Phase-weighted distribution for calculating C2M eye parameters

(in support of comment #39)

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Supporters

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Problem statement

- Changing the eye measurement to a region of t_s±0.05 UI resulted in significant degradation of EH/VEC
  - As demonstrated in calvin_3ck_adhoc_01_063021, with instrument-grade transmitter with high-loss channel, closing the calibration loop is a challenge
  - it may also be challenging to build/tune real transmitters to meet the current specification

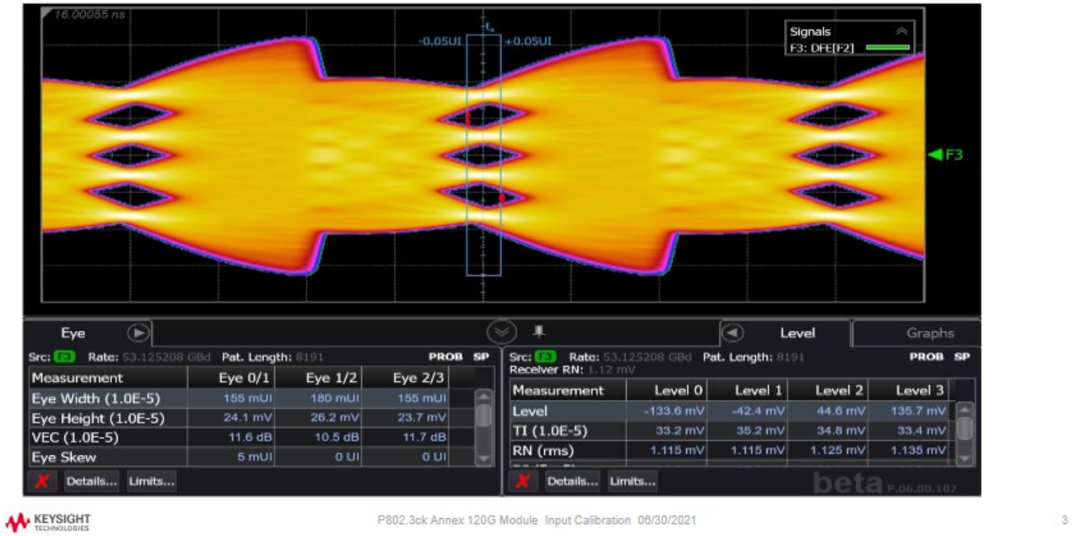
Possible solutions

- Move the EH and VEC limits/targets to compensate for the degradation
  - Comments #61, #68 propose moving from 12 dB / 15 mV to 13 dB/8.5 mV
  - This can make the current signals (transmitters+channel combinations) pass, but open the door to fast-noisy ones (where the eye is closed due to noise/jitter)
  - It takes the margin from the receiver (which would need to handle “rectangular eye”, unequalizable signals)
- Change the method to “a 10-cornered mask” (comment #106)
  - The eye shape expected from a band-limited transmitter is indeed not rectangular
  - However, the current methodology (120G.5.2) is not based on a mask – it’s unclear how this idea can be implemented
- The proposal in this presentation is similar to a “shaped mask” but based on the 120G.5.2 methodology
  - It is also aligned with reasonable receiver behavior

Current reference receiver effect

- The reference receiver includes CTLE and DFE
  - Both are adjustable
  - DFE is optimized based on the fitted pulse and maximizes the vertical opening at t_s
- The eye metrics are then taken from samples collected at t_s±0.05 UI <u>with equal weight to all phases</u>
- This matches a hypothetical receiver which opens the eye at t_s, but then samples anywhere within t_s±0.05 UI with equal probability
  - But it is not a likely behavior of a real receiver (see next slide)
- The 3 eyes are more vertically closed as the distance from t_s is increased (as shown) – so the 1e-5 limit is governed by the outer phases, and the larger vertical opening at t_s has little effect
- The 15 mV/12 dB specs at BER=1e-5 create the margin for real receivers (similar to the 3 dB COM)
  - But 12 dB VEC is a small margin! 13 dB is even worse

P802.3ck VEC centering (BoxCar) around ts



The signal above passes VEC – but high-loss TP1a eye fails

Test Point	Configuration **	Insertion Loss	Meas. EH SJ = 50mUI	Meas. VEC SJ = 50mUI	Spec. EH SJ = 50mUI	Spec. VEC SJ = 50mUI
TP4	Near-end short	6.6 dB	16.25 mV	11.6 dB	15 mV	12.5 dB
TP4	Far-end long	17.1 dB	15.45 mV	9 dB	15 mV	12.5 dB
TP1a	High Loss	16.4 dB	13.1 mV	13.5 dB	10 mV	12.5 dB*

(Source: calvin_3ck_adhoc_01_063021 slides 3-4)

Expected behavior of real receivers

- A real receiver has a CDR which selects a mean sampling phase (“t_s”)– based on some criterion
  - There is some distribution of the sampling phase around t_s, but it is not uniform – Gaussian-like is more likely
- Ideally the equalization is selected to optimize the BER given t_s and the distribution
  - In practice – it may be sub-optimal for various reasons
  - Non-ideality in equalization and phase selection can use the VEC/EH margin created by the reference receiver
- We can expect a receiver to spend more time near t_s than away from it
  - The infrequent samples that are away, will have less vertical margin and higher BER
  - The aggregate BER is less affected by the “outer phases” than the “inner phases”
  - Thus the current “equal weighted” reference receiver is too pessimistic
- This behavior can be emulated by per-phase weighting (conditional probability) of the sampled voltage in the reference receiver
  - If a transmitter has a “diamond shaped eye” or similar (as in slide 5), its calculated VEC/EH will be improved by this weighting
  - If the Tx eye shape is rectangular (governed by noise/jitter rather than ISI) it will not change the numbers
  - Expected to help good real transmitters meet the EH and VEC requirements and enable reasonable stressed eye creation

Illustration

Assume the scope collects a set of samples (t_i, v_i) as illustrated on the right.

The red samples should be weighted down compared to the green samples.

The probability of seeing a voltage level $V<V_{th}$ is the total probability created by

- the conditional probabilities of seeing $V<V_{th}$ at each phase (per-phase PDF),
- each weighted by the probability of being at that phase:

$$Prob(v < V_{th}) = \int_{t_{min}}^{t_{max}} prob(v < V_{th}|t) \cdot w(t)\, dt$$

Where $w(t)$ is the probability of sampling at t (characteristic of the reference receiver).

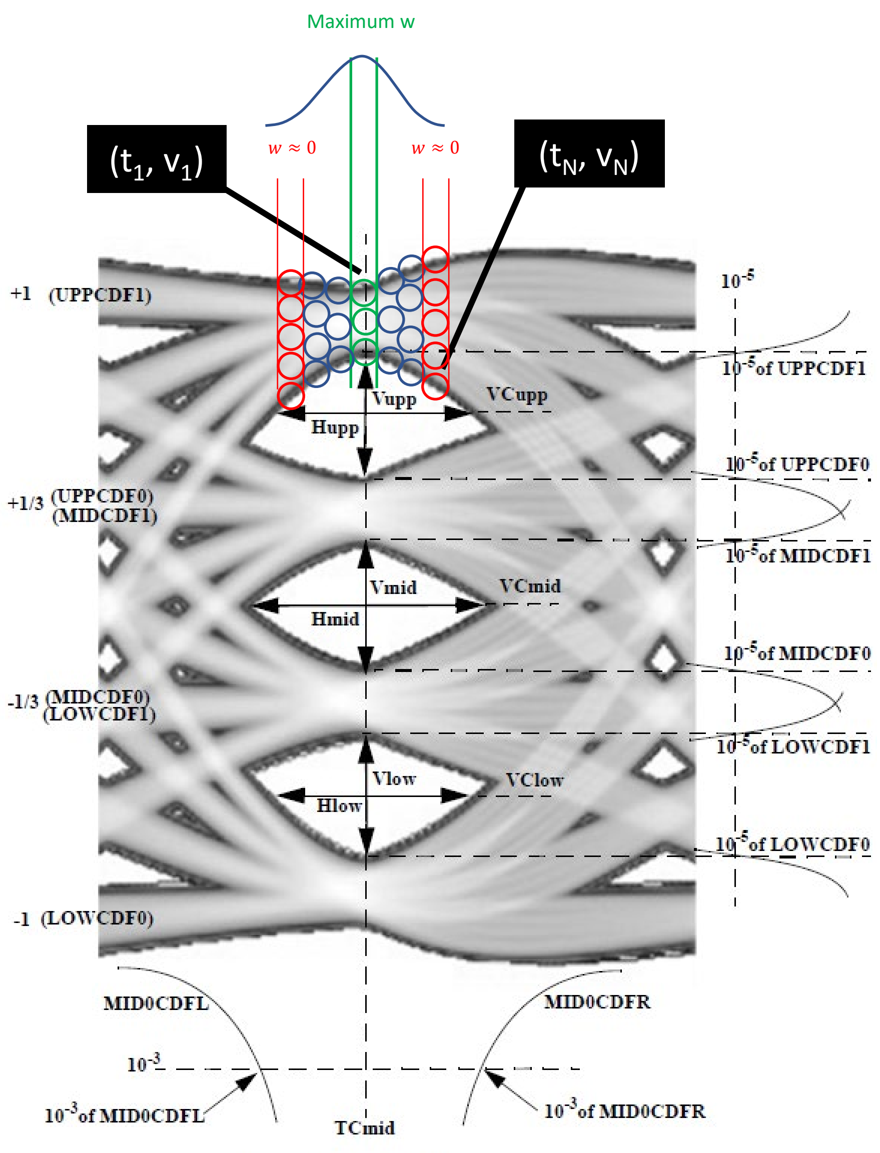


Figure 120E–13—PAM4 eye measurements

What is the expected phase distribution?

- It is characteristic of a CDR in the Rx, not of the Tx
- It is not a representation of scope jitter (which is expected to be lower)
- We have not addressed Rx jitter explicitly in past specifications and the proposed distribution is not expected to become a specification. Its use for receiver design/testing is outside the scope of the standard.
- Proposed weighting function is a truncated Gaussian with a standard deviation of 0.015 UI. Outside of the ±50 mUI window the weight is 0. This gives a minimum weight of ~1.5e-3 at ±50 mUI away from t_s.
  - It does not mean the BER covered by the eye is 1.5e-3! The EH/VEC are still from the CDFs at 1e-5.
  - Truncation to t_s±50 mUI means the eye outside this region can be completely closed without penalizing the transmitter – it is the receiver's responsibility not to sample outside of this region.
- We can consider expanding the region to ±75 mUI since a receiver's CDR may visit these areas (with the associated low probability). The truncated ±75 UI tails have a probability of <1e-6.

Proposed change

In 120G.5.2, change item o (to be renumbered to item h) as follows:

Compute Vmid, Vupp, Vlow, VCmid, VCupp, VClow from the eye diagram using 120E.4.2 steps 4) through 6) with the exception that the CDF of the signal voltage is ~~accumulated over the time interval $t_s \pm 0.05$ UI~~ calculated from voltage samples taken over the time interval $t_s \pm 0.05$ UI and weighted by the function $w(t)$ defined by Equation (120G–4), instead of "within 0.025 UI of time TCmid". For example, UPPCDF1 is calculated using Equation (120G–5).

Add equations 120G-4 and 120G-5 after the list:

$$w(t) = \begin{cases} \frac{1}{\sqrt{2\pi}\sigma_r} e^{-\frac{1}{2}\left(\frac{(t-t_s)\cdot f_b}{\sigma_r}\right)^2}, & |t-t_s|\cdot f_b \le 0.05 \\ 0, & |t-t_s|\cdot f_b > 0.05 \end{cases} \qquad (120G-4)$$

Where $\sigma_r = 0.015$.

$$\text{UPPCDF1}(v) = \frac{1}{\sum_{i=1}^{N} w(t_i)} \sum_{i=1}^{N} \int_{VCupp}^{v} \delta(u - v_i) w(t_i) du \qquad (120G-5)$$

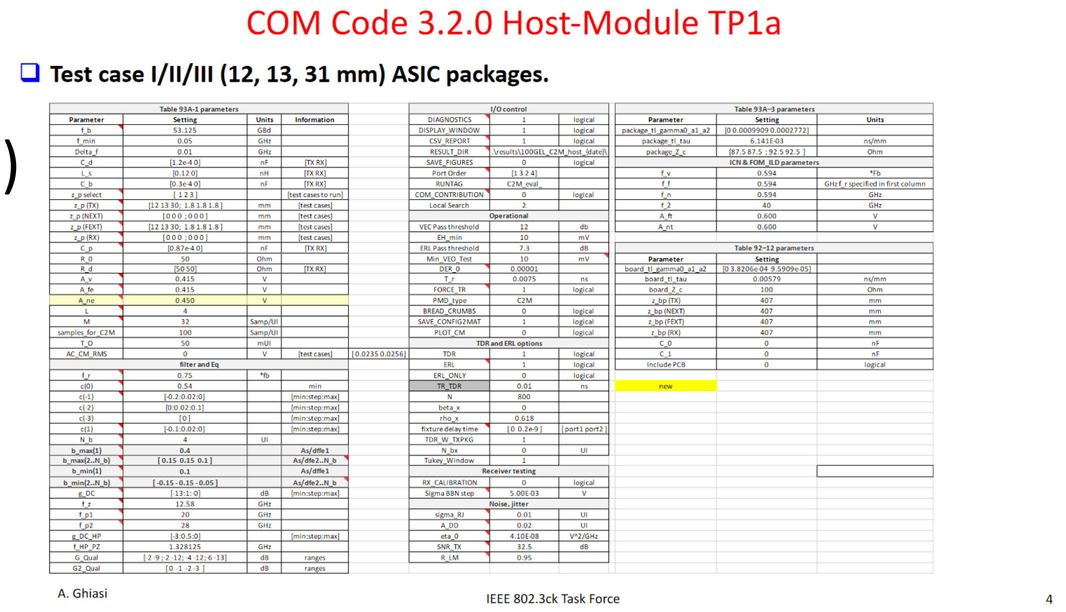
Where $\{(v_i, t_i)\}_{i=1}^{N}$ is the set of samples corresponding to the topmost symbol.

NOTE—The other CDFs in 120E.4.2 are calculated similarly but with different sets of samples and integration limits.

Add the missing definition of f_b=26.5625 GHz to Table 120G–11.

Update: COM analysis

- Repeated analysis in ghiasi_3ck_01_0721 and added some Gaussian window options
  - Only TP1a (host output)
- lim_3ck_adhoc_02_073119
  - Channels 5a (2”, 5.9 dB) and 5d (9”, 14.7 dB)
- COM v3.20
- Same configuration as in slide 4 ⇒
  - Including 12, 13, 30 mm Tx packages



COM Code 3.2.0 Host-Module TP1a

❑ **Test case I/II/III (12, 13, 31 mm) ASIC packages.**

Table 93A-1 parameters				
Parameter	**Setting**	**Units**	**Information**	
f_b	53.125	GBd		
f_min	0.05	GHz		
Delta_f	0.01	GHz		
C_d	[1.2e-4 0]	nF	[TX RX]	
L_s	[0.12 0]	nH	[TX RX]	
C_b	[0.3e-4 0]	nF	[TX RX]	
z_p select	[1 2 3]		[test cases to run]	
z_p (TX)	[12 13 30; 1.8 1.8 1.8]	mm	[test cases]	
z_p (NEXT)	[0 0 0 ; 0 0 0]	mm	[test cases]	
z_p (FEXT)	[12 13 30; 1.8 1.8 1.8]	mm	[test cases]	
z_p (RX)	[0 0 0 ; 0 0 0]	mm	[test cases]	
C_p	[0.87e-4 0]	nF	[TX RX]	
R_0	50	Ohm		
R_d	[50 50]	Ohm	[TX RX]	
A_v	0.415	V		
A_fe	0.415	V		
A_ne	0.450	V		
L	4			
M	32	Samp/UI		
samples_for_C2M	100	Samp/UI		
T_O	50	mUI		
AC_CM_RMS	0	V	[test cases]	[0.0235 0.0256]
filter and Eq				
f_r	0.75	*fb		
c(0)	0.54		min	
c(-1)	[-0.2:0.02:0]		[min:step:max]	
c(-2)	[0:0.02:0.1]		[min:step:max]	
c(-3)	[0]		[min:step:max]	
c(1)	[-0.1:0.02:0]		[min:step:max]	
N_b	4	UI		
b_max(1)	**0.4**		**As/dffe1**	
b_max(2..N_b)	**[0.15 0.15 0.1]**		**As/dfe2..N_b**	
b_min(1)	**0.1**		**As/dffe1**	
b_min(2..N_b)	**[-0.15 -0.15 -0.05]**		**As/dfe2..N_b**	
g_DC	[-13:1:-0]	dB	[min:step:max]	
f_z	12.58	GHz		
f_p1	20	GHz		
f_p2	28	GHz		
g_DC_HP	[-3:0.5:0]		[min:step:max]	
f_HP_PZ	1.328125	GHz		
G_Qual	[-2 -9 ;-2 -12; -4 -12;-6 -13]	dB	ranges	
G2_Qual	[0 -1 -2 -3]	dB	ranges	

I/O control		
DIAGNOSTICS	1	logical
DISPLAY_WINDOW	1	logical
CSV_REPORT	1	logical
RESULT_DIR	.\results\100GEL_C2M_host_{date}\	
SAVE_FIGURES	0	logical
Port Order	[1 3 2 4]	
RUNTAG	C2M_eval_	
COM_CONTRIBUTION	0	logical
Local Search	2	
Operational		
VEC Pass threshold	12	db
EH_min	10	mV
ERL Pass threshold	7.3	dB
Min_VEO_Test	10	mV
DER_0	0.00001	
T_r	0.0075	ns
FORCE_TR	1	logical
PMD_type	C2M	
BREAD_CRUMBS	0	logical
SAVE_CONFIG2MAT	1	logical
PLOT_CM	0	logical
TDR and ERL options		
TDR	1	logical
ERL	1	logical
ERL_ONLY	0	logical
TR_TDR	0.01	ns
N	800	
beta_x	0	
rho_x	0.618	
fixture delay time	[0 0.2e-9]	[port1 port2]
TDR_W_TXPKG	1	
N_bx	0	UI
Tukey_Window	1	
Receiver testing		
RX_CALIBRATION	0	logical
Sigma BBN step	5.00E-03	V
Noise, jitter		
sigma_RJ	0.01	UI
A_DD	0.02	UI
eta_0	4.10E-08	V^2/GHz
SNR_TX	32.5	dB
R_LM	0.95	

Table 93A–3 parameters		
Parameter	**Setting**	**Units**
package_tl_gamma0_a1_a2	[0 0.0009909 0.0002772]	
package_tl_tau	6.141E-03	ns/mm
package_Z_c	[87.5 87.5 ; 92.5 92.5]	Ohm
ICN & FOM_ILD parameters		
f_v	0.594	*Fb
f_f	0.594	GHz f_r specified in first column
f_n	0.594	GHz
f_2	40	GHz
A_ft	0.600	V
A_nt	0.600	V

Table 92–12 parameters		
Parameter	**Setting**	
board_tl_gamma0_a1_a2	[0 3.8206e-04 9.5909e-05]	
board_tl_tau	0.00579	ns/mm
board_Z_c	100	Ohm
z_bp (TX)	407	mm
z_bp (NEXT)	407	mm
z_bp (FEXT)	407	mm
z_bp (RX)	407	mm
C_0	0	nF
C_1	0	nF
Include PCB	0	logical

new

A. Ghiasi

IEEE 802.3ck Task Force

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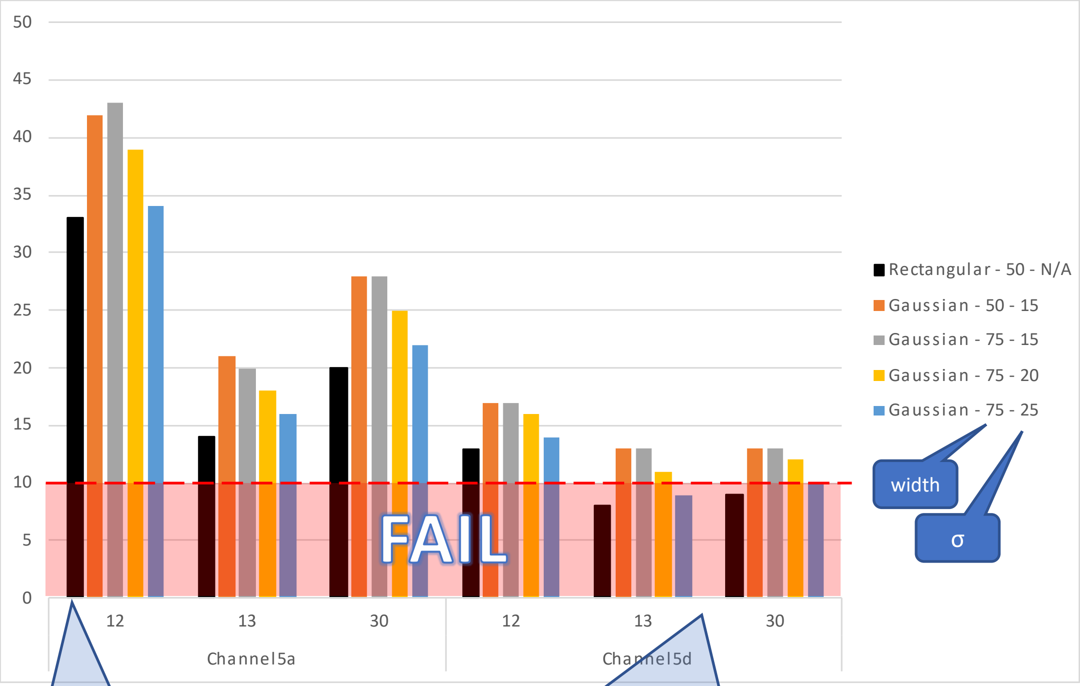
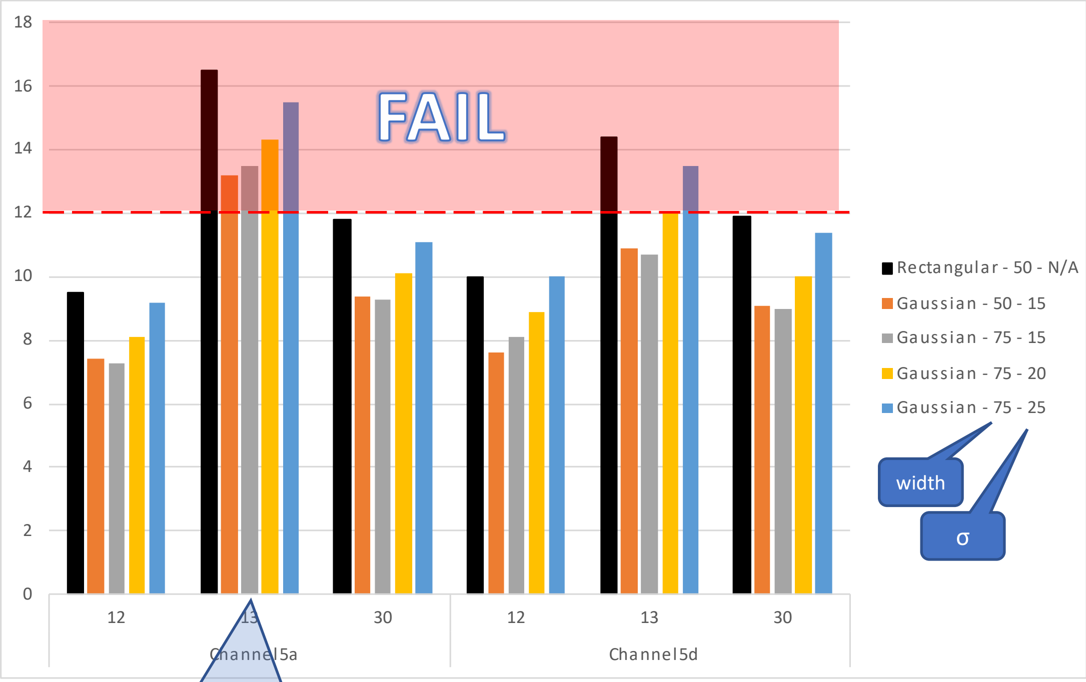
Results

EH



VEC



Results in black match slide 6 of ghiasi_01_0721

To make this channel pass with multiple packages we need Gaussian weighting with σ of 15-20 mUI

Window size (truncation of the Gaussian) has minor effect compared to σ

This short channel with bad reflection still fails VEC – as we want

Results in table form

EH

Average of EH		Window	T_O	sigma		
		Rectangular	Gaussian			
		50	50	75		
Channel	Tx zp	N/A	15	15	20	25
Channel5a	12	33	42	43	39	34
	13	14	21	20	18	16
	30	20	28	28	25	22
Channel5d	12	13	17	17	16	14
	13	8	13	13	11	9
	30	9	13	13	12	10

VEC

Average of VEC		Window	T_O	sigma		
		Rectangular	Gaussian			
		50	50	75		
Channel	Tx zp	N/A	15	15	20	25
Channel5a	12	9.5	7.4	7.3	8.1	9.2
	13	16.5	13.2	13.5	14.3	15.5
	30	11.8	9.4	9.3	10.1	11.1
Channel5d	12	10	7.6	8.1	8.9	10
	13	14.4	10.9	10.7	12	13.5
	30	11.9	9.1	9	10	11.4