

# Outer OMA Deep Dive

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*Addressing comment(s) #I-69, #I-218, #I-219*

# Introduction

- The CRG adopted a change to use  $OMA_{outer}$  as defined in clause 180.9.5 for the power penalty calculation (TDECQ) to reconcile the difference between  $OMA_{outer}$  and TDECQ.
- This presentation provides historical background on the history of  $OMA_{outer}$  in IEEE 802.3 and experimental data showing the impact of the adopted change on  $OMA_{outer}$  and TDECQ.
- The presentation examines different methods of measuring  $OMA_{outer}$  of equivalent waveforms at the input and output of the reference equalizer to study the impact of the adopted change on  $OMA_{outer}$  and TDECQ.

## Historical OMA Definitions 802.3

See addendum 1 for details and references

- Originally defined on a square wave with repetitions between 4 and 11
- The measurement bandwidth was required to be at least  $3/T$ , where  $T$  was the length of a level repetition (this allowed runs of length 4 when using  $0.75 \times \text{Baud Bandwidths}$ )
- With measurement bandwidth at  $\text{Baud}/2$ , this would indicate a repetition of at least 6
- Allows for a repetition up to 16 at this bandwidth, if the ratios are maintained
- During the 802.3bs discussions on OOMA, measuring the center 10UI of a run of 16UI on the linearity pattern was discussed.

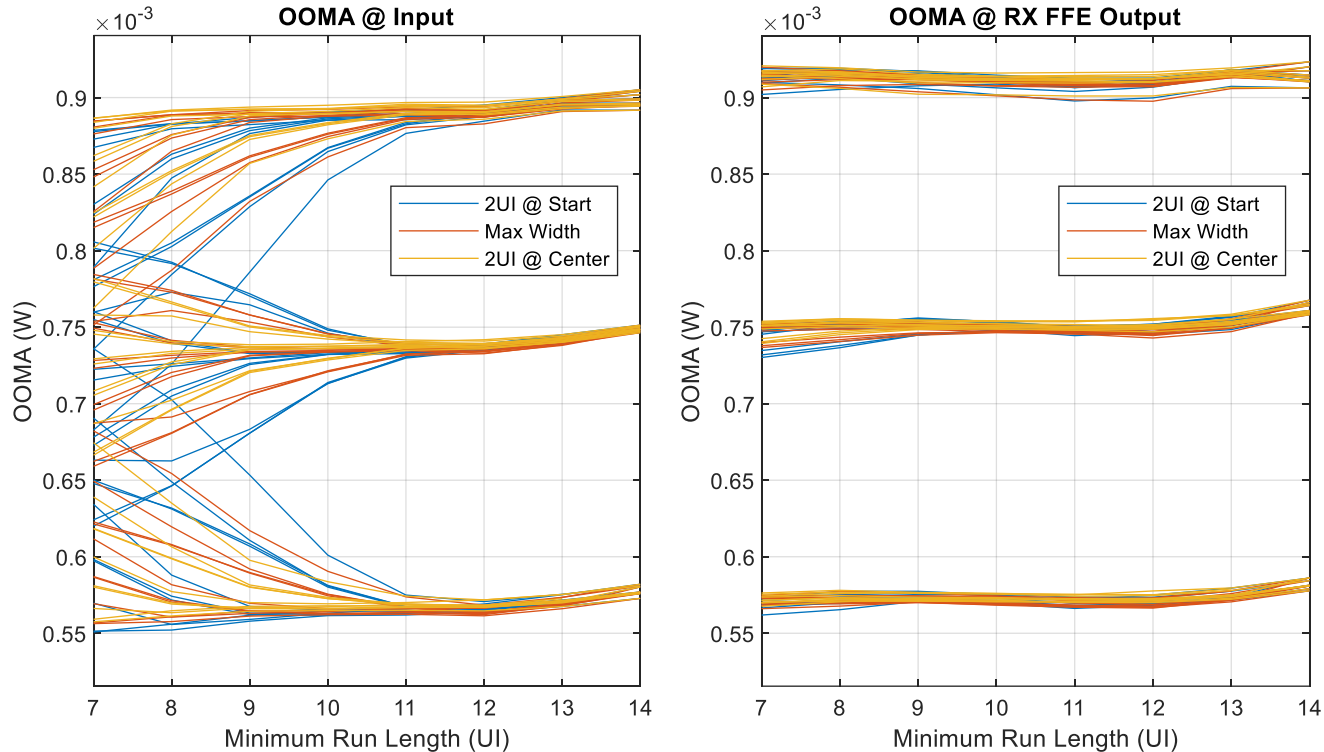
# Test Setup 1

See addendum 2 for more detail

- Equipment:
  - Keysight M8042A BERT
  - Keysight N7718C Reference Transmitter
  - Keysight N1093B Sampling Scope
- Using an SSPRQ and Bert TX FFE to simulate transmitter tuning or “near” reflections
- Sweep various TX FFE configurations where up to two taps are shifted
- Take 10 measurements on each setup.
- Waveform for channel @ 53.125GHz and output of Reference Equalizer (15 tap FFE + 1 DFE)
- Pattern is determined using equalized signal
- Runs of at least length 6 are extracted and saved
- FlexDCA OOMA measurement is not used (it is currently not pattern aware)

# TX FFE

## OOMA vs Minimum run Length for the three methods



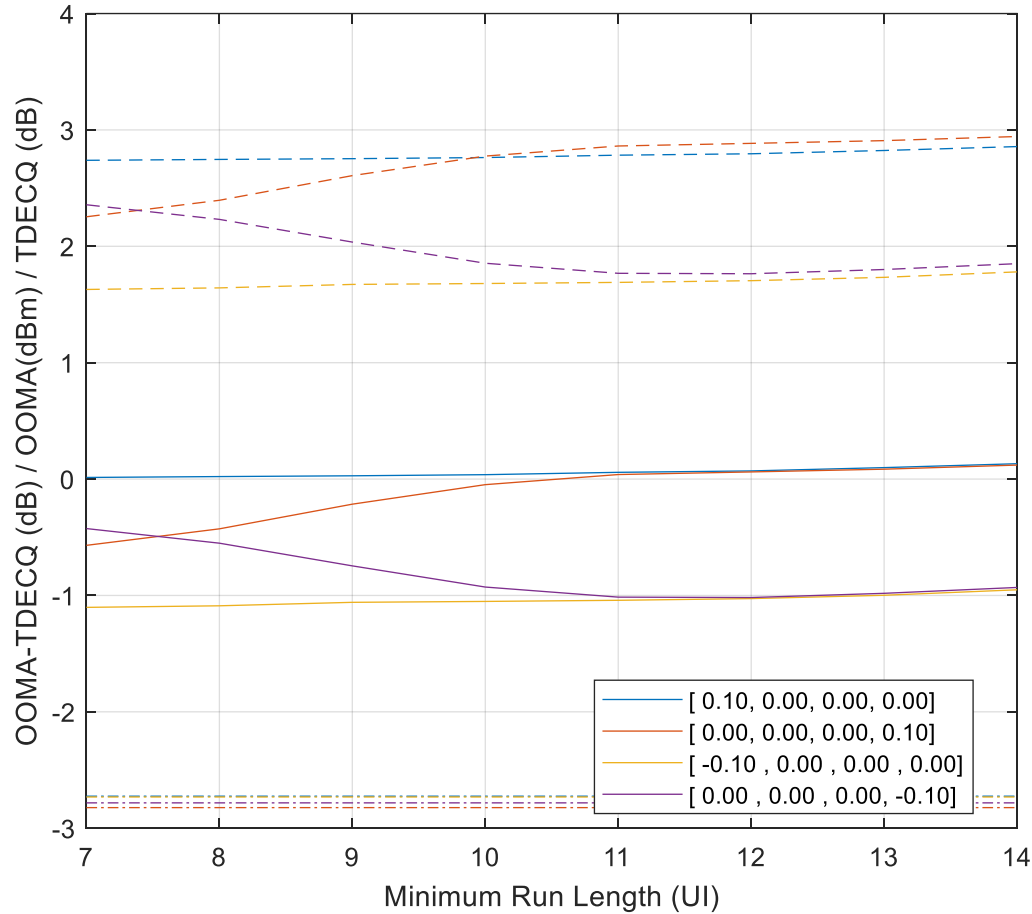
- Generates three different amplitudes depending on the sum of signed tap values (0.6, 0.8, 1.0)
- ~60 possible sets of taps used
- Measuring on the input waveform results in large variations in OOMA between different sets of taps
- Function is relatively stable, regardless of minimum run length.

# Test Setup 2

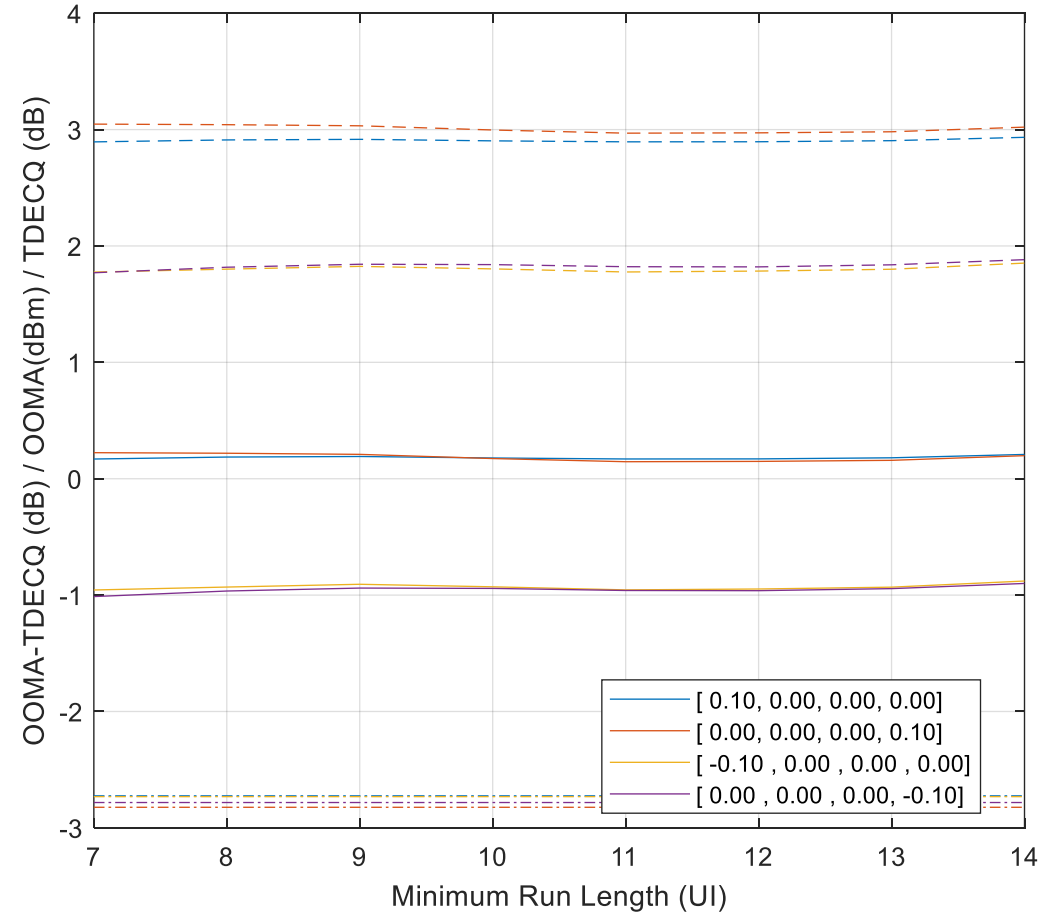


- Optimize Bert TX FFE to generate a “good” starting signal.
- Detune first postcursor to force use of DFE.
- Add +/- 0.1 to each post-cursor (allowing instrument to recalculate main tap based on normalization)
- Full Reference Equalizer is used, and Rx Tap limits are enforced.
- Measure: Include measurements for Noise margin, overshoot, undershoot, etc.

# Contrasting +/- 0.1 precursor at 1UI delay and 4 UI delay



OOMA and TDECQ up to 4 UI Delay  
Using Input Signal 2UI @ Start



OOMA and TDECQ up to 4 UI Delay  
Using Equalizer Output 2UI @ Start

# Simulation Test

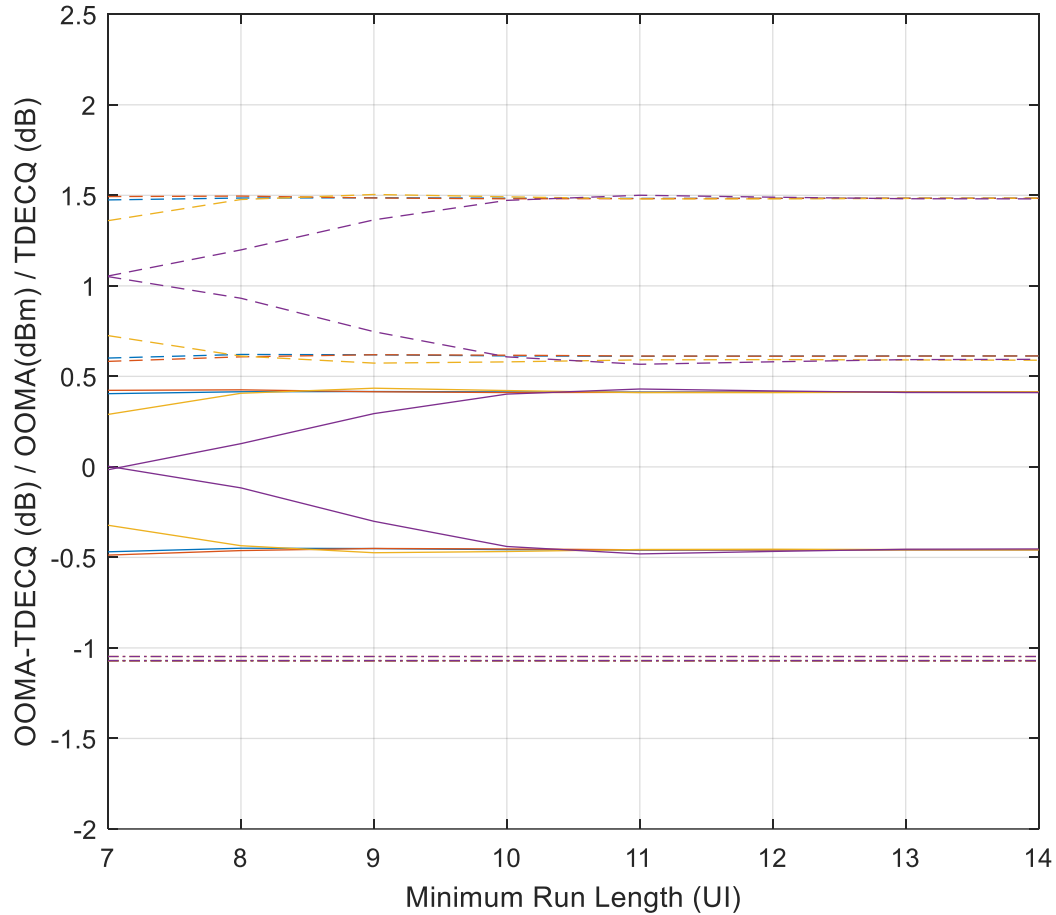
## Extending the Post Cursor Delay Beyond 4 UI



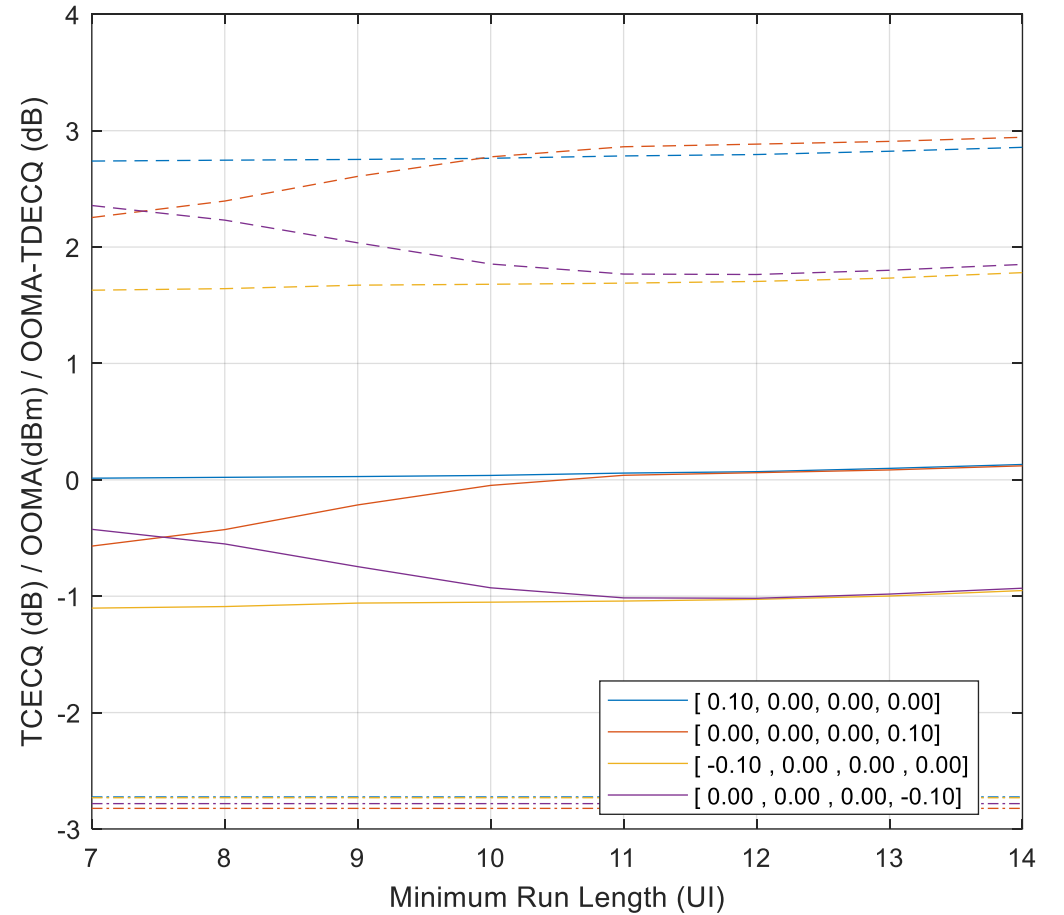
- Using FlexDCA to simulate a band limited signal with no noise modified by a linear equalizer with taps [1.0, 0,0,... +/-0.1]
- Sweep the delay of the single postcursor from 1UI to 20UI.
- Measure using standard RX Equalizer

# Simulation Results Agree and Test 2 Data

Up to 4 UI of delay for the postcursor



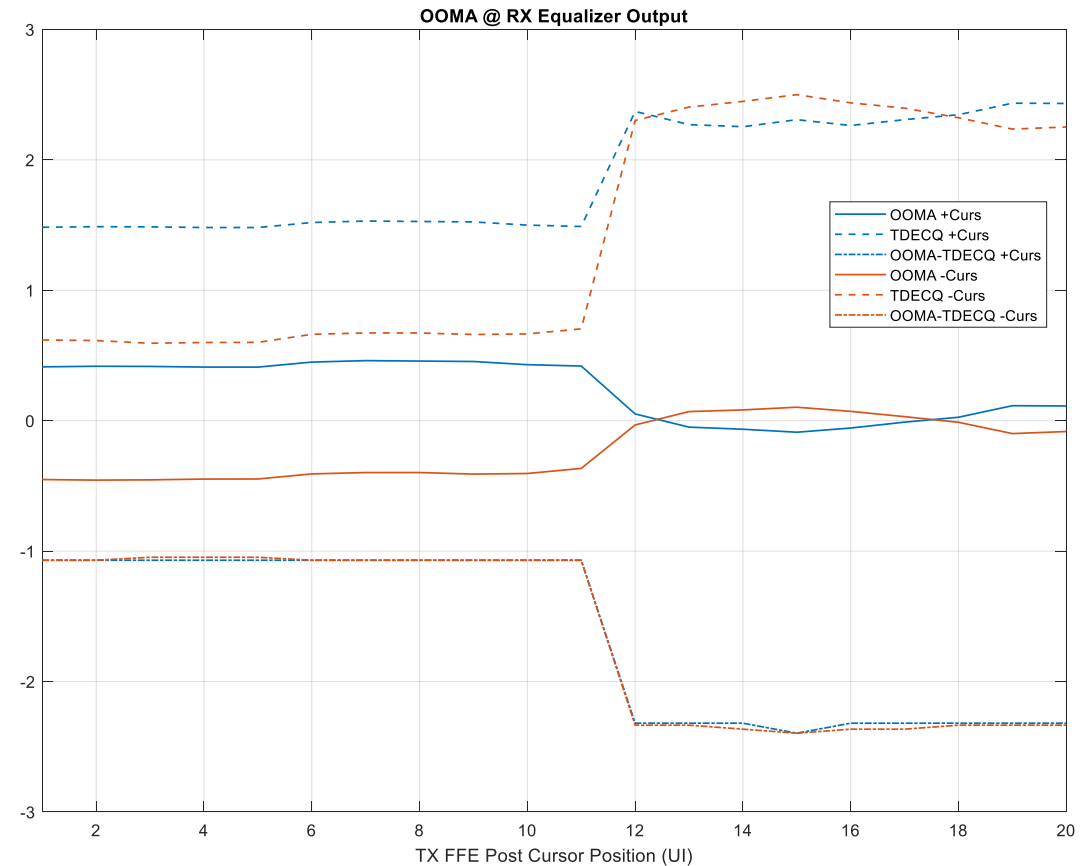
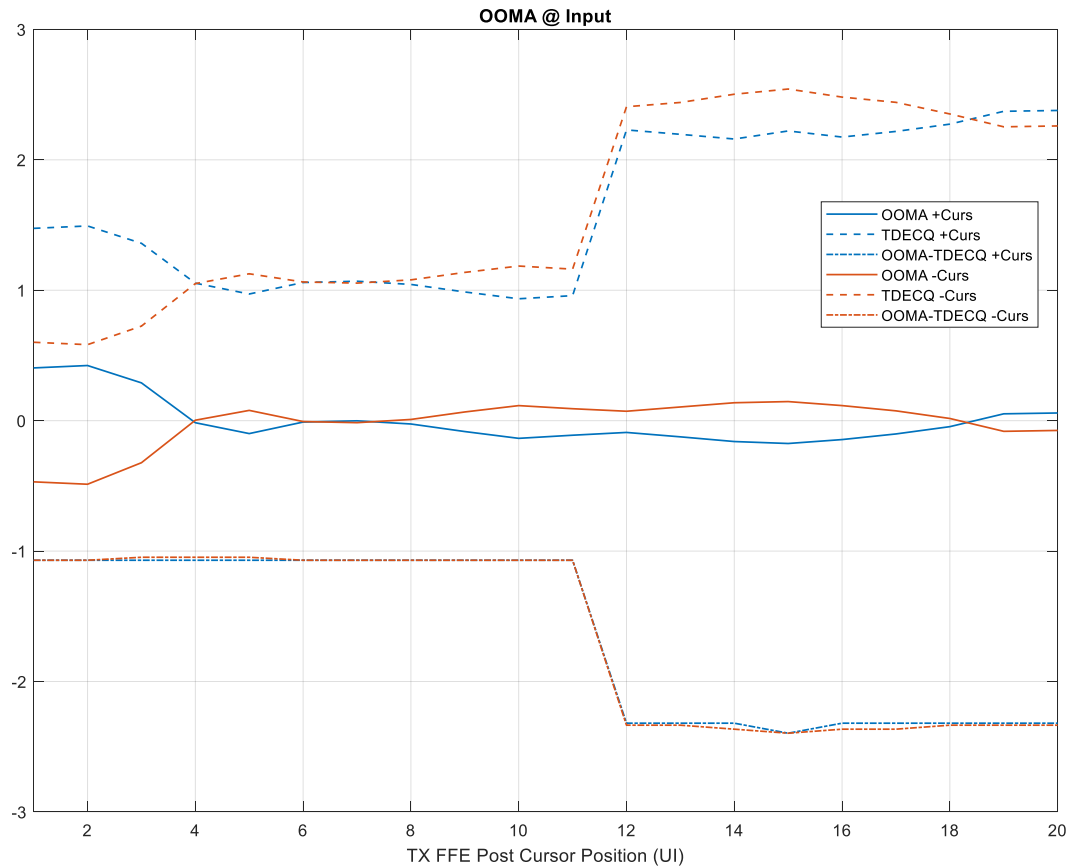
Simulated OOMA and TDECQ up to 4 UI Delay



Test OOMA and TDECQ up to 4 UI Delay

# Simulated Results out to 20 UI postcursor delay

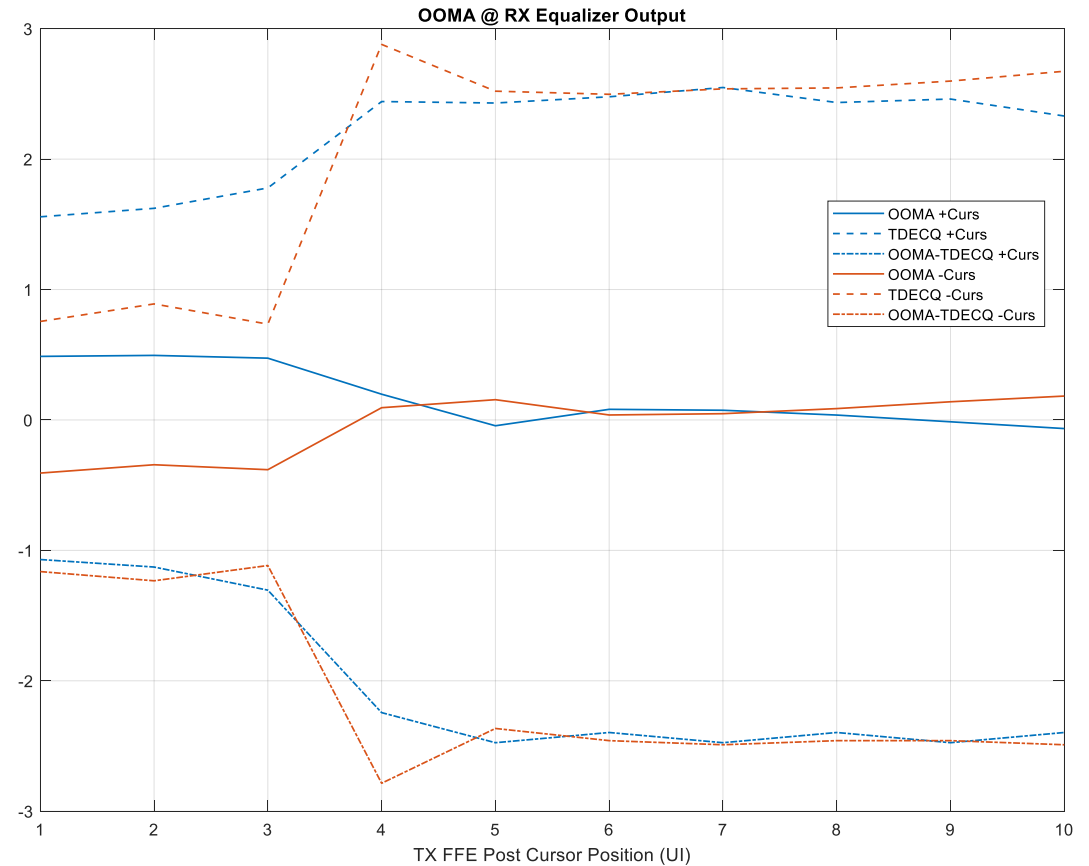
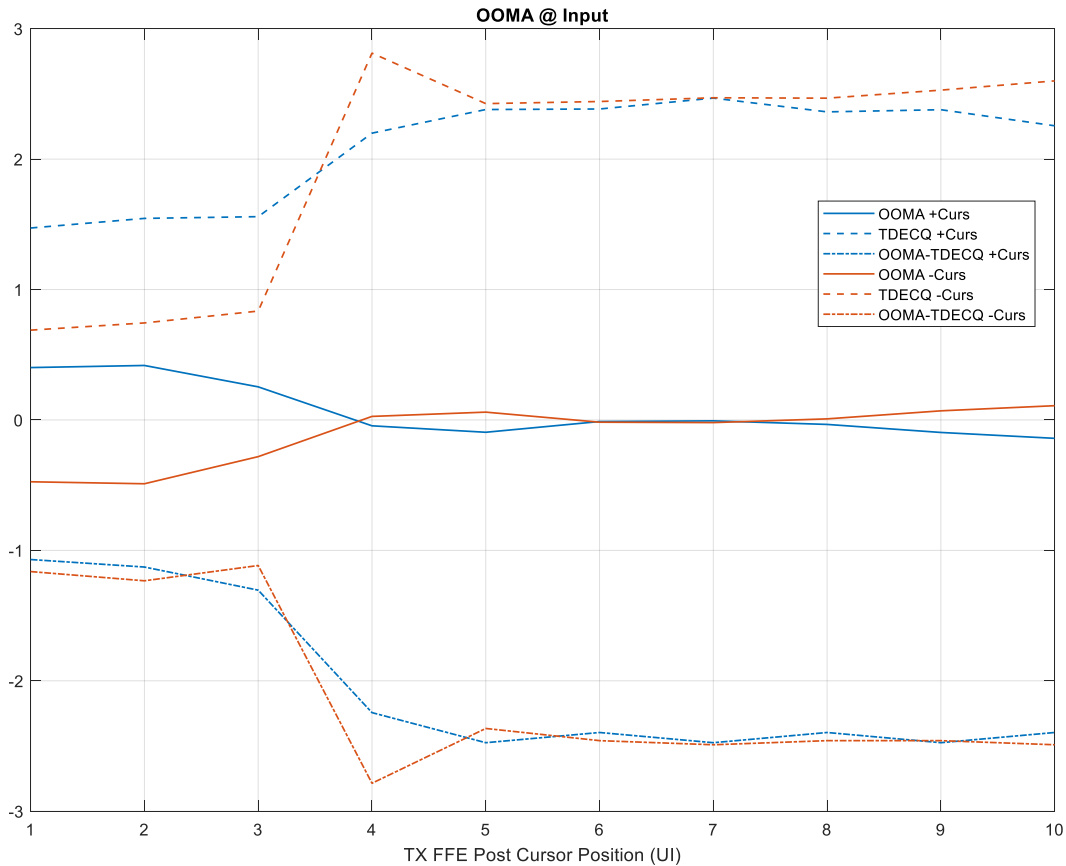
Measured using 2UI @ Start with Minimum Run Length of 7UI



- Note: Results are now plotted versus Post Cursor Delay. RX Equalizer is fixed at 3 Precursors
- The OOMA-TDECQ is stable as long as the equalizer can correct for the TX postcursor (11 UI)
- Using the RX Equalizer Output, OOMA and TDECQ are stable for the same duration as OOMA-TDECQ

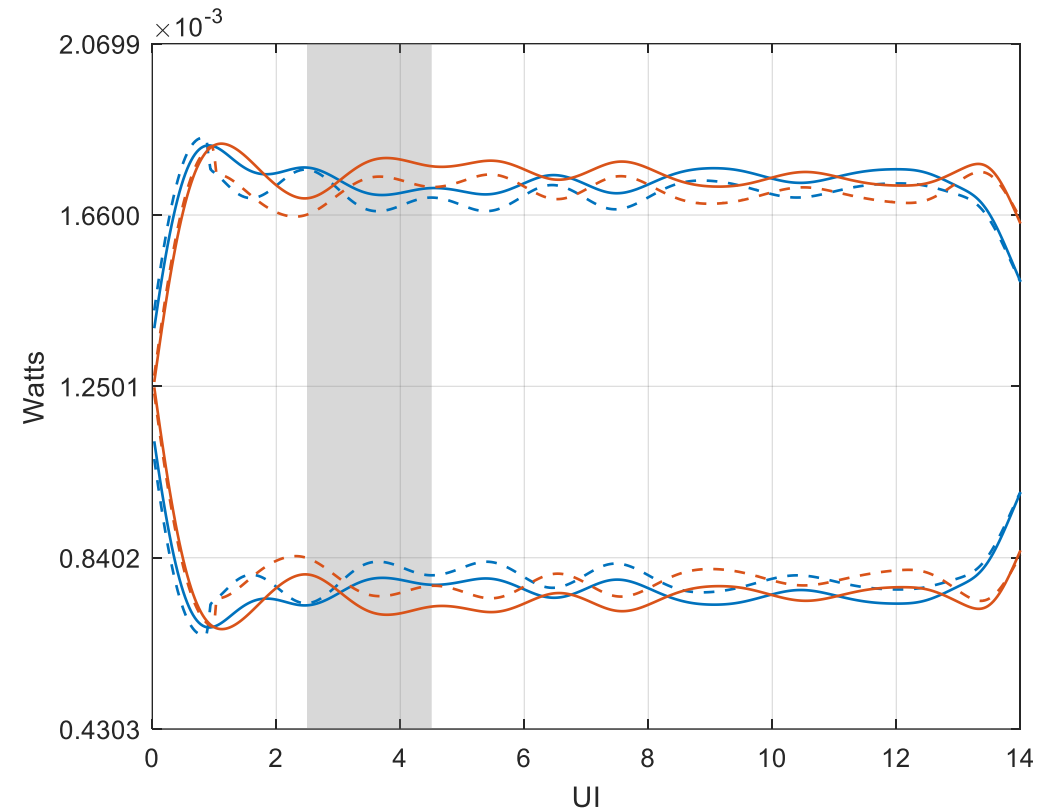
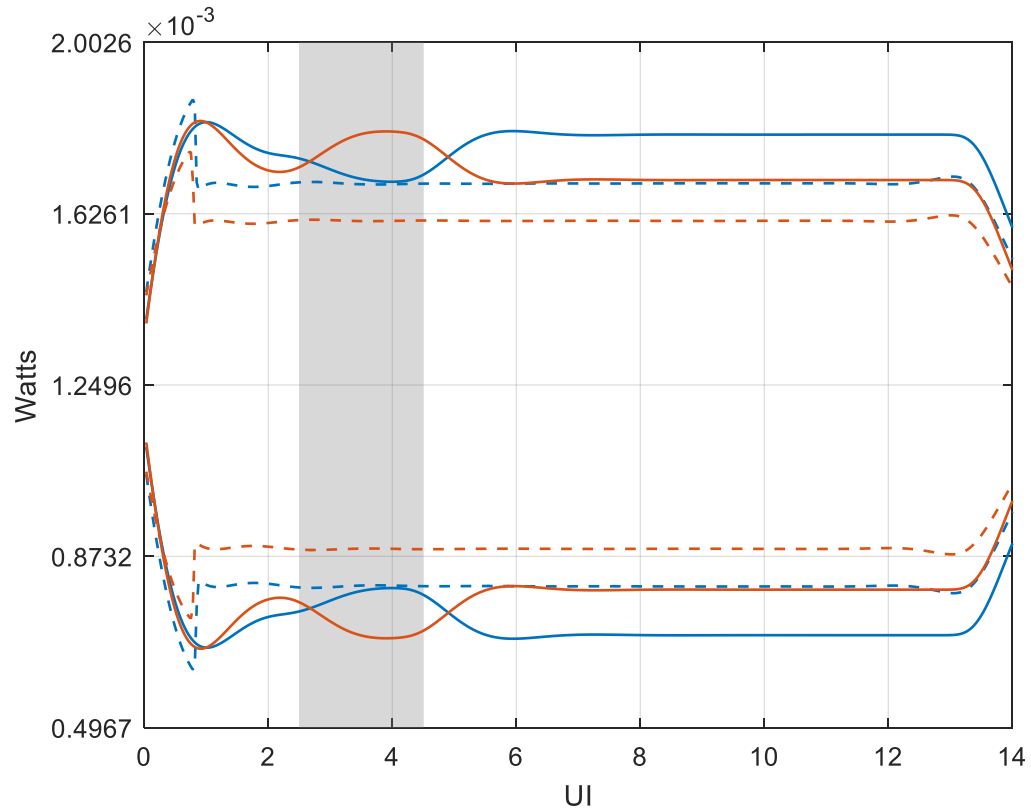
# Using a 5 Tap FFE up to 10 UI postcursor delay

Measured using 2UI @ Start with Minimum Run Length of 7UI



- Similar behavior when using a 5 Tap FFE with 1 precursor

# Closer look at 14 UI Run



- Dashed lines are equalizer output.
- Left plot shows +/-0.1 postcursor at 5UI delay – Right plot shows +/-0.1 at 15UI delay

# Summary

- This presentation brings additional test data to inform the task force's discussion on OOMA measurement method and location.
- The presentation compares the OOMA measurement of four waveforms having opposite sign post-cursors in different locations to simulate the effect of near and far reflections with opposite signs and study the impact of these reflections on the measurement.
- The waveforms corresponding to the positive and negative postcursor cases are expected to have the same performance in a link and should be getting the same OOMA.
- The near post-cursors getting a different OOMA is an artifact of the measurement and the waveform with a positive post-cursor in tap 1 is not something we expect to see.
- Despite the possibility of peaking a transmitter to get a lower penalty, this presentation recommends measuring OOMA at  $2UI/3UI$  from the start since it is not dependent on the signal bandwidth for any realistic range of frequencies.

# Thank you

# Historical OMA Definitions (IEEE 802.3)

## OMA Definitions (Clause 52.9.5)

### 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.

- First IEEE 802.3 definition of OMA.
- Targets measurement on a square wave pattern with between 4 and 11 repetitions of 0’s and 1’s.

#### 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).

## OMA Definitions (Clause 52.9.5 continued)

- Continuing from Clause 52.9.5:

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.
- A minimum bandwidth is specified based on the length of repetition
  - Assumption that at lower bandwidths a more significant amount of ISI would be present in the measurement region.
  - Typically, bandwidth was  $\sim 0.75 \times \text{Baud}$ , or 7.5GHz. Allows for testing OMA measurement on the shortest square wave.

## OMA Definitions (Clause 52.9.5 continued)

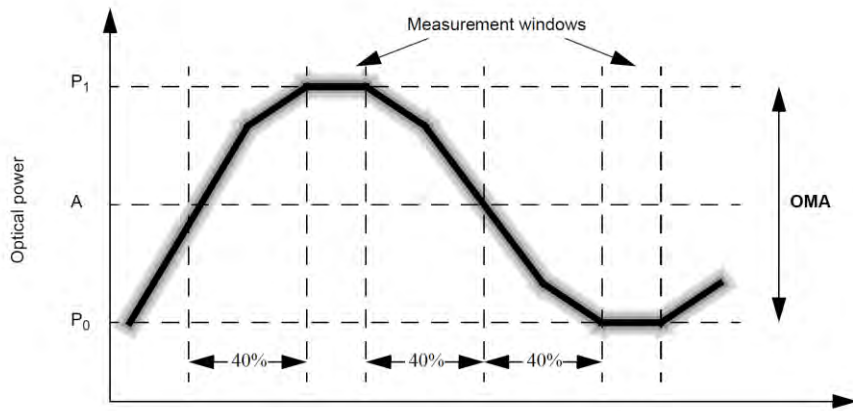


Figure 52-6—Optical modulation amplitude waveform measurement

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)  $OMA = P_1 - P_0$ .

- The 1 and 0 levels are measured in the center 20% of the interval
- Attempt to reduce impact of ISI as much as possible while allowing for a reasonably wide measurement region

## OMA Definitions (Clause 86.8.4.3)

### 86.8.4.3 Optical Modulation Amplitude (OMA)

OMA shall be as defined in 52.9.5 for measurement with a square wave (8 ones, 8 zeros) test pattern or 68.6.2 (from the variable MeasuredOMA in 68.6.6.2) for measurement with a PRBS9 test pattern, with the exception that each optical lane is tested individually. See 86.8.2 for test pattern information.

- A later revision to OMA requires repetitions of 8 symbols
- Maintains the previous definitions use of 20% measurement region

# Outer OMA Definition (P802.3bs\_D1.3)

- OOMA was added to the standard before TDECQ or SSPRQ were introduced. Relying on a PRBS13Q to generate a run of 6/7 zeros and threes.
- Only test pattern defined in this section that can be measured on an Equivalent Time Sampling Scope.
- First time 2 different length runs are specified for lower and upper levels.

## 122.8.4 Outer Optical Modulation Amplitude ( $OMA_{outer}$ )

The  $OMA_{outer}$  of each lane shall be within the limits given in Table 122–6 if measured using a PRBS13Q pattern as defined in 120.5.11.2.2. The  $OMA_{outer}$  is defined as the difference between the average optical launch power level  $P_3$ , measured over the central 2 UI of the run of 7 threes, and the average optical launch power level  $P_0$ , measured over the central 2 UI of the run of 6 zeros, as shown in Figure 122–3.

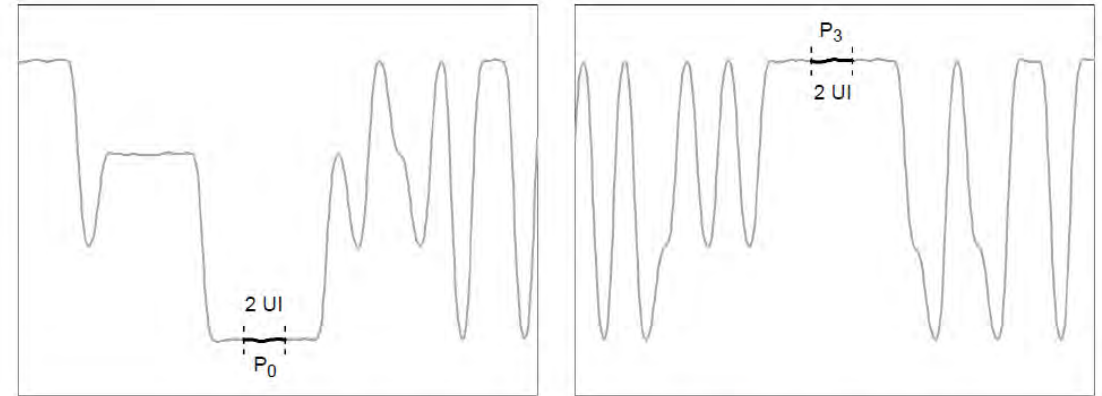


Figure 122–3—Power levels  $P_0$  and  $P_3$  from PRBS13Q test pattern

## 122.8.5 Transmitter and dispersion penalty (TDP)

*[Editor's note: we need a new definition for TDP for PAM4 modulated signals]*

Table 122–9—Test patterns

Pattern	Pattern description	Defined in
3	PRBS31Q	120.5.11.2.3
4	PRBS13Q	120.5.11.2.2
5	Scrambled idle	119.2.4.9

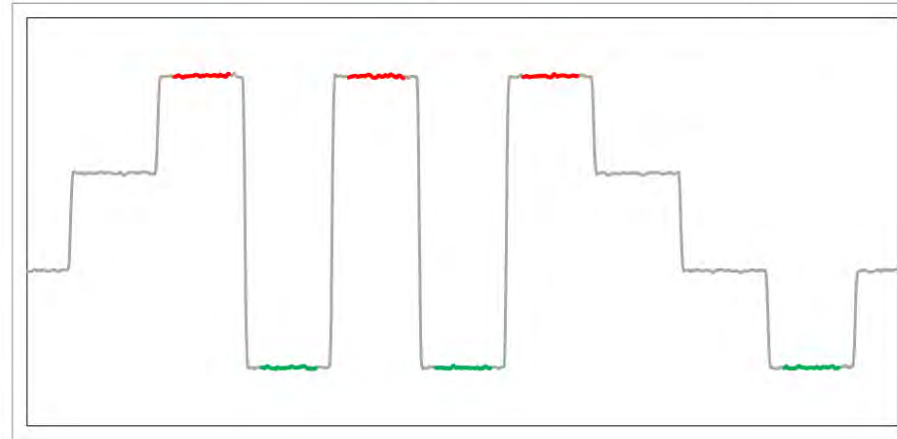
# Outer OMA adhoc Discussions 802.3bs

- Excerpt from:  
[https://www.ieee802.org/3/bs/public/adhoc/smf/16\\_02\\_02/anslow\\_01a\\_0216\\_smf.pdf](https://www.ieee802.org/3/bs/public/adhoc/smf/16_02_02/anslow_01a_0216_smf.pdf)
- The adhoc presentation discussed the use of central 10 symbols of runs of 16 symbols as a possibility
- A PRBS13Q was selected by the adhoc
- From the discussions, the intention is to measure the central symbols, equally padded on either side of the measurement region.

## OMA and ER definitions

The extinction ratio measurement method for NRZ optical signals is defined in IEC 61280-2-2. This is defined as the average of the "one" level for the central 20% of the eye divided by the average of the "zero" level for the central 20% of the eye.

The transmitter linearity test pattern has 3 x 16 UI blocks at level three and 3 x 16 UI blocks at level zero for each 160 UI repeat of the pattern. If this pattern is to be used, then the three and zero levels could be defined to be the average of the inner 10 symbols from each run of 16.



PRBS13Q has  
one run of 7  
threes and one  
run of 6 zeros

10

Page 9 (page 10 in anslow\_01a\_0216\_smf)

The consensus view was to base the OMA<sub>outer</sub> and ER definitions on the PRBS13Q sequence. The zero level was proposed to be the average of the central 2 unit intervals (symbols 3 and 4) of the run of 6 zeros and the three level was proposed to be the average of symbols 4 and 5 of the run of 7 threes.

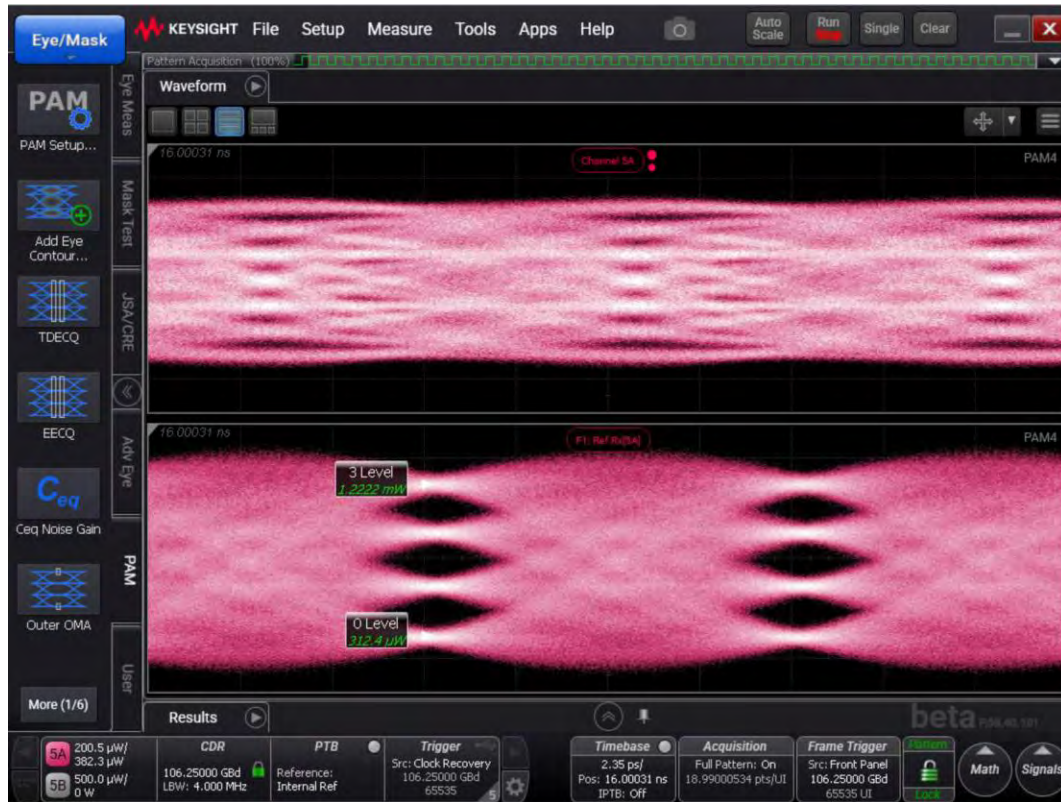
# OOMA Inconsistency For 4 TAP TX FFE

# Test Setup 1

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- Using an SSPRQ and Bert TX FFE to simulate transmitter tuning or “near” reflections
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- Waveform for channel @ 53.125GHz and output of Reference Equalizer (15 tap FFE + 1 DFE)
- Pattern is determined using equalized signal
- Runs of at least length 6 are extracted and saved
- FlexDCA OOMA measurement is not used (it is currently not pattern aware)

# Baseline – No TX FFE

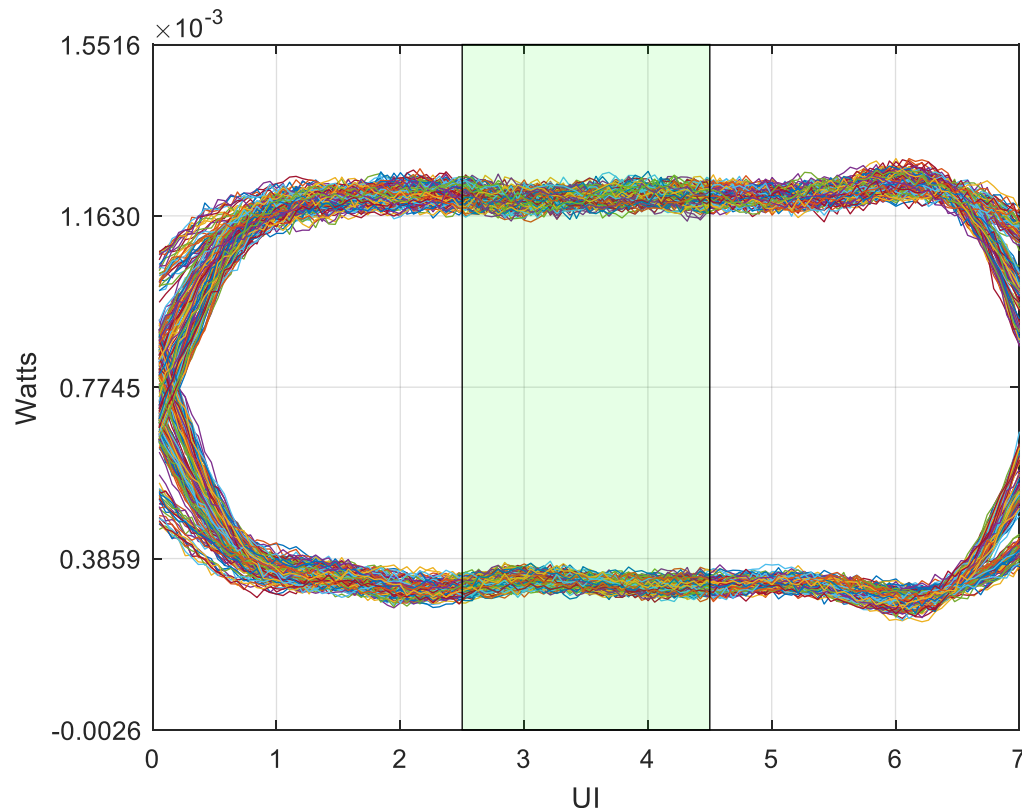
## Eye Diagram



- Generated using Keysight BERT + Reference Transmitter into an N1093.
- No TX FFE

# Baseline – No TX FFE

Runs of 7 zeros or threes only.

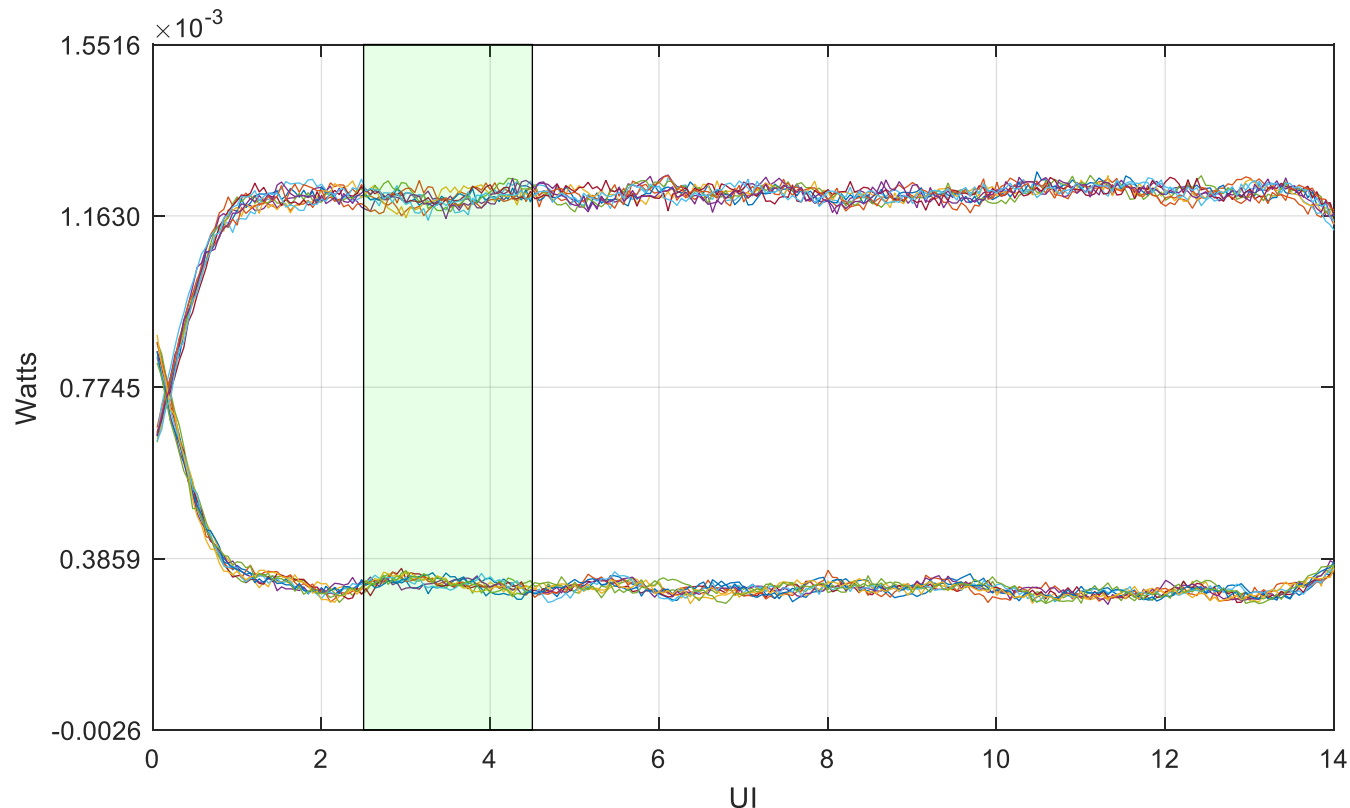


Showing all runs of 7 zeros or 7 threes  
across all ten trials with no TX FFE

- Simplify by limiting to equal length runs for both zeros and threes.
- Using runs of 7 as the basis, the central 2 UI are measured (from 2.5 UI to 4.5 UI).

# Baseline – No TX FFE

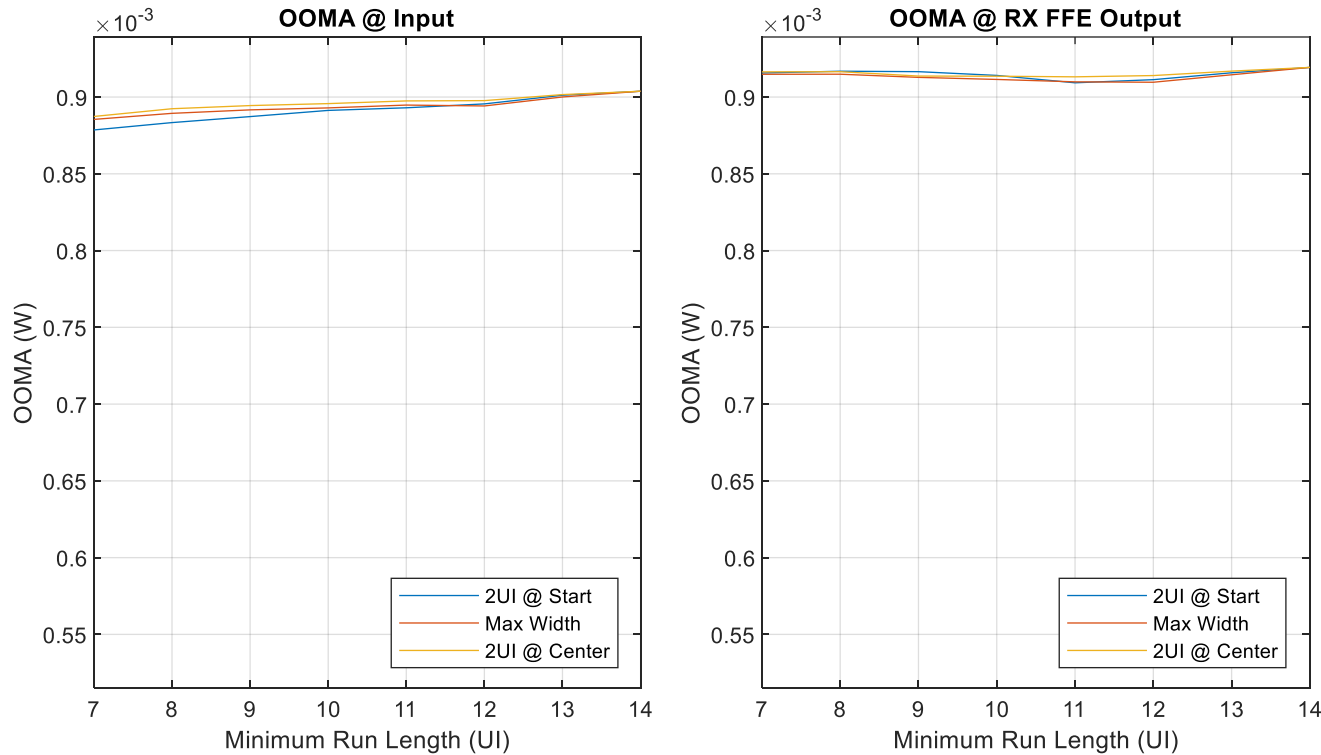
Runs of 14 zeros or threes only.



Showing all runs of 14 zeros or 14 threes  
across all ten trials with no TX FFE

- We want to include data runs that are longer than the minimum to calculate OOMA. Why? We already have the data, and it increases stability of the measurement.
- For runs longer than the minimum the options we considered are:
  1. Measure the same region as offset from the start of the run.
  2. Remove the same amount from the region (front and back)
  3. Measure the same number of UI from the center of the run.

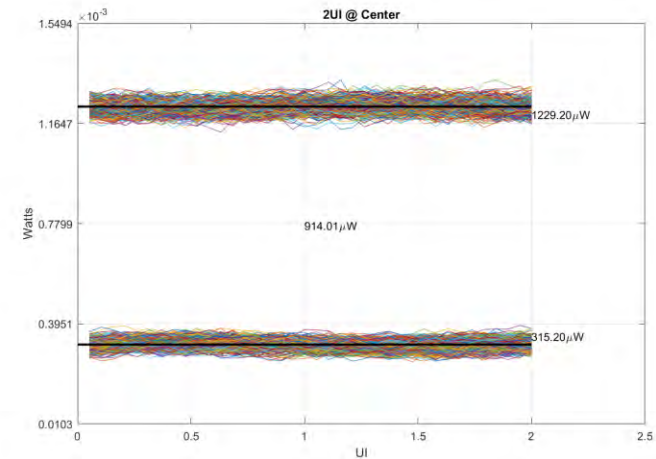
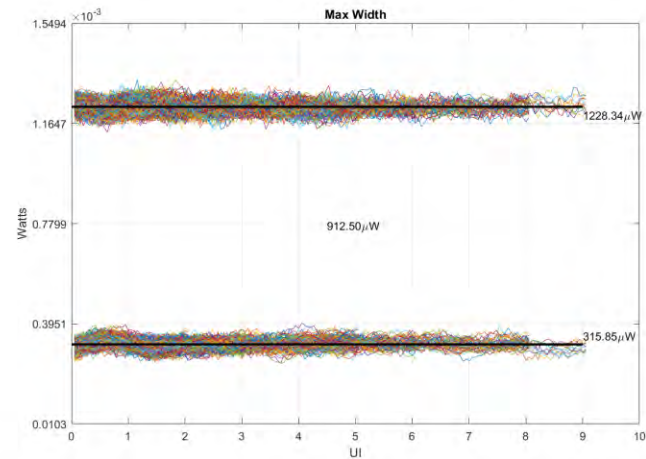
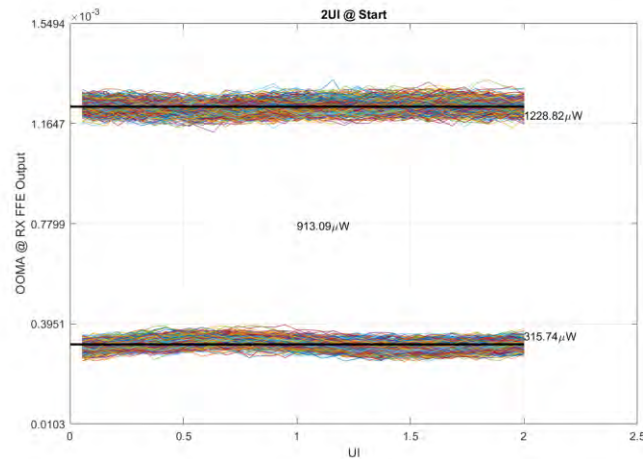
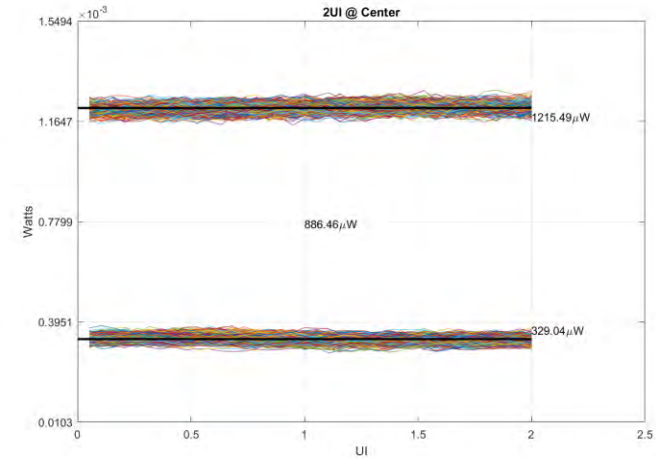
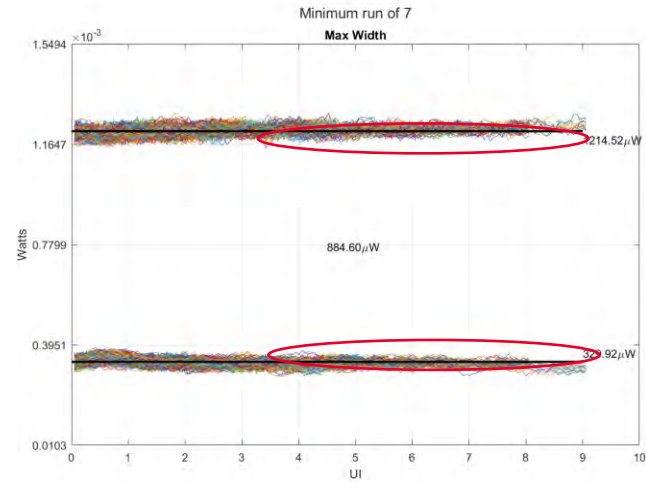
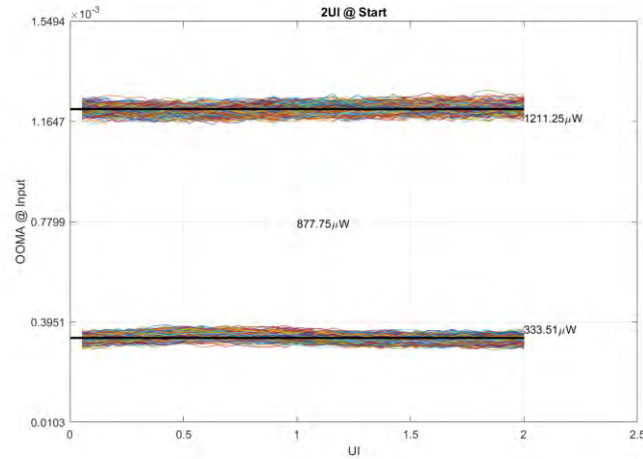
# Baseline – No TX FFE



Slow increase in OOMA vs Minimum run length when no FFE (Tx or Rx) in use.

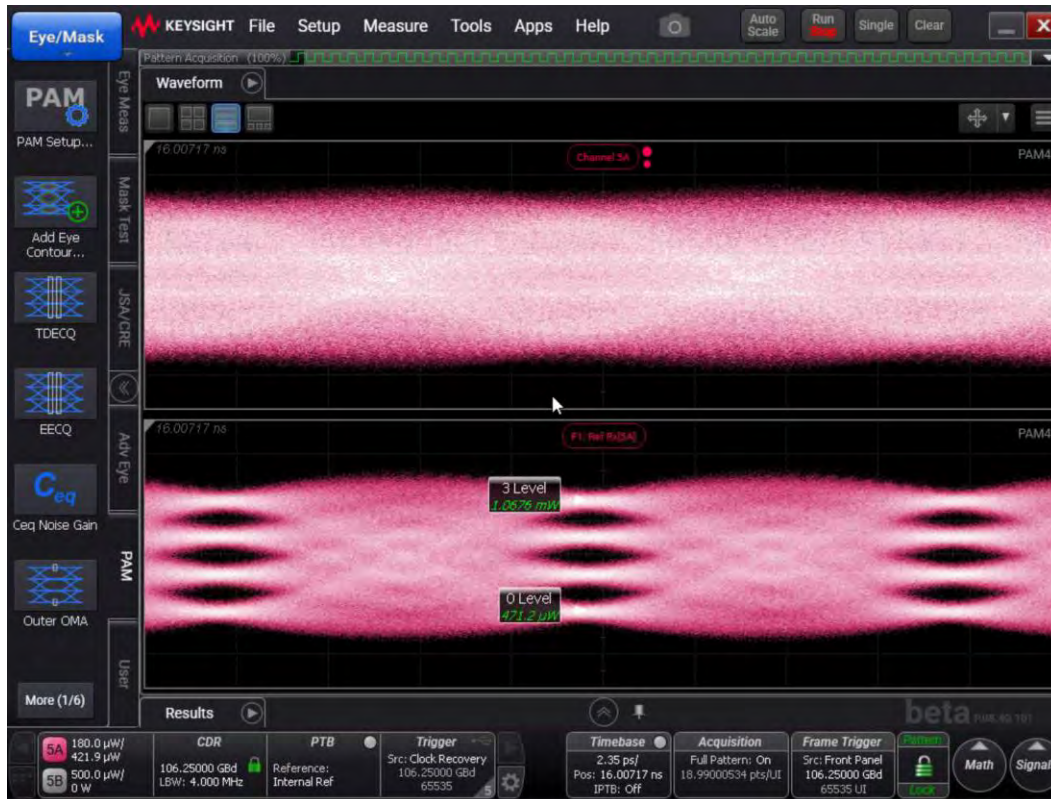
- The experiment:
  - Sweep minimum run lengths from 7 to 14
  - Measure OOMA using the three methods with a target of at least 2 UI.
  - All three methods are equivalent if min run length == max run length.
- The methods are:
  - **(2UI @ Start)**
    - The starting location is  $\frac{1}{2} * (\text{Min Run Length} - 2 \text{ UI})$ . (2.5 for min run length of 7)
    - Measure 2 UI from there.
  - **(Max Width)**
    - The margin from start/end of the run is also  $\frac{1}{2} * (\text{Min Run Length} - 2 \text{ UI})$ .
    - Measure everything between the two margins
  - **(2UI @ Center)**
    - The starting location is  $\frac{1}{2} * (\text{Current Run Length} - 2 \text{ UI})$ .
    - Measure 2 UI Starting from there.

# Baseline – No TX FFE



Can see from the top middle graph, the raw response of the BERT + Ref TX has a slowly approaches a final value. Causing OOMA to go up slightly as minimum run length increases.

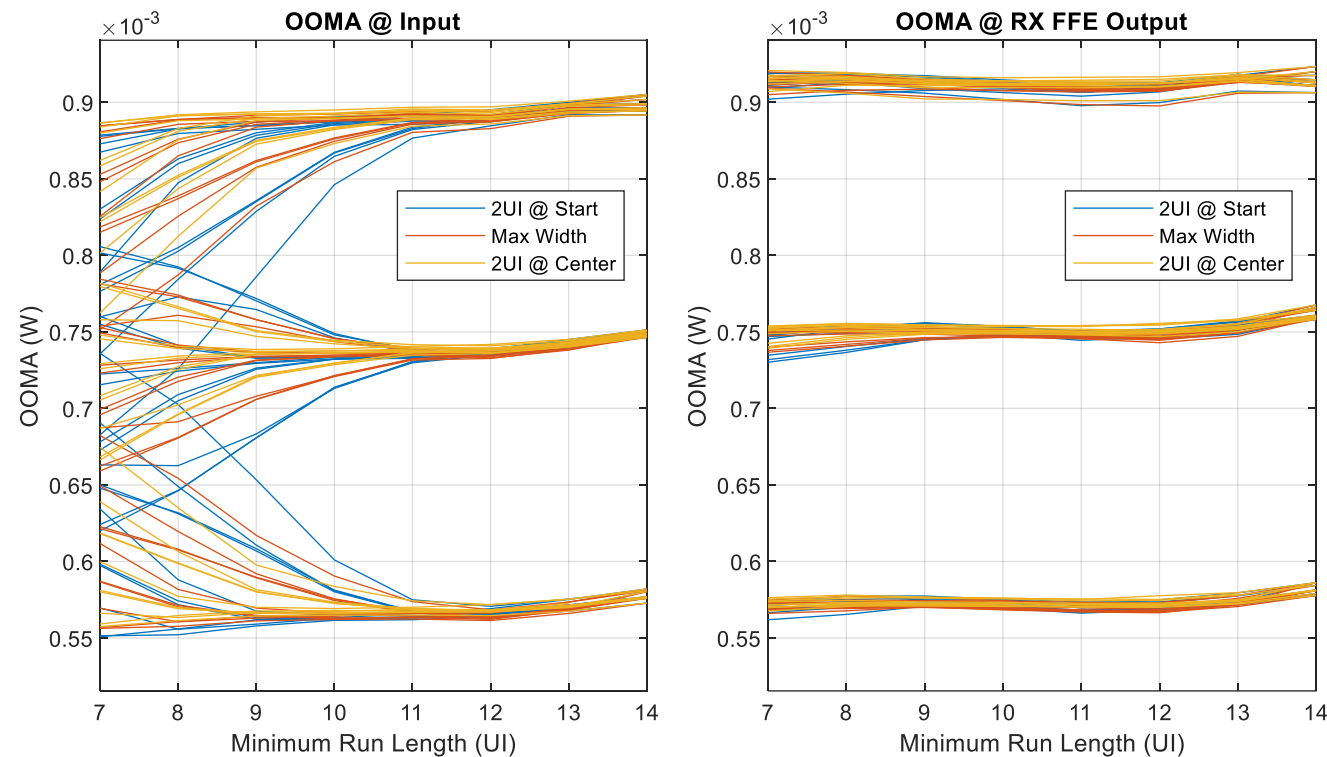
# TX FFE



- BERT FFE has 7 taps with up to 4 post cursors and forces  $\sum |w_i| = 1$
- Main tap is kept at  $w_0 = 0.8$ , so other tap magnitudes sum to 0.2.
- Limited post cursor weights to be  $0, \pm 0.1, \pm 0.2$  and no pre-cursors
- Swept through all possible post cursor combinations. eg
  - $[0.8, 0.0, 0.0, 0.1, 0.1]$
  - $[0.8, 0.1, 0.0, -0.1, 0.0]$
  - $[0.8, 0.0, -0.2, 0.0, 0.0]$

# TX FFE

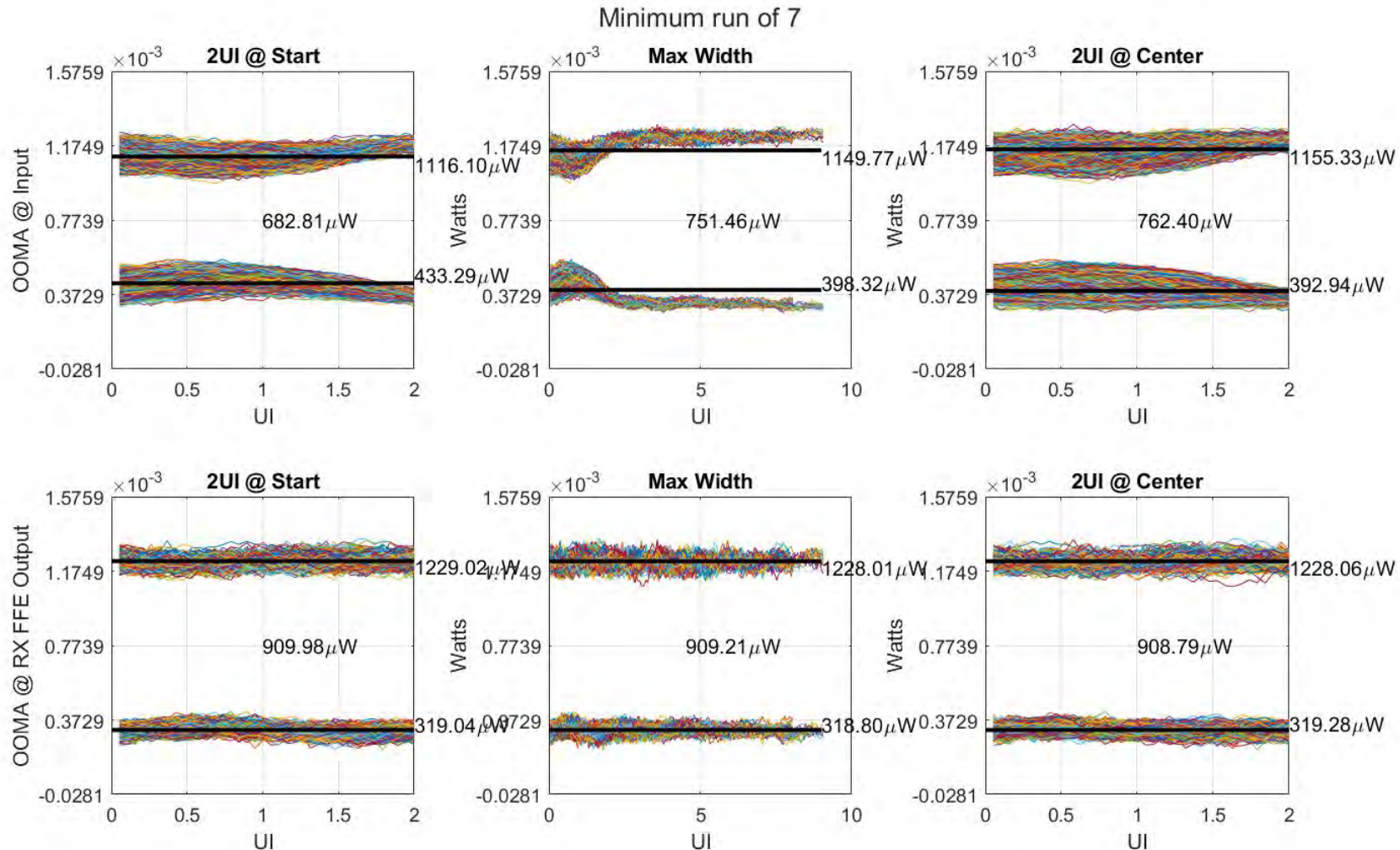
## OOMA vs Minimum run Length for the three methods



- Generates three different amplitudes depending on the sum of signed tap values (0.6, 0.8, 1.0)
- Measuring on the input waveform results in large variations in OOMA between different sets of taps
- Function is relatively stable, regardless of minimum run length.

# In Depth Look

TX FFE - [0.8, 0.0, 0.0, 0.0, 0.2] – Minimum run of 7 CID

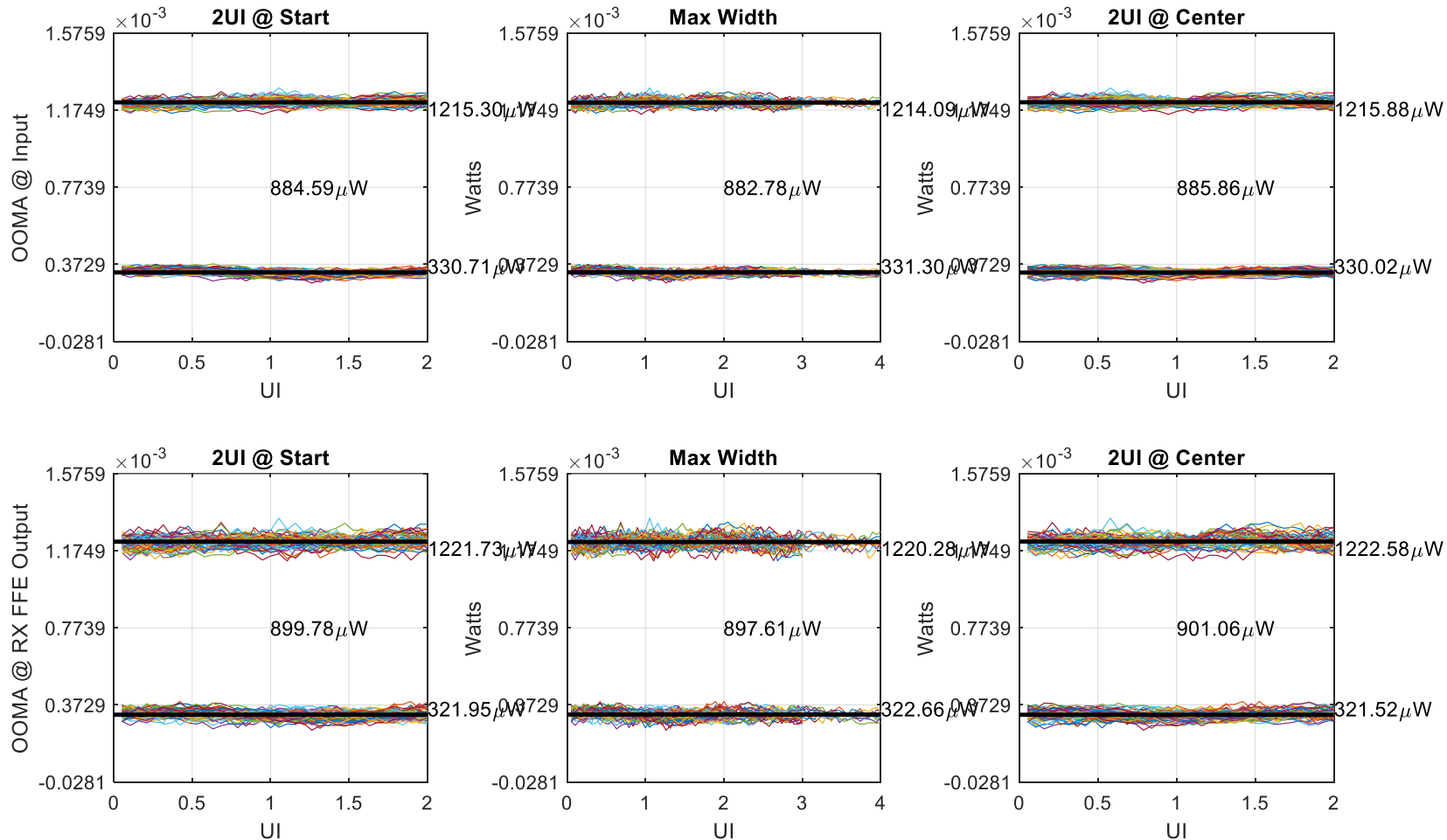


- Very different values for OMA between the three algorithms when using the Input waveform
- Consistent results between algorithms when using the FFE output
- Which OMA is correct?
  - ~0.76 dBm difference between Input and FFE OMA.

# In Depth Look

## TX FFE - [0.8, 0.0, 0.0, 0.0, 0.2] – Minimum run of 12 CID

Minimum run of 12

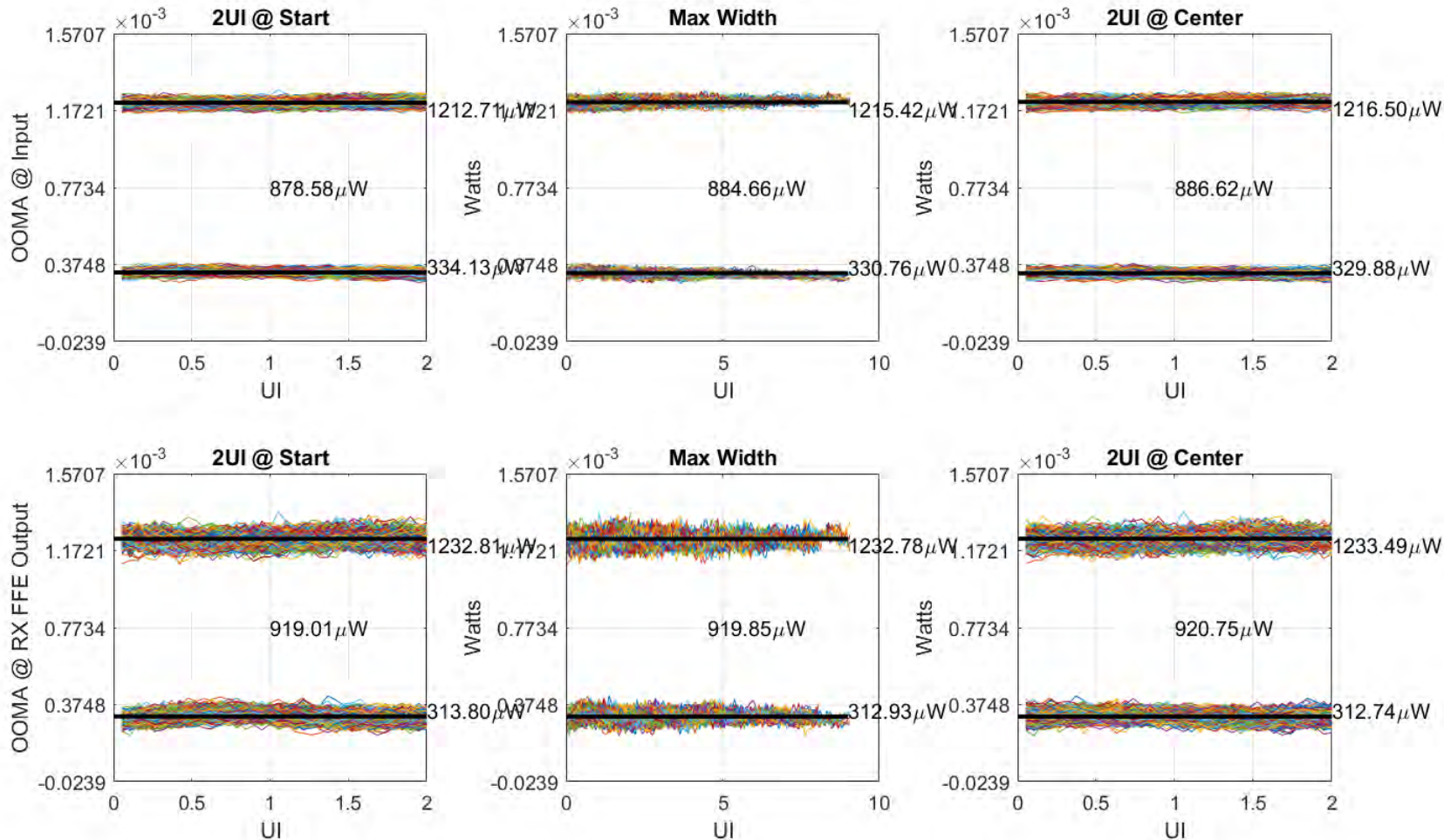


- Consistent results across algorithms for either input waveform or FFE output
- FFE output is still slightly higher.
- Which OMA is correct?
  - <0.1dBm difference

# In Depth Look

TX FFE - [0.8, 0.2, 0.0, 0.0, 0.0] – Minimum run of 7 CID

Minimum run of 7

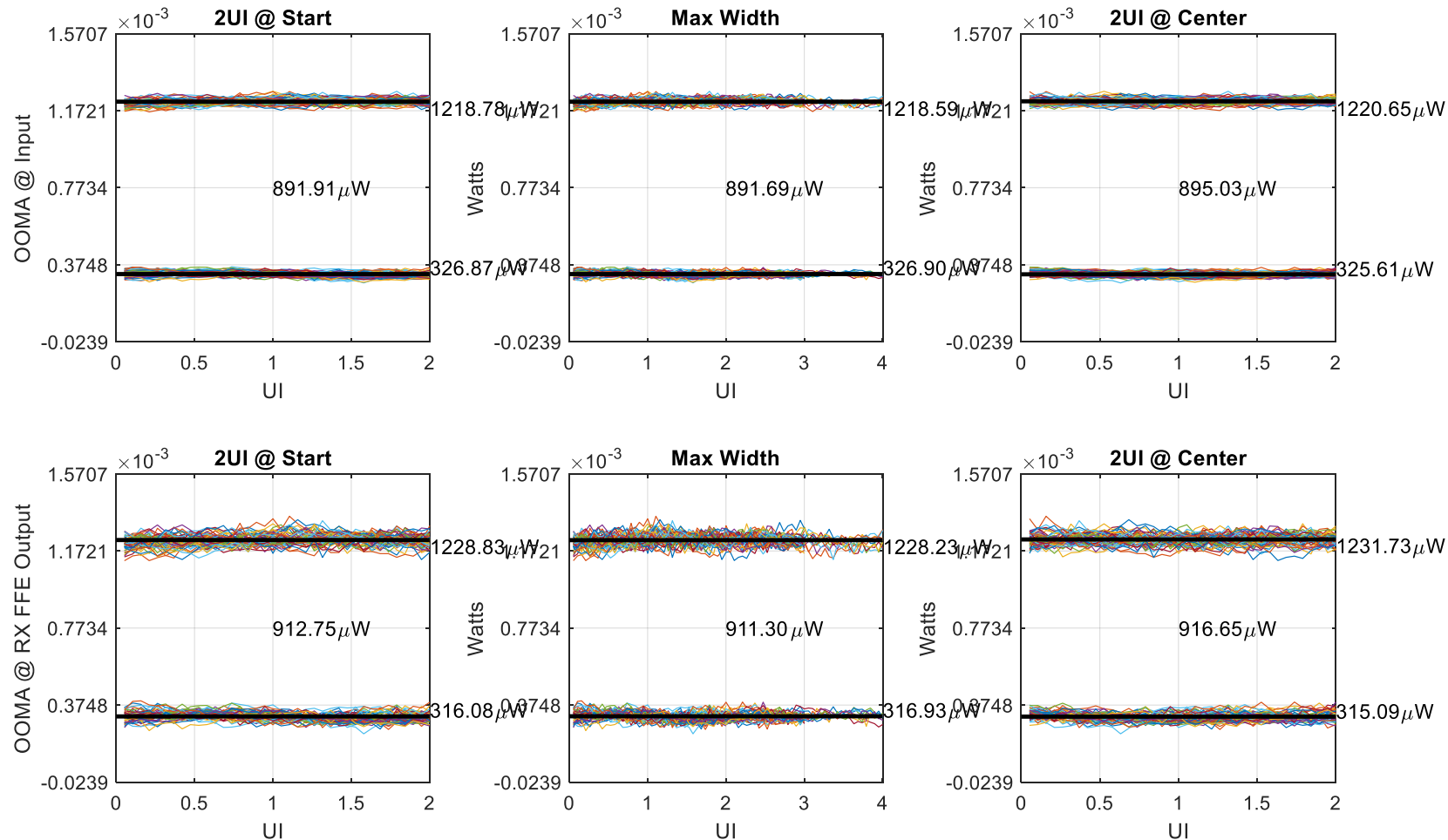


- Reflection is before the range, so consistent results
- FFE output is still slightly higher.
- Which OMA is correct?
  - ~0.15dBm difference

# In Depth Look

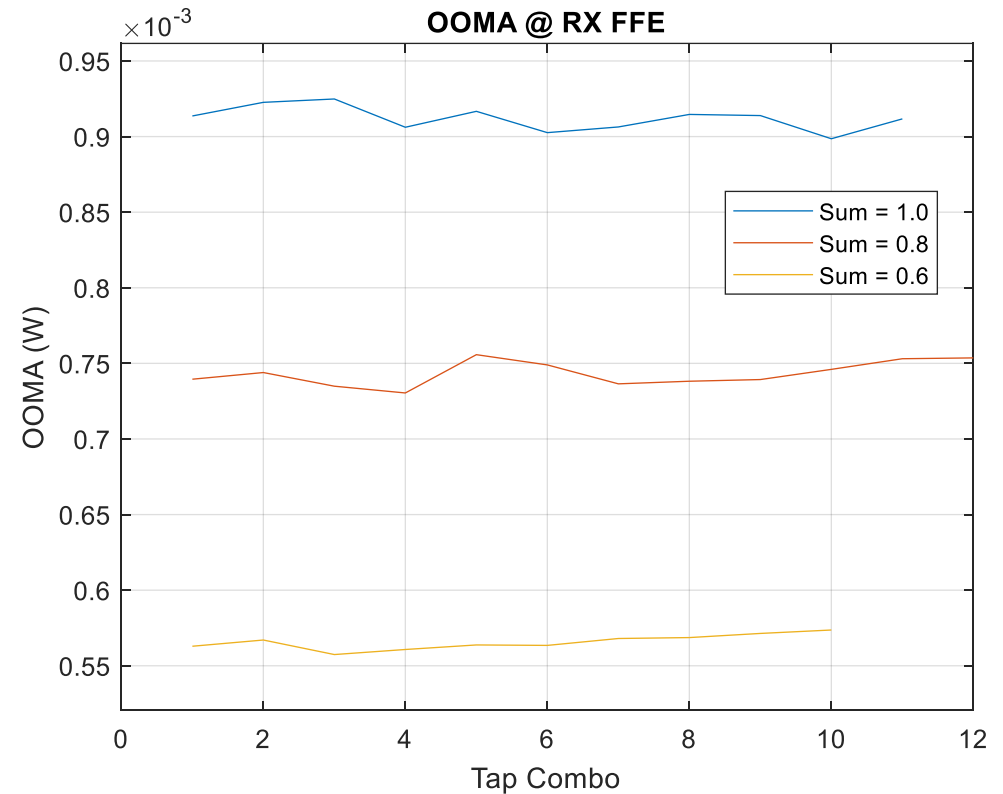
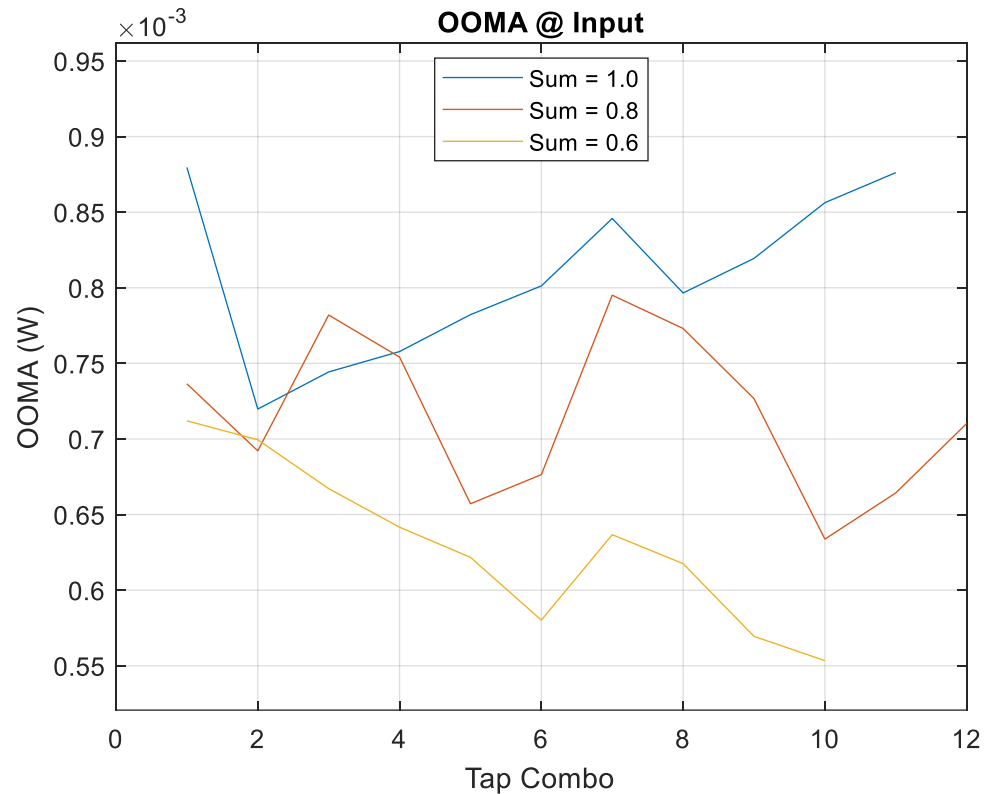
TX FFE - [0.8, 0.2, 0.0, 0.0, 0.0] – Minimum run of 12 CID

Minimum run of 12



- Reflection is before the range, so consistent results
- FFE output is still slightly higher.
- Which OMA is correct?
  - ~0.1dBm difference

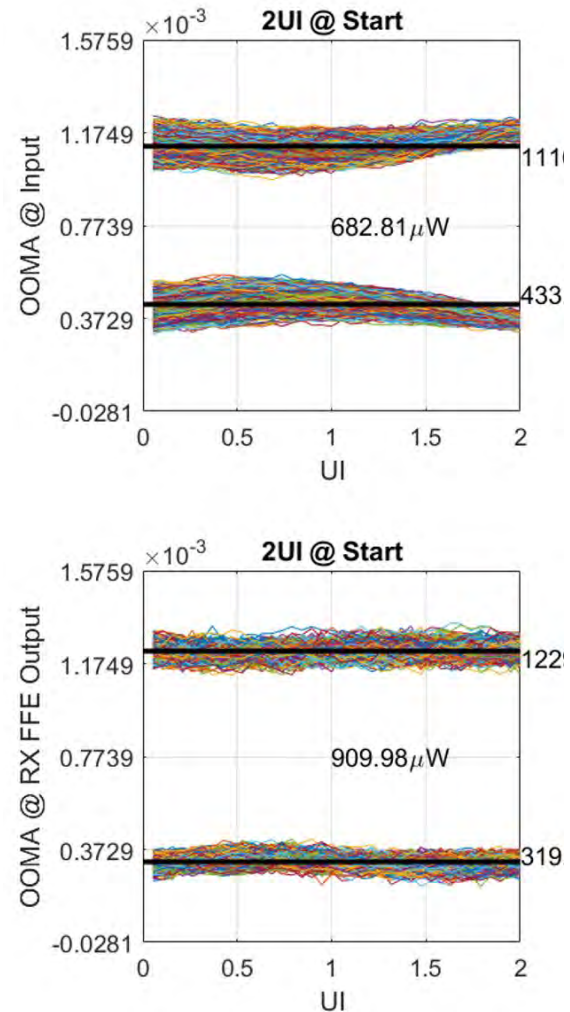
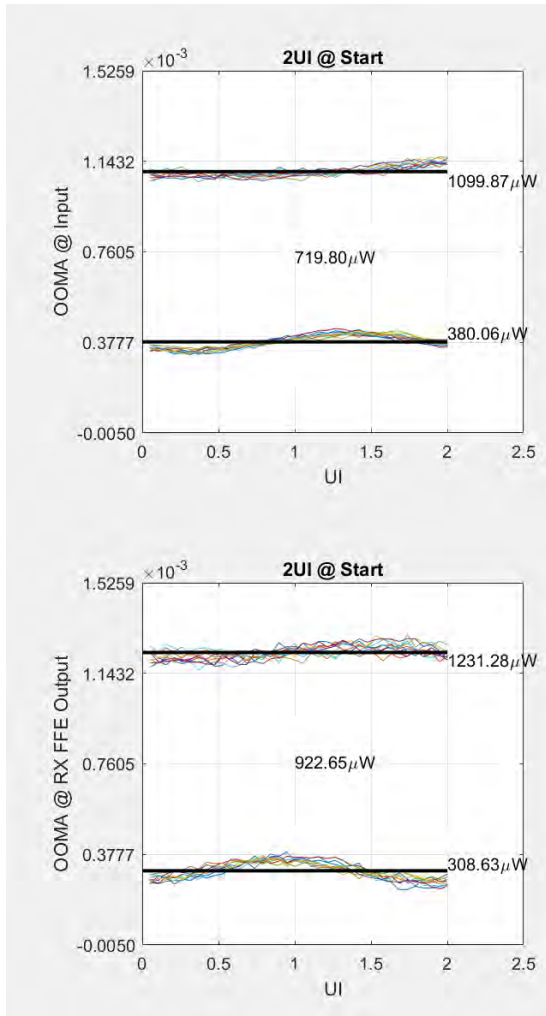
# PRBS13Q



- Measuring OOMA on PRBS13Q, with various TX FFE (grouped by sum of taps).
- Large variability when measuring at the raw channel.
- Consistent results at the output of RX FFE

# In Depth Look

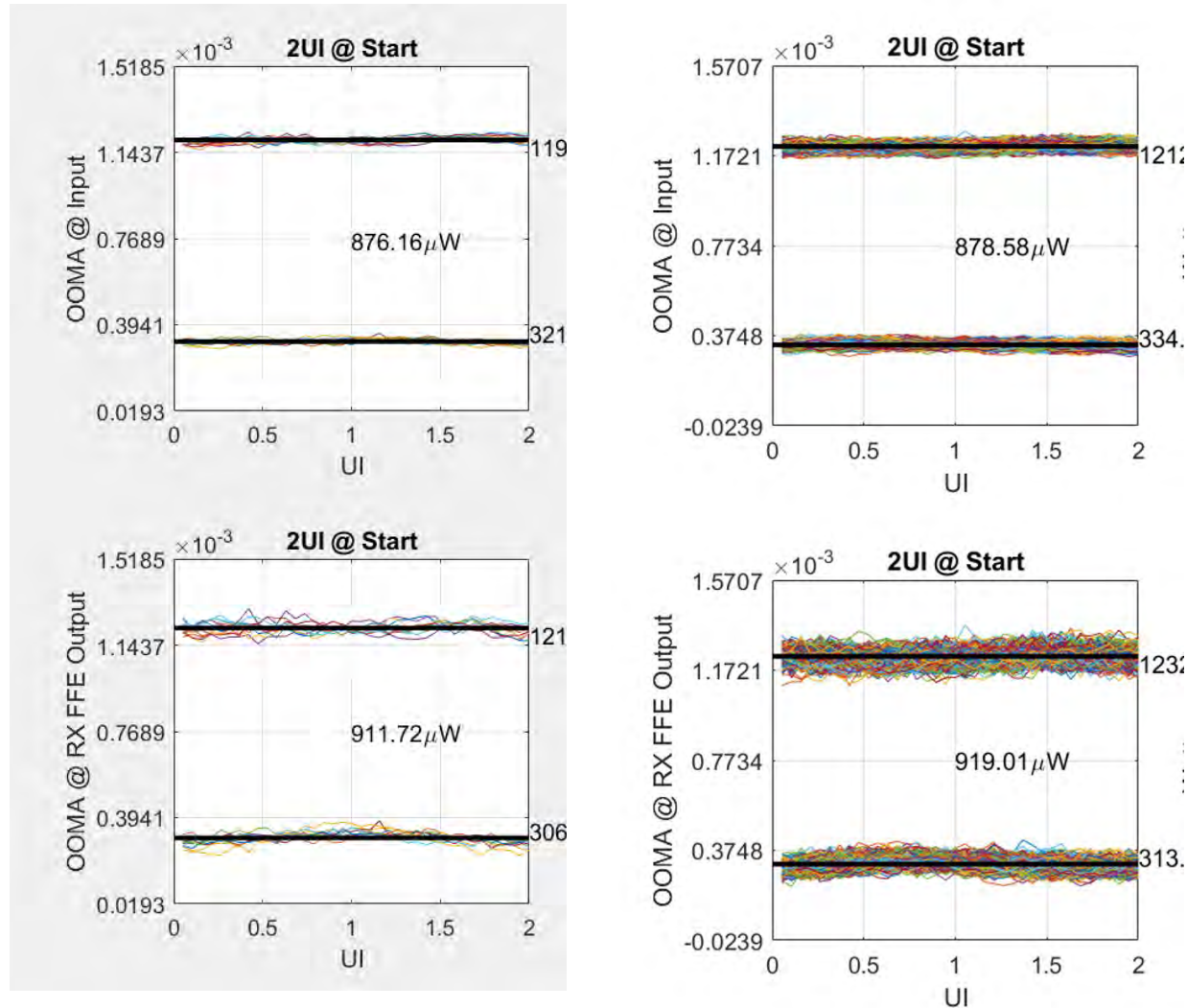
## TX FFE - [0.8, 0.0, 0.0, 0.0, 0.2] – PRBS13Q vs SSPRQ



- PRBS13Q, all three methods are equivalent
- For simplicity, looking at runs of length 6
- Left is PRBS13Q with runs of 6.
- Right is SSPRQ, runs of 7.
- Fairly large deviation of OOMA when using the channel waveform but not when using the output of the FFE.

# In Depth Look

## TX FFE - [0.8, 0.2, 0.0, 0.0, 0.0] – PRBS13Q vs SSPRQ



- PRBS13Q, all three methods are equivalent
- For simplicity, looking at runs of length 6
- Left is PRBS13Q with runs of 6.
- Right is SSPRQ, runs of 7.
- Both are consistent because the reflection is before the range.