How is a CMC Standard Model Implemented And Verified in a Simulator?

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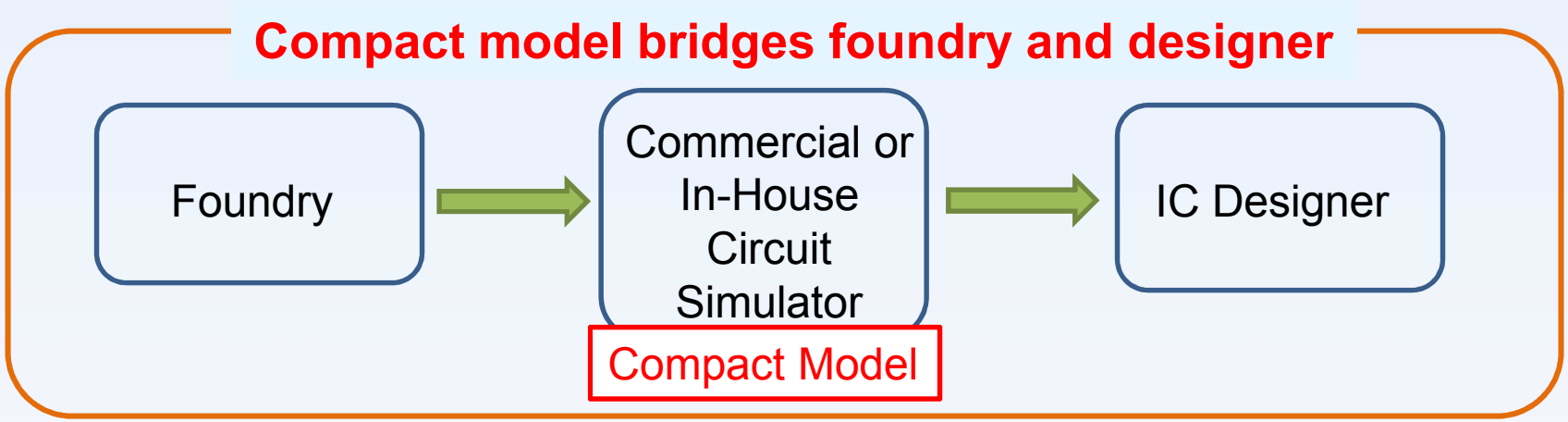
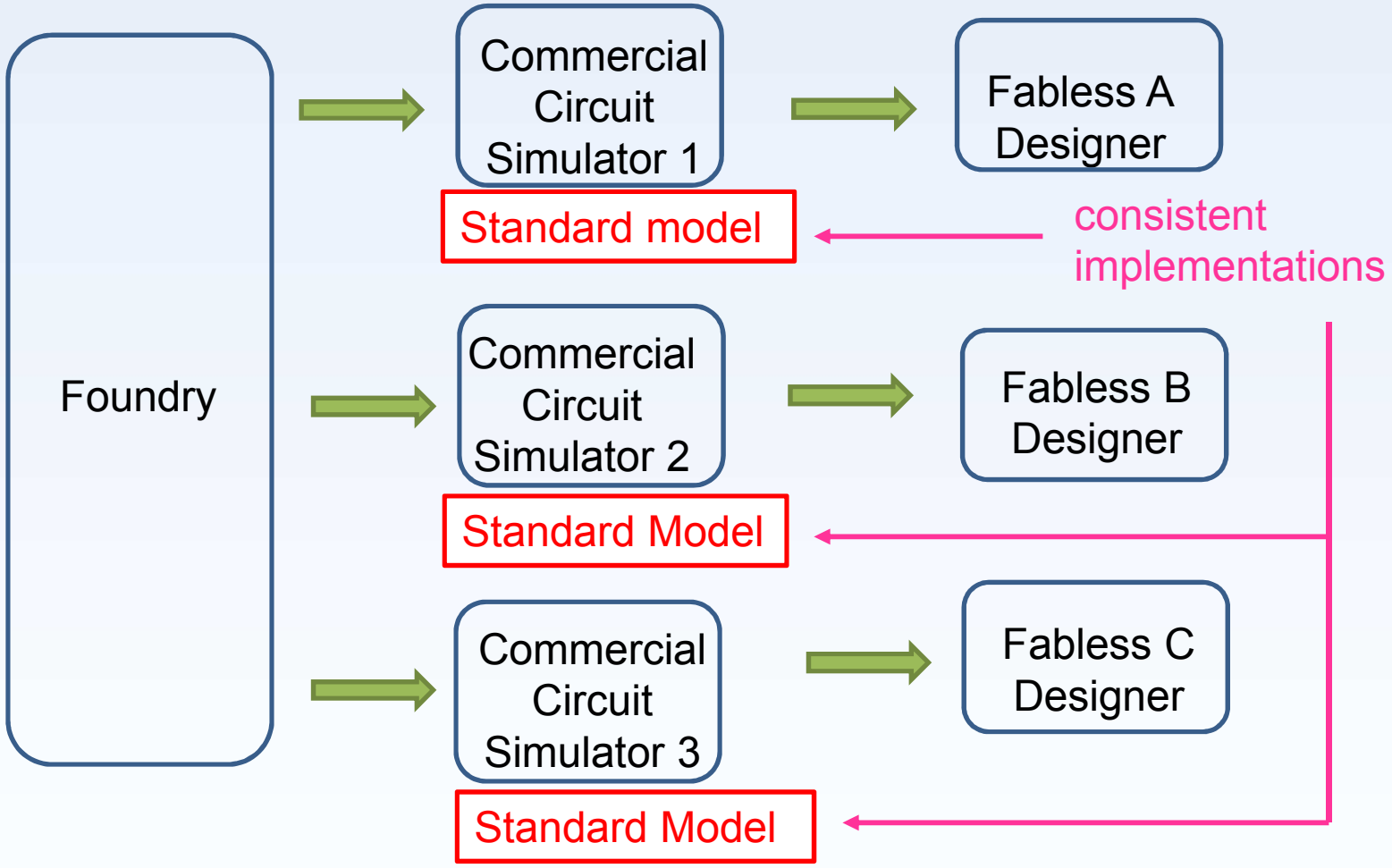
Benefit of a standard model



- Compact models provide the vital connection between foundry and designer
- Bring detailed physical behavior of devices to circuit behavior
- Enable circuit designer to create the most optimum circuit taking into account the details of device physics.

Foundry/Fabless Model



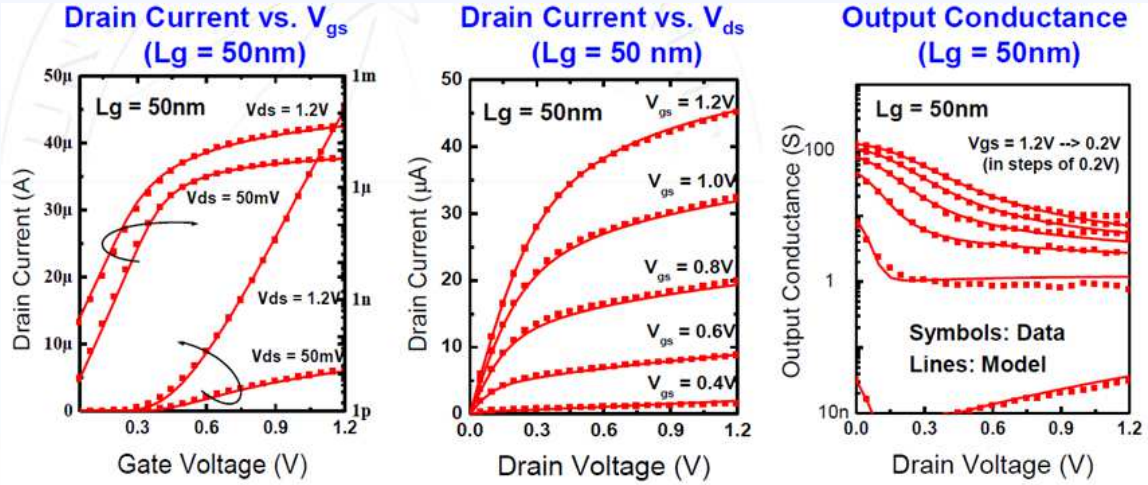
Standard compact model is critical for foundry / fabless model

Examples of CMC Standard SPICE Models

Device Type	CMC Standard Spice models
MOSFET	BSIM3v3, BSIM4, BSIMBulk, PSP, HiSIM2
FinFET	BSIMCMG
SOI	BSIMSOI, BSIMIMG (FDSOI), HiSIM-SOI, HiSIM-SOTB
HVMOS	HiSIM_HV
Bipolar	Mextram and HiCUM
HEMT/GaN (almost a standard)	ASM_HEMT and MVSG_HEMT
Others	MOSVAR, Diode, R2, R3

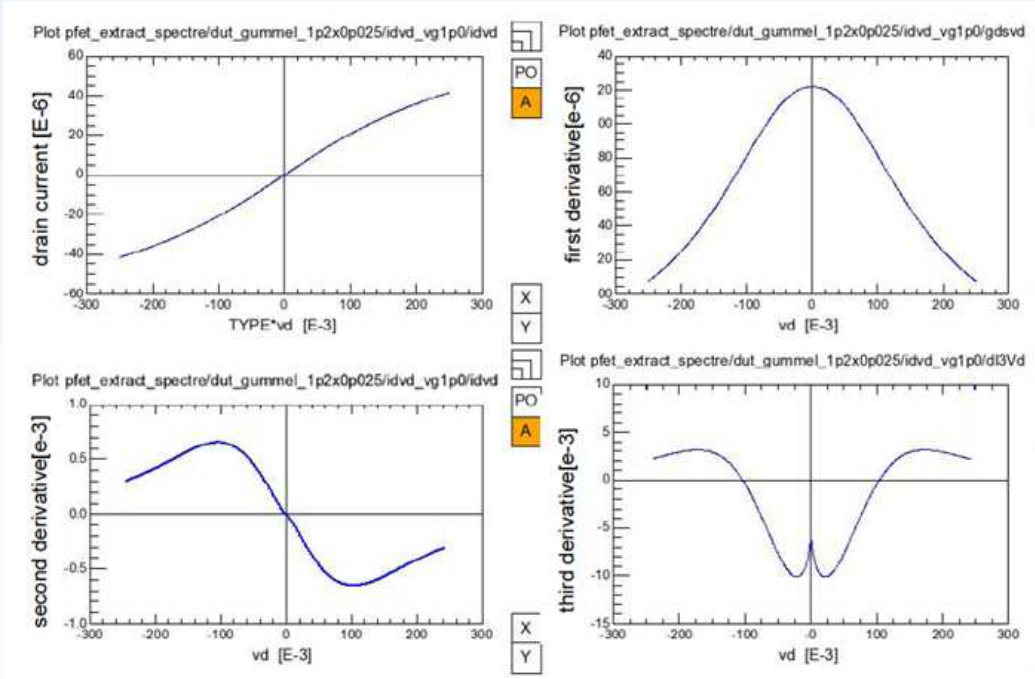
CMC Model Test During Standardization

- Intensive model evaluation performed during model standardization
  - CMC defined a set of tests (device behavior, accuracy, symmetric, etc.)
  - Fitting IV, CV, conductance (Gm, Gds, …), capacitance, leakage, etc.
  - Various physical effect, like short channel effect, DIBL, CLM, etc.
  - Spice model geometric scaling, temperature effect, ….
- CMC member companies can do more testing if they think it is necessary



CMC Model Test During Standardization

- Spice model robustness test
  - Discontinuity
  - Symmetric (MOSFET)
  - Coding bug
- Circuit level test
  - Convergence
  - Performance
  - Memory



EDA Model Implementation

- Model equations (CMC Standard model, open source)
  - C-code (Spice3)
  - Verilog-A
- C-code model
  - C-code has model equations
  - Explicit derivatives needed in the C code model
  - Directly uses the model equations and derivatives for implementation
- Verilog-A model (most recent CMC model)
  - Only uses the model equation
  - No derivatives needed (AHDL compiler generates derivatives)
    - Or manually derive the derivatives
  - Or ADMS (Translate Verilog-A model into simulator C code, generates derivatives)

Model Test

- Reference simulator
  - C-code model: Spice3 test case vs. implementation
  - Verilog-A model: Build Verilog-A test case as reference
- Accuracy test
  - Very intensive DC sweep to check currents, charges, conductance, capacitance
  - All possible working regions
    - MOSFET (sub-threshold, linear, saturation)
    - Forward / reverse mode
    - Large voltage
  - Different device geometries
  - Different device type
  - Possible physical effects
  - Turn on/off model parameter flags / combination
  - ….

Model Test (cont.)

- Various analyses
  - DC, transient, noise, pss, etc.
  - Monte Carlo
- Functionality
  - Alter / Altergroup
  - Mfactor
  - Temperature setting, trise
- Circuit test
  - Performance and memory
  - Benchmark and compare with other model (same type)
- All tools
  - Spectre, SpectreRF, APS, XPS (fast Spice), RelXpert,…
  - All possible functionalities in each tools

Independent Test by Product Verification (PV) Engineer

- Product Verification (PV) R&D
  - Dedicated to test various quality issues
  - Independent of test of each model
  - A lot of automated tools
  - Accumulated huge amount of test cases
- Accuracy test
- Functionality test
- Benchmark
  - Performance
  - Memory

Regression Testing

- Build regression tests for each Spice model
  - Build regressions after model testing is completed
  - Most test cases from model implementation and testing
  - Covers accuracy tests, performance tests, and functionality tests
  - Add new regression cases for each bug fix (make sure the same bug doesn't reoccur)
- Purpose of regression testing
  - Monitor simulator quality
  - Preserve backward compatibility
  - Sign-off the regression tests for each release
- A huge number of regression tests is accumulated for simulator

CMC Model QA suite

- CMC model QA
  - CMC requirement: Each CMC standard model must generate a model QA suite
  - Model QA golden results are prepared by the model developer (not EDA vendor)
- Cross simulator verification for CMC standard models
  - Mainly focus on accuracy tests
    - DC sweep, forward/reverse mode
    - Mfactor, temperature
    - Device type
- All simulators consistent

CMC QA Testing Status

Silicon Integration Initiative

Models/ Simulators	PSP	BSIM3/4	BSIMSOI	MEXTRAM	HICUM	HiSiM-HV	HiSIM2	BSIM-CMG	R2	R3	MOSVAR
Simulator A	Complete	Complete	NA	NA	NA	NA	NA	NA	NA	NA	NA
Simulator B	Complete	Complete	Complete	V504.9: Complete	Complete	v2.1: Complete v2.2: NA	V2.7: Complete V2.8: NA	V107: Complete V108: NA	Complete	Complete	Complete
Simulator C	complete	complete	NA	complete	complete	complete	complete	NA	complete	complete	complete
Simulator D	Complete	Complete	Complete	Complete	Complete	Complete	Complete	Complete	Complete	Complete	Complete
Simulator E	Complete	Complete	Complete	Complete	Complete	Complete	Complete	Complete	Complete	Complete	Complete
Simulator F	Complete	Complete	Complete	Complete	Complete	Complete	Complete	NA	Complete	Complete	NA

Complete if the QA suite tests have been completed for the latest version of the model
NA if the QA suite tests have not been completed for the latest version of the model

Challenge

- Device test
  - Compact model is very complex
  - Many hundreds of parameters (instance / model parameter)
  - Many physical effects (some controlled with flags)
  - Supported different technologies, e.g. BSIM4 supports, 20nm, 28nm, 32nm, 45nm, …
  - Many possible combinations
  - Very challenging to do full testing with all combinations
- Circuit test
  - Sufficient test circuit coverage
- Environment
  - Simulator in design environment

Summary

- Multiple-stage tests
  - Model developer test
  - CMC model standardization test
    - Foundry fitting the data with silicon
    - EDA robustness test
    - CMC member test
  - EDA model implementation test
    - To be consistent with original model
  - Product verification R&D independent test
  - Regression
    - Backward compatible
  - CMC Model QA
    - Cross simulator verification
- Challenging
  - Spice models are very complex
  - Many tests are required to be comprehensive
  - Very hard to test all possible combinations

CMC (Compact Model Coalition)

- The CMC enhances the IC development process
  - ❖ Standardizing high-quality device models and simulator interfaces
  - ❖ Providing a forum and mechanism to keep these standards current to expanding industry needs

- The CMC is a member-driven organization open to any company in the semiconductor business

http://projects.si2.org/cmc_index.php