ML-based High-Sigma Verification Methodology: SVS Methodology

Samsung Electronics : Kwonchil Kang, Himchan Park, Seongkyun (Gabriel) Shin

Siemens EDA : Sungyoun Lee

Challenges of Analog IP High-Sigma Verification

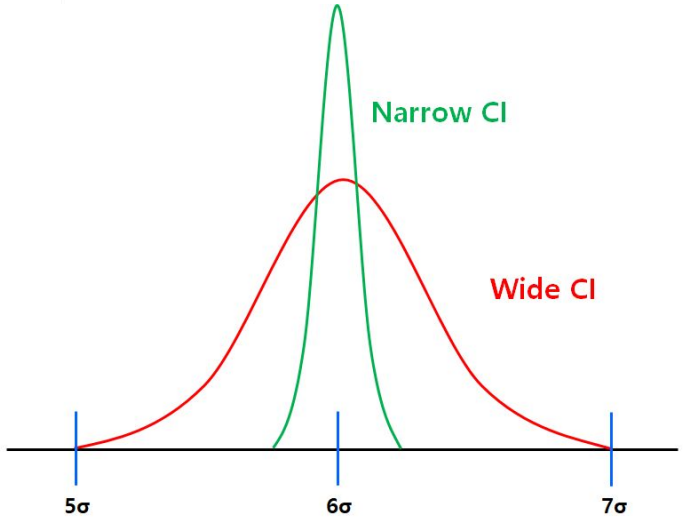
- Demands of analog IP high-sigma verification
  - As technology developed, analog IP designers require high-sigma verification (e.g., 6-sigma) to ensure design quality
- Traditional brute-force Monte Carlo simulation not practical for high-sigma
  - E.g., 6-sigma verification requires 10.1 billion simulations
- Limitation of high-sigma verification
  - ML-based high-sigma solution
  - Fast high-sigma solution

The latest high-sigma solution trends

- ML-based brute-force-accurate high-sigma solution
  - Brute-force-accurate
  - Verified answers with machine learning (ML)
  - Too much time to apply to all PVT sets
  - Example: Solido High-Sigma Verifier (HSV)
- Fast high-sigma solution
  - Using scaled sigma method
  - Relatively wide confidence interval (CI)
  - Example: Solido PVTMC Verifier (PVTMC)

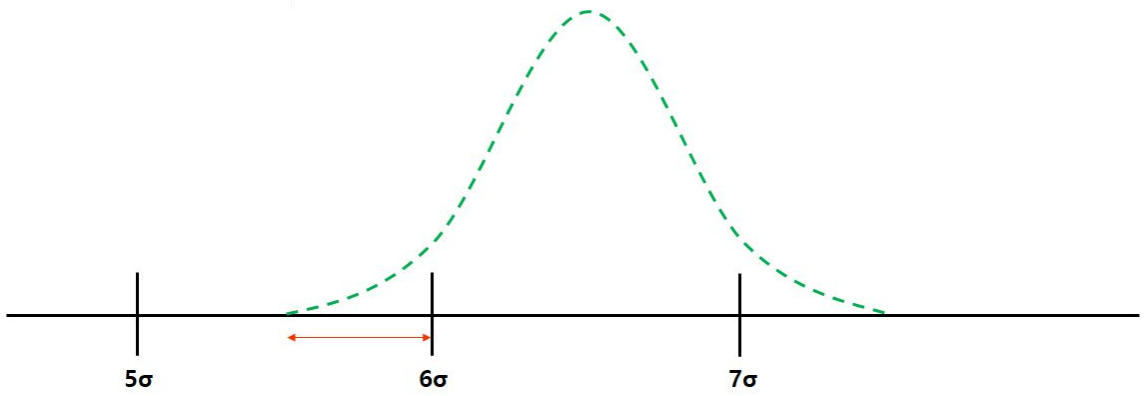
Confidence interval

- Confidence interval (CI)
  - A range of estimates for unknown parameter



- Narrow Confidence interval
  - a smaller range of estimates at a particular confidence level
- Wide Confidence interval
  - a wide range of estimates at a particular confidence level
- For a narrow confidence interval, we need to simulate a lot of samples

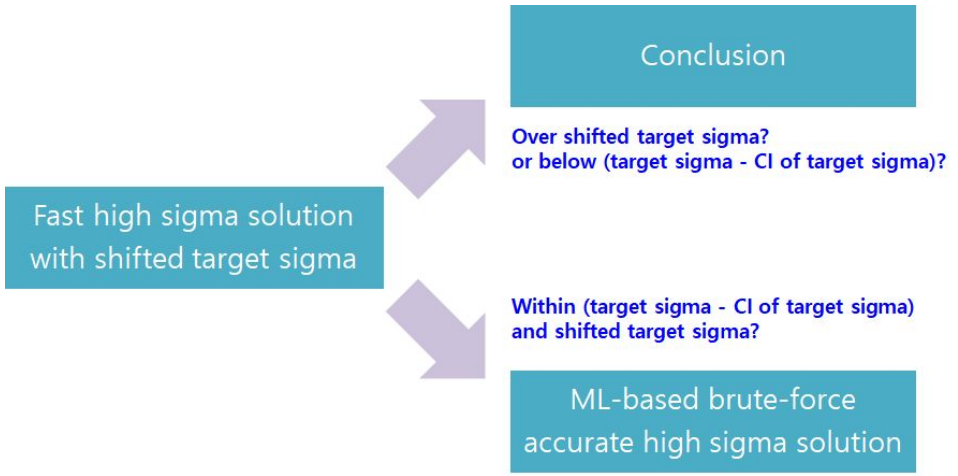
Wide confidence interval problem



- For example, the result of 6.5 sigma (green line) using a high-sigma tool with ± 1 CI may be a value between 5.5 sigma and 7.5 sigma
- In a 6-sigma verification, even if the 6.5 sigma result by a high-sigma tool passes, serious errors may occur because the actual results may be less than 6-sigma (red arrow line) for a statistical reason of CI

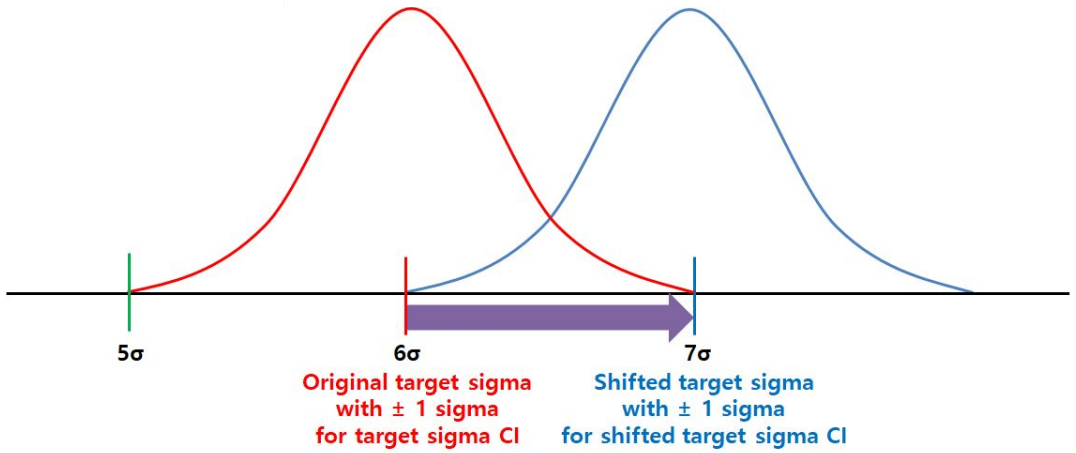
Shifted Vector Sampling (SVS) Verification Methodology

- Shifted Vector Sampling (SVS) Verification
  - Using fast high-sigma solution with shifted target sigma reflecting confidence interval (CI)
    - Due to wide CI in fast high-sigma solution, we apply shifted target sigma to determine whether it is a statistically verified area
  - Using ML-based brute-force-accurate high-sigma solution for clear results
    - If output result is within unclear range considering CI, we can verify by ML-based brute-force-accurate high-sigma solution

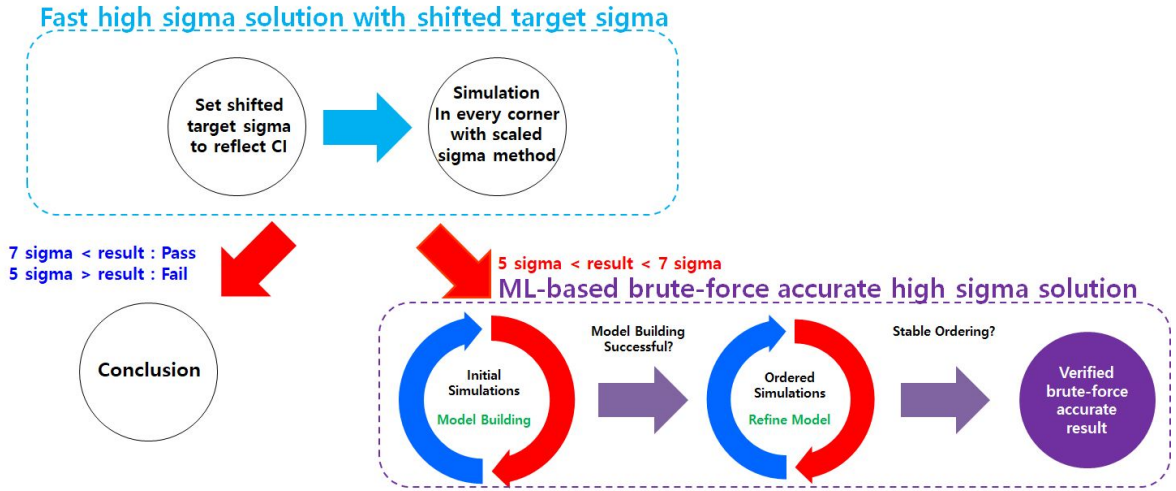


Schematic of SVS Verification at 6-sigma

- Shifted target sigma @ 6-sigma

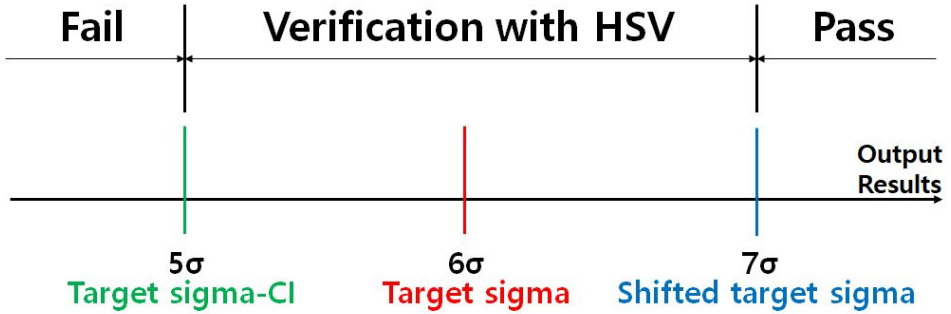


- Schematic SVS Flow @ 6-sigma



Example of SVS Verification at 6-sigma

- SVS Verification at 6-sigma
  - Set up 7 sigma as shifted target sigma, using ± 1 sigma of CI in fast high-sigma solution
  - Run fast high-sigma solution
  - Make a decision as below:
    - > 7 sigma: All pass
    - 5~7 sigma: run ML-based brute-force-accurate high-sigma solution
      - Optimism should be verified (6~7 sigma): If the actual result is “Fail” but predicted by “Pass”
      - Pessimism should also be examined (5~6 sigma): If the actual result is “Pass” but predicted by “Fail”
    - < 5 sigma: Fail



- Using SVS verification, we can conclude only with fast high-sigma solution within a specific output without ML-based brute-force-accurate high-sigma solution

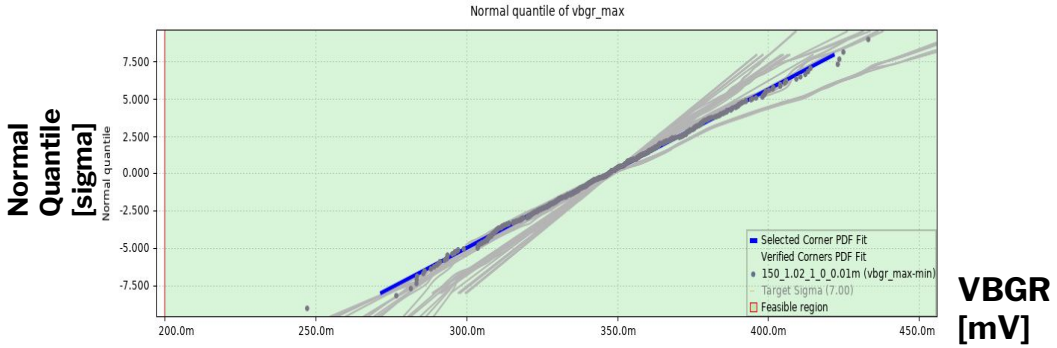
SVS results at the Best Cost Reduction Case

- BGR Case1 (without HSV case)

	ML-based brute-force-accurate high-sigma solution	SVS Method	Cost Reduction
Runtime	4 weeks*	1 day	**~28X**
Samples	771600*	18000	**~43X**

* estimated

- PVTMC Verifier Results with shifted sigma target



For the verification, we use Solido PVTMC Verifier and High-Sigma Verifier (HSV), as representative tools for fast high-sigma solution and ML-based brute-force-accurate high-sigma solution, respectively

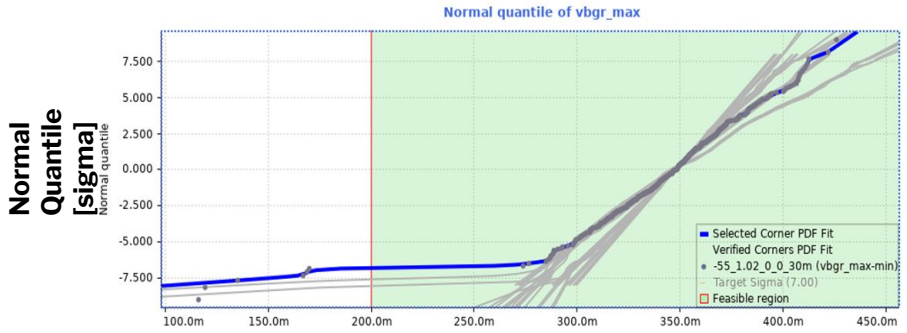
SVS results at the Worst Cost Reduction Case

- BGR Case2 (with HSV case)

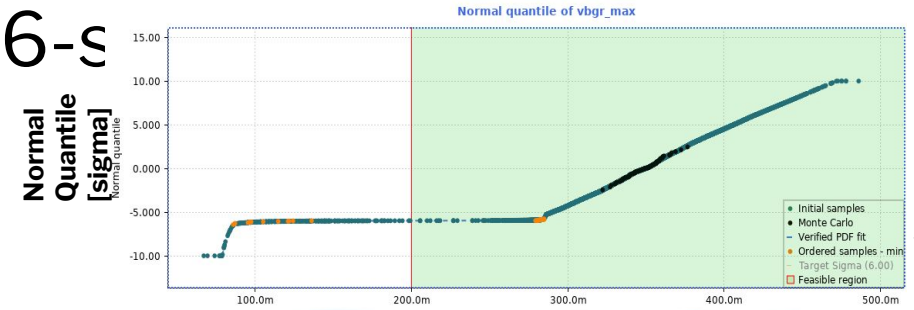
	ML-based brute-force-accurate high-sigma solution	SVS Method	Cost Reduction
Runtime	4 weeks*	7 days	**~4X**
Samples	771600*	18000+25100	**~18X**

* estimated

- PVTMC Verifier Results with shifted sigma target



- Additional HSV Results @ 6-s



Summary

- High-sigma verification is required for analog IPs for advanced process nodes
- Traditional brute-force Monte Carlo method, ML-based brute-force-accurate high-sigma solution, and fast high-sigma solution not practical
  - Brute-force Monte Carlo: 6.0 sigma verification require 10 billion simulations
  - ML-based brute-force-accurate high-sigma solution: too much time to apply to every condition
  - Fast high-sigma solution: wide confidence interval to conclude alone
- Shifted Vector Sampling (SVS) methodology verifies BGR efficiently to 6-sigma
  - To avoid using ML-based brute-force-accurate high-sigma solution, we proposed SVS methodology
  - We use HSV and PVTMC Verifier as a representative tool for ML-based brute-force-accurate high-sigma solution and fast high-sigma solution, respectively
  - We can save up to 4X~43x time using SVS methodology