Reference point for OMA_{outer} (comments #94, #62)

Adee Ran, Cisco

Background and goal

- OMA_{outer} is part of PAM4 optical transmitter specifications starting from clause 121 (802.3bs)
- It has matched the previous definition of OMA in NRZ transmitters
- In 802.3dj we have effectively changed the definition to OMA_{outer} and created a new definition OMA_{TDECQ}
- This presentation suggest a simpler and more natural way to define OMA_{outer} which will be
  - consistent with previous definitions
  - compatible with existing measurements
  - Physically meaningful

The comments

Cl **180** *SC* **180.9.5** *P* **478** *L* **43** # 94

Ran, Adee Cisco Systems

Comment Type **T** *Comment Status* **X**

"OMAouter is measured using the waveforms captured at the output of the reference receiver defined in 180.9.2"
As noted in previous comments, the illustration of the signal in Figure 180-8 does not match this statement; the signal in the figure is fully equalized. Indeed, in a non-equalized signal, there will likely be no flat region in a 6-UI run (noting that the reference equalizer is longer).

In another comment I am suggesting that the reference equalizer should be normalized to have c(0)=1. With this modification, the nominal 0 and 3 levels will be the same before and after the equalizer, but the eye diagram will be open, and thus OMA_outer will be measurable at the equalizer output on flat regions. This will also match the illustration in Figure 180-8.

The benefit of these two changes is that OMA_outer matches the original meaning of the distance between nominal levels measured without equalization (e.g. with an NRZ modulated pattern). Also, there is no need for two different definitions of OMA.

SuggestedRemedy

Change "at the output of the reference receiver defined in 180.9.2" to "at the output of the reference equalizer defined in 180.9.6.3".
Apply corresponding changes in clauses 181, 182, and 183.
A detailed proposal is planned.

The suggested remedies were initial thoughts
Consider them overridden by this presentation

Cl **180** *SC* **180.9.6.3** *P* **482** *L* **23** # 62

Ran, Adee Cisco Systems

Comment Type **T** *Comment Status* **X**

Footnote a (attached to the "Equalizer DC gain" row) says "The sum of all 15 equalizer coefficients, w(i)."

The DC gain is the response to an infinite run of identical symbols (with a certain nominal level) at the input, divided by that level. When the equalizer consists of only an FFE, it is indeed the sum of the coefficients. But with the DFE (which subtracts the nominal symbol level from the output) the sum of the FFE taps is no longer the DC gain. If the sum of w(i) is set to 1 then the DC gain will be 1-b(1).

However, "unity DC gain" is an arbitrary choice and perhaps not the best requirement.

Since the reference equalizer is long, it is likely to address not just limited bandwidth but also frequency ripple (e.g. reflections). In this case it is preferable to normalize the equalizer in a different way, to maintain the nominal levels equal before and after the equalizer; This requires that the normalization is to have w(0)=1 instead.
(rationale: in convolution of the equalizer and the pulse response, w(0) is multiplied by the nominal level of the symbol x(n)*h(0), creating the four levels of the eye diagram; other coefficients are multiplied by previous or subsequent symbols x(n+k)h(n-k+i); these terms have zero mean because the symbols are uncorrelated and equiprobable).

This would enable measuring OMA at the equalizer output and having only one definition of OMA.

A related change in the calculation of OMA_outer is suggested in another comment.

Note that this change does not affect TDECQ because the noise amplification is calculated from the equalizer's response, which is scaled by the same factor.

SuggestedRemedy

Add limits for i=0: min=1, max=1.
Change the "symbol" for limits to w(i) (no need to divide by w(0) since it is 1).
Delete the row for "Equalizer DC gain" and the footnote.
In equation 180-10, delete the middle term "H_eq(f=0)=" (the DC gain), because it is not equal to 1 anymore.

Delete the definition of OMA_TDECQ and change all instances of "OMA_TDECQ" to "OMA_outer".

Apply corresponding changes in clauses 181, 182, and 183.
A detailed proposal is planned.

Original OMA definition – clause 52 (10GBASE-S, 10 GBd NRZ)

52.9.5 Optical modulation amplitude (OMA) test procedure

OMA is the difference in optical power for the nominal "1" and "0" levels of the optical signal. OMA in Figure 52–6, using waveform averaging or histogram means. OMA should be measured for a node transmitting the square wave pattern defined in 52.9.1.

The recommended technique for measuring optical modulation amplitude is illustrated in Figure 52–5. Optionally, a fourth-order Bessel-Thomson filter as specified in 52.9.7 can be used after the O/E converter. The measurement system consisting of the O/E converter, the optional filter and the oscilloscope has the following requirements:

a) The bandwidth of the measurement system shall be at least 3/T where T is the time at high or low (00001111 giving approximately T = 400 ps and 7.5 GHz as an example); and
b) The measurement system is calibrated at the appropriate wavelength for the transmitter under test.

With the device under test transmitting the square wave described above, use the following procedure to measure optical modulation amplitude:

c) Configure the test equipment as illustrated in Figure 52–5.
d) Measure the mean optical power P_1 of the logic "1" as defined over the center 20% of the time interval where the signal is in the high state. (See Figure 52–6.)
e) Measure the mean optical power P_0 of the logic "0" as defined over the center 20% of the time interval where the signal is in the low state. (See Figure 52–6.)
f) OMA = $P_1 - P_0$.

52.9.1.2 Square wave pattern definition

A pattern consisting of four to eleven consecutive ones followed by an equal run of zeros may be used as a square wave. These patterns have fundamental frequencies between approximately 452 MHz (10GBASE-W) and 1289 MHz (10GBASE-R).

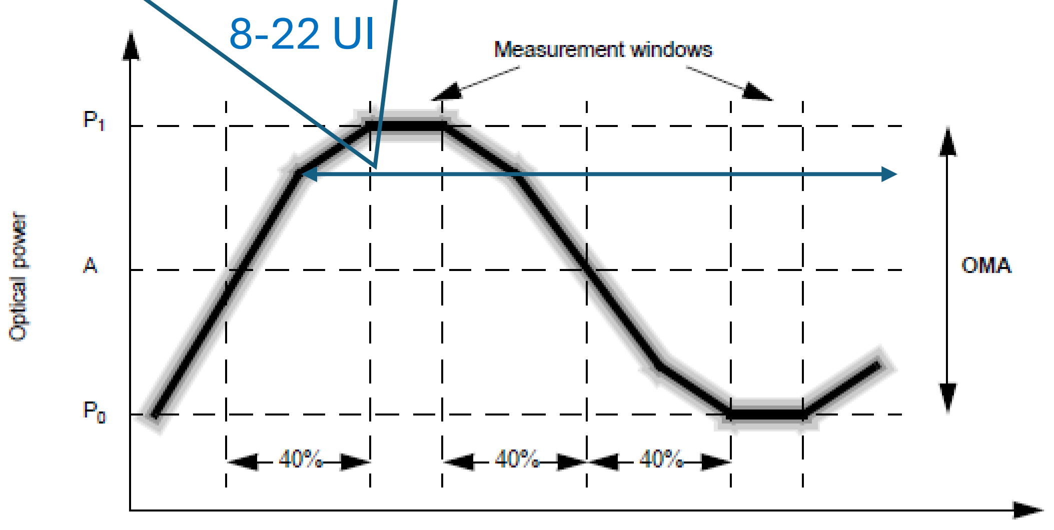


Figure 52–6—Optical modulation amplitude waveform measurement

Note that some NRZ clauses (58-60, 75) use a different definition

Defined with a square wave pattern – easy to measure
If the measurement region is flat (as in the figure), P0 and P1 represent DC levels

Original OMA_{outer} definition – clause 121 (200GBASE-DR4, 50 GBd PAM4)

121.8.4 Outer Optical Modulation Amplitude (OMA_{outer})

The OMA_{outer} of each lane shall be within the limits given in Table 121–6. The OMA_{outer} is measured using a test pattern specified for OMA_{outer} in Table 121–10 as the difference between the average optical launch power level P_3, measured over the central 2 UI of a run of 7 threes, and the average optical launch power level P_0, measured over the central 2 UI of a run of 6 zeros, as shown in Figure 121–3.

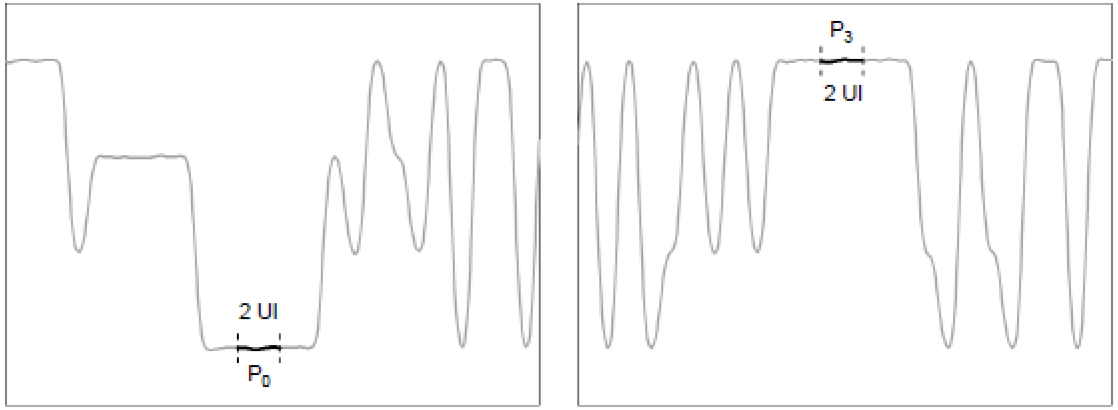


Figure 121–3—Example power levels P_0 and P_3 from PRBS13Q test pattern

The measurement point (before/after equalizer) is not specified here - but the signal in Figure 121-3 is clearly equalized…
The TDECQ definition provides the answer

Table 121–10—Test-pattern definitions and related subclauses

Parameter	Pattern	Related subclause
Wavelength	Square wave, 3, 4, 5, 6 or valid 200GBASE-R signal	121.8.2
Side mode suppression ratio	3, 5, 6 or valid 200GBASE-R signal	121.8.2
Average optical power	3, 5, 6 or valid 200GBASE-R signal	121.8.3
Outer Optical Modulation Amplitude (OMA_{outer})	4 or 6	121.8.4

Table 121–9—Test patterns

Pattern	Pattern description	Defined in
Square wave	Square wave (8 threes, 8 zeros)	120.5.11.2.4
3	PRBS31Q	120.5.11.2.2
4	PRBS13Q	120.5.11.2.1
5	Scrambled idle	119.2.4.9
6	SSPRQ	120.5.11.2.3

Defined with a choice of two "rich" PAM4 patterns – not square wave

OMA_{outer} and TDECQ in clause 121

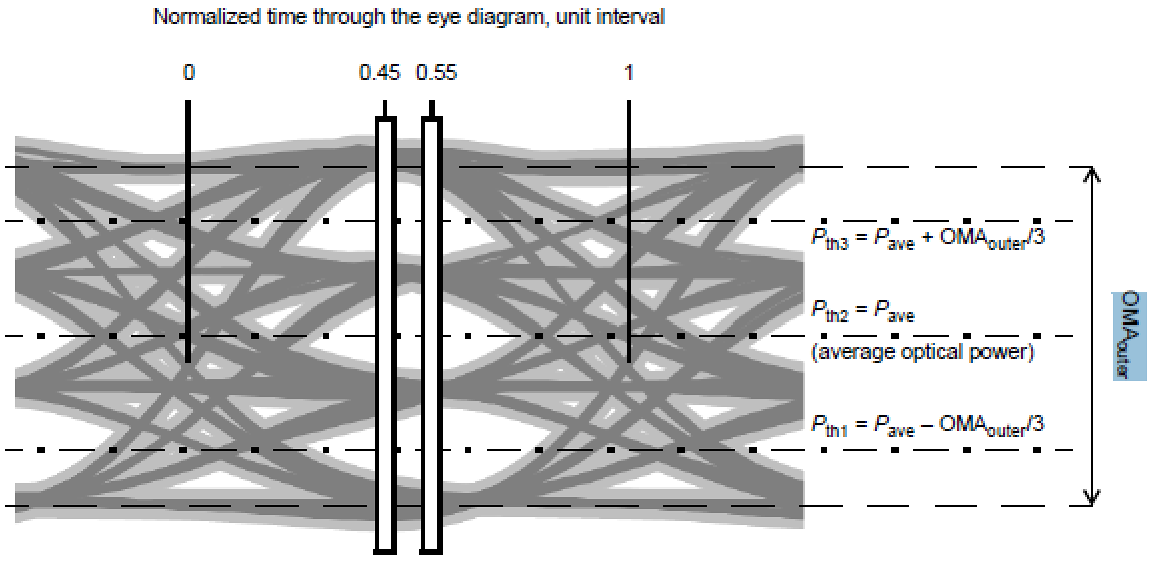


Figure 121–5—Illustration of the TDECQ measurement

121.8.5.3 TDECQ measurement method

The standard deviation of the noise of the O/E and oscilloscope combination, σ_S, is determined with no optical input signal and the same settings as used to capture the histograms described below.

OMA_{outer} is measured according to 121.8.4 on the equalized signal.

<...>

The reference equalizer (specified in 121.8.5.4) is applied to the waveform. The sum of the equalizer tap coefficients is equal to 1. An eye diagram is formed from the equalized captured waveform.

<... ... ...>

$$TDECQ = 10\log_{10}\left(\frac{OMA_{outer}}{6} \times \frac{1}{Q_t R}\right) \qquad (121\text{–}12)$$

where
OMA_{outer} is the Outer Optical Modulation Amplitude as defined in 121.8.4
Q_t is 3.414 consistent with the BER and target symbol error ratio for Gray coded PAM4

In the TDECQ definition , OMA_{outer} is used both as a term in the calculation and for calculating the decision thresholds.
This OMA_{outer} **is explicitly the same** as the one in 121.8.4.

Thus, OMA_{outer} is defined to be measured at the output of an equalizer with unity gain at DC.

OMA and OMA_{outer}

- OMA_{outer} is (intended to be) consistent with the original OMA definition
  - Measurement after the reference equalizer (with unity DC gain) preserves the DC level
  - Assuming the measurement is done on a flat region (as in the figure) the signal should reach the DC level
  - So P0 and P3 are the outer DC levels
- Both specifications were referenced without change for specifications in several subsequent optical PMD clauses
  - OMA with NRZ modulation up to ~26 GBd: clauses **53, 68, 86-88, 95, 112**
  - OMA_{outer} with PAM4 modulation up to ~53 GBd: clauses **122-124, 138-140, 150-151, 160, 167**
  - Apparently there was no issue with the definitions
- These metrics are also used in the definitions of $RIN_{xx}OMA$ and receiver sensitivity
  - Fundamental to specifications (more than TDECQ)
  - People know what they mean

Modifications in 802.3dj

During the review of D1.3 I submitted comment #333 requesting clarification of transition time measurement:

Cl 180 *SC* 180.9.10 *P* 432 *L* 35 # 333

Ran, Adee Cisco

Comment Type TR *Comment Status* A *channel requirements*

Transmitter transition time measurement is defined with good detail, but it is unclear whether the reference equalizer is to be used in the measurement or not (this will likely affect the result).

Note that for RINxxOMA (180.9.11) it is specified explicitly that the noise is measured before the reference equalizer. I assume this should apply to the transition time too.

SuggestedRemedy

Specify whether the reference equalizer is to be used or not.

Implement similarly in other optical PMD clauses as necessary, with editorial license.

Response *Response Status* C

ACCEPT IN PRINCIPLE.

The CRG reviewed https://www.ieee802.org/3/dj/public/25_01/issenhuth_3dj_01a_2501.pdf.

After CRG discussion there was consensus to implement slides 7-11 with editorial license.

The response adopted the suggested change in Slide 8 of issenhuth_3dj_01a_2501:

The OMA_{outer} of each lane shall be within the limit given in Table 180–7. The OMA_{outer} is measured using a test pattern specified for OMA_{outer} in Table 180–17 as the difference between the average optical launch power level P_3, measured over the central 2 UI of a run of 7 threes, and the average optical launch power level P_0, measured over the central 2 UI of a run of 6 zeros, as shown in Figure 180–11. OMAouter is measured using waveforms captured at the output of the reference receiver defined in 180.9.5, before the reference equalizer.

The text in the slide says "There is a definition of how OMAouter is measured for TDECQ calculation in 121.8.5.3, but there is no indication if the same is to be used in 121.8.4 for OMAouter in general."

But Equation 121-12 **does** indicate that it is the same (See previous slide)

This change went beyond what the comment asked for (transition time)… and no reasoning was recorded

Modifications in 802.3dj

Measuring **before** the reference equalizer (new specification) means the measurement region is not flat anymore…

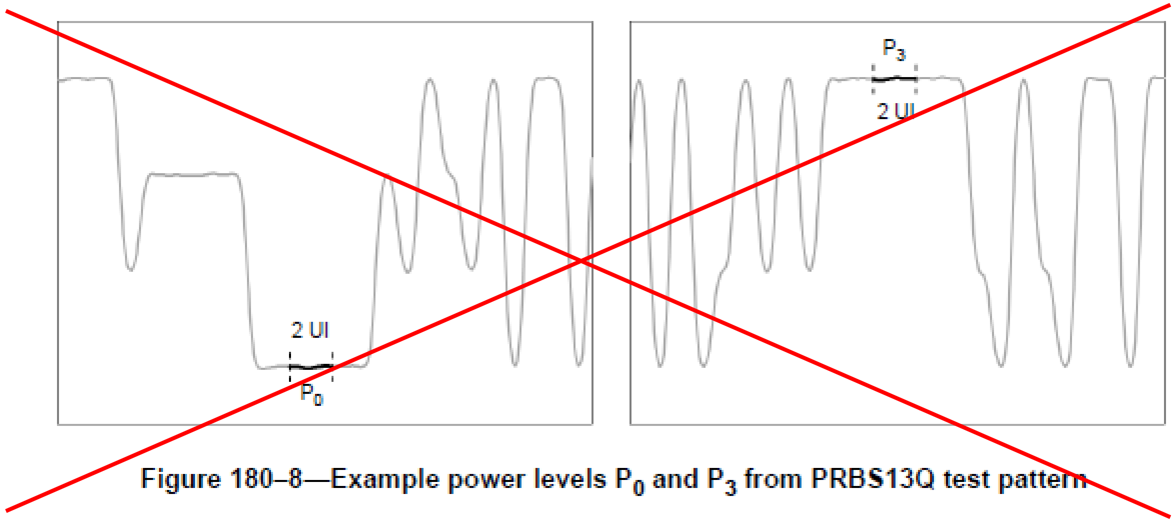


Figure 180–8—Example power levels P_0 and P_3 from PRBS13Q test pattern

This is what you expect to see **after** the reference equalizer – not **before** it (it can only be the same if the equalizer does nothing)

The measured P0 and P3 before equalization depend on the bandwidth, peaking, etc. of the Tx DUT, and **may be higher or lower** than the DC levels

This deviates from the original meaning of OMA_{outer} and results in ambiguity (any possibly noisiness) of the result
Indirectly, it changes the meaning of RINxxOMA and receiver sensitivity
Many people are likely unaware of this

Modifications in 802.3dj

Subsequent to the change of OMA_{outer}, in D2.2 the TDECQ definition was written explicitly in 180.9.6 instead of referring to clause 121.
The definition now includes a new parameter OMA_{TDECQ} – which appears in 180.9.6.4 initially without a definition… other than a "reference point":

The TDECQ reference point where OMA_{TDECQ} is referenced to and noise is added is at the input of the reference equalizer.

This may be worth correcting; OMA_{TDECQ} is measured at the equalizer output

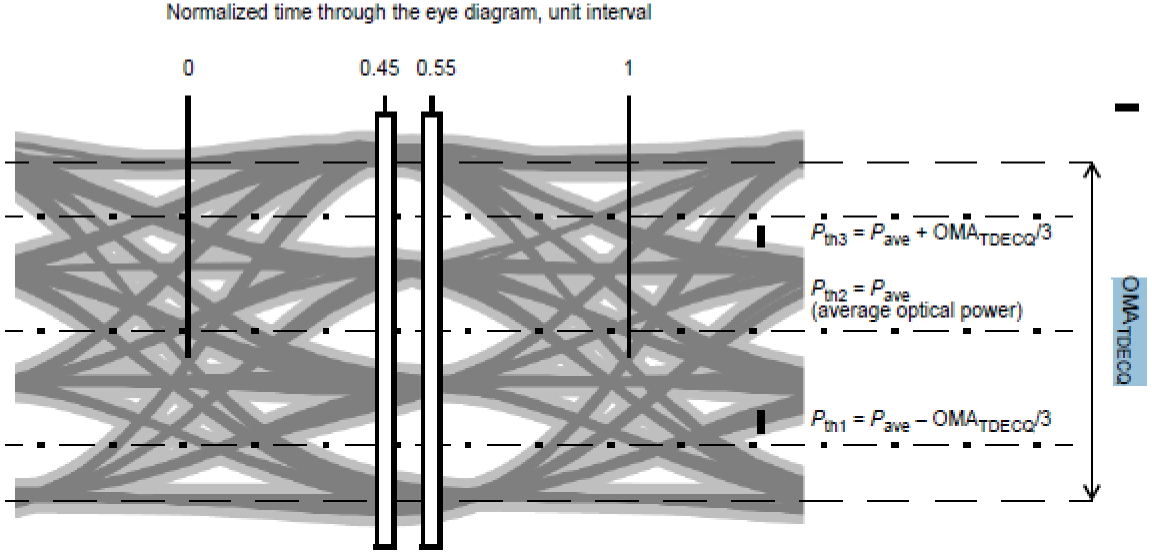
But eventually it is defined as the equalizer output

$$TDECQ = 10\log_{10}\left(\frac{OMA_{TDECQ}}{6} \times \frac{1}{Q_t R}\right) \quad (180\text{–}12)$$

where

OMA_{TDECQ} is measured as defined in 180.9.5 except using waveforms captured at the output of the reference equalizer

This matches the open eye diagram illustrating the TDECQ measurement



This is what you expect to see **after** the reference equalizer – not **before** it

Figure 180–11—Illustration of the TDECQ measurement

What if…

Should we redefine OMA_{outer} to be at the output of the reference equalizer (merge with OMA_{TDECQ})?

Table 180–16—Reference equalizer tap coefficients

Parameter	Symbol	Value	
		Minimum	Maximum
Normalized equalizer coefficient limits:	$w(i)/w(0)$		
$i = -3$		−0.15	0.1
$i = -2$		−0.1	0.25
$i = -1$		−0.5	0.1
$i = 1$		−0.6	0.2
$i = 2$		−0.2	0.3
$i = 3$		−0.15	0.15
$i = 4$		−0.15	0.15
$i = 5$		−0.15	0.15
$i = 6$		−0.15	0.15
$i \geq 7$		−0.1	0.1
Pre-post equalizer coefficient difference limit: $\lvert w(1)/w(0) - b(1) - w(-1)/w(0) \rvert$	—	—	0.25
Equalizer DC gain[a]	—	1	
Decision feedback equalizer (DFE) length	N_b	1	
DFE coefficient limit[b]	$b(1)$	0	0.3

[a] The sum of all 15 equalizer coefficients, $w(i)$.
[b] The DFE coefficient $b(1)$ is referenced to $OMA_{outer}/2$ measured at the input of the FFE equalizer.

- Problem: the current definition of the reference equalizer has **an FFE** with unity gain at DC – but there is also a DFE
- The DC level after the DFE is multiplied by a factor of $1 - b(1)$, which can make a big difference
  - a typical DFE with $b(1) > 1$ “expands” high frequency patterns and “compresses” low frequency patterns
  - The resulting “DC gain” is likely <1 leading to reduction of OMA_{TDECQ} (and artificial improvement of TDECQ)
- In order to maintain the original meaning of OMA_{outer}, we should also either
  - A. Redefine the equalizer to have “unity DC gain” such that $\sum w(i) - b(1) = 1$
  - B. Divide the measured value by the DC gain (currently $1 - b(1)$)
- This should be considered for OMA_{TDECQ} as well

What about unequalized ISI

- It was noted in alloin_3dj_01b_2509 that the signal can be affected by reflections that the reference equalizer will not correct
  - When the measurement of each level is done once per pattern (e.g. PRBS13Q) the reflections can either increase or decrease the measured value
  - If that happens the measurement region will likely not be flat even after the equalizer
- Possible solutions
  - Measure on multiple points in the pattern (possible in SSPRQ, not clear if PRBS13Q too)
  - Measure on a slow square wave pattern, as in OMA (back to basics)
  - Perhaps others, see **alloin_3dj_01_2601**

What should we do

- Ignoring the temporary procedural considerations – what's technically correct?
- To keep the original meaning of OMA_{outer} (and OMA) we can
    A. Keep the current measurement method (specific points on a pattern, e.g. SSPRQ) but measure at the equalizer **output**, and correct for the "DC gain" of the equalizer (including DFE)
    B. Change the definition to measurement on the flat regions of a square wave pattern (preferably slow). This can be done at the equalizer **input** (unambiguous) or output (common with TDECQ)
- If we don't make any of these changes, we should use a new name for the new parameter

Summary

- OMA_{outer} definition in 802.3dj deviates from all preceding definitions due to measurement before the equalizer
  - The change was done in D1.4, reasoning was not recorded and might have been an error
  - The name was kept the same, so people might assume the old meaning
- Options to realign OMA_{outer} with the preceding definitions were presented

That’s all!

Questions?