter to TP1a, the measured peak-to-peak with PRBS13Q will not be indicative of the real swing and the peak-to-peak that can occur with mission data. The difference can be large, and the existing limit can lead to excessive swing that can overstress devices, e.g. in amplitude tolerance.

The specified max peak-to-peak voltage is intended to hold with any data pattern, not just PRBS13Q, and at any equalization setting, and any violations should be extremely rare - 1e-5 is too high and can create an error floor. It is a clear design requirement that does not require a specific measurement method (the standard is not a measurement specification).

For compliance purposes, the peak-to-peak measurement needs to be verified at least with equalization off, and to be performed with a sufficiently rich test pattern, such as PRBS31Q. Compare to "Average optical power" which is specified with PRBS31, scrambled idle, or "valid xGBASE-R signal".

This also applies to module output and to CR and KR transmitter output specifications, although the loss to the measurement point for those is smaller.

SuggestedRemedy

Delete footnote b.

Replace the editor's note in 176E.6.1 with new text defining the maximum peak-to-peak differential voltage as an absolute requirement for any equalization setting. For compliance testing it is measured with equalization off (preset 1) and may use PRBS31Q, scrambled idle, or any valid PMD pattern. The measurement excludes voltages that occurs with a probability less than 1e-9.

Apply similar changes in clauses 178 and 179 and in annex 176D

Response *Response Status* C

REJECT.

The CRG reviewed the presentation
https://www.ieee802.org/3/dj/public/24_09/ran_3dj_02a_2409.pdf.

It was suggested that measurement with a pattern such as SSPRQ may be more adequate than the PRBS13Q defined in D1.1. The probability of the peak should also be addressed.
However, there was no consensus to adopt the changes proposed in the presentation.

Further work on this topic is encouraged.

Proposal:

Modify 176E.6.1 based on the text below, with editorial license. Refer to this subclause for differential and common-mode specifications in clauses 178 and 179, and annexes 176D and 176E. Delete the definition common-mode AC in 179.9.4.4.

176E.6.1 Maximum voltages

Differential and common-mode signals are defined in 93.8.1.3.

Peak-to-peak output voltages are defined to a probability P, with respect to the distribution of the output voltage V_{out} sampled at an effective rate of between two and three samples per UI. The sampling may be either synchronous or asynchronous.

A maximum output voltage is defined as the value V_{max} such that the probability that $V_{out} > V_{max}$ is $P/2$. A minimum output voltage is defined as the value V_{min} such that the probability that $V_{out} < V_{min}$ is $P/2$. A peak-to-peak output voltage is defined as $V_{max} - V_{min}$.

Specifications of peak-to-peak output voltage apply with any pattern that appears on the service interface, at any equalizer setting. Since the specification is a statistics-based estimate, measurement should be performed with a typical pattern such as scrambled idle, over a period long enough to enable calculation with the desired level of confidence.

NOTE 1—For short measurement purposes, PRBS31Q or a square wave with a period of at least 128 UI can be used to estimate V_{max} and V_{min}, but the values created by these patterns might be different than those of scrambled data.

Differential peak-to-peak output voltage is defined with $P=10^{-9}$ for the differential output signal.

Full-band AC common-mode peak-to-peak voltage, VCM_{FB}, is defined with $P=10^{-7}$ for the common-mode output signal.

Low-frequency AC common-mode peak-to-peak voltage, VCM_{LF}, is defined with $P=10^{-7}$ for the common-mode output signal filtered by a low-pass filter as defined by Equation (93A–20) with f_r set to 100 MHz.

NOTE 2—The common-mode noise measurement may be sensitive to mismatches between the single-ended paths in the test fixture and the test setup. Careful design and calibration of the test system are recommended.

NOTE 3—The common-mode noise measurement should take into consideration frequencies down to the specified AC-coupling frequency.

Demonstration of the pattern dependence of pk-pk differential voltage measurement

- Setup:
  - Packaged Transmitter at 106.25 GBd
  - Tx FFE: 2 taps, [-0.1, 0.9]
  - Test channel (board+cables+DC block) with IL ~7.5 dB
  - Same device settings generate all test patterns
- Measurement:
  - Keysight UXR
  - Measurement filter: 56 GHz Bessel-Thomson

Test pattern	Vmin	Vmax	Pk-Pk	% of "true"* Pk-Pk
PRBS13Q	-353.7	358.7	710.4	79%
PRBS31Q	-379.1	375.8	754.9	84%
Slow clock	-445.5	450	895.5	100%

* The measurement was performed with Tx equalization, which reduces the peak-to-peak seen after the channel (DC attenuation of ~1.9 dB).
The % results are relative to the "slow clock" pattern.

The specification should be for measurement with no equalization.

Feedback on previous proposal

- “It was suggested that measurement with a pattern such as SSPRQ may be more adequate than the PRBS13Q defined in D1.1. The probability of the peak should also be addressed.”
  - SSPRQ is not defined for electrical interfaces and may not be widely implemented. In addition, like PRBS31Q, it does not capture the true peak-to-peak either.
- Specifying the test pattern will reduce ambiguity of results
  - PRBS31Q may cause concerns of measurement time and repeatabilty.
  - Peak-to-peak measurement using a slow square wave would capture the true value quickly and accurately to very low probability. Such patterns are expected to be available in all transmitter implementations.
    - We can add formal test pattern definitions… but it is not necessary for practical measurements.
- Less prescriptive definition (e.g., number of samples per UI) may be preferable.

AC common-mode peak-to-peak

Cl **179** *SC* **179.9.4.4** *P* **361** *L* **52** # 93

Ran, Adee — Cisco Systems, Inc.

Comment Type **T** *Comment Status* **D** *Tx AC common mode*

The specification of AC-common mode voltage is "all but 1e-4 of the measured distribution". This does not prevent extreme spikes of common mode noise to occur in a transmitter output as long as they are not too frequent.

It is impossible to design a receiver that can handle unspecified levels of occasional common mode noise without creating errors. Therefore we should assume that the current specification can cause errors in the receiver, currently at a probability of 1e-4. These errors can occur in addition to ones that are currently modeled by COM. Additionally, they can be correlated and cause unexpected FEC failures.

We should not allow potential sources of errors that are not budgeted to have such high probability.

The suggested probably of 1e-7 is low enough to enable it to be used for all interfaces. This increases the measurement time, but the specification is not for specific points in the pattern, so measurement can use the whole pattern and be very fast.

SuggestedRemedy

Change the specification to be all but 1e-7 of the measured distribution, from 5e-6 to 1-5e-6 of the cumulative distribution.
Use the same definition for KR, C2C, and C2M.
Implement with editorial license.

Cl **179** *SC* **179.9.4.4** *P* **361** *L* **53** # 94

Ran, Adee — Cisco Systems, Inc.

Comment Type **T** *Comment Status* **D** *Tx AC common mode*

The common-mode measurement method is not specified in detail; It is unclear what the "measured distribution" represents. The distribution can depend on the measurement method, e.g., whether or not whether the sampling is synchronous with the clock, the number of samples per UI and the sampling phase.

For example, sampling once per PRBS13Q repetition at a fixed point (as in the measurement of differential noise used in SNDR) may miss common-mode that is correlated with the signal; conversely, capturing a test pattern with many times per UI can cause large enough population to create a distribution from only part of the test pattern, but may miss events at other parts in the test pattern.

We should protect against having excessive noise anywhere within a UI and anywhere in the test pattern. The suggested change ensures that, and allows either synchronous or asynchronous measurement.

SuggestedRemedy

Add a sentence that the distribution is created from measurements over the whole PRBS13Q test pattern, that include between 2 to 3 samples per UI.

(These comments are resubmission of comments against D1.1 that were left open)

Updated proposal (pk-pk differential and AC CM)

Modify 176E.6.1 based on the text below, and refer to this subclause for differential and common-mode specifications in clauses 178 and 179, and annexes 176D and 176E.
Delete the definition common-mode AC in 179.9.4.4. Implement with editorial license.

176E.6.1 Maximum voltages

Differential and common-mode signals are defined in 93.8.1.3.

Peak-to-peak output voltages are defined to a probability *P*, with respect to the distribution of the output voltage V_{out} sampled at an effective rate of at least two samples per UI. The sampling may be either synchronous or asynchronous.

A maximum output voltage is defined as the value V_{max} such that the probability that $V_{out} > V_{max}$ is *P*/2. A minimum output voltage is defined as the value V_{min} such that the probability that $V_{out} < V_{min}$ is *P*/2. A peak-to-peak output voltage is defined as $V_{max} – V_{min}$.

Specifications of peak-to-peak output voltage apply with any pattern that appears on the service interface, at any equalizer setting. For compliance testing, it is sufficient to perform measurements with the transmitter set to preset 1 (maximum swing without equalization) on all lanes.

Differential peak-to-peak output voltage is defined with $P=10^{-9}$ for the differential output signal. For compliance testing, it is sufficient to measure it from a square wave output with a period of at least 128 UI, while lanes not under test transmit PRBS31Q.

Full-band AC common-mode peak-to-peak voltage, VCM_{FB}, is defined with $P=10^{-7}$ for the common-mode output signal. For compliance testing, it is sufficient to measure it from the PRBS13Q test pattern, while lanes not under test transmit PRBS31Q.

Low-frequency AC common-mode peak-to-peak voltage, VCM_{LF}, is defined with $P=10^{-7}$ for the common-mode output signal filtered by a low-pass filter as defined by Equation (93A–20) with f_r set to 100 MHz. For compliance testing, it is sufficient to measure it from a square wave output with a period of at least 128 UI, while lanes not under test transmit PRBS31Q.

NOTE 1—AC common-mode measurement may be sensitive to mismatches between the single-ended paths in the test fixture and the test setup. Careful design and calibration of the test system are recommended.

NOTE 2—AC common-mode measurement should take into consideration frequencies down to the specified AC-coupling frequency.

Summary

- Updated proposal for differential and common-mode peak-to-peak definitions
- Replaces outdated, partial and irrelevant definitions
- Definitions include specific probability “depths”
- Measurement for compliance defined with specific patterns that would enable fast results

That’s all

Questions?