White Paper

Synopsys
Predictable Success

PrimeTime® Advanced OCV Technology

Easy-to-Adopt, Variation-Aware Timing Analysis for 65-nm and below

April 2009

Sunil Walia
Product Marketing Manager, Synopsys

Introduction

An accepted trend in the semiconductor industry, where process geometry is continuously shrinking, is the growing impact of variation in static timing analysis (STA). Similar to Signal Integrity (SI), which was introduced as a first order effect in 130-nm and then became more sophisticated over geometry nodes, on-chip-variation (OCV) started at 130-nm and its effects are increasing with shrinking geometry nodes. A preliminary solution to account for OCV was to apply a flat global margin across the entire chip. However, the growing impact of variation in modern designs requires an improved OCV handling capability that takes advantage of improved device-level variation techniques.

This white paper highlights the Advanced OCV solution, a sophisticated technology from PrimeTime for providing the right balance between accuracy and performance.

Why Advanced OCV?

On-chip-variation (OCV), the current standard model for variation in a designer's STA flow is the first-order approach that applies a blanket margin across the chip. With increasing variations due to process, voltage, and temperature, as well as increasing variations across the same die and from die-to-die, arriving at a single blanket margin number is difficult. There are growing concerns about OCV regarding overdesign, reduced design performance, and longer timing closure cycles. As this once practical and safe approach of applying the worst-case variation across the entire chip has become less acceptable, designers have sought ways to waive and relax the OCV effects. Questions such as "Why do adjacent cells see such a large variation swing?" and "Why do cells in paths of differing logic depths see the same variation?" illustrate the need for relaxation techniques and for the blanket OCV approach to take a different form.

The Advanced OCV capability in PrimeTime provides a better and more accurate solution that naturally extends OCV analysis to deliver an improved method of adding variation-related margin in the design.

What is Advanced OCV?

Advanced OCV technology in PrimeTime is an easy-to-adopt solution that takes into consideration the needs of today's designers to provide the right balance of accuracy and runtime for STA. It uses intelligent techniques for context specific derating instead of a single global derate value, thus reducing the excessive design margins and leading to fewer timing violations. This represents a more realistic and practical method of margining, alleviating the concerns of overdesign, reduced design performance, and longer timing closure cycles

The Advanced OCV solution determines derate values as a function of logic depth and/or cell, and net location. These two variables provide further granularity to the margining methodology by determining how much a specific path in a design is impacted by the process variation. Now, let us briefly discuss how these are related to variation terminologies used in the industry.

There are two kinds of variation: random and systematic. Random variation is proportional to the logic depth of each path being analyzed. Systematic variation is proportional to the cell location of the path being analyzed. The random component of variation occurs from lot-to-lot, wafer-to-wafer, on-die and die-to-die. Examples of random variation are variations in gate-oxide thickness, implant doses, and metal or dielectric thickness. The systematic component of variation is predicted from the location on the wafer or the nature of the surrounding patterns. These variations relate to proximity effects, density effects, and the relative distance of devices. Examples of systematic variation are variations in gate length or width and interconnect width. For more information, see the Variation Effects on Extraction and Timing Analysis Synopsys white paper.

Take the example of random variation, given the buffer chain shown in Figure 1, with nominal cell delay of 20, nominal path delay @ stage N = N * 20. In a traditional OCV approach, timing derates are applied to scale the path delay by a fixed percentage, `set_timing_derate –late 1.2; set_timing_derate –early 0.8`

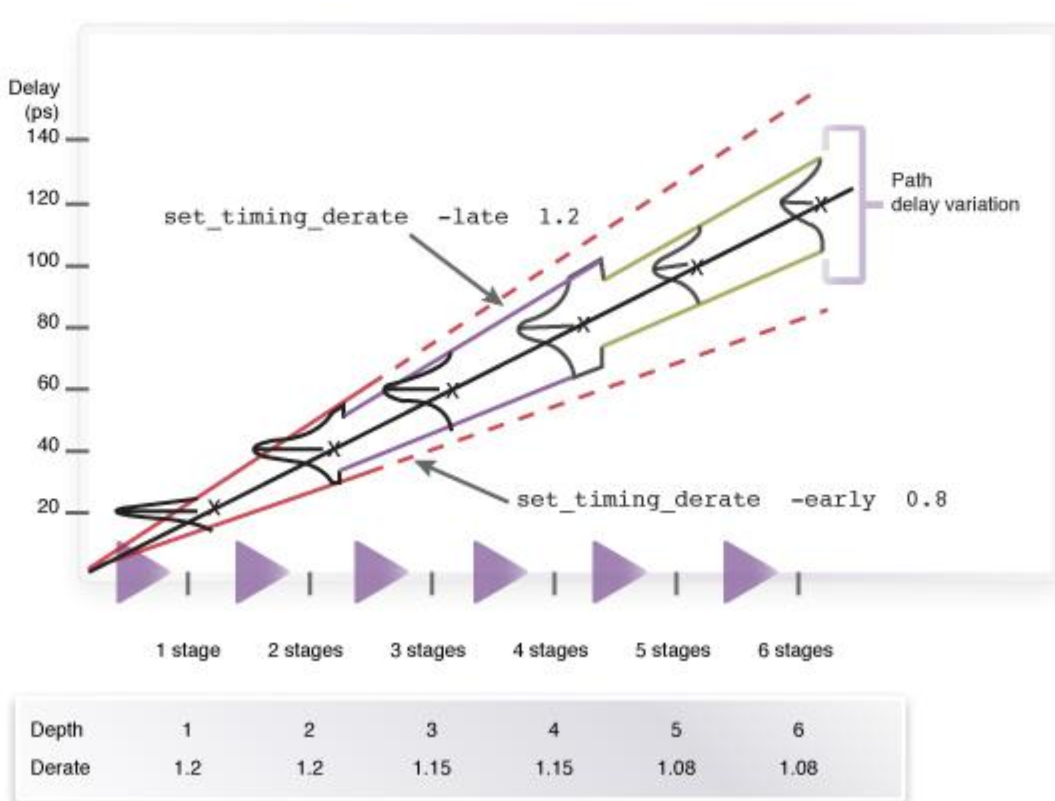


Figure 1: Depth-Based Statistical Analysis

Statistical analysis shows that the random variation is less for deeper timing paths and not all cells are simultaneously fast or slow. Using statistical HSPICE models, Monte-Carlo analysis can be performed to measure the accurate delay variation at each stage. Advanced OCV derate factors can then be computed as a function of cell depth to apply accurate, less pessimistic margins to the path.

Figure 2a shows an example of how PrimeTime Advanced OCV would determine the path depth for both launch and capture. These values index the derate table, as shown in Figure 7, to select the appropriate derate values.

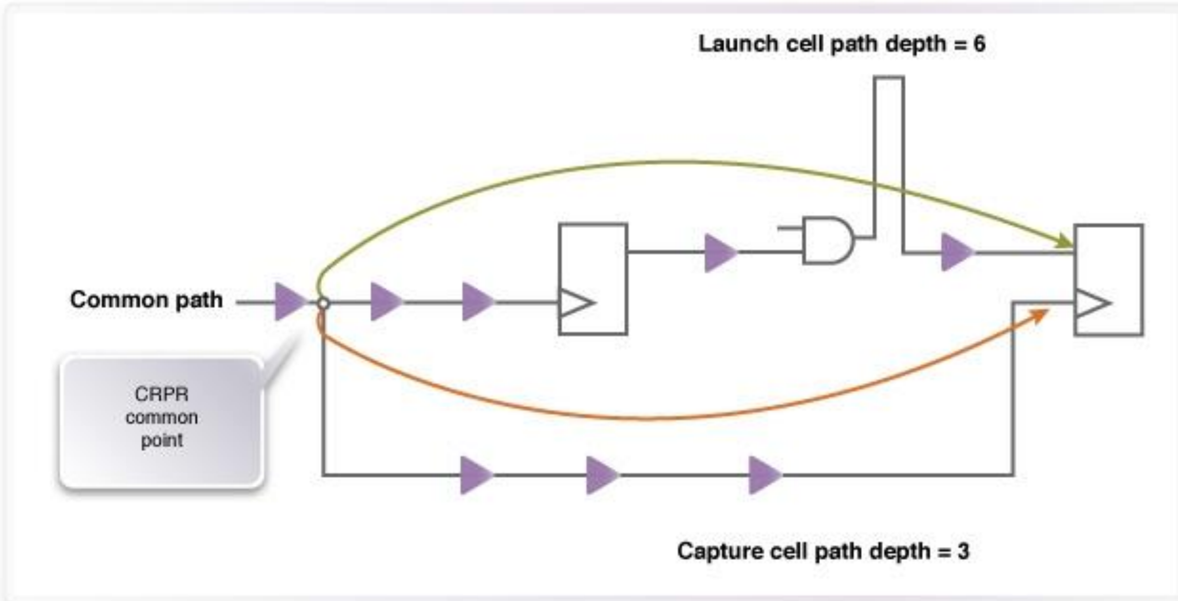


Figure 2a: Depth-Based Advanced OCV

Effects of systematic variation shows that paths comprised of cells in close proximity exhibit less variation relative to one another. Using silicon data from test-chips, Advanced OCV derate factors based on relative cell-location are then applied to further improve accuracy and reduce pessimism on the path. Advanced OCV computes the length of the diagonal of the bounding box, as shown in Figure 2b, to select the appropriate derate value from the table.

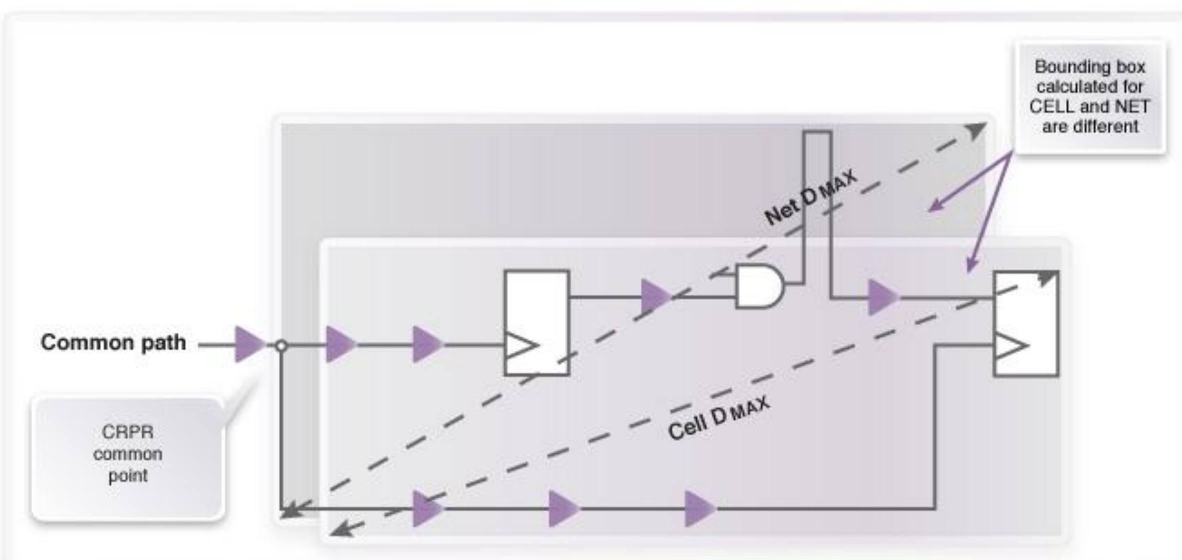


Figure 2b: Distance-Based Advanced OCV

PrimeTime Advanced OCV Flow

PrimeTime internally computes depth and distance metrics for every cell arc and net arc in the design. It picks the conservative values of depth and distance thus bounding the worst-case path through a cell.

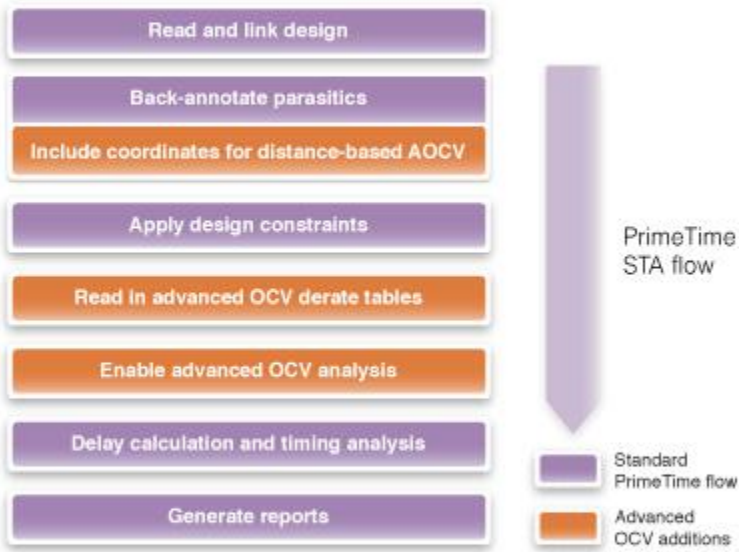


Figure 3: Minimal Script Edits Needed for Advanced OCV

The Advanced OCV flow in PrimeTime is simple to adopt with minimal script changes required, as shown in Figure 3**.**

For more information about the above steps of the flow, see the *stage-based on-chip variation analysis and optimization* application note in the TSMC Reference Flow 9.0.

PrimeTime provides a step-by-step approach to adopt Advanced OCV with the ease of deployment versus accuracy tradeoff as shown in Figure 4.

Beginning with Random Variation

As described earlier, there are two kinds of variation, random and systematic. The reason to begin with random variation is fairly straightforward – easy accessibility. The statistical HSPICE models required to calculate the depth-based derates are more easily accessible than the silicon data required for distance-based derates. These statistical HSPICE models are now provided by major foundries and IDMs upon request.

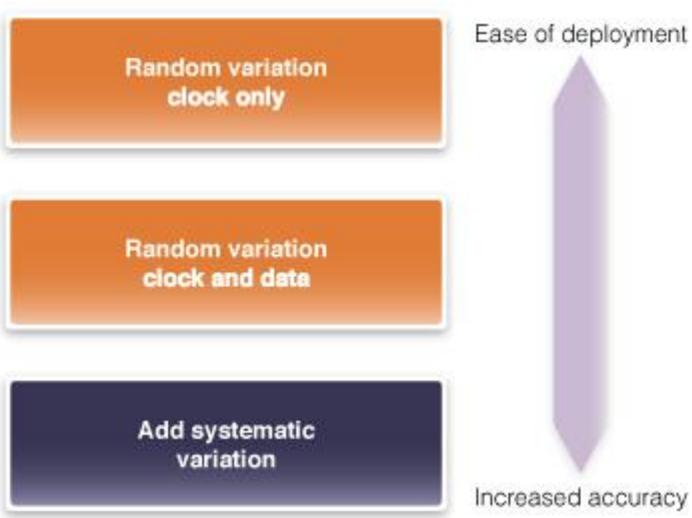


Figure 4: Advanced OCV Flow Recommendation

A. Begin with clock-based analysis

A clock network-only analysis can simplify the adoption of Advanced OCV. By limiting the analysis to clocks, the derate tables are only required for the clock cells, which are typically a small portion of the full cell library.

From the example provided in the Benefits of Advanced OCV section, the slack improvement obtained by considering just the clock network is significant. The reason is because the clock tree is one of the most variation-sensitive parts of the design. Because of the complexity of the deep-submicron processes, designers can no longer ignore the variation between devices and interconnect characteristics on the same die. This fact is more evident on the clock network, in which speedup and slowdown in the clock latency to logically dependent flip-flops can lead to slower parts and failure to hit the performance targets. In the worst case, these issues can lead to hold failures and, ultimately, inoperable devices.

B. Include clock and data for further improvements

The next level of Advanced OCV analysis is to include both clock and data cells in the timing analysis. This requires derate tables for both the clock and data cells in the library which may add a significant amount of effort and time for derate calculations depending on how many data cells there are in the library. The return is improved accuracy and reduced pessimism in PrimeTime, as variation effects along the entirety of each path are taken into consideration.

Adding Systematic Variation

The derate factors for systematic variation are based on silicon data. Unlike random variations, which generally assume a type of distribution, modeling of these variations is based on detailed empirical measurements of how variation relates to the geometric separation between devices. Due to the accessibility difficulties, most customers do not have appropriate tables or data readily available.

Design Closure with Advanced OCV

There are two phases for performing timing engineering change order (ECO) fixing with Advanced OCV to achieve timing closure on a design.

PrimeTime ECO Flow for Timing Convergence

As designers start their initial timing analysis runs, the timing convergence process can benefit from using actual PrimeTime sign-off timing analysis. This is to ensure that design timing is converging to closure across all modes and corners. PrimeTime ECO flow is recommended for early ECOs and Advanced OCV fixing is supported in this flow. One of the main benefits of this flow is the quick estimation that can be performed without any timing updates or netlist changes for faster prediction. This step allows you to identify possible solutions to fix the timing violations and also review the impact of these fixes.

IC Compiler Exact Link for Timing Closure

The ECO flow between IC Compiler and PrimeTime has been in place for several years. IC Compiler implementation uses timing and extraction engines that are tightly correlated to PrimeTime and StarRC™. As designs move into final ECO's for timing closure, increased change control is necessary and this is when IC Compiler utilizes the `signoff_opt` command with its exact link to PrimeTime and StarRC. Its –`aocvm` option enables IC Compiler to automatically fix timing violations using Advanced OCV information. The IC Compiler `signoff_opt` command is recommended for final ECOs for precision ECO fixing as it has the complete physical context. For more information about the IC Compiler sign-off flow, see the IC Compiler user guides.

Customizing Advanced OCV Timing Flows

There is added flexibility for customizing the Advanced OCV timing flow with the below mentioned features.

- Guard-Banding

  In addition to Advanced OCV derates, you can specify guard-band timing derates, to model non-process related effects in an Advanced OCV flow (for example, IR drop). The resulting derate factor applied to an arc is a product of the Advanced OCV derate and guard-band derate.

$$F_{\text{Total}} = [\, F_{\text{Process Variability}} \,] \quad X \quad [\, F_{\text{IR Drop}} \; x \; F_{\text{Margin}} \; x \; F_{\text{Tool Error}} \; x \; \ldots]$$
$$= [\, F_{\text{Advanced OCV}} \,] \quad X \quad [\, F_{\text{Guardband}} \,]$$

- Cell-Based Depth Coefficients

  By default, all cells count as “1” for depth computation. However, cells comprised of many transistors can exhibit less variation than other standard library cells. This feature, as shown in Figure 5, provides the added flexibility of using a different depth coefficient to provide a larger depth count for such cells and, therefore, improving accuracy.

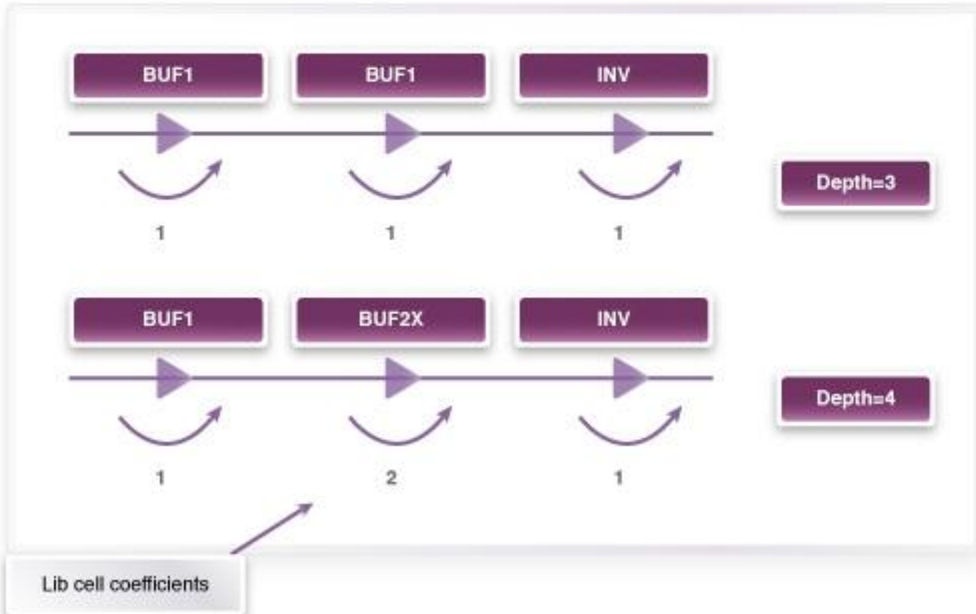


Figure 5: Cell-Based Depth Coefficients

- Compression and Encryption of Advanced OCV Tables

  PrimeTime provides encryption facility in a binary format to protect sensitive process related information in the tables. A compression technique is also available to reduce the size of the output binary Advanced OCV file.

- Graph-Based and Path-Based Solutions

  You can use the Advanced OCV technology in PrimeTime for both graph-based and path-based solutions. Graph-based solutions provide faster results with some accuracy tradeoff. Path-based solutions provide highly accurate results for selective applications during sign-off analysis, as they take longer to run.

Advanced OCV Table Generation

PrimeTime provides a derate table-based solution to specify the Advanced OCV information. Depth is used to index the random component of variation, and distance is used to index the systematic component in an Advanced OCV derate table, as shown in Figure 6. The tables can be annotated on a design, library cells, or hierarchical cells, in a pre-defined prioritized order.

Depth

Distance	1	2	3	4	5	10	50	100
1000	1.130	1.099	1.085	1.078	1.074	1.063	1.055	1.053
2000	1.130	1.099	1.086	1.079	1.074	1.063	1.055	1.054
3000	1.131	1.100	1.186	1.079	1.075	1.064	1.056	1.054
4000	1.131	1.100	1.187	1.080	1.076	1.065	1.057	1.056
5000	1.133	1.102	1.189	1.082	1.078	1.068	1.061	1.059
6000	1.135	1.105	1.192	1.086	1.082	1.072	1.065	1.063
8000	1.137	1.108	1.195	1.089	1.085	1.076	1.070	1.068
10000	1.140	1.112	1.100	1.094	1.090	1.082	1.075	1.074
15000	1.147	1.120	1.110	1.104	1.101	1.093	1.088	1.087

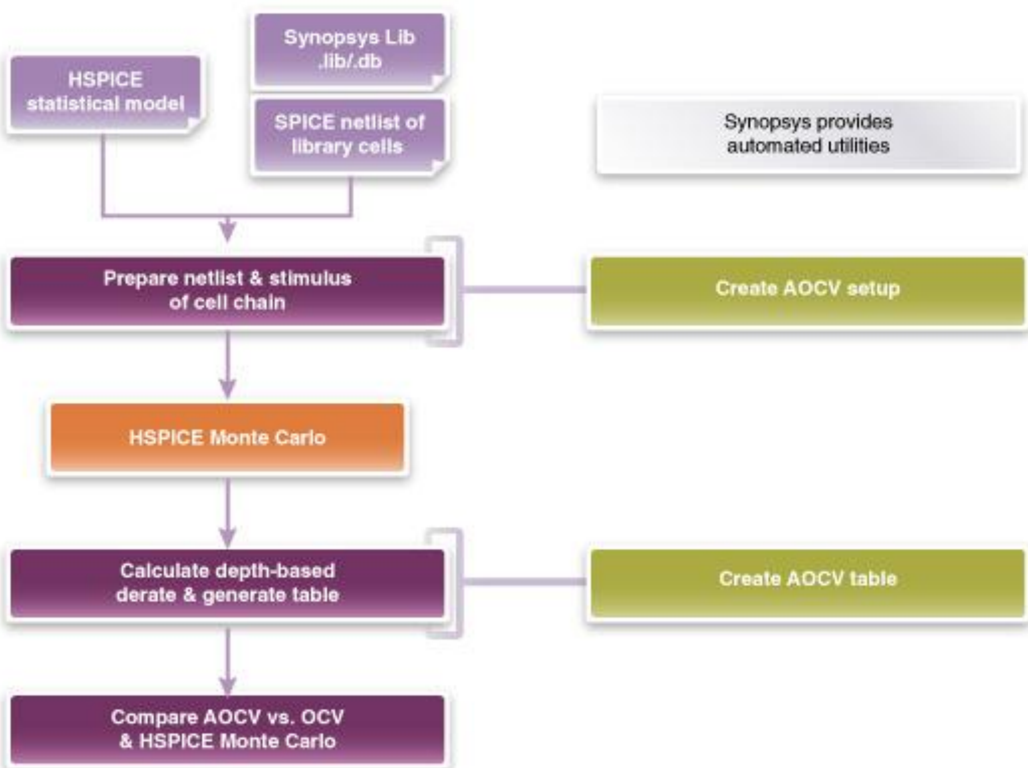
Derates increase with distance

Derates decrease for longer paths

Figure 6: Advanced OCV Derate Table

Synopsys provides automated utilities to make the table generation process easier. The inputs required to generate the table are the statistical HSPICE models, sub-circuits, and .lib or .db files. The three steps for this process, as shown in Figure 7 are:

1. Create input and stimulus for Monte-Carlo HSPICE.
2. Run Monte-Carlo HSPICE.
3. Generate the depth-based derate tables.



-

Figure 7: Depth-Based Derate Table Generation Process

The validation step ensures that the table can be read successfully by PrimeTime. It checks the monotonicity of the derate data, and consistency between the depth level and derate data.

Benefits of Advanced OCV

The largest benefit of moving from traditional OCV to Advanced OCV is higher accuracy. Note the results in Figure 8 on an inverter chain for arrival path times, which are much closer to Monte-Carlo HSPICE in advanced OCV than traditional OCV. This has been proven with silicon data by customers on their designs that have taped-out using Advanced OCV.

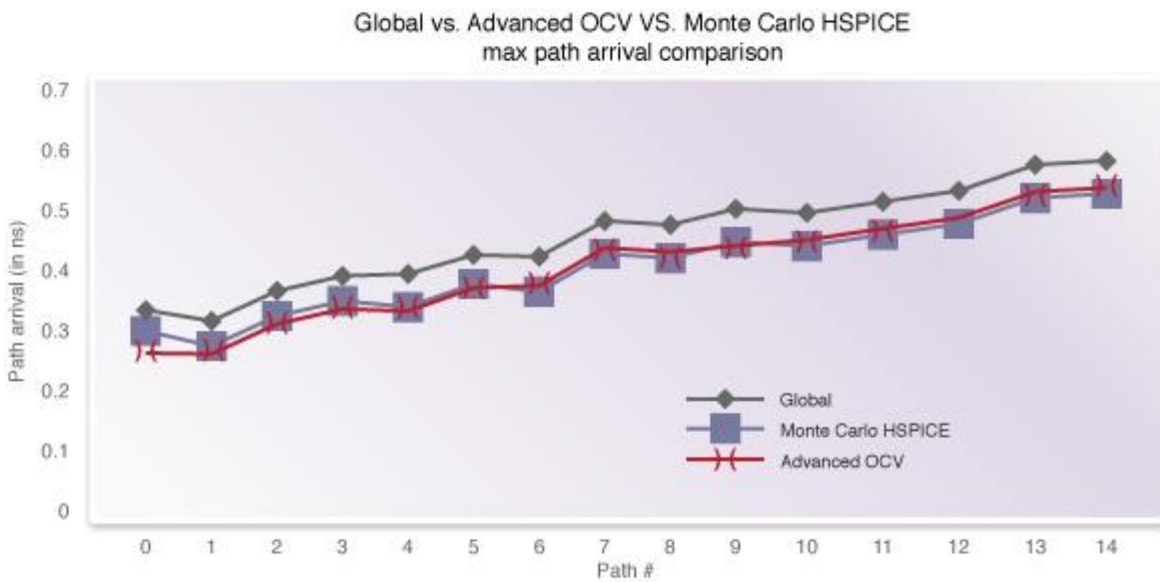
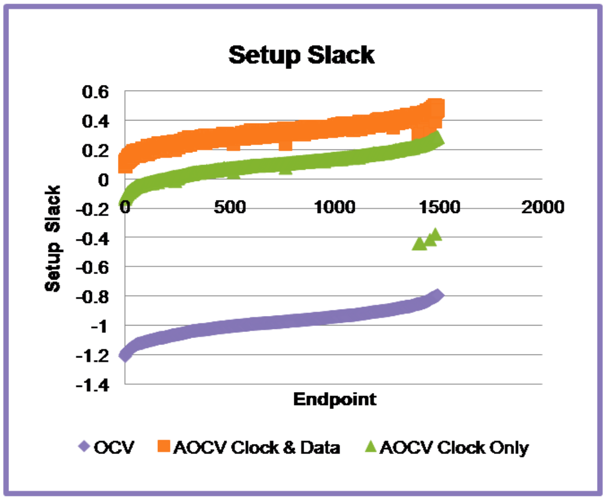
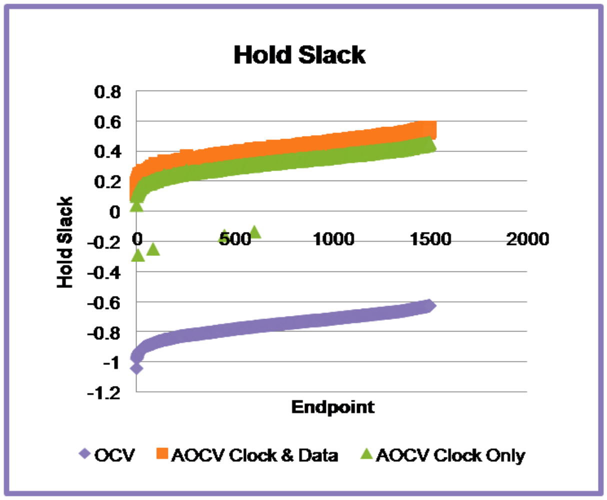


Figure 8: Advanced OCV Accuracy Results

Another benefit of Advanced OCV is the significant slack improvement or pessimism reduction compared to traditional OCV. The reason is due to the intelligent margining based on logic depth and cell location applied in Advanced OCV compared to a flat derate applied in traditional OCV.

In the results shown in Figure 9, the slack improvement with the clock-based Advanced OCV analysis and both the clock and data Advanced OCV analysis, as compared to traditional OCV, can be observed on a 65-nm customer design. On this particular design, the customer noticed an average 32% worst negative slack (WNS) improvement with respect to the clock period on hold slack. Advanced OCV clock analysis cut the violation count by half and Advanced OCV clock and data analysis further reduced it by 25%.





OCV Method	# Violations
Global Derate	1778
Advanced OCV Clock Only	1551
Advanced OCV Clock & Data	595

OCV Method	# Violations
Global Derate	1704
Advanced OCV Clock Only	850
Advanced OCV Clock & Data	176

Figure 9 Advanced OCV Slack Improvement on customer design

Clock-only Advanced OCV analysis provides the lowest adoption cost with significant reduction in outliers and the least effort required to generate the Advanced OCV derate tables. Further data analysis on this same 65-nm design shows an improved clock skew estimation due to accurate clock variation. The clock skew was reduced by 60 ps on one of the main clocks in the design.

The net effect of the above benefits of Advanced OCV is faster design closure due to optimization on fewer paths needed at sign-off. This saves time and effort for designers during the last crucial phases of the design process and avoids post-processing or complicated waiver mechanisms, which could be prone to human error.

Conclusion

Advanced OCV in PrimeTime calculates and applies variable derate factors that model process variations more closely than traditional OCV's global derating. Advanced OCV supports both random (depth-based) and systematic (distance-based) effects for cell and net delays.

Synopsys recommends a step-by-step, easy-to-adopt Advanced OCV flow with minimal changes to the script starting with random variation on clock network only. Synopsys also provides automated utilities to generate a depth-based Advanced OCV derate table for easy plug-and-play.

Advanced OCV usage is growing day-by-day with user community observing the clear benefits of reduced pessimism and faster design closure for 65-nm technologies and below. Advanced OCV is also a practical step towards statistical STA.

References

[1] *Variation Effects on Extraction and Timing Analysis*, White Paper by Chris Papademetrious and Omar Shah, October 2006 (SolvNet Doc ID 020920)

[2] *On-chip variation and timing closure* by Anis Jarrar and Kirk Taylor, Freescale Semiconductor, EDN, June 22 2006

[3] *Stage-based on-chip variation analysis and optimization*, Application Note, TSMC Reference Flow 9.0, June 2008

SYNOPSYS
Predictable Success Synopsys, Inc. • 700 East Middlefield Road • Mountain View, CA 94043 • www.synopsys.com