



# Transmitter distortion parameters: measurement results and method validation

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# Agenda

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- Introduction and motivation
- Tutorial on the transmitter distortion parameters
- Measurement results

# Introduction and motivation



- This presentation has as objective to provide measurement results to validate the transmitter distortion parameters in the draft P802.3bv/D3.0 as requested by comment 118 against P802.3bv/D2.0
- In order to cover the above objective, it will be also provided a detailed explanation of the script of 115.6.4.8 specified to calculate the transmitter distortion parameters.
- Characterization of 4 different almost compliant PMD TX implementations are presented:
  - Each PMD TX implementation integrates different LED chip design, different driver design and different optics
  - Each PMD TX is packaged in an optical MDI connector together with a PMD RX to be able to establish bidirectional Gigabit link with a golden link partner (unique for all the tests)
  - Each PMD implementation under test is connected to a different part of the same PCS/PMA KDPOF chip design
  - The 4 PMD implementations are able to establish a full-duplex Gigabit link with BER <math>10^{-12}</math> with good receiver sensitivity in the link partner
  - The 4 PMD are evaluated in the temperature range of -40 and 110 °C
  - PMD implementation #4 was used in the past to develop the specification of the transmitter distortion parameters in P802.3bv/D3.0
  - Implementations #1, #2 and #3 are new.
- Characterization of 2 non-compliant PMD TX implementations is also provided
  - These implementations are non-compliant so they are not able to establish link with the partner
  - Though these implementation may meet the specification of ER, RIN, rise-time/fall-time, and other parameters, the transmitter distortion parameters are not met, so the link cannot be established.



# Tutorial on the transmitter distortion parameters

# Tutorial on the transmitter distortion parameters



- As specified in P802.3bv/D3.0, the transmitter distortion is determined by 4 parameters:
  - Second order harmonic distortion ( $HD_2$ )
  - Third order harmonic distortion ( $HD_3$ )
  - Fourth order harmonic distortion ( $HD_4$ )
  - Residual distortion (RD)
- The 4 parameters are calculated by a Matlab script from a capture of the over-sampled (i.e. oversample ratio  $> 10$ ) PMD transmit signal at TP2.
- The PHY is configured to generate test mode 6 signal.
- Acquisition clock and PHY symbol clock are generated from a common reference to guarantee null frequency deviation between the transmitter and the clock used to sample the transmit waveform.

# Steps to get transmitter distortion parameters



- The Matlab script computes distortion parameters in several steps:

1. Baseline compensation (any DC bias is eliminated from the captured samples)

```
xcap = xcap - mean(xcap);
```

2. Signal is processed with a 2<sup>nd</sup> order Butterworth low-pass anti-alias filter with cut-off frequency one half of the symbol rate

```
[hb, ha] = butter(2, 1/ov, 'low');  
xcap = filter(hb, ha, xcap);
```

3. Synchronization for sample alignment based on cross-correlation of the oversampled signal

```
tm6_ov = reshape repmat(tm6, ov, 1), 1, []);  
xc = filter(tm6_ov(end:-1:1), 1, [xcap zeros(1, length(tm6_ov))]);  
[mv mi] = max(abs(xc));  
dly = mi - length(tm6_ov);  
xcap = xcap(1+dly:end);  
xcap = xcap(1:length(tm6_ov));
```

4. Symbol rate clock phase recovery based on a modified Mueller-Müller criterion (K. H. Mueller et al., “*Timing recovery in digital synchronous data receivers*”, IEEE Trans on Comm., May 1976) and decimation (alpha = 0.7 vs. 0.5 because the fact of transmitter responses show larger post-cursor than pre-cursor)

```
alpha = 0.7;  
min_ted = Inf;  
for i = 0:ov-1,  
    xcap_dec = xcap(1+i:ov:end);  
    len0 = min([length(xcap_dec) length(tm6)]);  
    ted = mean((1 - alpha)*xcap_dec(2:len0).*tm6(1:len0-1) - alpha*xcap_dec(1:len0-1).*tm6(2:len0));  
    if abs(ted) < min_ted, min_ted = abs(ted); dly = i; end  
end  
xcap_dec = xcap(1+dly:ov:end);
```

# Steps to get transmitter distortion parameters



## 5. Signal amplitude normalization

```
xcap_dec = xcap_dec/max(abs(xcap_dec));
```

## 6. MMSE (Minimum Mean Square Error) estimation of Volterra's symbol-rate time-domain response of the transmitter under test

```
for k = n:length(x),  
    % Volterra products  
    xi = [1 ...  
        x(k:-1:k-n+1) ...  
        x(k:-1:k-n+1) .*x(k:-1:k-n+1) ...  
        x(k:-1:k-n+1+1) .*x(k-1:-1:k-n+1) ...  
        x(k:-1:k-n+1+2) .*x(k-2:-1:k-n+1) ...  
        x(k:-1:k-n+1) .*x(k:-1:k-n+1) .*x(k:-1:k-n+1) ...  
        x(k:-1:k-n+1+1) .*x(k:-1:k-n+1+1) .*x(k-1:-1:k-n+1) ...  
        x(k:-1:k-n+1+2) .*x(k:-1:k-n+1+2) .*x(k-2:-1:k-n+1) ...  
        x(k:-1:k-n+1+1) .*x(k-1:-1:k-n+1) .*x(k-1:-1:k-n+1) ...  
        x(k:-1:k-n+1+2) .*x(k-1:-1:k-n+1+1) .*x(k-2:-1:k-n+1) ...  
        x(k:-1:k-n+1+2) .*x(k-2:-1:k-n+1) .*x(k-2:-1:k-n+1) ...  
        x(k:-1:k-n+1) .*x(k:-1:k-n+1) .*x(k:-1:k-n+1) .*x(k:-1:k-n+1) ...  
        x(k:-1:k-n+1+1) .*x(k:-1:k-n+1+1) .*x(k:-1:k-n+1+1) .*x(k-1:-1:k-n+1) ...  
        x(k:-1:k-n+1+1) .*x(k:-1:k-n+1+1) .*x(k-1:-1:k-n+1) .*x(k-1:-1:k-n+1) ...  
        x(k:-1:k-n+1+1) .*x(k-1:-1:k-n+1) .*x(k-1:-1:k-n+1) .*x(k-1:-1:k-n+1)];  
  
    % Autocorrelation matrix  
    R = R + xi.'*xi;  
    % Cross-correlation vector  
    rD = rD + d(k-dly)*xi.;  
end  
  
% Wiener's MMSE solution  
hw = (R\rD).;
```

# Steps to get transmitter distortion parameters



## 7. Separate the Volterra's kernels per Volterra's linear filter (channel)

```
lw = [1 ...
      n ...
      n (n-1) (n-2) ...
      n (n-1) (n-2) (n-1) (n-2) (n-2) ...
      n (n-1) (n-1) (n-1)];
```

```
ofst = 0;
for i = 1:15,
    h{i} = hw(ofst+1:ofst+lw(i));
    ofst = ofst + lw(i);
end
```

## 8. Distortion parameters calculation based on the Volterra's identification. The factors 1/3, 1/5, 1/7, 1/9, etc. are the term 0 of the autocorrelations of the input signals to each Volterra's linear filter, taking into account that test mode 6 signal takes values from a uniform distribution between -1 and 1 and is an almost white stochastic process. We take into account the energy of each random signal feeding each Volterra's linear filter, and based on that, we calculate the ratios HD<sub>2</sub>, HD<sub>3</sub> and HD<sub>4</sub>.

```
HD2 = -10*log10(1/3*axc(h{2})/ ...
            (1/5*axc(h{3}) + 1/9*axc(h{4}) + 1/9*axc(h{5})));
```

```
HD3 = -10*log10(1/3*axc(h{2})/ ...
            (1/7*axc(h{6}) + 1/15*axc(h{7}) + 1/15*axc(h{8}) + ...
            1/15*axc(h{9}) + 1/27*axc(h{10}) + 1/15*axc(h{11})));
```

```
HD4 = -10*log10(1/3*axc(h{2})/ ...
            (1/9*axc(h{12}) + 1/21*axc(h{13}) + 1/25*axc(h{14}) + ...
            1/21*axc(h{15})));
```



# Steps to get transmitter distortion parameters



9. The test mode 6 signal is filtered through the estimated Volterra's system that represents the non-linear identification of the DUT response

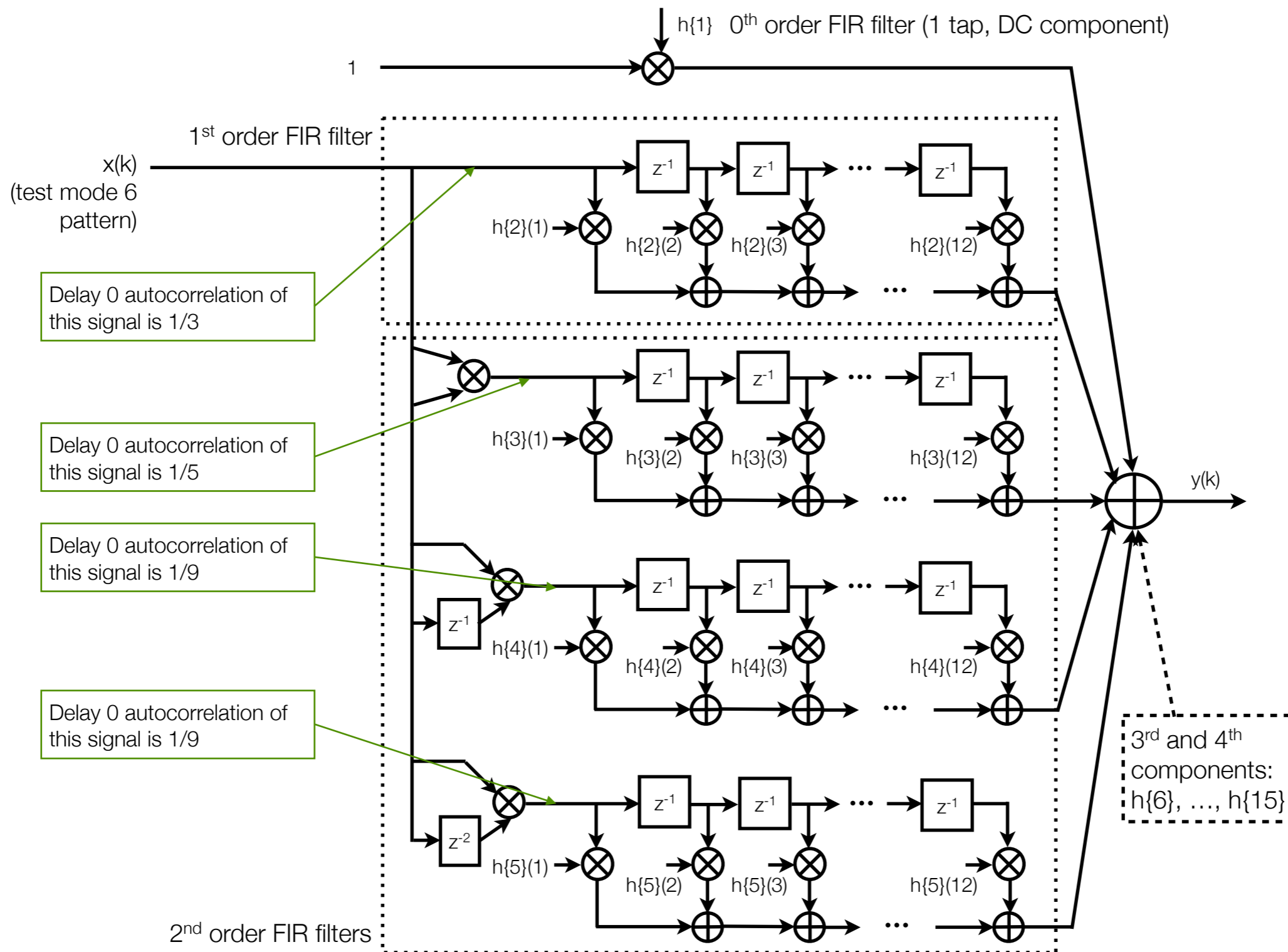
```
z = h{1} + ...
    filter(h{2}, 1, x(3:end)) + ...
    filter(h{3}, 1, x(3:end).*x(3:end)) + ...
    filter(h{4}, 1, x(3:end).*x(2:end-1)) + ...
    filter(h{5}, 1, x(3:end).*x(1:end-2)) + ...
    filter(h{6}, 1, x(3:end).*x(3:end) .*x(3:end)) + ...
    filter(h{7}, 1, x(3:end).*x(3:end) .*x(2:end-1)) + ...
    filter(h{8}, 1, x(3:end).*x(3:end) .*x(1:end-2)) + ...
    filter(h{9}, 1, x(3:end).*x(2:end-1).*x(2:end-1)) + ...
    filter(h{10}, 1, x(3:end).*x(2:end-1).*x(1:end-2)) + ...
    filter(h{11}, 1, x(3:end).*x(1:end-2).*x(1:end-2)) + ...
    filter(h{12}, 1, x(3:end).*x(3:end) .*x(3:end) .*x(3:end)) + ...
    filter(h{13}, 1, x(3:end).*x(3:end) .*x(3:end) .*x(2:end-1)) + ...
    filter(h{14}, 1, x(3:end).*x(3:end) .*x(2:end-1).*x(2:end-1)) + ...
    filter(h{15}, 1, x(3:end).*x(2:end-1).*x(2:end-1).*x(2:end-1));
```

10. The resulting signal from step 9 is aligned and compared with the captured signal in TP2, and the error sequence between both is calculated. The residual distortion (RD) is computed as the relation between the energy of the first order Volterra's linear filter and the energy of the error sequence. The error sequence collects:

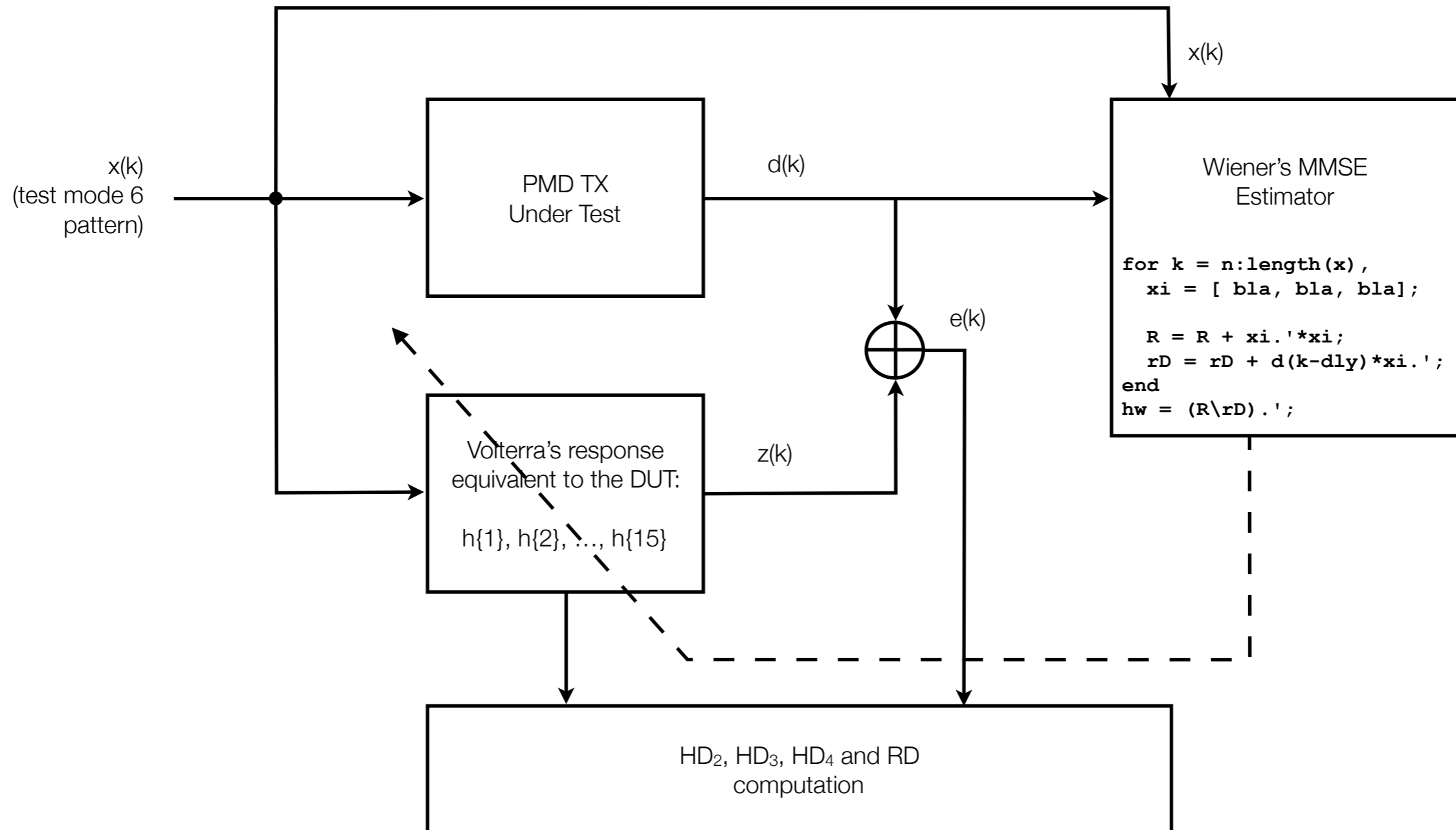
- Distortion components not captured by the constrained Volterra's identification
- Noise component already captured by the RIN measurement
- Noise component due to quantization of the DAC

```
z = z(1+dly-2+n:end);
d = d(1+n:end);
l = min([length(z) length(d)]);
e = z(1:l) - d(1:l);
RD = -10*log10(1/3*axc(h{2})/var(e));
```

# Volterra's response equivalent to PMD TX



# MMSE estimation of Volterra's response



# Notes on Volterra's estimation

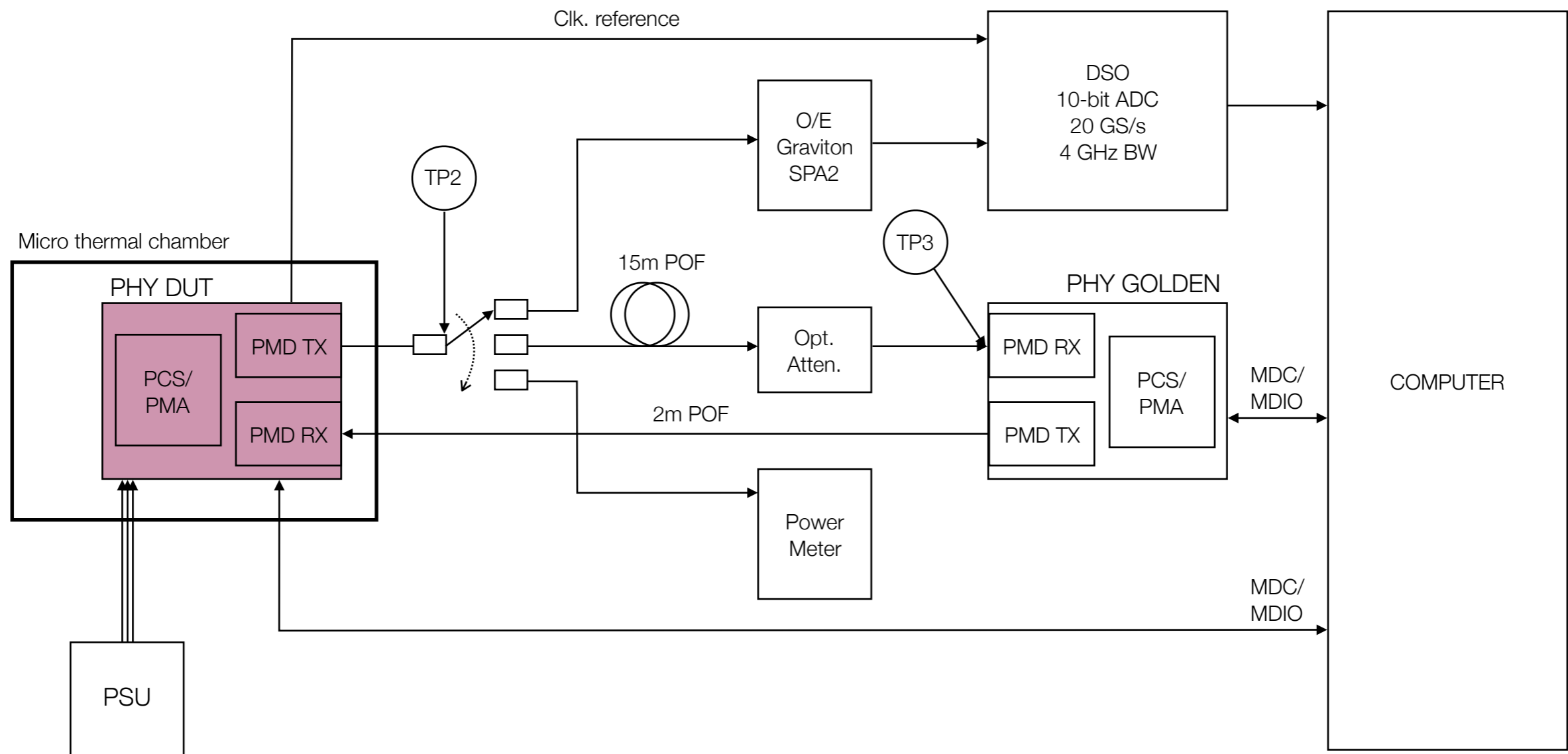


- Volterra's system that is MMSE estimated is a Volterra's truncated series, which topology has been selected based on experience with AlGaInP LED based transmitters (typical light source used in existing POF products):
  - The length of impulse response is limited based on the restrictions imposed to rise-time and fall-time
  - The delay-group is also limited based on experience
  - The maximum delay between products of signal with itself is limited based on measurement results
- Limitations on the filter length and delays between products are also imposed considering a reasonable complexity of the receiver DSP.
- It is important to note that the script specified to calculate the transmitter distortion parameters is, in essence, very similar to subclauses 97.5.3.2, 96.5.4.2 and 40.6.1.2.4. The differences are:
  - The script of 115.6.4.8 carries out a constrained non-linear Volterra's estimation, versus linear estimation of the other subclauses.
  - Limits are defined for the non-linearities assuming that the receiver implements a finite complexity channel linearization; linearization is necessary because the nature of the light emitters (AlGaInP LEDs that are foreseen as feasible implementation).

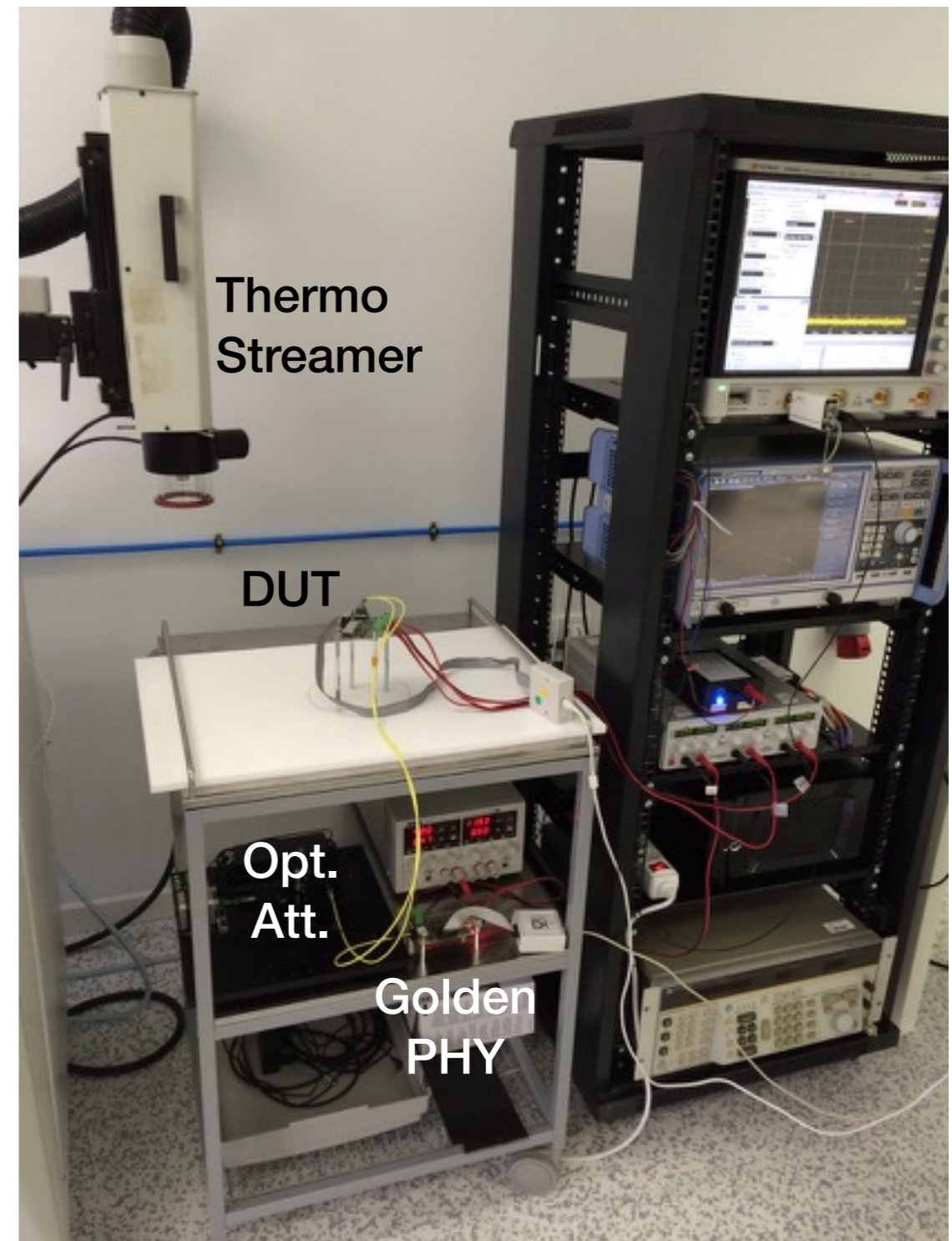
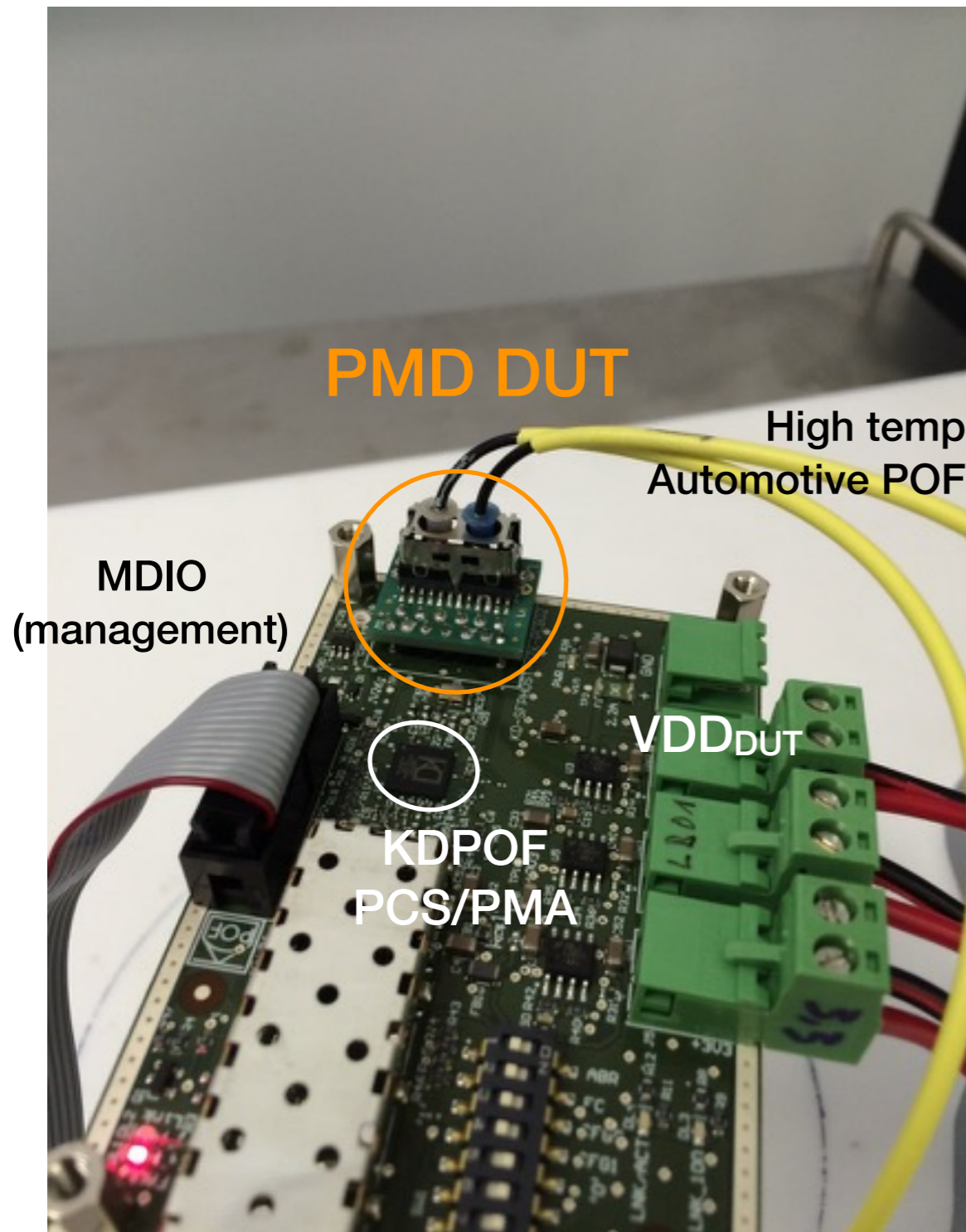


# Measurement results

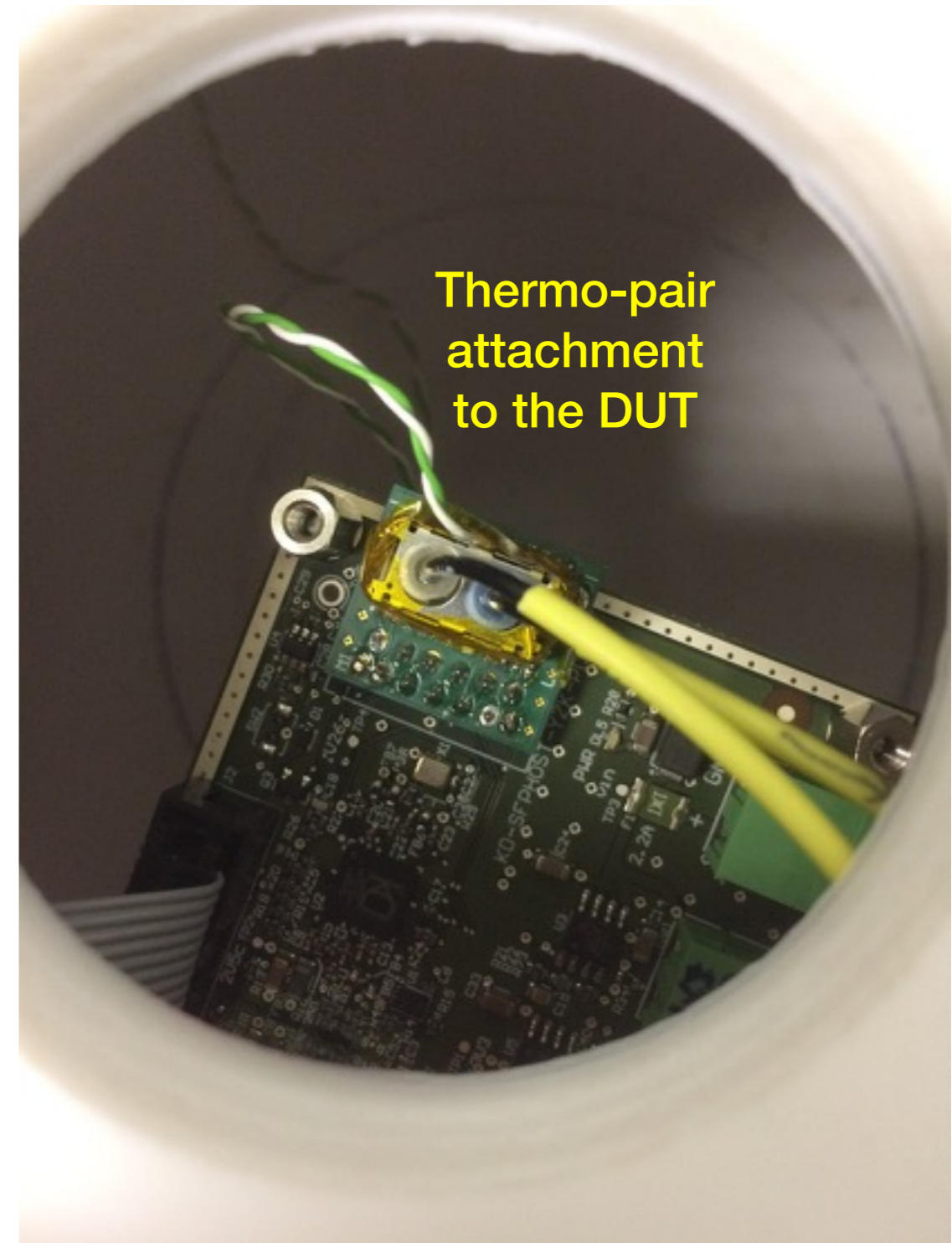
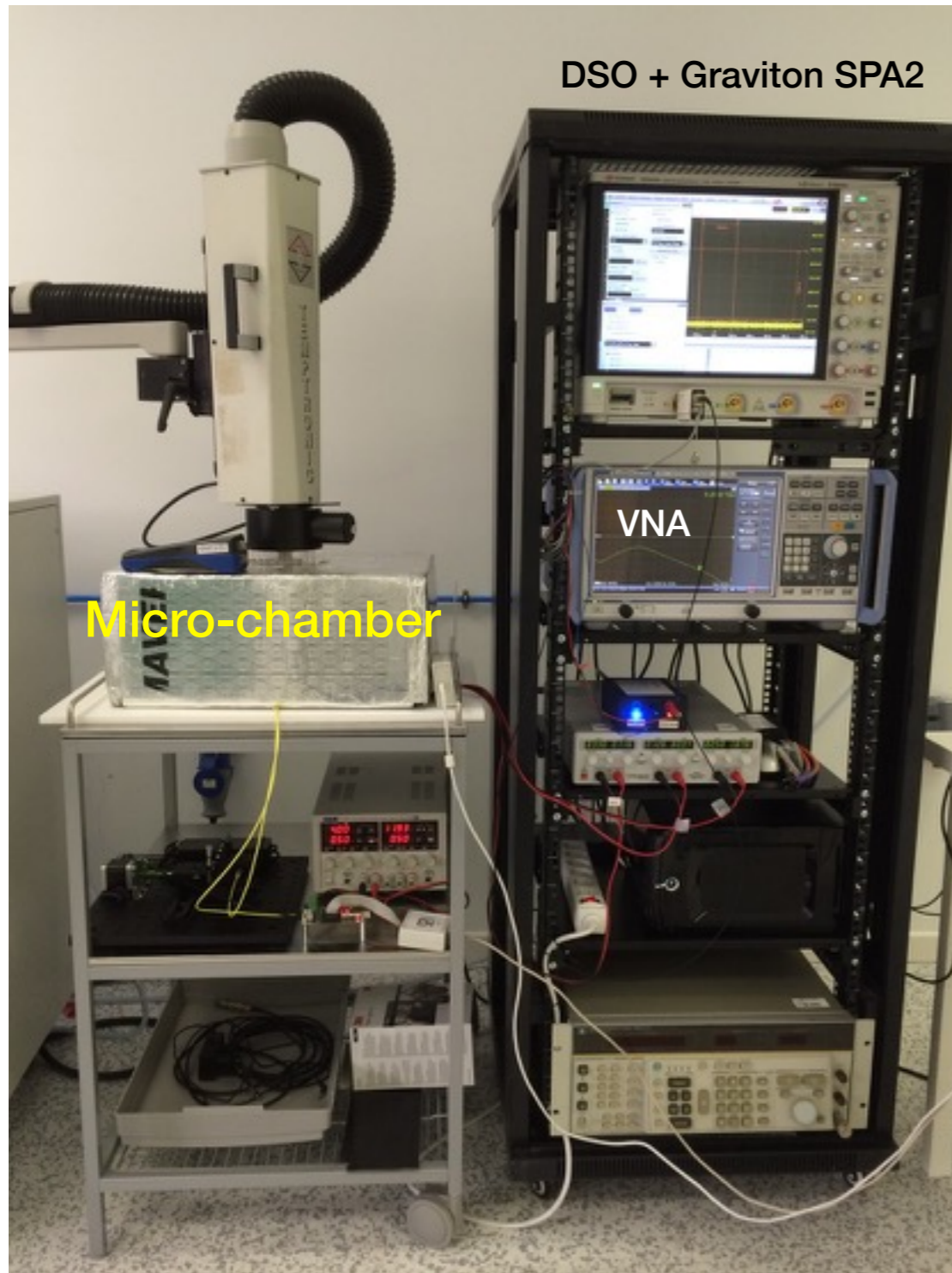
# Characterization setup



# Characterization setup

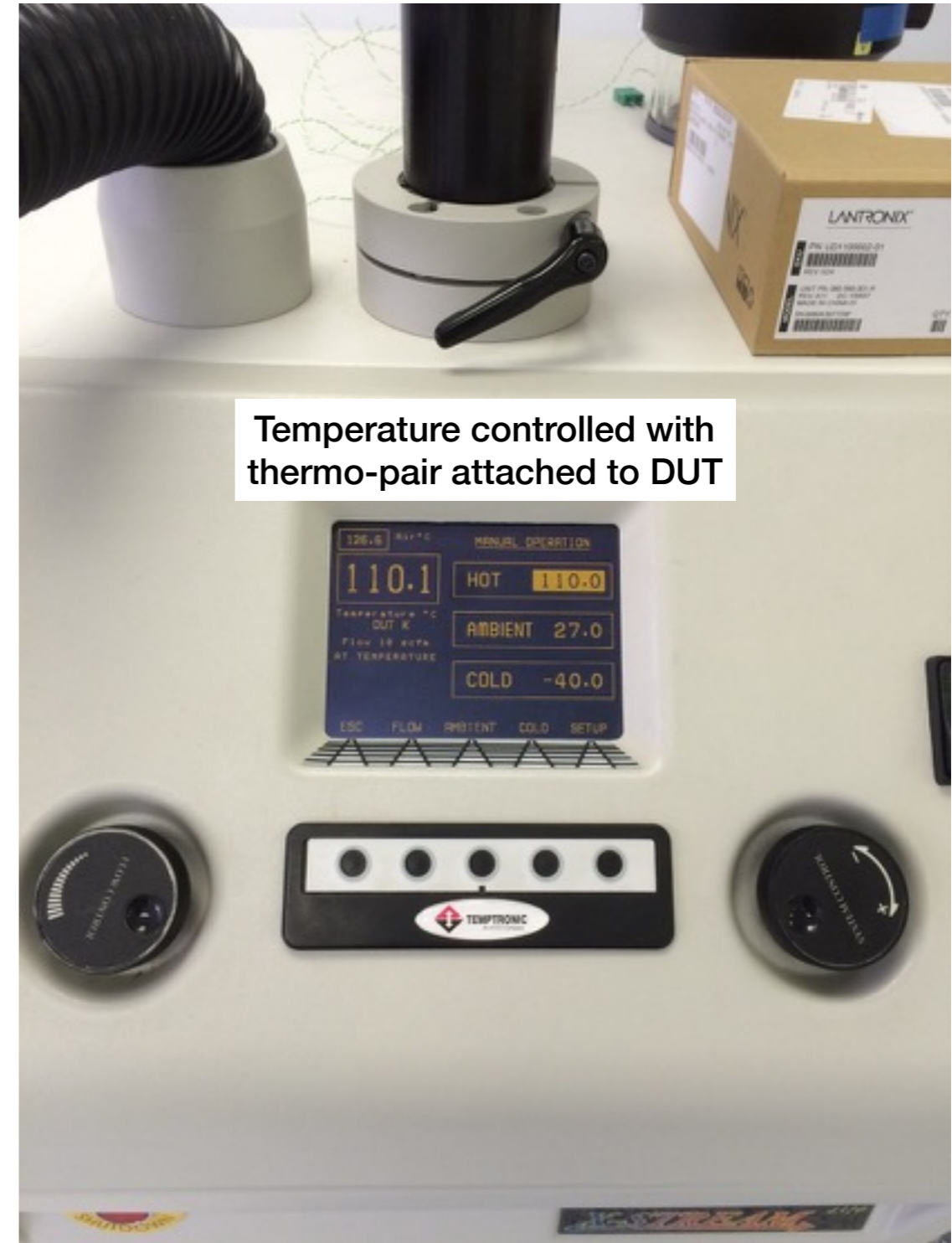


# Characterization setup





# Characterization setup



# Measurement results



- 4 different PMD TX almost compliant implementations:
  - Each PMD TX implementation integrates different LED chip design, different driver design and different optics (each optics optimally designed for each LED)
  - Each PMD TX is packaged in an optical MDI connector together with a PMD RX to be able to establish bidirectional Gigabit link with a golden link partner (unique for all the tests)
  - Each PMD implementation under test is connected to a different part of the same PCS/PMA KDPOF chip design
- Results for implementations #1 and #2:

PMD TX Implementation	#1			#2		
Temperature (°C)	27,00	110,00	-40,00	27,00	110,00	-40,00
AOP <sub>TP2</sub> (dBm)	-1,97	-5,01	-2,69	-3,30	-11,20	-0,50
Delta AOP (dB)	0,00	-3,04	-0,72	0,00	-7,90	2,80
ER (dB)	10,96	10,75	12,47	10,70	10,41	11,53
Rise-time (10%-90%)	3,26	2,67	2,43	1,33	0,96	1,76
Rise-time (20%-80%)	2,00	1,65	1,57	0,83	0,55	0,96
Fall-time (10%-90%)	4,14	2,91	2,39	1,50	1,03	1,86
Fall-time (20%-80%)	2,11	1,62	1,24	0,91	0,70	1,08
HD2 (dBc)	-21,20	-20,40	-24,00	-20,10	-20,40	-22,00
HD3 (dBc)	-25,50	-25,20	-24,30	-24,40	-23,40	-24,10
HD4 (dBc)	-37,50	-36,00	-37,60	-34,80	-34,70	-35,00
RD < -40 dBc	1,00	1,00	1,00	1,00	1,00	1,00
TP3 sensitivity (dBm)	-17,47	-18,25	-18,04	-18,37	-18,73	-18,21
TP3 sensitivity delta (dB)	0,00	-0,78	-0,57	0,00	-0,36	0,16

Green: pass.  
Red: fail.

# Measurement results



- Results for implementations #3 and #4:

PMD TX Implementation	#3			#4		
Temperature (°C)	27,00	110,00	-40,00	27,00	110,00	-40,00
AOP <sub>TP2</sub> (dBm)	-3,10	-6,32	-3,88	-3,24	-8,66	-1,65
Delta AOP (dB)	0,00	-3,22	-0,78	0,00	-5,42	1,59
ER (dB)	12,05	10,27	13,50	9,68	11,41	8,10
Rise-time (10%-90%)	2,11	1,19	2,70	1,85	1,60	1,88
Rise-time (20%-80%)	1,25	0,79	1,70	1,26	1,10	1,30
Fall-time (10%-90%)	2,09	1,39	2,18	2,20	2,00	2,18
Fall-time (20%-80%)	1,21	0,91	1,35	1,47	1,35	1,49
HD2 (dBc)	-22,00	-20,50	-22,80	-24,20	-21,30	-26,70
HD3 (dBc)	-23,70	-23,20	-23,00	-28,70	-27,20	-27,90
HD4 (dBc)	-37,40	-34,30	-36,30	-38,40	-34,80	-38,40
RD < -40 dBc	1,00	1,00	1,00	1,00	1,00	1,00
TP3 sensitivity (dBm)	-18,49	-18,29	-18,62	-18,13	-19,08	-18,09
TP3 sensitivity delta (dB)	0,00	0,20	-0,13	0,00	-0,95	0,04

Green: pass.  
Red: fail.

# Measurement results — correlation analysis



Relative TP3 sensitivity (dB) for 15m of POF as a function of Tr and ER. Linear models simulation. 802.3bv POF response limits.  
Important note: results for a given RX model. Results may differ depending on the RX implementation.

Trans-time (ns)	ER (dB)										
	4	5	6	7	8	9	10	11	12	13	
1,0	2,6	1,4	0,7	0,2	-0,3	-0,7	-1,0	-1,2	-1,4	-1,6	
1,5	2,9	1,6	0,9	0,4	0,0	-0,4	-0,8	-1,0	-1,2	-1,3	
2,0	3,3	1,9	1,2	0,6	0,2	-0,1	-0,5	-0,7	-0,9	-1,0	
2,5	3,7	2,2	1,5	0,9	0,5	0,2	-0,1	-0,4	-0,6	-0,7	
3,0	4,2	2,6	1,8	1,2	0,8	0,5	0,2	0,0	-0,2	-0,4	
3,5	4,6	3,0	2,1	1,5	1,1	0,7	0,5	0,3	0,1	0,0	
4,0	5,0	3,5	2,5	1,8	1,4	1,0	0,8	0,6	0,4	0,3	
4,5	5,4	3,9	2,9	2,2	1,7	1,4	1,1	0,9	0,7	0,6	
5,0	5,8	4,3	3,2	2,5	2,0	1,7	1,4	1,2	1,0	0,9	
5,5	6,4	4,7	3,6	2,9	2,4	2,0	1,7	1,5	1,3	1,2	

Cyan: specification compliant

Magenta: non-compliant points where some implementations are today (depending on temperature)

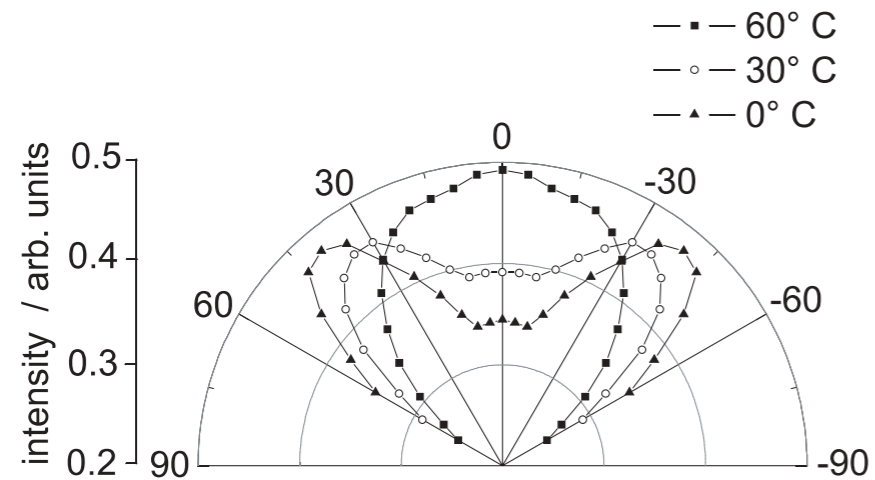
- All the sensitivity measurements are in the range of -17.5 to -19.1 dBm ( $\Delta = 1.6$  dB)
- Variance of TP3 sensitivity: ER and Tr model prediction at 27 and 110 °C:
  - For #1 (black border): the model approximates the variation with Tr (0.6 vs. 0.78 dB) from 27 to 110 °C.
  - For #2 (gray border): the model approximates the variation with Tr (0.2 vs. 0.36 dB) from 27 to 110 °C.
  - For #3 (red border): the model approximates the variation with Tr and ER (0.1 vs. 0.2 dB) from 27 to 110 °C.
  - For #4 (green border): the model approximates the variation with Tr and ER (0.8 vs. 0.95 dB) from 27 to 110 °C.
  - Cross-variance between #1 and #4 is well predicted: 0.1 dB.

# Measurement results — correlation analysis

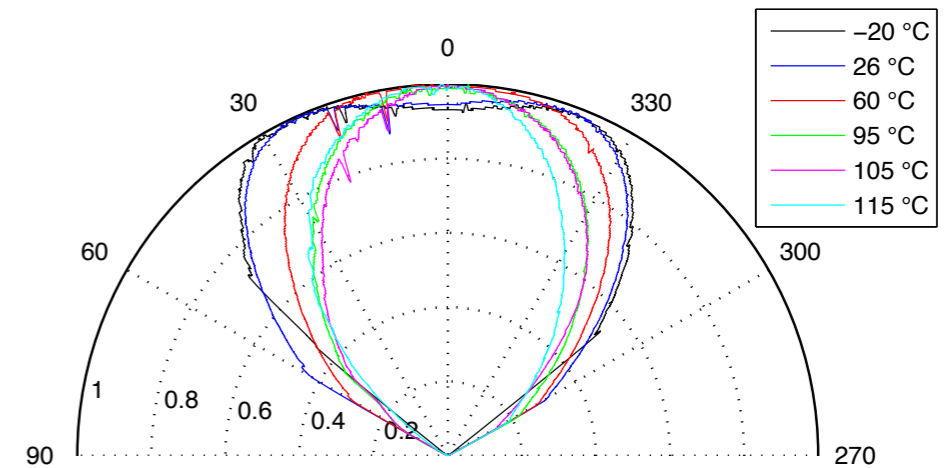


- From the table we see that ER and Tr variation does not explain:
  - Cross-variation between some different implementations
  - Variation for -40 °C for any implementation
- What is the reason? — Different TP2 MPD for each implementation and dependency of MPD with temperature.
  - Each PMD implementation integrates a different LED chip with different optics, producing different modal power distribution (MPD) when light is coupled to the fiber.
    - Different internal structure of RCLED (n° of DBRs, n° of QW, etc) produce different MPD
    - Different optics geometry (ball lens, overmolded lens, parabolic taper, etc ) and materials (glass, epoxy, etc) produce different MPD
  - Because MPD at TP2 per EAF measurement specified in P802.3bv/D3.0 is below the equilibrium mode distribution (EMD) of the POF cable, equilibrium cannot be achieved after 15m at TP3 (different modal dispersion)
  - Therefore, different PMDs, although compliant with EAF at TP2 (Table 115-9), are producing different POF responses, also compliant with Table 115-13.
  - Typically the designer optimizes the design of the LED chip and the design of the lens for the worst-case conditions (smaller power produced in TP2 because smaller internal quantum efficiency, the highest temperature), trying to get the best sensitivity in TP3 and highest yield of the lens in that condition
  - This typically produces performance biasing at lowest temperature, where typically the light sources used in POF increase the internal quantum efficiency, but the far-field pattern is wider and hence the yield of the lens is reduced
- Cross-correlation of parameters is very difficult between implementations and in the whole range of temperature because:
  - The ER and the Tr of all the implementations are in a range where the impact in TP3 sensitivity is relatively small
  - The effect of MPD differences in TP3 sensitivity
  - Small range of variation (1.6 dB) among all the implementations and temperatures

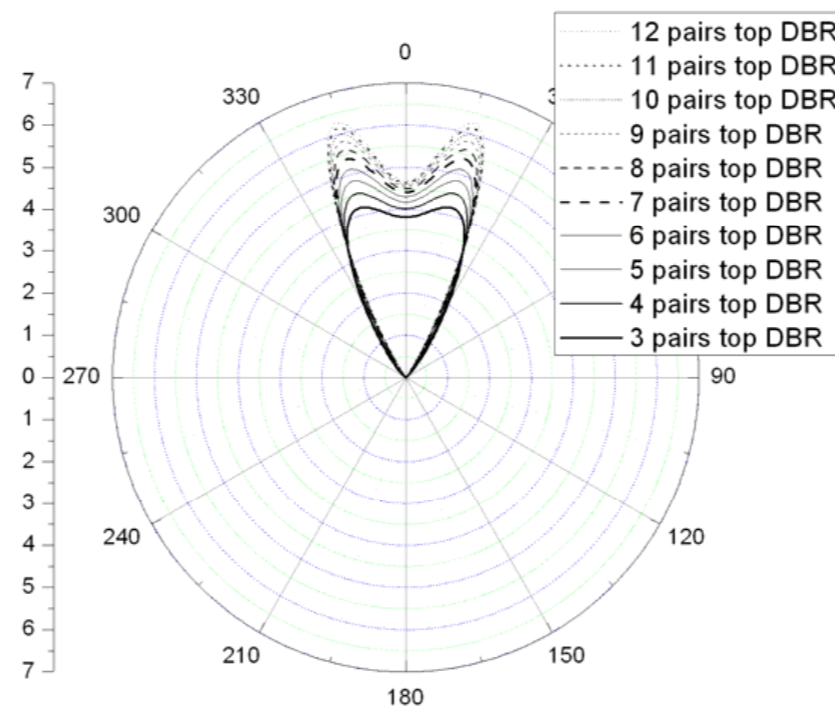
# Measurement results — correlation analysis



LED FFP dependence with temperature. Example 1



LED FFP dependence with temperature. Example 2



RCLED FFP dependence with different top DBRs (internal structure)  
Ambient temperature

# Measurement results — conclusions on #1 to #4



- None of the 4 implementations are fully compliant, but it is expected an iteration of the designs would be compliant
- However, all of them are very close to P802.3bv/D3.0 spec and are functional, i.e. Gigabit link @BER <  $10^{-12}$ , in automotive temperature range with good sensitivity in the golden receiver
- Implementation #2, although it shows the best sensitivity because is the fastest one, it also shows a large variation of  $AOP_{TP2}$  with temperature and probably the implementation should be limited to Class Regular (see Table 115-19)
- We can see that all the implementations produce very similar sensitivity in the receiver:
  - Analysis shows good correlation with predicted TP3 sensitivity as function of ER and Tr
  - If we assume that speed problem is corrected in a 2nd iteration for implementation #1, the total difference of sensitivity at TP3 will be in a range of less than 1 dB for the four implementations.
- Differences of <1 dB between implementations are explained by the MPD differences.
- #1, #2, and #3 do not meet HD3 specification, however the equalizer is able to compensate it without relevant TP3 sensitivity deviation respect to #4 that meets HD3 spec
- #2, #3, and #4 does not meet HD4 at 110°C. The HD4 parameter was selected to be far enough of the SNR needed in the detector for sensitivity (25 dB), avoiding the necessity of HD4 compensation in the receiver. Also no correlation with TP3 sensitivity differences

# Measurement results — discussion on #1 to #4



- ER and rise/fall-time deviations are expected to be solved in further iterations of the driver (topologies and tuning)
- The harmonic distortion (HD3, HD4) depends overall on the physics of the AlGaInP LED and RCLED. HD is not feasible to be solved by driver iteration. On the other hand, the 4 LED chips are already qualified and in production, so design iteration is not expected.
- Discussion on refinement of HD3 and HD4 parameters:
  - The measurement results show that we may relax the specifications of HD3 and HD4 without impact on the sensitivity at TP3 ... but the question is: how much?
  - It is important to note that it is not possible to fine tune independent parameters in the lab (as HD2, HD3 and HD4) and see the impact in the receiver without affecting others: different chips show differences in all the parameters (real life).
  - From the measurement results, the only conclusion is that no clear correlation exists between the HD3 and HD4 deviations and the TP3 sensitivity .
  - Max measured deviations wrt the spec are: 3 dB for HD3, and 1.7 dB for HD4.
  - By simulation we know that we cannot permit any value of HDx, because the compensation of non-linearities is not perfect and always produce capacity loss (i.e. concept that is analogous to the noise enhancement produced by linear equalizers). See perezaranda\_3bv\_3\_0316.pdf.
  - Proposal: do refinement of HD3 and HD4 specifications to allow more implementations.



# Proposal for HD3 and HD4 refinement



- Proposal for refined parameter specifications based on test of multiple implementations:

	P802.3bv/D3.0	P802.3bv/D3.1
HD2 <sub>max</sub> (dB)	-20	-20
HD3 <sub>max</sub> (dB)	-26	-23
HD4 <sub>max</sub> (dB)	-36	-34
RD <sub>max</sub> (dB)	-40	-40

# Why other parameters should not be moved?



- Only a refinement of HD parameters is proposed to support more implementations and because the impact is small
- Other parameters like the rise/fall times and the ER should not be moved to avoid increasing the complexity (reduced noise, higher bandwidth, higher power consumption) of the receiver.
- The impact of ER and Tr on the TP3 sensitivity is predicted assuming linear models of TX and RX as well as the specified transfer functions of the channels.
- Follows the impact for 50 m of POF. The impact of ER and Tr is larger than for 15m of POF, as expected.
- Note: the table shows a “soft” transition between the specification point (0,0) and the NO-LINK condition, where TP3 sensitivity is worsen as ER is reduced and/or Tr is increased: there is no a “break-wall” in the results

Relative TP3 sensitivity (dB) for 50m of POF as a function of Tr and ER. Linear models simulation. 802.3bv POF response limits.  
Important note: results for a given RX model. Results may differ depending on the RX implementation.

Trans-time (ns)	ER (dB)									
	4	5	6	7	8	9	10	11	12	13
1,0	3,8	1,7	0,7	0,0	-0,5	-0,9	-1,2	-1,5	-1,6	-1,8
1,5	4,6	2,0	1,0	0,3	-0,2	-0,6	-1,0	-1,2	-1,4	-1,5
2,0	5,2	2,4	1,4	0,7	0,1	-0,3	-0,6	-0,8	-1,0	-1,2
2,5	5,7	2,9	1,9	1,1	0,6	0,1	-0,2	-0,4	-0,6	-0,8
3,0	6,3	3,7	2,4	1,6	1,0	0,6	0,3	0,0	-0,2	-0,3
3,5	7,0	4,8	2,9	2,1	1,5	1,0	0,7	0,5	0,3	0,1
4,0	7,8	5,4	3,6	2,6	2,0	1,6	1,2	0,9	0,7	0,6
4,5	8,7	5,9	4,3	3,3	2,6	2,1	1,7	1,4	1,2	1,0
5,0	NO LINK	6,5	5,1	4,0	3,2	2,6	2,3	2,0	1,8	1,6
5,5	NO LINK	7,1	5,7	4,8	3,9	3,3	2,9	2,6	2,3	2,1

Cyan: specification compliant

Magenta: non-compliant points where some implementations are today (depending on temperature)

# Measurement results of non-compliant implementations



- Implementation #5:

- The PMA TX is connected to a PMD TX designed for OOK transmission through an impedance matching circuit. Also the current reference of the current steering DAC is configured for voltage matching.
- It is important to note that measurement results of many parameters are compliant
- No Gigabit link is possible
- Results:

PMD TX Implementation	#5
Temperature (°C)	27,00
AOP <sub>TP2</sub> (dBm)	-1,45
Delta AOP (dB)	—
ER (dB)	14,70
Rise-time (10%-90%)	1,50
Rise-time (20%-80%)	—
Fall-time (10%-90%)	1,80
Fall-time (20%-80%)	—
HD2 (dBc)	4,50
HD3 (dBc)	-4,90
HD4 (dBc)	-1,40
RD (dBc)	-8,65
RIN (dB/Hz)	-137,30
TP3 sensitivity (dBm)	NO LINK

# Measurement results of non-compliant implementations



- Implementation #6:

- The least significant bits of DAC in PMA TX are fixed to 0 and unconnected from transmit power scaling block (see 115.3.1.2), so the ENOB of the DAC is drastically reduced. DAC full scale current is also adjusted for similar peak-to-peak input to driver.
- The PMD TX is a different part of design #1
- RIN is compliant and is not able to capture the quantization noise (as expected)
- No Gigabit link is possible for some of the DAC ENOB configurations
- Results:

PMD TX Implementation	#6					
DAC ENOB	3,00	4,00	5,00	6,00	7,00	Default
Temperature (°C)	27,00	27,00	27,00	27,00	27,00	27,00
AOP <sub>TP2</sub> (dBm)	-2,00	-2,00	-2,00	-2,00	-2,00	-2,00
ER (dB)	10,70	10,80	10,90	11,00	11,00	11,00
Rise-time (10%-90%)	3,30	3,30	3,30	3,30	3,30	3,30
Rise-time (20%-80%)	—	—	—	—	—	—
Fall-time (10%-90%)	4,20	4,20	4,10	4,10	4,10	4,10
Fall-time (20%-80%)	—	—	—	—	—	—
HD2 (dBc)	-17,10	-19,70	-20,50	-21,00	-21,40	-21,30
HD3 (dBc)	-17,30	-22,20	-25,30	-26,00	-26,60	-25,60
HD4 (dBc)	-15,10	-21,70	-29,70	-34,10	-36,30	-37,00
RD (dBc)	-19,30	-25,00	-30,90	-37,10	-42,90	-46,20
RIN (dB/Hz)	-135,40	-135,40	-135,40	-135,40	-135,40	-135,40
TP3 sensitivity (dBm)	NO LINK	NO LINK	-11,20	-15,70	-17,30	-17,50

# Measurement results — conclusions on #5 to #6



- Some parameters (e.g. ER, rise-time, AOP) of #5 meet the specifications, but because the linearity is not good, the Gigabit link cannot be established:
  - This is a very worst case scenario, because the PMD TX is only able to transmit 2 levels of light.
  - The measurement result of the transmitter distortion parameters detect this condition.
- Implementation #6 uses exactly the same PMD TX design of #1 that was able to establish the Gigabit link with good sensitivity. However, when the DAC performance is not good enough, the link cannot be established (i.e. good precision of DAC is important for THP operation).
- Again, there is no break-wall behavior of TP3 sensitivity wrt TX distortion parameters, and we see a soft degradation as ENOB is decreased until link cannot be established.
- As can be seen, results of  $HD_x$  and RD that meet the specification, guarantee that the transmitter is linear enough to implement THP and to allow the receiver to compensate the continuous non-linearities produced by transmitter opto-electronics with low impact in sensitivity.
- On the other hand, when specifications are not met, there are two situations:
  - The link can be established but with penalty in the receiver sensitivity.
  - No link can be established

# Robustness of the specification against channel response



- In previous slides, we saw the effect on TP3 sensitivity of several parameters specified for the transmitter, like ER, Tr, distortion, etc. that indicates that there is a margin with respect to the No Link condition
- What happen if the transfer function of the real channel greatly differs from the lower bound limits specified in P802.3bv/D3.0 (the real life in an uncontrolled environment like home-networking)?
- See video [http://http://www.ieee802.org/3/bv/public/Sep\\_2016/perezaranda\\_3bv\\_2\\_0916.mov](http://http://www.ieee802.org/3/bv/public/Sep_2016/perezaranda_3bv_2_0916.mov):
  - PMD implementation #4 is used for this test.
  - A cable of 70 m of POF compliant with P802.3bv/D3.0 for 50, 40 and 15 meters, is cut-back down to 50 m in steps of 5 m and finally the two PHYs are connected with 2 m of the same type of POF.
  - We can see how the PHYs are able to establish the link automatically for the different channels responses that deviates above and below the limits of the transfer function magnitude
- See video [http://http://www.ieee802.org/3/bv/public/Sep\\_2016/perezaranda\\_3bv\\_3\\_0916.mov](http://http://www.ieee802.org/3/bv/public/Sep_2016/perezaranda_3bv_3_0916.mov):
  - PMD implementation #4 is used for this test
  - A cable of 40 m is bent in several 4 points trying to simulate a real home environment
  - Bends of 90° with radii of 10mm, 8mm and 6mm are performed
  - Note: fiber bending produces several effects:
    - The transfer function magnitude per measurement method of 115.7.5 is improved in terms of bandwidth because higher order modes are destroyed (and not recovered by scattering) reducing the modal dispersion and then the pulse spread produced by the fiber
    - The insertion loss per measurement method of 115.7.4 of the fiber is increased, because the modes destruction
    - Typically, it is expected better sensitivity in the receiver because the effect of bandwidth enhancement, but, as drawback, extra insertion loss has to be allocated by the link budget