A Slew/Load-Dependent Approach to Single-variable Statistical Delay Modeling

Tau Workshop 2014

Brandon Bautz & Swamy Lokanadham
Cadence

cādence®

Abstract

Industrial demand for higher performing digital semiconductor products has highlighted the clear need to reduce design guard-band without sacrificing time-to-market.

Improvements to on-chip variation modeling are a driving component of this guard-band reduction strategy.

In this presentation we review current industry approaches to on-chip variation modeling

introduce Statistical OCV (SOCV) method, which utilizes a single statistical parameter representing sigma variation. SOCV extends existing single-variable statistical approaches by adding slew and load-dependent sigma per timing arc.

We highlight accuracy benefits of the slew/load dependency by presenting test circuit simulation results using Monte-Carlo simulation as a reference.

SOCV implementation details including target performance metrics, user-interface details, and library characterization process. Enhancements to the industry-standard .lib format are also introduced.

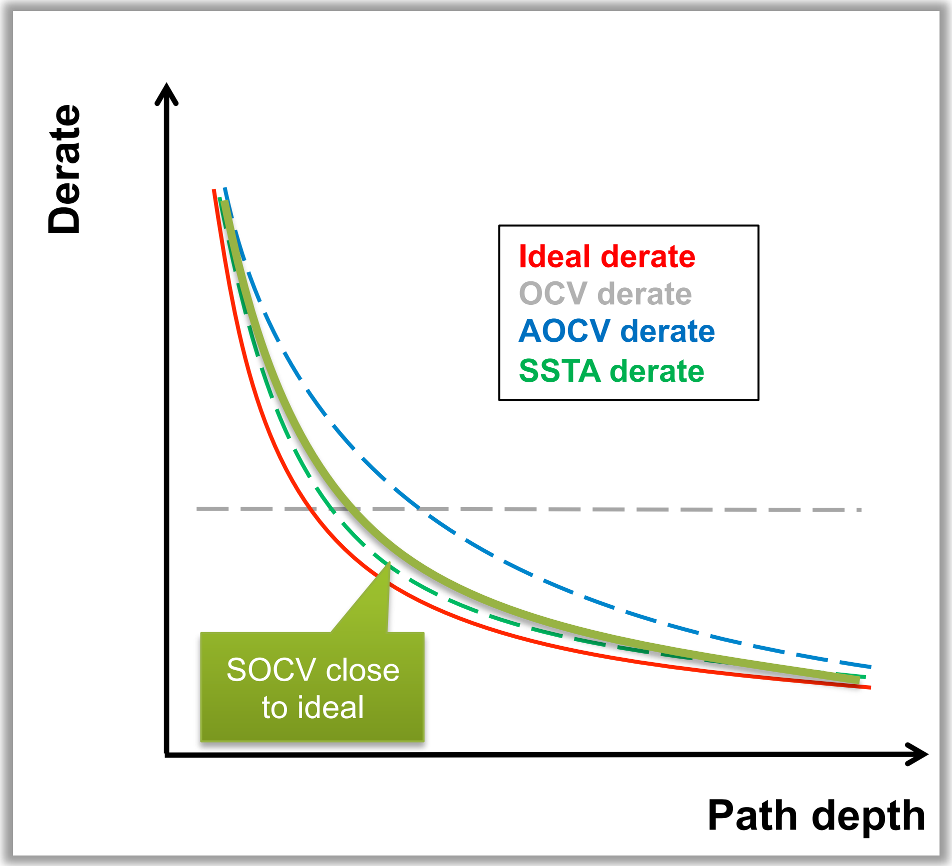
Agenda

- Review of Industry variation modeling approaches
- Introduction to Load/slew-dependent SOCV
- SOCV implementation details

Industry Trends

Industry variation modeling approaches

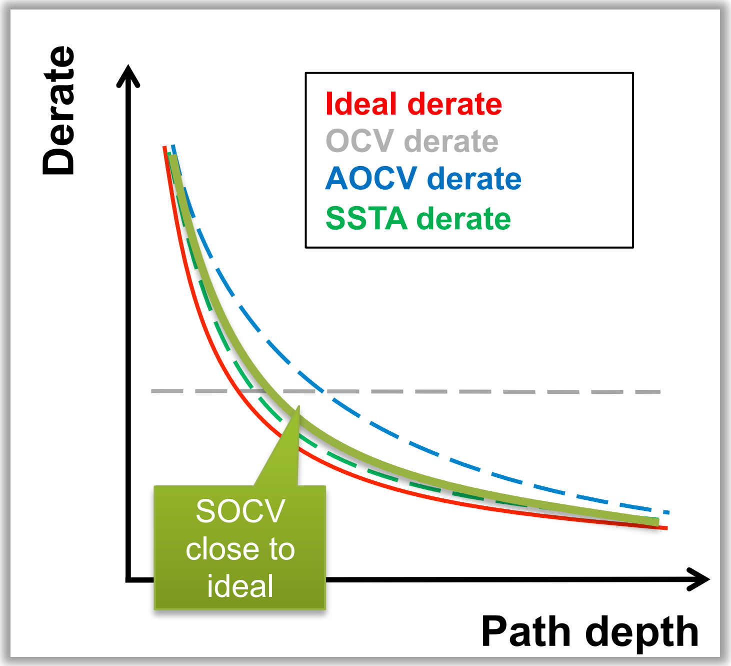
- Customer demands
  - Reduce pessimism in variation modeling
  - Faster runtimes than traditional SSTA
  - Improved correlation with Spice (and silicon)
- Current short-comings:
  - OCV
    - Excessive over/under derate
  - SSTA
    - CPU-intensive (analysis & characterization)
  - AOCV
    - GBA depth count over-derates
    - Lacks slew/load dependence



cadence

Statistical OCV (SOCV) Overview

- SOCV highlights
  - Statistical parameter as a delay sigma variation
  - A function of input slew and output load
  - Arc level granularity
  - Accuracy and correlation with Spice (silicon)
  - Close correlation of GBA and PBA
- Benefits
  - Close correlation to ideal derate profile
  - Fast runtimes approaching traditional STA
  - In-house characterization through Variety or reuse of existing AOCV tables

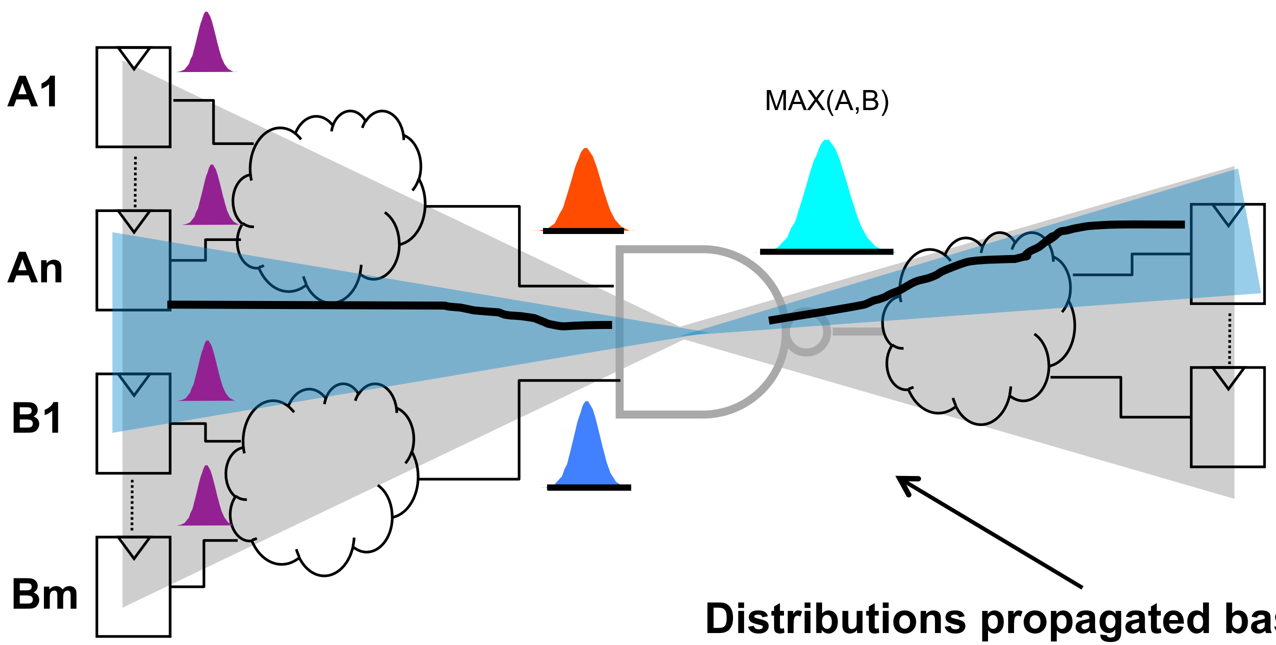


cadence®

Introduction to SOCV

Statistical OCV - SOCV

- A simplified flavor of SSTA using single local variation (single variable SSTA)
- Accurately captures statistical cancellation of uncorrelated variations
- Solves the major limitation of AOCV
  - Slew/load dependency of variation
  - Assumption of same cell/load in the path
- Provides near-SSTA accuracy with touch-n-feel of STA
- Small additional cost of runtime/memory over AOCV
- Signoff-accurate SI handling



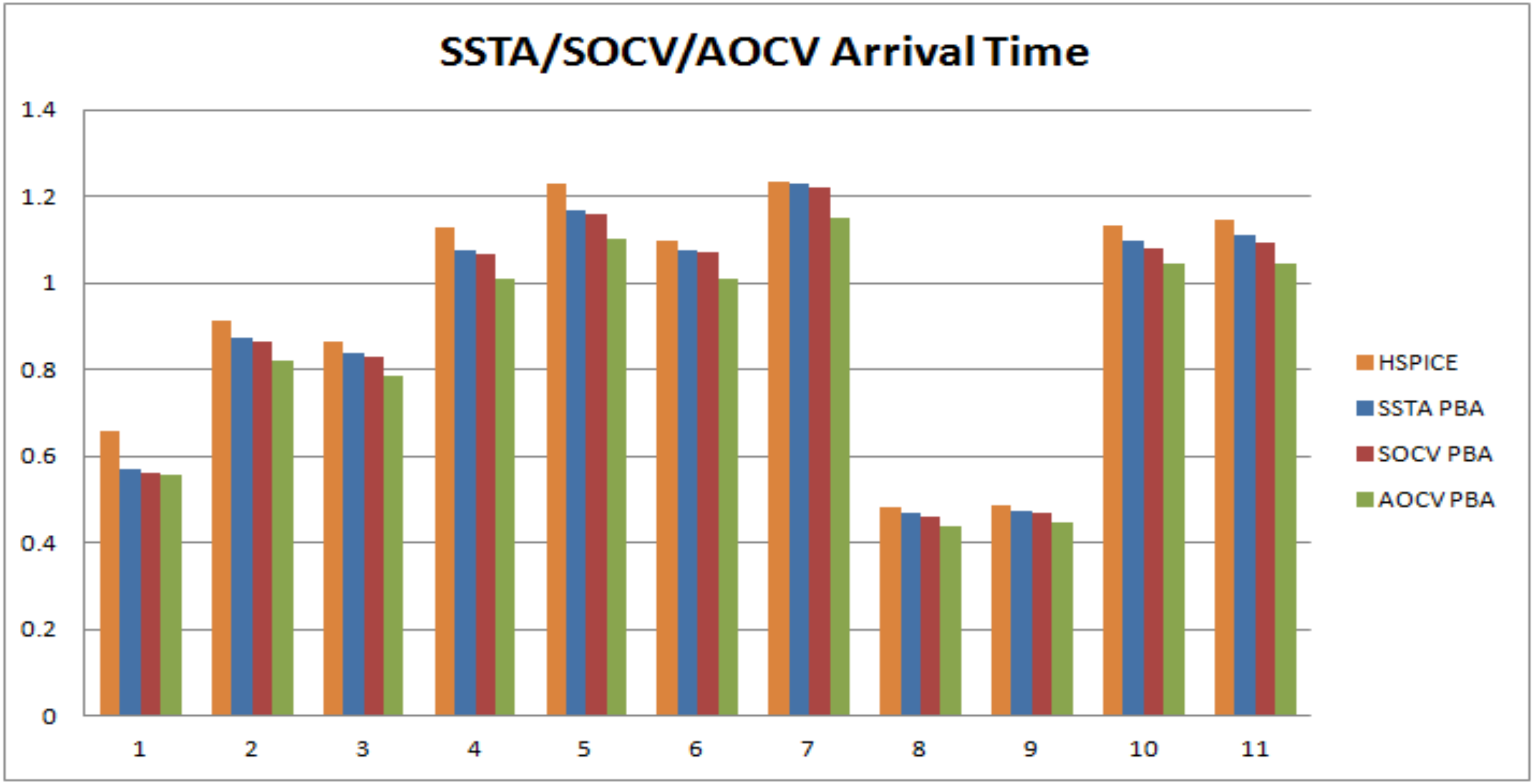
Distributions propagated based on cell delay sigmas

SOCV Modeling

- Models each cell for variation
  - Per timing arc
  - Per load
  - Per slew
- Delay sigmas are correctly derived vs. AOCV derates
  - AOCV derates based on unrealistic homogeneous structures
  - AOCV lacks slew / load dependence
- Faster generation than AOCV
  - Does not require stage by stage characterization
  - Cannot extend AOCV easily to allow load and slew
- Excellent correlation with Spice (Monte Carlo)

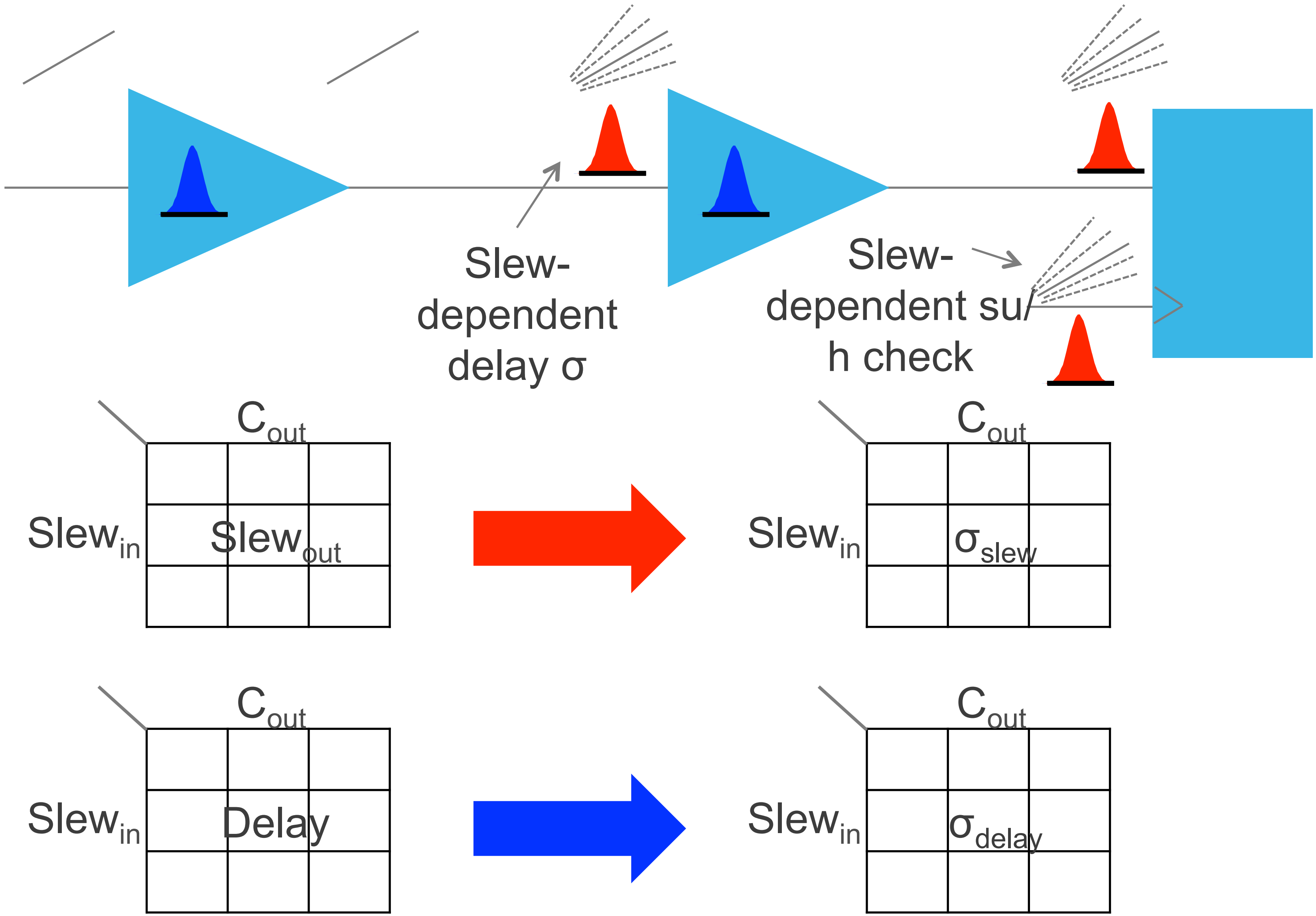
Correlation to Monte-Carlo Spice Simulation

The plot below shows the Arrival Time values from SSTA PBA, SOCV PBA and AOCV PBA and Monte Carlo SPICE for a few paths in a 28nm testcase



cādence®

SOCV with Slew/Load Dependency



cadence®

Slew/Load Dependency Accuracy Improvement

cadence®

Implementation Details

Internal SOCV library format

in partnership with TSMC

- Slew, load dependent sigma per timing arc (pin, related_pin, when) for delay, slew & constraint

SOCV Format

Keyword	Parameter
version	v0.1
sigma_unit	ps
distance_unit	um
begin	cell | wire | spatial
object_type	design | library
object_spec	library_name | cell_name
pin	pin_name (output | constraint_pin)
pin_direction	rise | fall
related_pin	pin_name
related_direction	rise | fall
type	delay | slew | setup | hold | removal | recovery
when	when_condition
related_transition	cell_transition
constraint_transition	constraint_transition
output_loading	cell_loading | wire_loading
distance	cell_distance
sigma	1-sigma value
end	cell | wire | spatial

Example

object_type: library
object_spec: lib_0p885v_125c_cworst/INVD1
pin: Z
pin_direction: rise
related_pin: I
related_direction: fall
type: delay
When: “”
input_transition: 0.0035 0.0133 0.0327 0.0717 0.1496 0.3053 0.6269
output_loading: 0.00023 0.00081 0.00196 0.00426 0.00887 0.01807 0.03649
distance:
sigma:
1.1 1.2 1.3 1.4 1.5 1.6 1.7 — (slew 0.0035, loads 0.00023,…,0.03649)
2.1 2.2 2.3 2.4 2.5 2.6 2.7
…
…
7.1 7.2 7.3 7.4 7.5 7.6 7.7 — (slew 0.6269, loads 0.00023,…,0.03649)

Liberty Variation Format (LVF)
Slew/Load Dependent Delay Sigmas

2.1.1.4 ocv_sigma_cell_rise and ocv_sigma_cell_fall groups

Similar to cell_rise and cell_fall groups, the ocv_sigma_cell_rise and ocv_sigma_cell_fall groups are defined under timing group.

While the cell_rise and cell_fall groups specify nominal delay value, the ocv_sigma_cell_rise and ocv_sigma_cell_fall groups specify absolute amount of variation offset values from nominal delay ***at one sigma***.

Delay value at +/- sigma can be calculated using variation delay values:

rise delay at +sigma = nominal rise delay + ocv_sigma_cell_rise value
fall delay at +sigma = nominal fall delay + ocv_sigma_cell_fall value
rise delay at –sigma = nominal rise delay – ocv_sigma_cell_rise value
fall delay at –sigma = nominal fall delay – ocv_sigma_cell_fall value

This table can be 3-dimensional, 2-dimensional, 1-dimensional or scalar.

The table index should be input_net_transition and total_output_net_capacitance. The table index_3 should be related_out_total_output_net_capacitance

cādence®

Liberty Variation Format (LVF)

Slew/Load Dependent Transition Sigmas

2.1.1.1 ocv_sigma_rise_transition, ocv_sigma_fall_transition group

Similar to rise_transition and fall_transition groups, the ocv_sigma_rise_transition and ocv_sigma_fall_transition groups are defined under timing group.

While the rise_transition and fall_transition groups specify nominal output transition value, the ocv_sigma_rise_transition and ocv_sigma_fall_transition groups specify absolute amount of variation **offset** values from nominal output transition **at one sigma**.

Output transition value at +/- sigma can be calculated using variation output transition values:

rise transition at +sigma = nominal rise transition + ocv_sigma_rise_transition value
fall transition at +sigma = nominal fall transition + ocv_sigma_fall_transition value
rise transition at –sigma = nominal rise transition – ocv_sigma_rise_transition value
fall transition at –sigma = nominal fall transition – ocv_sigma_fall_transition value

This table can be 3-dimensional, 2-dimensional, 1-dimensional table and scalar.

The valid values for index variable_1 and variable_2 are input_net_transition and total_output_net_capacitance.

The valid value for index variable_3 is related_out_total_output_net_capacitance.

cādence®

Example SOCV Report

- The format below is set as follows:

```
set timing_report_enable_verbose_ssta_mode true
set timing_set_nsigma_multiplier 3
set report_timing_format [list \
  timing_point edge cell delay_mean delay_sigma delay
  arrival_mean arrival_sigma arrival pin_location]
```

```
Path 1: MET Setup Check with Pin BLK/BR2/CK
Endpoint:   BLK/BR2/D (v) checked with  leading edge of 'WAVE'
Beginpoint: BLK/BR1/Q (^) triggered by  leading edge of 'WAVE'
Path Groups: {WAVE}
Analysis View: default_analysis_view_setup
Other End Arrival Time          0.639 (-3.00S) |  1.341 |  0.234
- Setup                         0.299 (+3.00S) |  0.299 |  0.000
+ Phase Shift                  10.000
+ CPPR Adjustment               1.125 (+3.00S) |  0.126 |  0.333
- Spatial Adjustment            0.161 (+3.00S) |  0.046 |  0.038
= Required Time                10.411 (-3.00S) | 11.122 |  0.237
- Arrival Time                  3.115 (+3.00S) |  2.244 |  0.290
= Slack Time                    8.363 (-3.00S) |  8.878 |  0.172
     Clock Rise Edge                      0.000
     = Beginpoint Arrival Time            0.000 (+3.00S) |  0.000 |  0.000
     Timing Path:
      -----------------------------------------------------------------------------------------------------------------------------------
       Timing Point                      Edge   Cell             Delay     Delay     Delay     Arrival    Arrival    Arrival    Pin
                                                                 Mean      Sigma               Mean       Sigma      Time       Location
      -----------------------------------------------------------------------------------------------------------------------------------
      tclk                              ^                                                     0.000      0.000      0.000      (499.00, 0.00)
      tclk                                     (net)
      CG/BC1/A                          ^      BUFX2            0.000     0.000     0.000     0.000      0.000      0.000      (499.00, 8.00)
      CG/BC1/Y                          ^      BUFX2            0.180     0.054     0.341     0.180      0.054      0.341      (498.00, 6.00)
```

Detailed header information shows

mean+nSigma (nSigma definition) | mean | sigma

cadence®

SOCV Performance Objectives

13M instance	Runtime (hr:min)	Memory
AOCV	0:59	28GB
SOCV	1:15	33GB

cadence®

cādence®

SOCV Accuracy Results

Tempus Nominal	Spice Nominal	% Diff Nominal	Tempus Sigma with Slew variation	Spice Sigma	% Diff Sigma
573.5	601.1	-4.59%	23.824	25.2	-5.4%
1100.2	1143.9	-3.82%	51.409	50.9	1.0%
640.9	667.2	-3.94%	17.355	18.3	-5.0%
887.8	897.9	-1.13%	20.716	19.7	4.9%
1351	1378.6	-2.00%	41.643	38.4	8.4%
1363.5	1390.7	-1.96%	40.694	40.2	1.1%
680.3	686.5	-0.90%	8.653	8.5	1.8%
916.8	946.5	-3.14%	40.182	41.1	-2.3%
727.8	734.5	-0.91%	13.253	13.3	-0.4%
539.1	547.2	-1.48%	10.621	10.4	2.2%
835.8	878.8	-4.90%	47.211	47.6	-0.8%
545.2	583.6	-6.58%	34.468	39.6	-13.0%
246.8	267.6	-7.78%	3.002	3.7	-18.2%
297.2	322.1	-7.73%	6.467	7.4	-12.6%
921.8	948.7	-2.84%	40.258	39.3	2.4%
706.2	733.1	-3.67%	30.741	30.2	1.7%
248.6	269.1	-7.62%	3.016	3.5	-13.8%
425.3	459.7	-7.48%	18.724	22.2	-15.6%
670.5	732.3	-8.44%	52.682	63.3	-16.8%
416.2	450.7	-7.66%	17.697	20.7	-14.3%
1108.1	1145.4	-3.26%	49.123	50.8	-3.3%
469.3	477.3	-1.67%	20.166	20.0	0.7%
273	275.5	-0.89%	4.788	4.8	0.6%

cadence®

SOCV Accuracy Results – BRCM structures without slew variation considered

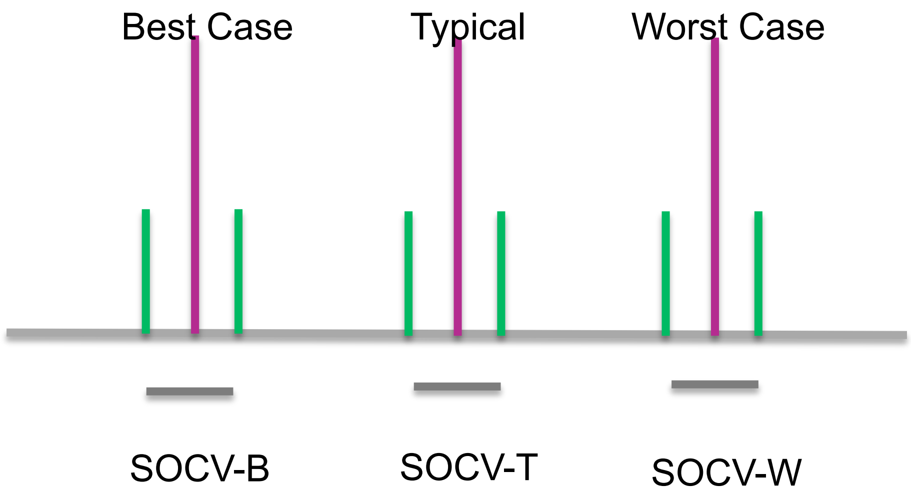
Sigma without Slew variation	Spice Sigma	Tempus Sigma **without Slew variation**
13.811	25.2	-45.15%
34.702	50.9	-31.84%
10.819	18.3	-40.76%
15.313	19.7	-22.44%
32.684	38.4	-14.93%
34.63	40.2	-13.93%
7.051	8.5	-17.05%
25.794	41.1	-37.27%
10.609	13.3	-20.23%
8.637	10.4	-16.87%
31.878	47.6	-32.99%
18.15	39.6	-54.17%
1.717	3.7	-53.22%
3.489	7.4	-52.85%
25.907	39.3	-34.08%
22.002	30.2	-27.24%
1.74	3.5	-50.29%
9.906	22.2	-55.33%
27.794	63.3	-56.09%
9.42	20.7	-54.39%
31.898	50.8	-37.20%
13.321	20.0	-33.48%
3.375	4.8	-29.10%

- Results show considerable degradation to MC reference when slew variation is **not** considered by Tempus

cadence®

Application of SOCV

- Better modeling of on chip variation at operating corners



- Utilize SOCV with global corner libraries
  - Minimizes double counting of embedded within-die-variation

Library	Variation Modeling	Accuracy
SS	AOCV	standard
SS	SOCV	better
SSG	SOCV	best