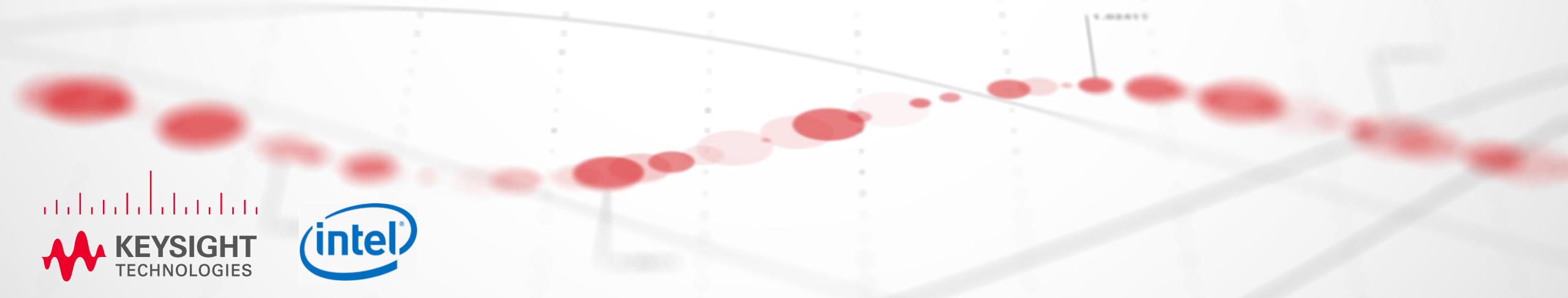
Clock Forwarding BIRD Discussion

Fangyi Rao, Keysight Technologies

Wendem Beyene, Intel



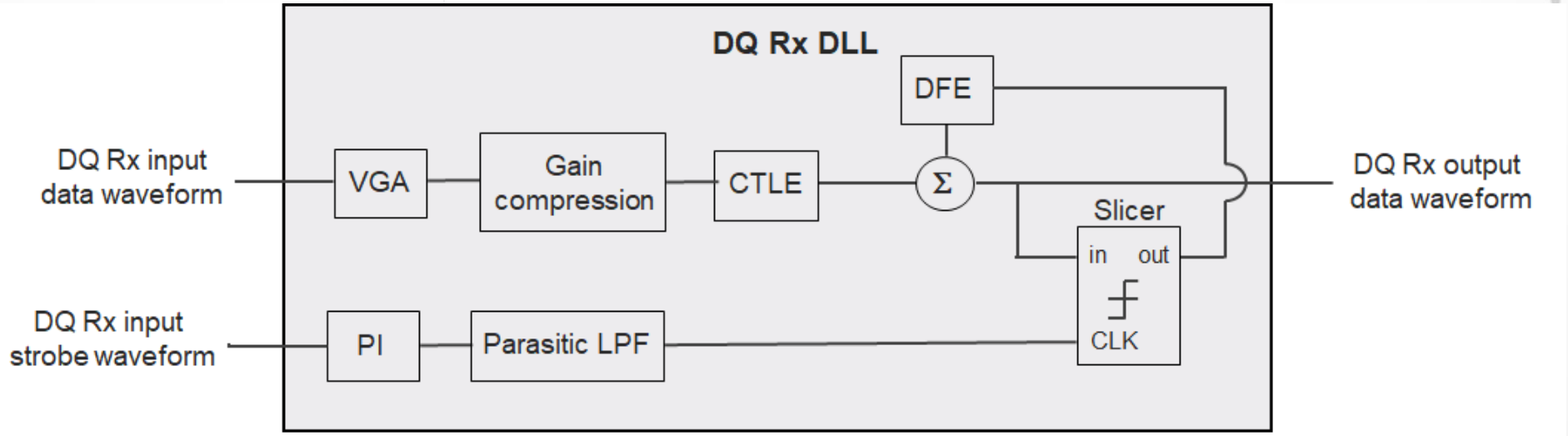
KEYSIGHT TECHNOLOGIES

intel

Effects Can Be Modeled by GetWave2

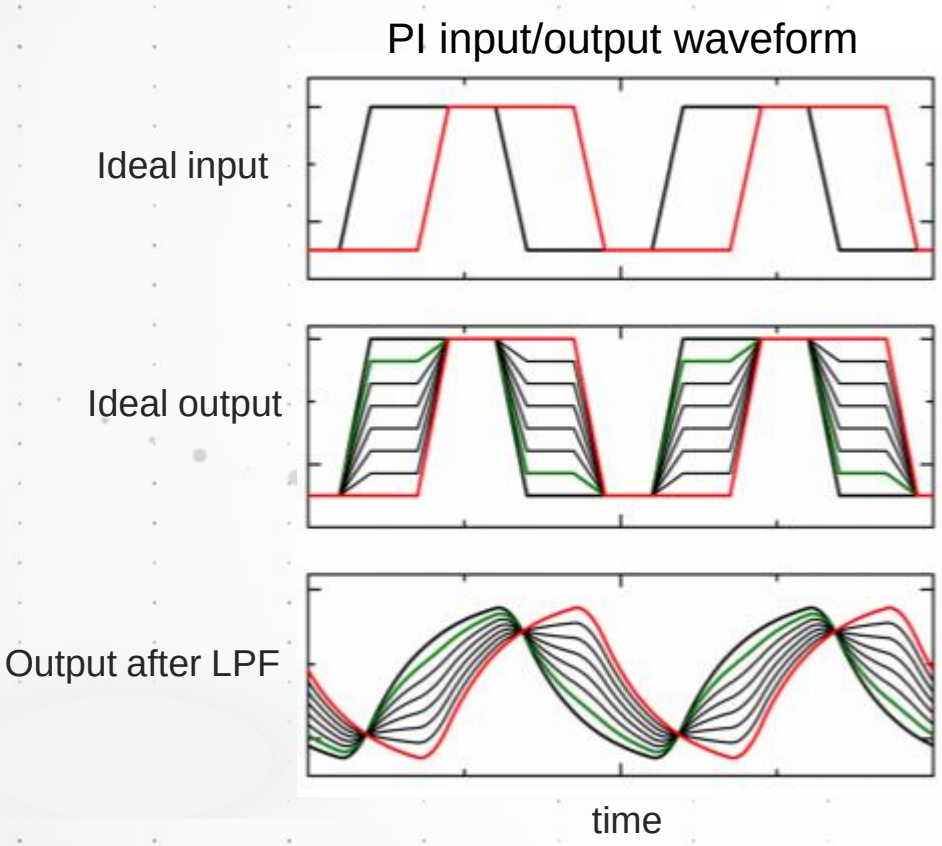
With the input DQS waveform, a DQ Rx model's GetWave2 can

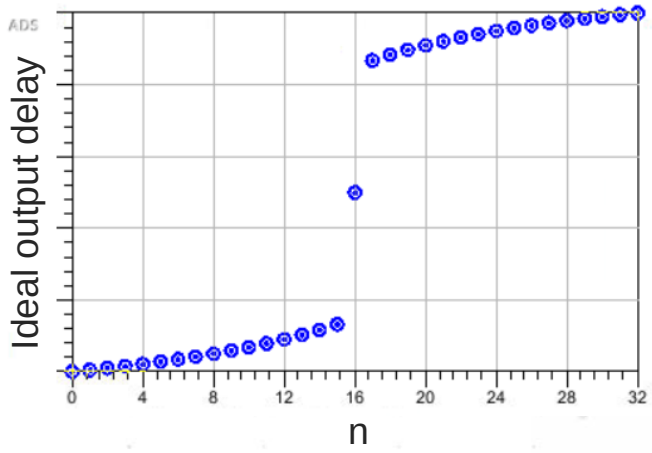
- Model clock forwarding and DQ-DQS correlated jitter tracking
- Capture DQ slicer sensitivity in terms of DQS slew rate
- Physically model DQ Rx phase interpolator (PI)
- Capture nonlinearity and discretization in phase interpolator output delay
- Capture DQS jitter amplification by phase interpolator
- Capture impacts of DQS correlated voltage noise on phase interpolator, slicer and DFE

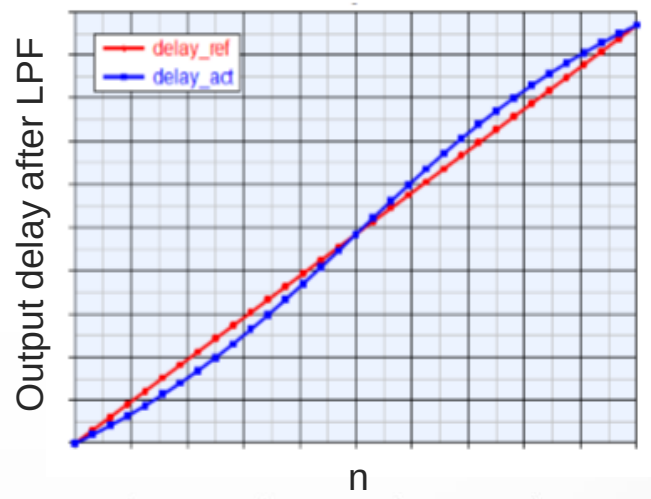


Phase Interpolator Output Delay Nonlinearity and Discretization

$$v_{out}(t) = \frac{n}{N} v_{in}(t - \tau_1) + \frac{N - n}{N} v_{in}(t - \tau_2), \qquad n = 0,1, \ldots, N$$







Delay nonlinearity and discretization can only be captured by physical model of phase interpolator

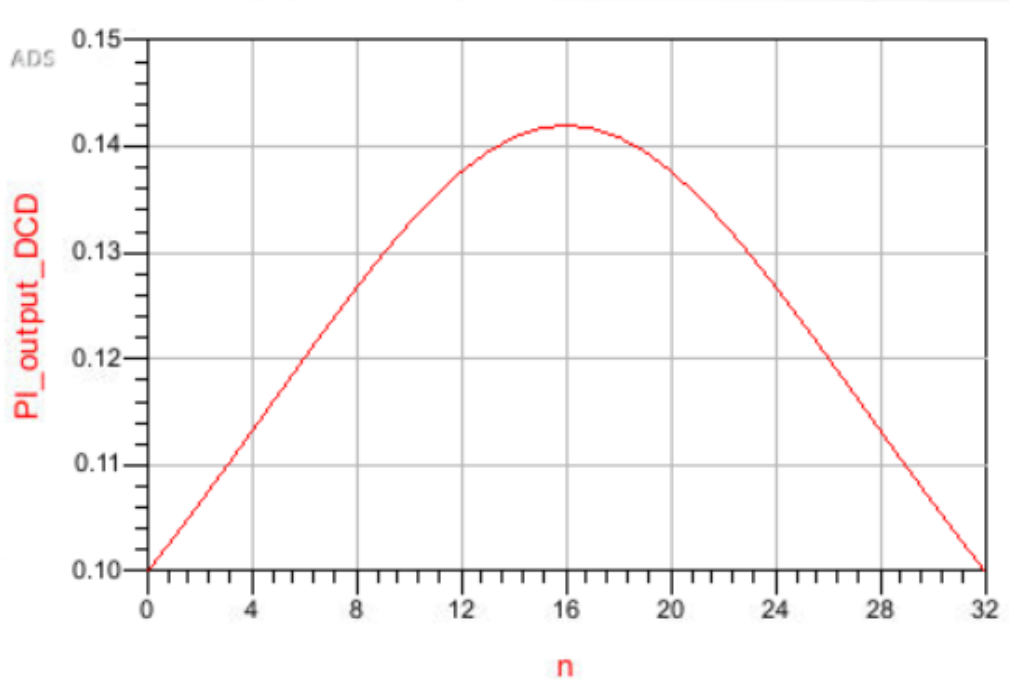
- Reference linear delay
- Actual delay

DQS Jitter Amplification by Phase Interpolator

Example of DQS jitter amplification by phase interpolator (PI)

$$v_{out}(t) = \frac{n}{N} v_{in}(t - \tau_1) + \frac{N - n}{N} v_{in}(t - \tau_2), \qquad n = 0,1, \dots, N$$

- N=32, τ_1=0, τ_2=UI/2. No LPF
- 10% DCD in phase interpolator input DQS
- Output DQS DCD >= 10% and varies with n
- Jitter amplification is a direct result of mixing
- With LPF the amplification is even larger



Impossible to model this effect without DQS waveform

DQS Correlated Voltage Noise

- DQ and DQS voltage noise can be correlated
- If this effect is not modeled, eye width can be underestimated by up to 10%
- DQS waveform is needed to model voltage noise impacts on phase interpolator, slicer and hence DFE

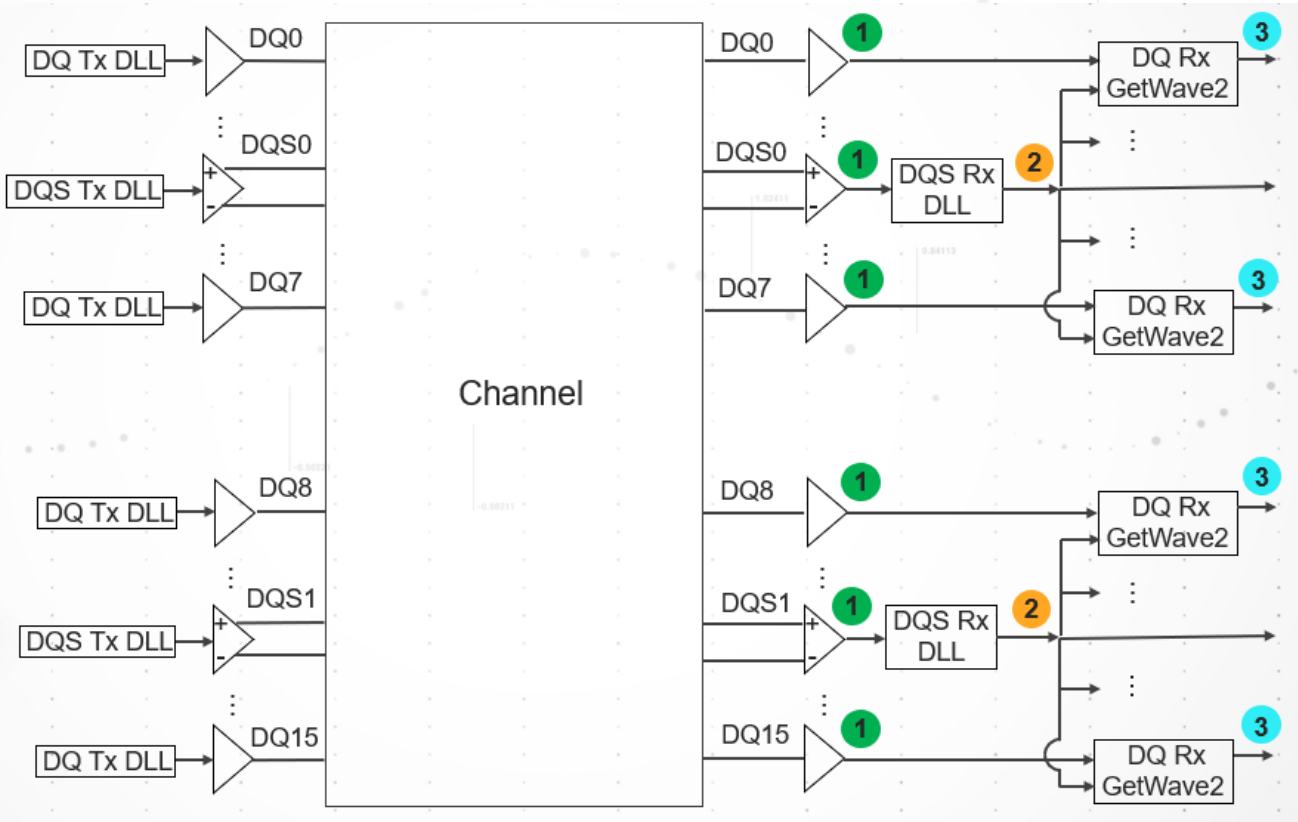
Comparison Between GetWave2 and GetWave

Effect to model	GetWave2	GetWave with clock time input	GetWave with internal CDR
Clock forwarding and DQ-DQS jitter tracking	Yes	Yes	No
DQ slicer sensitivity in terms of DQS slew rate	Yes	No	No
Physical model of phase interpolator (PI)	Yes	No	No
PI output delay nonlinearity and discretization	Yes	No	No
DQS correlated voltage noise	Yes	No	No
DQS jitter amplification by PI	Yes	No	No

- These factors critically impact system performance
- IC vendors specifically request these effects to be modeled
- Note that GetWave is still supported and can coexists with GetWave2. A model can still implement GetWave that uses clock time input or internal CDR

Simulation Flow Complexity

- Complexity added to the flow by GetWave2 is minimal
- Note that all steps already exist in current flow. Just need to make sure step 2 is done before step 3.
- The flow is even more complex with GetWave that uses clock time input because clock times need to be extracted from DQS waveform by EDA tools



Step 1: compute analog channel output according to current flow (crosstalk taken into account)
Step 2: compute output of all **DQS** Rx DLLs
Step 3: compute output of all **DQ** Rx DLLs

Summary

- GetWave2 addresses critical DDR5 modeling requirements that GetWave cannot meet.
- GetWave coexists with GetWave2 in simulation. Models implement GetWave still work as before.
- The GetWave2 approach is technically solid. So far no issue regarding its technical viability.
- ATM members had collaborated successfully on the DC offset issue previously. We plead with the group to collaborate again on the clock forwarding issue.