In-depth Analysis of DDR3/DDR4 Channel with Active Termination

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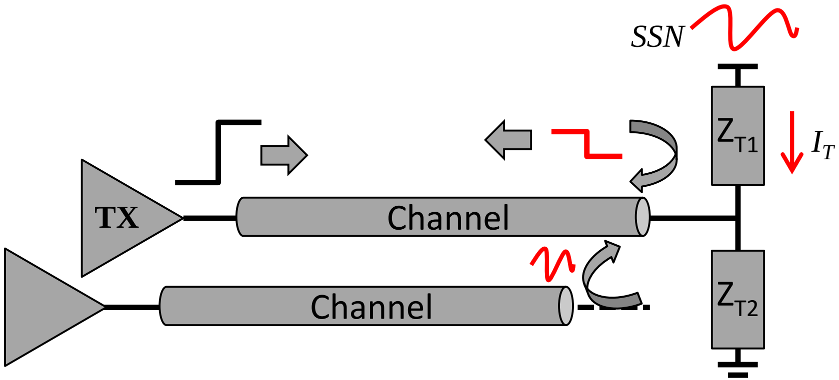
Agenda

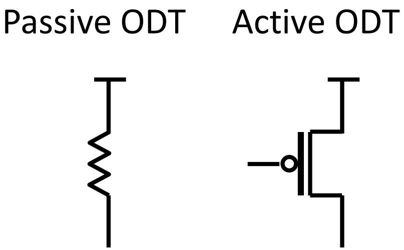
- Introduction
  - Basic of On-die termination
  - Comparison of on-die termination: Passive/Active
- Non-Linearity in Active Termination
  - I-V curve in active termination
  - Impacts
- Impact of Non-Linearity in Active Termination
  - SSN variation
  - Timing variation
- Summary

Basic of Active Termination



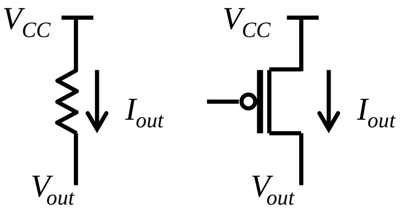
- Active termination is hard to meet desirable impedance
- Unexpected impedance determines signal quality in
  - DC level
  - Reflection noise
  - Crosstalk
  - SSN

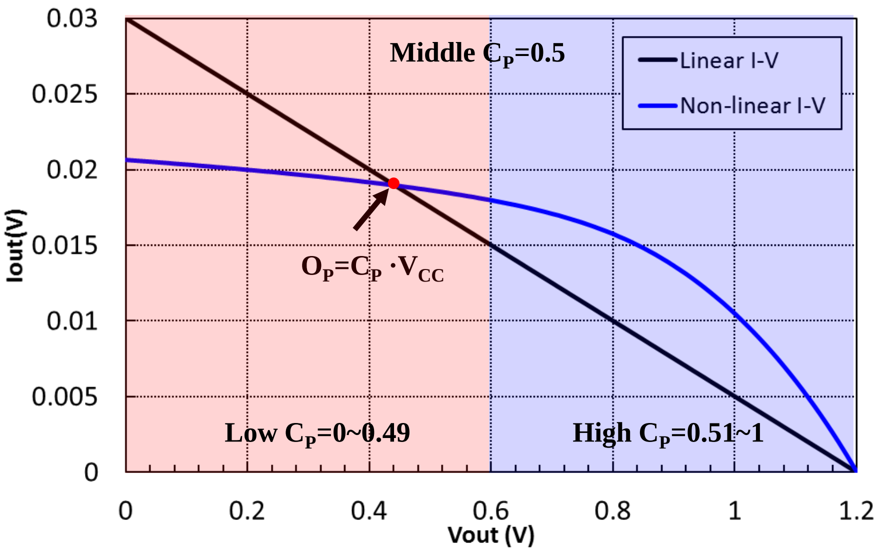
Comparison of Active Termination



	Passive	Active
Layer	Poly	PMOS
Area	Large	Small
PVT variation	Less-sensitive	sensitive
I-V Linearity	Good	Bad

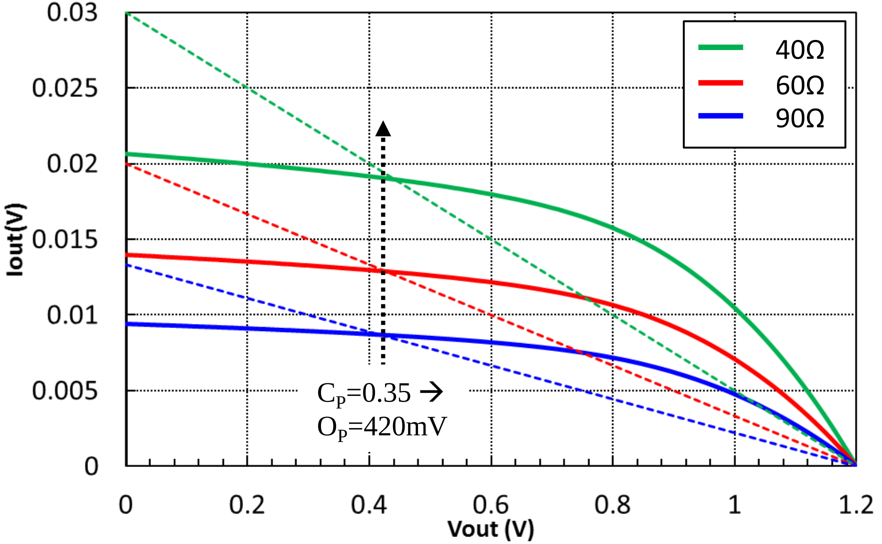
I-V Curve in Active & Passive Termination

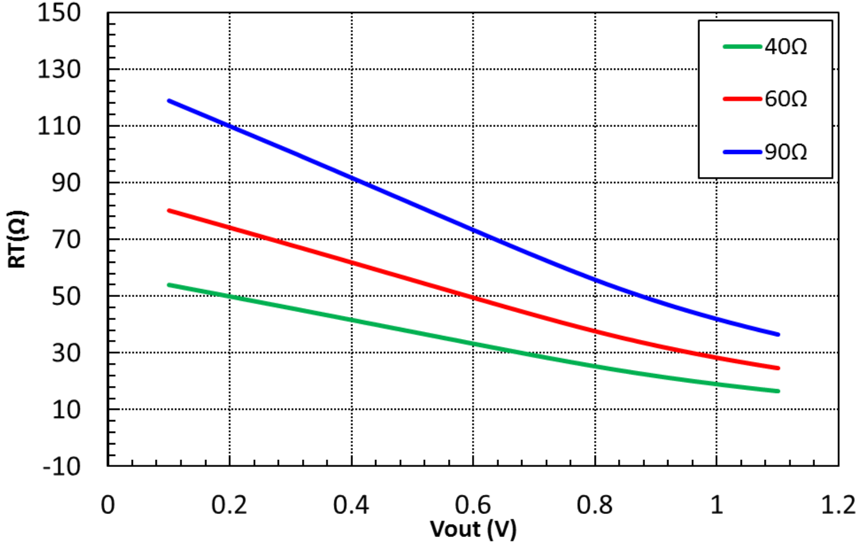




- Passive termination: current is inversely linear to output voltage
- Active termination: current is NOT linear to output voltage
- Calibration point is an operating voltage at desirable impedance

I-V Curve & Impedance



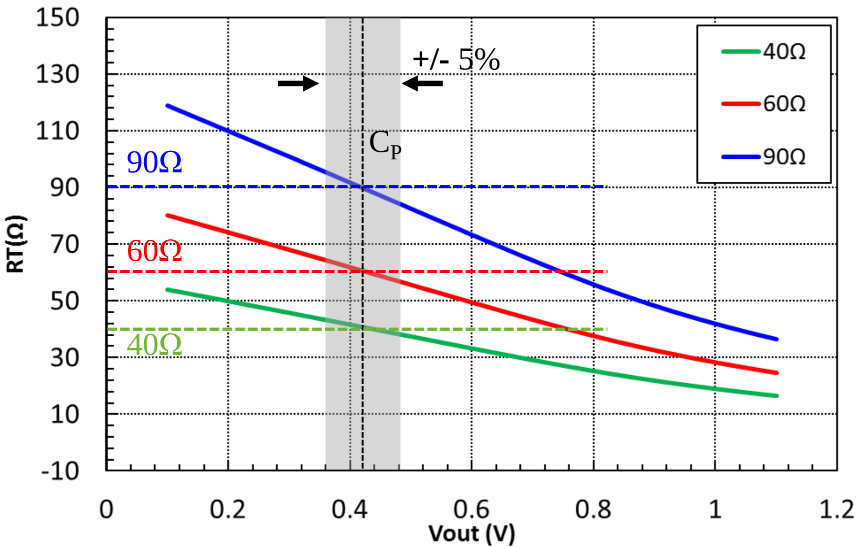


- As R_T is getting less, I_{OUT} becomes larger
- I_{OUT} at Lower V_{OUT} is more stable than Higher V_{OUT} → More NON-Linear
- R_T is more constant at higher V_{OUT} → Need to measure linearity

Non-linearity Coefficient

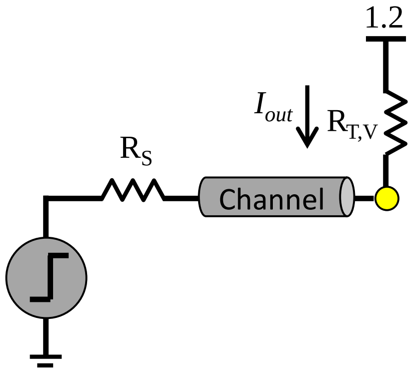
$$L_C = \left| \frac{\Delta R}{\Delta V_{X\%}} \right|$$

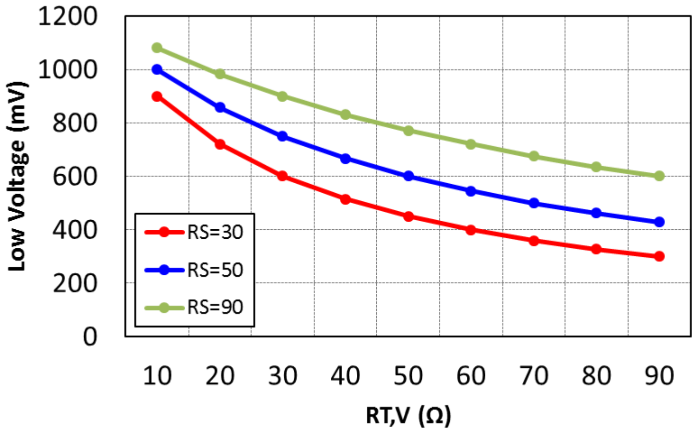
	-5%	O_P	+5%	L_C (Ω/V)
40Ω	43.3	40.9	38.3	41.7
60Ω	64.2	60.6	56.8	61.7
90Ω	95.5	90	84.4	92.5

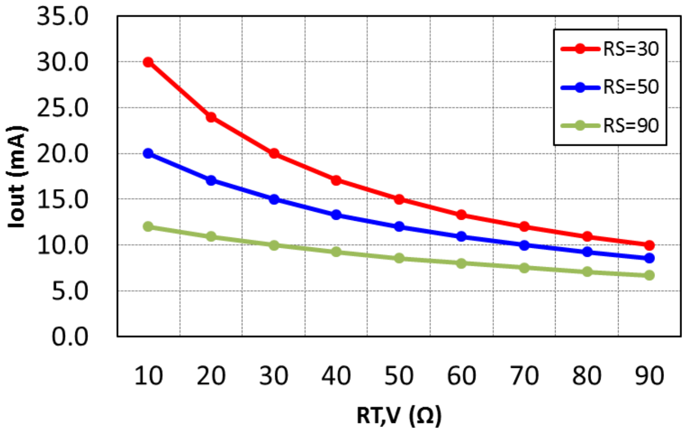


- At calibration point, voltage range needs to be defined first.
- Linearity at C_P is R_T variation within defined voltage variation
- High LCP means High NON-linearity

DC Level

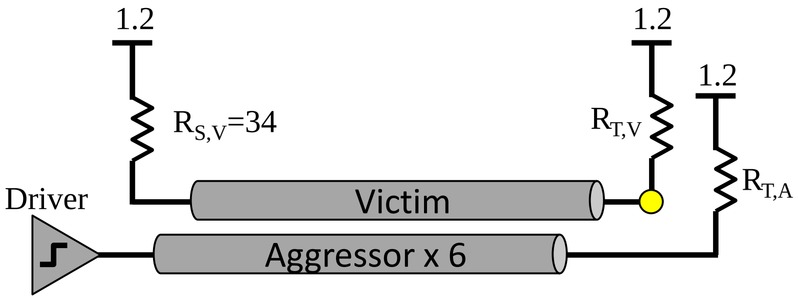


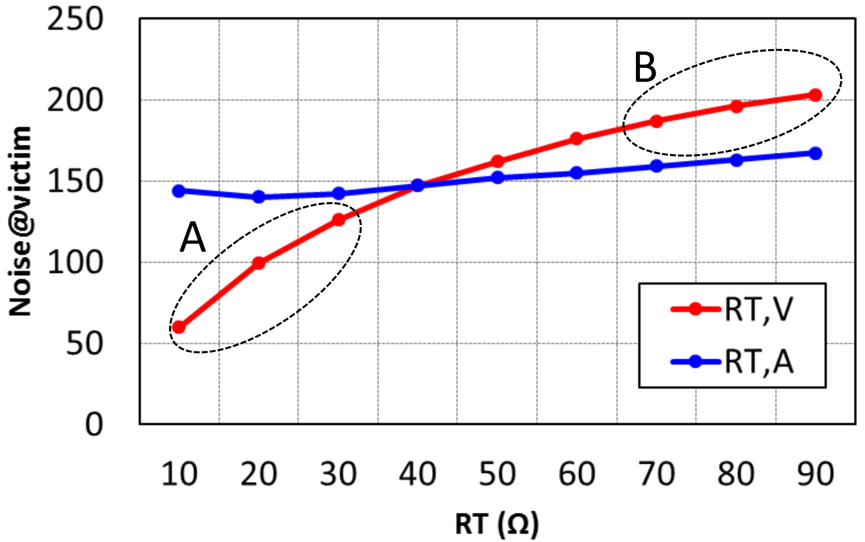




- As R_T goes higher, low-voltage and current becomes lower (Larger eye-height)
- As R_S goes higher, low-voltage goes higher (smaller eye-height) and current goes lower (less power)

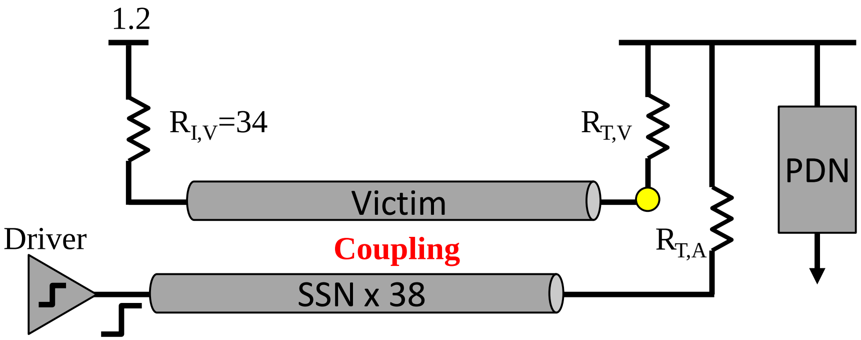
Crosstalk from Active Termination

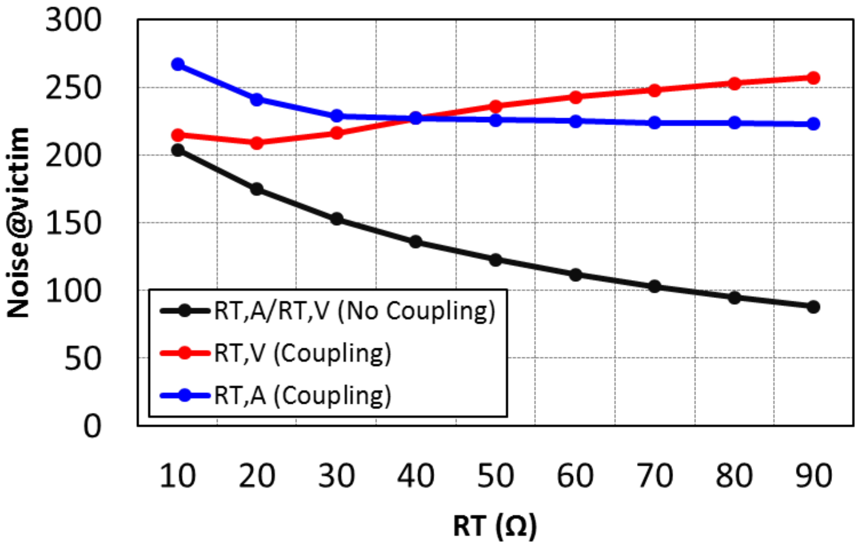




- Measured crosstalk at victim depending on $R_{T,A}$ or $R_{T,V}$
- Crosstalk is more sensitive to $R_{T,V}$ than $R_{T,A}$
- Lower R_T (A) has less noise but larger noise variation than higher R_T (B)

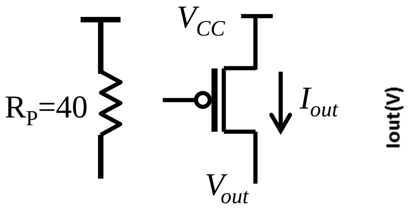
SSN from Active Termination



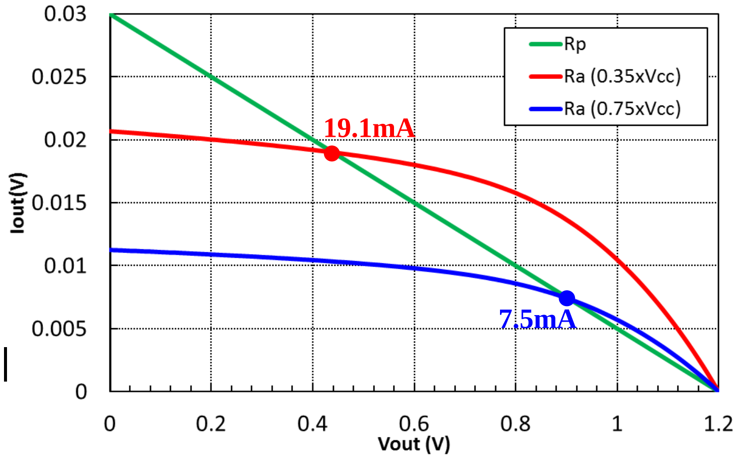


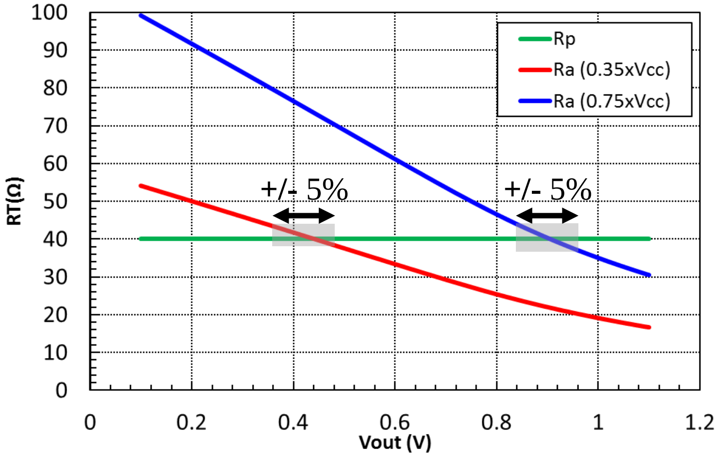
- Measured SSN at victim depending on $R_{T,A}$ or $R_{T,V}$ under Coupling and No Coupling
- Without coupling, SSN becomes less as $R_{T,A}$ or $R_{T,V}$ goes higher
- With coupling, noise follows crosstalk trend at $R_{T,V}$ but SSN trend at $R_{T,A}$

Active Impedance Setting



$$R_a = \left| \frac{V_{CC} - Vout}{I_{out}} \right|$$

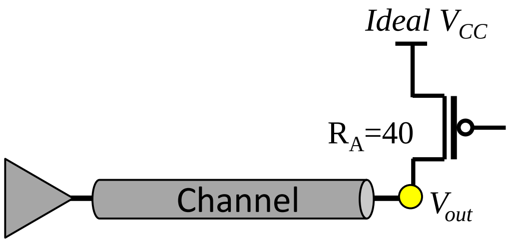




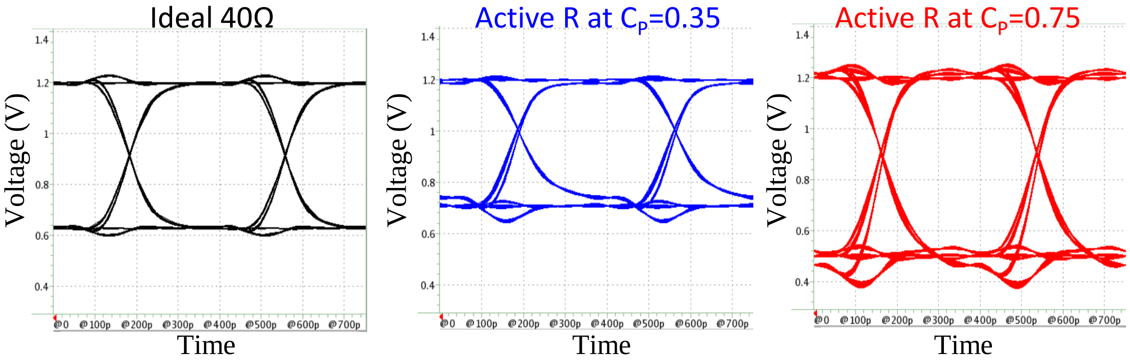
- 0.35VCC needs higher current to make 40ohm than 0.75VCC
- Linearity (+/-5%) at 0.35VCC is smaller than 0.75VCC

C_P (0~1)	Linearity (Ω/V)
Low C_P (0.35)	40.8
High C_P(0.75)	57.5

ISI Waveform

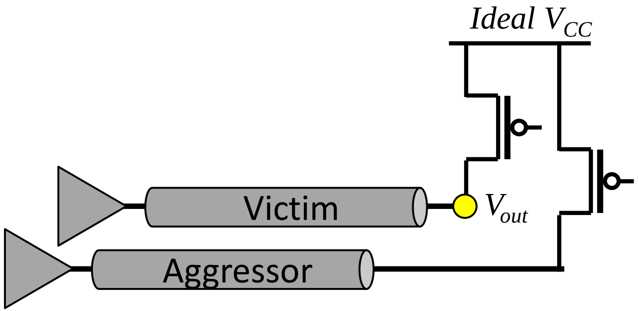


C_P (0~1)	Linearity (Ω/V)	V_{LOW} (mV)	R_{TERM} (Ω)	Jitter (UI)
Ideal 40	-	-	-	0.058
Low C_P (0.35)	40.8	700	**24.5**	0.078
High C_P(0.75)	57.5	500	**47**	0.064

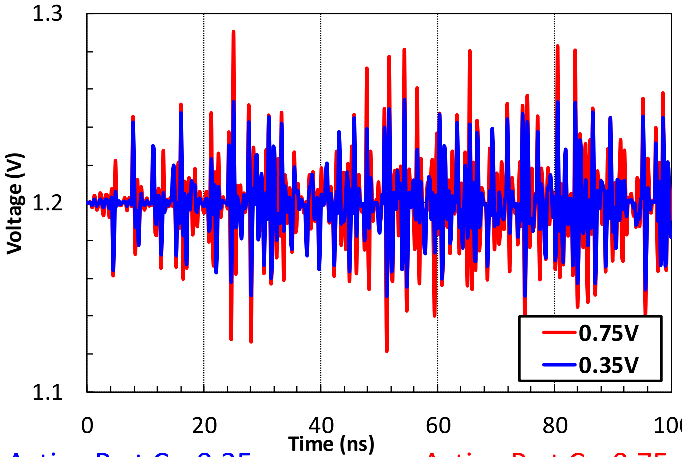


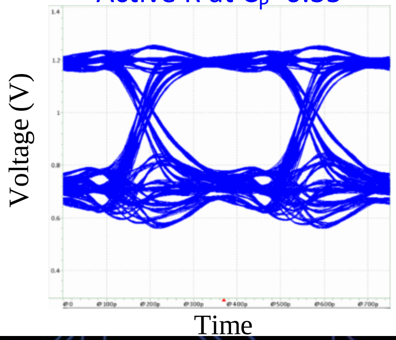
- At POD, low-voltage at 0.75xVCC is close to ideal 40
- Though linearity is bad, calibration point is more important to get better timing error

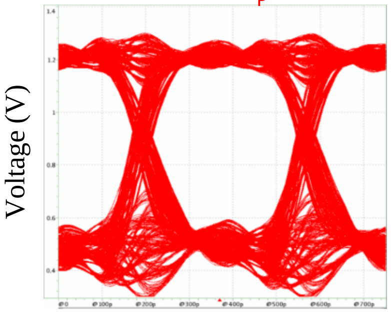
ISI+Crosstalk Waveform



C_P (0~1)	Linearity (Ω/V)	IO Noise (mV)	Jitter (UI)
Low C_P (0.35)	40.8	105	0.183
High C_P(0.75)	57.5	184	0.168

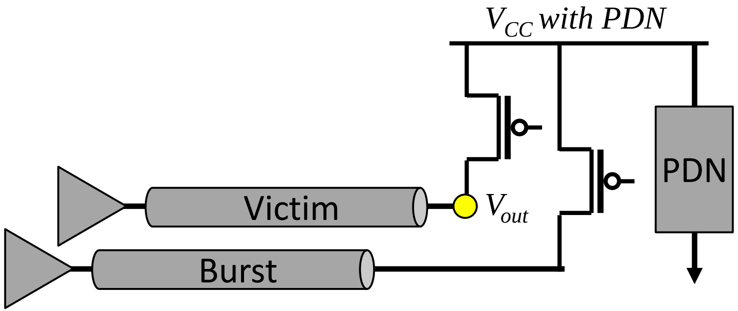


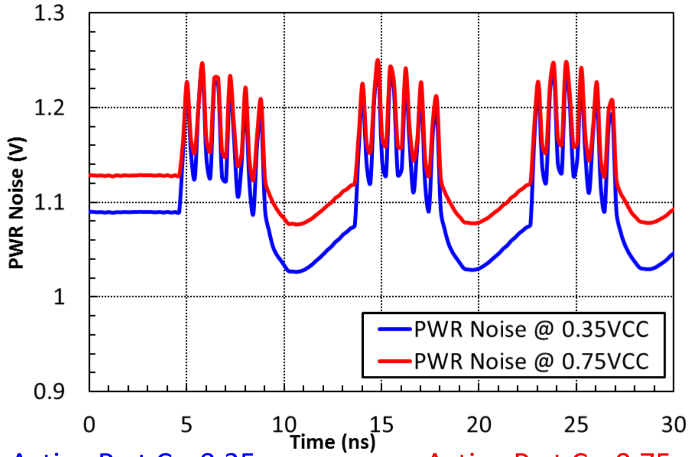




- Crosstalk is bigger at 0.75xVCC but jitter is less

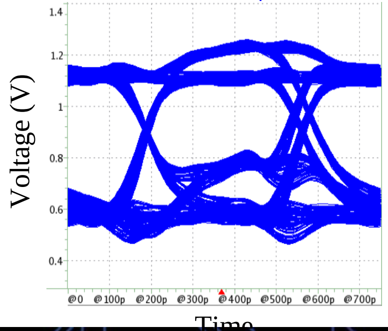
ISI+SSN Waveform



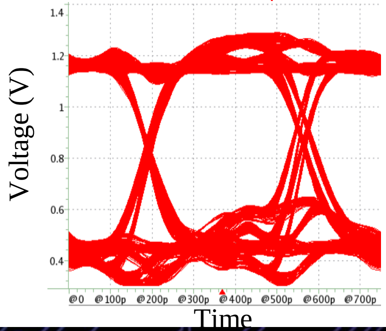


C_P (0~1)	Linearity (Ω/V)	PWR Noise (mV)	IO Noise (mV)	Jitter (UI)
Low C_P (0.35)	40.8	219	166	0.216
High C_P(0.75)	57.5	178	158	0.166

Active R at C_P=0.35

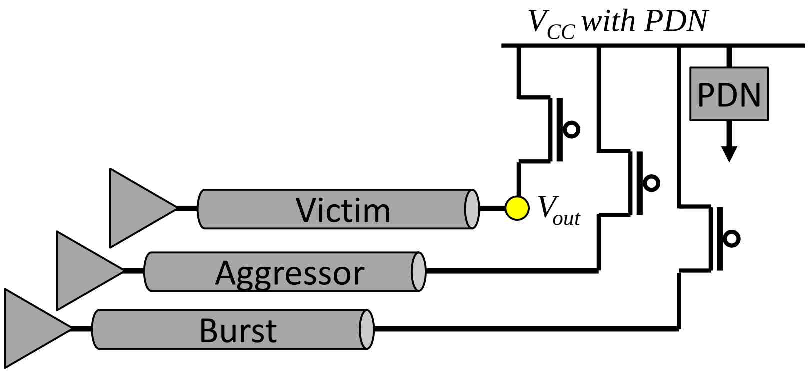


Active R at C_P=0.75



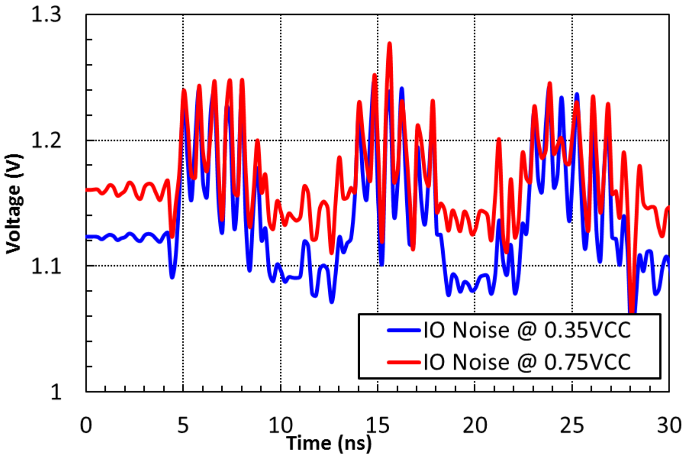
- PWR & IO noise at 0.35xVCC is bigger due to larger current
- Noise ratio at 0.75xVCC is bigger due to larger R_T

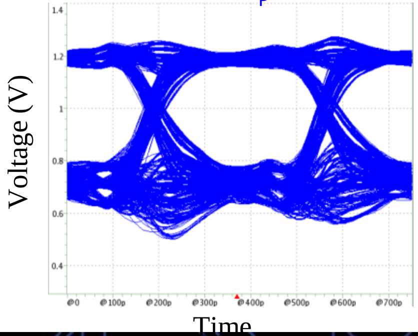
ISI+Crosstalk+SSN Waveform

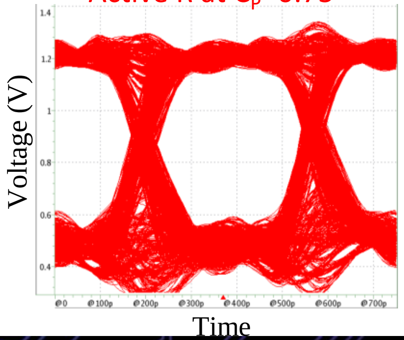


C_P (0~1)	Linearity (Ω/V)	PWR Noise (mV)	IO Noise (mV)	Jitter (UI)
Low C_P (0.35)	40.8	240	251	0.31
High C_P(0.75)	57.5	193	344	0.254

- PWR noise at 0.35xVCC is worsen, but IO noise is better
- Timing error at 0.75xVCC is better despite larger IO noise





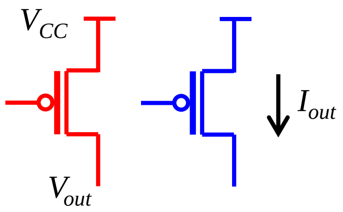


Channel Summary

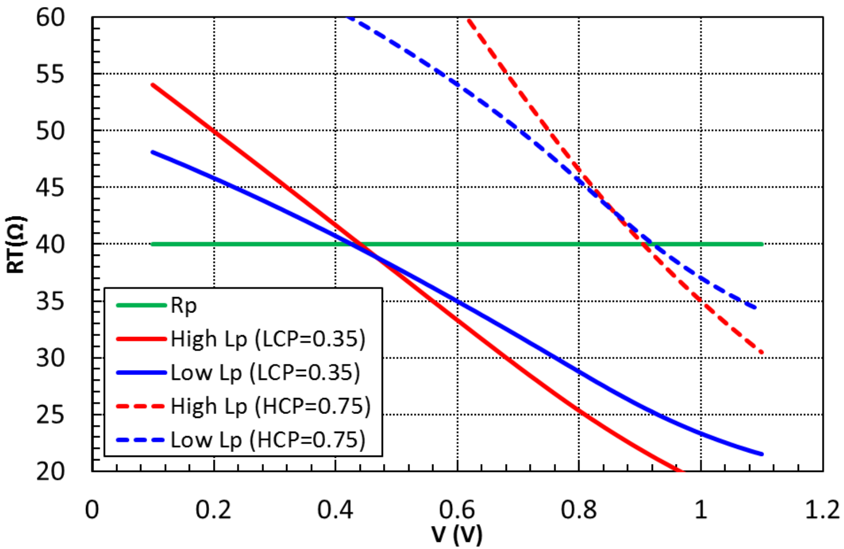
	C_p	PWR Noise	IO Noise	Jitter
ISI	Low C_p (0.35)	-	-	0.078
	High C_p(0.75)	-	-	0.064
Xtalk	Low C_p (0.35)	-	105	0.183
	High C_p(0.75)	-	184	0.168
SSN	Low C_p (0.35)	219	166	0.216
	High C_p(0.75)	178	158	0.166
ALL	Low C_p (0.35)	240	**251**	**0.31**
	High C_p(0.75)	193	**344**	**0.254**

- High calibration point is better jitter than low calibration point in POD topology
- Crosstalk is worsen at high calibration point
- SSN is better at high calibration point BUT noise reduction ratio is smaller
- Under larger IO noise, jitter can be smaller due to low voltage level

Lower Linearity

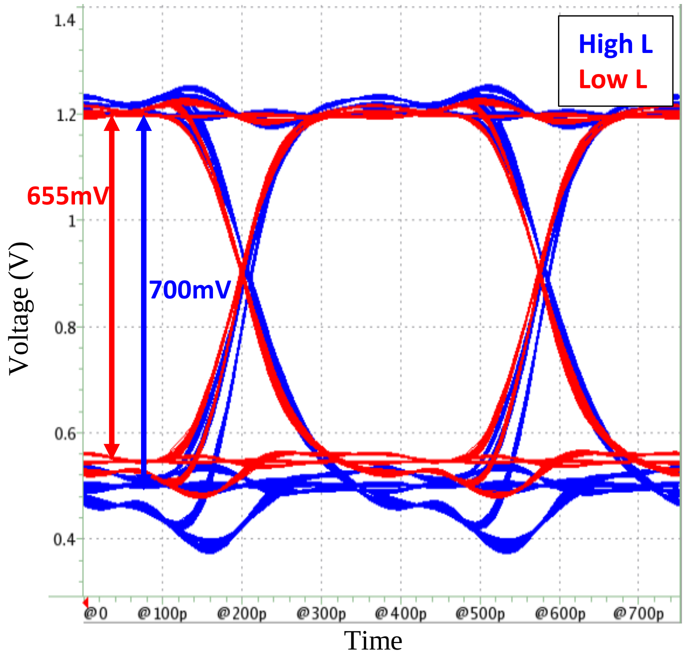


C_P (0~1)	High L	Low L
Low C_P (0.35)	20.8	13.3
High C_P(0.75)	29.2	21.7



ISI from Linear Termination

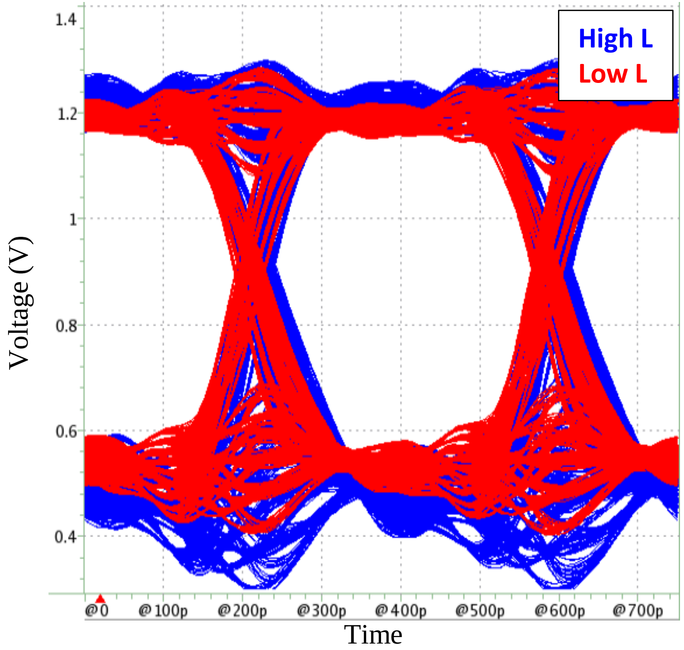
	C_P (0~1)	Linearity (Ω/V)	V_{LOW} (mV)	R_{TERM} (Ω)	Jitter (UI)
	Ideal 40	-	-	-	0.058
High L	Low C_P (0.35)	20.8	700	**24.5**	0.078
	High C_P(0.75)	**29.2**	**500**	**47**	**0.072**
Low L	Low C_P (0.35)	13.3	676	**26.5**	0.071
	High C_P(0.75)	**21.7**	**545**	**41**	**0.058**



- Low linearity has more similar low-voltage (VLOW) to passive termination
- Under smaller eye-height (-45mV), 13% jitter is improved

Crosstalk from Linear Termination

	C_P (0~1)	Linearity (Ω/V)	IO Noise (mV)	Jitter (UI)
High L	Low C_P (0.35)	20.8	**105**	0.183
	High C_P(0.75)	**29.2**	**182**	0.168
Low L	Low C_P (0.35)	13.3	**150**	0.167
	High C_P(0.75)	**21.7**	**191**	**0.149**



- Low linearity has more similar low-voltage (VLOW) to passive termination
- Under smaller eye-height (-75mV), 12% jitter is improved

Summary

- Correct non-linear termination setting is necessary
  - Appropriate calibration point (C_P:0~1)
  - At calibration point, non-linear coefficient is calculated

- Non-linear termination degrades signal quality with
  - DC level shifting
  - Change of crosstalk magnitude
  - Leveling SSN impact on the channel

- DC shifting from non-linearity is major noise effect in DDR channel

Thank you!

QUESTIONS?