

Quantization Noise Feature in COM Matlab Code

COM Commit Request Number 4p6_5

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Introduction

- In contribution [shakiba_3dj_02_2405.pdf](#) effects of including ADC quantization noise in COM channel compliance verifications was analyzed and its significance was demonstrated
- Similarly, contribution [healey_3dj_01b_2405.pdf](#) also considered adding a new eta_1 noise term between CTLE and RxFFE to represent quantization noise
- This contribution also suggested another option that scales the existing eta_0 noise term
- Straw poll #1 in the May interim meeting did not support addition of a new noise term
- Despite that, there has been continuous interest and request to include this capability to the COM Matlab code for the purposes of investigations and explorations
- With the capability added, parameter ENOB, which represents ADC number of bits, can be set to a large value to disable the feature for standard COM channel compliance purposes

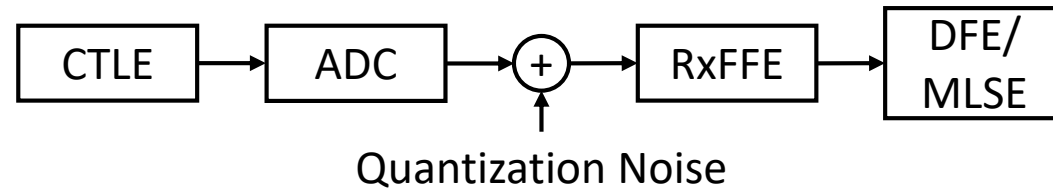
Straw Poll #1

I support adding a new noise term (such as 'eta_1' in healey_3dj_01a_2405, slide 6) to the COM reference receiver.

Results (all) Y: 13, , N: 37 , A: 31

Background

- Quantization noise is a new noise term added between CTLE and RxFFE



- It is modeled by a uniform distribution over $-LSB/2$ to $+LSB/2$



- ADC clip level is chosen so that clipping frequency is equal to the target error rate
- For details see contribution [shakiba_3dj_02_2405.pdf](#)

Changes to the Code (1 of 8)

1) Insert 4 lines:

```
841 - chdata(i).eq_imp_response=eq_ir;  
842 - eq_pulse=filter(ones(1, param.samples_per_ui), 1, chdata(i).eq_imp_response);  
843 -  
844 - if isequal(chdata(i).type, 'FEXT') || isequal(chdata(i).type, 'THRU')  
845 -     eq_pulse = FFE( fom_result.txffe ,fom_result.cur-1 , param.samples_per_ui, eq_pulse );  
846 - end
```

```
841 - chdata(i).eq_imp_response=eq_ir;  
842 - eq_pulse=filter(ones(1, param.samples_per_ui), 1, chdata(i).eq_imp_response);  
843 - chdata(i).ctle_pulse = eq_pulse;  
844 - sample_start = find(min(abs(chdata(i).t-fom_result.sampled_best_sbr_precursors_t(1))) == abs(chdata(i).t-fom_result.sampled_best_sbr_precursors_t(1)));  
845 - chdata(i).ctle_pulse_s = eq_pulse(sample_start(1):param.samples_per_ui:end);  
846 - chdata(i).t_s = chdata(i).t(sample_start(1):param.samples_per_ui:end);  
847 -  
848 - if isequal(chdata(i).type, 'FEXT') || isequal(chdata(i).type, 'THRU')  
849 -     eq_pulse = FFE( fom_result.txffe ,fom_result.cur-1 , param.samples_per_ui, eq_pulse );  
850 - end
```

Changes to the Code (2 of 8)

2) Insert 24 lines:

```
1483 % Equation 93A-45
1484 - combined_interference_and_noise_pdf = conv_fct(NS.isi_and_xtalk_pdf, NS.noise_pdf);
1485 - PDF=combined_interference_and_noise_pdf;
1486
1487 % Equation 93A-37
```

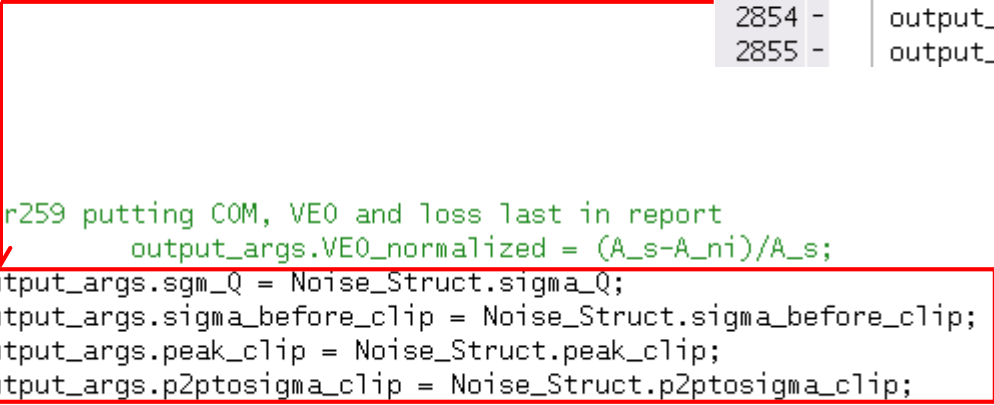
```
1487 % Equation 93A-45
1488 - combined_interference_and_noise_pdf = conv_fct(NS.isi_and_xtalk_pdf, NS.noise_pdf);
1489 - chdata(1).ctle_pulse_pdf = get_pdf_from_sampled_signal(chdata(1).ctle_pulse_s, param.levels, param.delta_y);
1490 - ctle_pulse_cdf = cumsum(chdata(1).ctle_pulse_pdf.y);
1491 - adc_clip = -CDF_inv_ev(2*param.specBER, chdata(1).ctle_pulse_pdf, ctle_pulse_cdf);
1492 - ctle_pulse_sigma = sqrt(sum((chdata(1).ctle_pulse_pdf.x.^2).*chdata(1).ctle_pulse_pdf.y));
1493 - adc_lsb = 2*adc_clip/(2^param.ENOB-1);
1494 - NS.sigma_Q = adc_lsb/sqrt(12);
1495 - NS.sigma_before_clip = ctle_pulse_sigma;
1496 - NS.peak_clip = adc_clip;
1497 - NS.p2ptosigma_clip = 2*adc_clip/ctle_pulse_sigma;
1498 - quantizaion_noise_pdf = combined_interference_and_noise_pdf; % This is to copy the fields of the structure
1499 - adc_ind_right = find(min(abs(quantizaion_noise_pdf.x-adc_lsb/2)) == abs(quantizaion_noise_pdf.x-adc_lsb/2));
1500 - adc_ind_left = find(min(abs(quantizaion_noise_pdf.x+adc_lsb/2)) == abs(quantizaion_noise_pdf.x+adc_lsb/2));
1501 - quantizaion_noise_pdf.y = zeros(size(quantizaion_noise_pdf.x));
1502 - quantizaion_noise_pdf.y(adc_ind_left:adc_ind_right) = 1/(adc_ind_right-adc_ind_left+1);
1503 - % Calculate quantization noise PDF after RxFFE
1504 - h_rxffe = fom_result.RxFFE(find(fom_result.RxFFE ~= 0));
1505 - for irxffe = 1:length(h_rxffe)
1506 -     if irxffe ~= param.ffe_pre_tap_len
1507 -         quantizaion_noise_pdf_scale = scalePDF(quantizaion_noise_pdf, abs(h_rxffe(irxffe)));
1508 -         quantizaion_noise_pdf = conv_fct(quantizaion_noise_pdf, quantizaion_noise_pdf_scale);
1509 -     end
1510 - end
1511 - combined_interference_and_noise_pdf = conv_fct(combined_interference_and_noise_pdf, quantizaion_noise_pdf);
1512 - NS.quantizaion_noise_pdf = quantizaion_noise_pdf;
1513 - PDF=combined_interference_and_noise_pdf;
1514
1515 % Equation 93A-37
```

Changes to the Code (3 of 8)

3) Insert 4 lines

```
2852 | % r259 putting COM, VEO and loss last in report
2853 | %           output_args.VEO_normalized = (A_s-A_ni)/A_s;
2854 - | output_args.VEC_dB = COM_SNR_Struct.VEC_dB;
2855 - | output_args.VEO_mV = COM_SNR_Struct.VEO_mV;

2880 | % r259 putting COM, VEO and loss last in report
2881 | %           output_args.VEO_normalized = (A_s-A_ni)/A_s;
2882 - | output_args.sgm_Q = Noise_Struct.sigma_Q;
2883 - | output_args.sigma_before_clip = Noise_Struct.sigma_before_clip;
2884 - | output_args.peak_clip = Noise_Struct.peak_clip;
2885 - | output_args.p2ptosigma_clip = Noise_Struct.p2ptosigma_clip;
2886 - | output_args.VEC_dB = COM_SNR_Struct.VEC_dB;
2887 - | output_args.VEO_mV = COM_SNR_Struct.VEO_mV;
```



Changes to the Code (4 & 5 of 8)

4 & 5) Insert 23 lines and change 1 line

```
5340 % result.S_jn
5341 - FB = param.fb;
5342 - GDC = G_DC;
5343 - FP1 = param.CTLE_fp1(1);
5344 - FP2 = param.CTLE_fp2(1);
5345 - FZ = param.CTLE_fz(1);
5346 - FHP = param.f_HP(1);
5347 - GDCHP = G_DC2;
5348 - uneq_ir = chdata(1).uneq_imp_response;
5349 - if OP.INCLUDE_CTLE == 1
5350 -     eq_ir = TD_CTLE(uneq_ir, FB, FZ, FP1, FP2, GDC, param.samples_per_ui);
5351 -     eq_ir = TD_CTLE(eq_ir, FB, FHP, FHP, 100e100 , GDCHP, param.samples_per_ui);
5352 - else
5353 -     eq_ir = uneq_ir;
5354 - end
5355 - ctle_pulse = filter(ones(1, param.samples_per_ui), 1, eq_ir);
5356 - ind_max = find(ctle_pulse == max(ctle_pulse));
5357 - adc_clip = sum(abs([ctle_pulse(ind_max-param.samples_per_ui:-param.samples_per_ui:1);
5358 - ctle_pulse(ind_max:param.samples_per_ui:end)]));
5359 - adc_lsb = 2*adc_clip/(2^param.ENOB-1);
5360 - sigma_Q = adc_lsb/sqrt(12);
5361 - S_qn = sigma_Q^2/(length(result.S_rn)*delta_f)*ones(size(result.S_rn));
5362 - result.S_qn = S_qn;
5363 - result.qn_rms = sqrt(sum(result.S_qn)* delta_f);
5364 % result.S_n=result.S_rn+ result.S_tn+ result.S_xn+ result.S_jn;
5365 - result.S_n=result.S_rn+ result.S_tn+ result.S_xn+ result.S_jn+ result.S_qn;
5366 - result.S_n_rms = sqrt(sum(result.S_n)* delta_f);
5367
5368 %%
5369 %% Hisi to be included in MLSE rho eq 178a-28
```

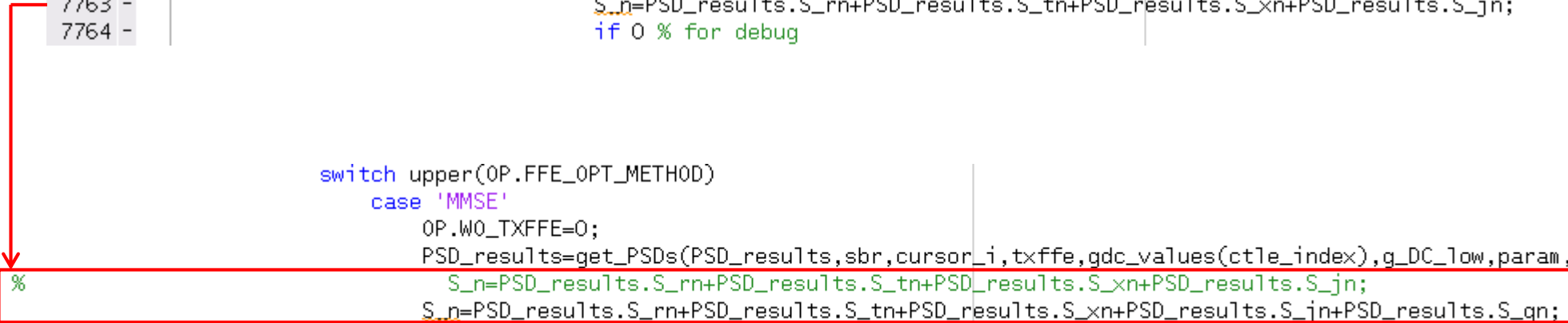
```
5308
5309 -
5310 -
5311
5312
5313 % result.S_jn
result.S_n=result.S_rn+ result.S_tn+ result.S_xn+ result.S_jn;
result.S_n_rms = sqrt(sum(result.S_n)* delta_f);
%%
%% Hisi to be included in MLSE rho eq 178a-28
```

Changes to the Code (6 of 8)

6) Change 1 line

```
7759 - |
7760 - |
7761 - |
7762 - |
7763 - |
7764 - |
switch upper(OP.FFE_OPT_METHOD)
  case 'MMSE'
    OP.WO_TXFFE=0;
    PSD_results=get_PSDs(PSD_results,sbr,cursor_i,txffe,gdc_values(ctle_index),g_DC_low,param,chdata,OP);
    S_n=PSD_results.S_rn+PSD_results.S_tn+PSD_results.S_xn+PSD_results.S_jn;
    if 0 % for debug
```

```
7815 - |
7816 - |
7817 - |
7818 - |
7819 - |
7820 - |
7821 - |
switch upper(OP.FFE_OPT_METHOD)
  case 'MMSE'
    OP.WO_TXFFE=0;
    PSD_results=get_PSDs(PSD_results,sbr,cursor_i,txffe,gdc_values(ctle_index),g_DC_low,param,chdata,OP);
    % S_n=PSD_results.S_rn+PSD_results.S_tn+PSD_results.S_xn+PSD_results.S_jn;
    S_n=PSD_results.S_rn+PSD_results.S_tn+PSD_results.S_xn+PSD_results.S_jn+PSD_results.S_qn;
    if 0 % for debug
```

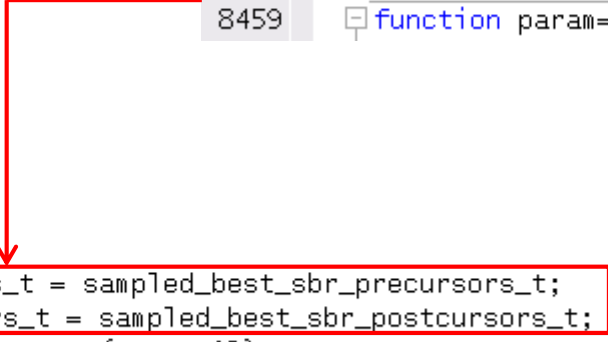


Changes to the Code (7 of 8)

7) Insert 2 lines

```
8513 | %AJG021820
8514 - | result.best_bmin=best_bmin;
8515 - | result.tail_RSS=best_tail_RSS;
8516 - | result.sampled_best_sbr_precursors_t = sampled_best_sbr_precursors_t;
8517 - | result.sampled_best_sbr_postcursors_t = sampled_best_sbr_postcursors_t;
8518 | function param=parameter_size_adjustment(param,OP)

8456 | %AJG021820
8457 - | result.best_bmin=best_bmin;
8458 - | result.tail_RSS=best_tail_RSS;
8459 | function param=parameter_size_adjustment(param,OP)
```



Changes to the Code (8 of 8)

8) Insert 1 line

```
9223 %% add default to support multiple packages
9224 - param.a_thru = xls_parameter(parameter, 'A_v', true, 0.5); % Victim differential peak source output voltage (half of peak to peak)
9225 - param.a_fext = xls_parameter(parameter, 'A_fe', true,0.5); % FEXT aggressor differential peak source output voltage (half of peak to peak)
9226 - param.a_next = xls_parameter(parameter, 'A_ne', true,0.5); % NEXT aggressor differential peak source output voltage (half of peak to peak)
9227 - param.a_icn_fext = xls_parameter(parameter, 'A_ft', true, param.a_fext); % FEXT aggressor amplitude for ICN. Defaults to A_fe if not specified
9228 - param.a_icn_next = xls_parameter(parameter, 'A_nt', true, param.a_next );% NEXT aggressor amplitude for ICN. Defaults to A_ne if not specified
9229 - param.levels = xls_parameter(parameter, 'L'); % number of symbols levels (PAM-4 is 4, NRZ is 2)
9230 - param.specBER = xls_parameter(parameter, 'DER_O'); % Target detector error ratio
9231 - param.DER_CDR = xls_parameter(parameter, 'DER_CDR',true,1e-2); % min DER required for a CDR
9232 - param.pass_threshold = xls_parameter(parameter, 'COM Pass threshold',false,0); % the pass fail threshold for COM in dB
9233 - param.ERL_pass_threshold = xls_parameter(parameter, 'ERL Pass threshold',false,0); % the pass fail threshold for ERL in dB
9234 - param.VEC_pass_threshold = xls_parameter(parameter, 'VEC Pass threshold',false,0);% the pass fail threshold for VEC in dB only used when PMD_type is C2M

9282 %% add default to support multiple packages
9283 - param.a_thru = xls_parameter(parameter, 'A_v', true, 0.5); % Victim differential peak source output voltage (half of peak to peak)
9284 - param.a_fext = xls_parameter(parameter, 'A_fe', true,0.5); % FEXT aggressor differential peak source output voltage (half of peak to peak)
9285 - param.a_next = xls_parameter(parameter, 'A_ne', true,0.5); % NEXT aggressor differential peak source output voltage (half of peak to peak)
9286 - param.a_icn_fext = xls_parameter(parameter, 'A_ft', true, param.a_fext); % FEXT aggressor amplitude for ICN. Defaults to A_fe if not specified
9287 - param.a_icn_next = xls_parameter(parameter, 'A_nt', true, param.a_next );% NEXT aggressor amplitude for ICN. Defaults to A_ne if not specified
9288 - param.levels = xls_parameter(parameter, 'L'); % number of symbols levels (PAM-4 is 4, NRZ is 2)
9289 - param.specBER = xls_parameter(parameter, 'DER_O'); % Target detector error ratio
9290 - param.DER_CDR = xls_parameter(parameter, 'DER_CDR',true,1e-2); % min DER required for a CDR
9291 - param.ENOB = xls_parameter(parameter, 'ENOB', 'false', 32); % ADC Number of bits
9292 - param.pass_threshold = xls_parameter(parameter, 'COM Pass threshold',false,0); % the pass fail threshold for COM in dB
9293 - param.ERL_pass_threshold = xls_parameter(parameter, 'ERL Pass threshold',false,0); % the pass fail threshold for ERL in dB
9294 - param.VEC_pass_threshold = xls_parameter(parameter, 'VEC Pass threshold',false,0);% the pass fail threshold for VEC in dB only used when PMD_type is C2M
```

Example Outputs

	Before Change	After Change
Without Quantization (Default)	<p>Com_ieee8023_93a_470beta1 (N_tc = 128)</p> <p>DER_MLSE_trunc: 2.0764e-06 Q_budget_adj: 0 COM_from_matlab: -0.7246</p>	<p>Com_ieee8023_93a_470beta1_quant (ENOB = 32)</p> <p>DER_MLSE_trunc: 2.0764e-06 Q_budget_adj: 0 COM_from_matlab: -0.7246 DER_MLSE: 2.0764e-06 DER_DFE: 1.4608e-04 COM: 1.0876 delta_com: 1.8122</p>
With Quantization (ENOB of 6)	<p>DER_MLSE: 2.0764e-06 DER_DFE: 1.4827e-04 COM: 1.0876 delta_com: 1.8122</p>	<p>Com_ieee8023_93a_470beta1_quant (ENOB = 6)</p> <p>DER_MLSE_trunc: 3.0762e-05 Q_budget_adj: 0 COM_from_matlab: -1.6987 DER_MLSE: 3.0762e-05 DER_DFE: 6.6515e-04 COM: -0.1006 delta_com: 1.5981</p>

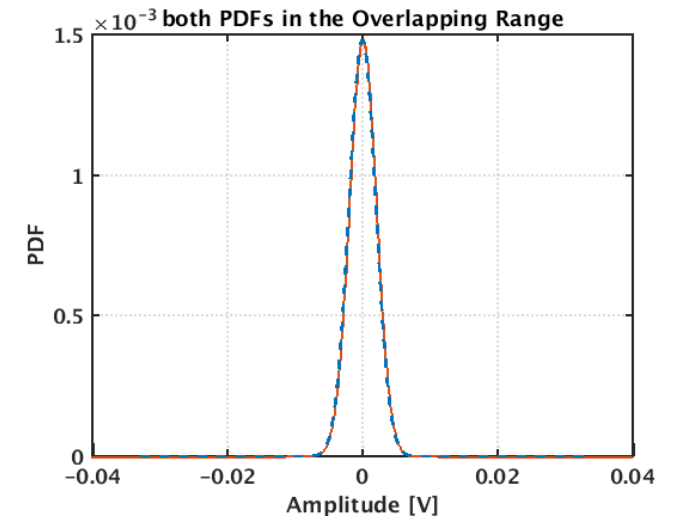
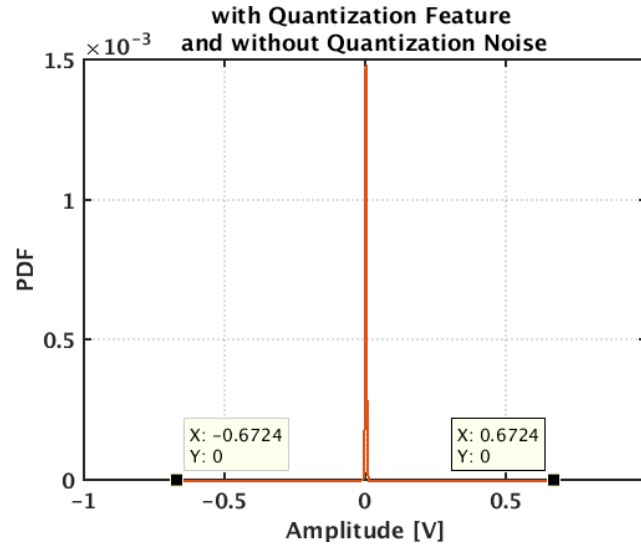
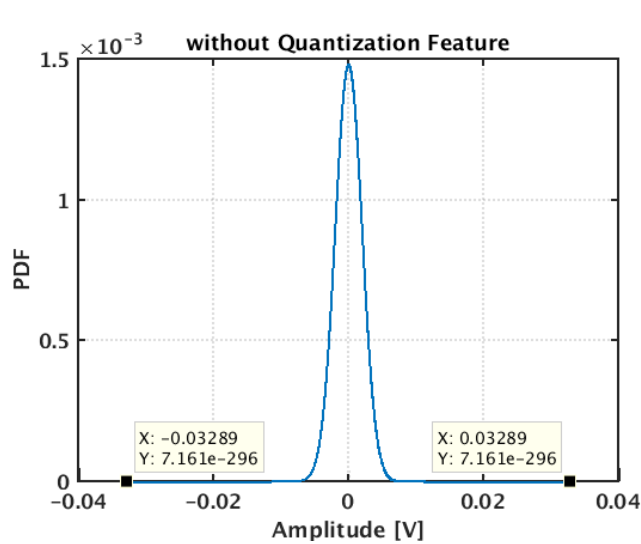
- It is recommended that this change be made along with the change for MLSE truncation
- There is a negligible difference in DER_DFE (see the backup slide)

Thank You 😊

**Hossein Shakiba
Huawei Technologies Canada
October 2024**

Backup

- The negligible difference in DER_DFE was traced back to the way COM decides on the range of the noise PDF
- In one case COM limits the range to $\pm 32.89\text{mV}$ and in the other to $\pm 672.4\text{mV}$ and although the PDFs are exactly the same within the overlapping range, integration of the extra tail of the extended range PDF causes a slight numerical difference in calculating error rate DER



- This is a normal behavior in numerical calculation of functions and is limited by the accuracy of computations