Accurate design of mixed-mode circuits by using advanced MOSFET modelling

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Outline:

- MOSFET models in use at EMM
  EKV2.6, EKV3.0
- Examples of design and modelling challenges (EKV2.6 → EKV3)
  - Leakage I_{off} in ultra low-power digital design
  - Accuracy of analog parameters around V_{th}
  - Good model of output conductance
  - Model of native MOST
  - NQS effects in long MOST
  - Model of 2T-flash cell
  - Other challenges: BIN continuity, IV, AC and CV accuracy, RF…

MOSFET models at EMM

EKV2.6 – EM's own processes (1.0µm, 0.5µm, 0.35µm CMOS)

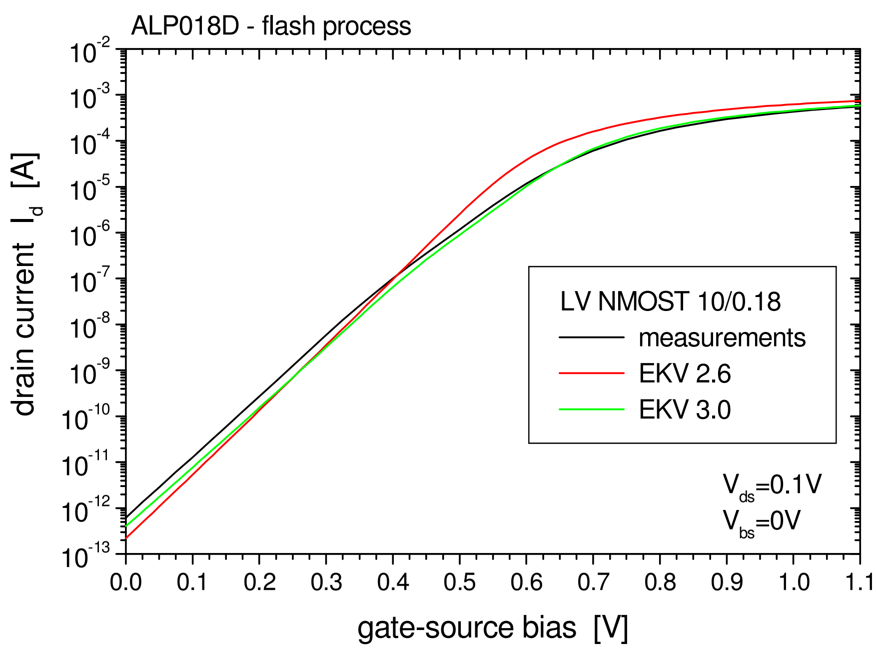
- many sucessful mixed-signal designs (with embedded E^2)
- was good for analog and weak-inversion designs
- physical parameters, natural process corners, easy to adapt process change
- ELDO, SPECTRE
- HSIM (native implementation)

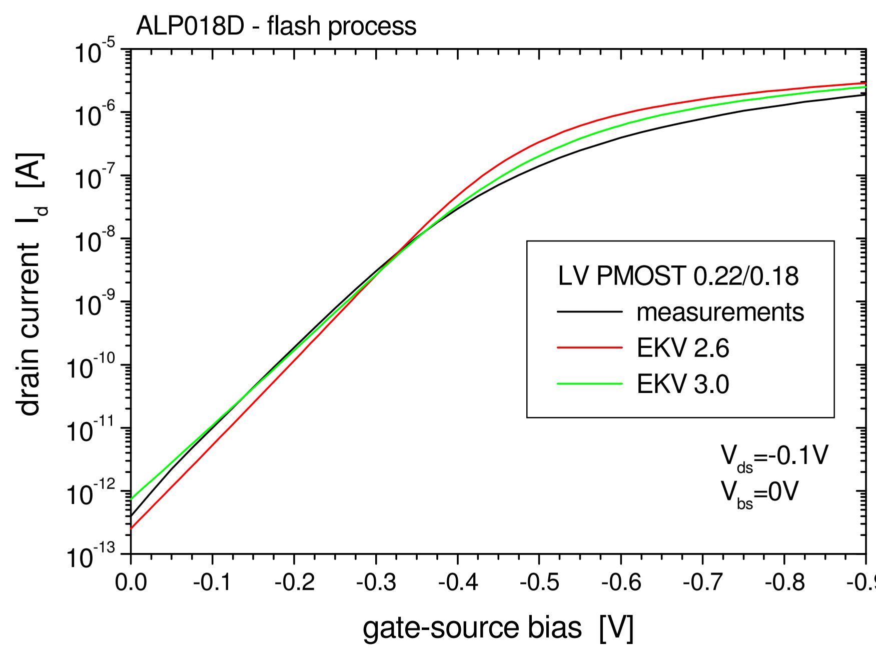
EKV3.0 – EM's own processes 0.18µm logic and FLASH

- SPECTRE
- HSIM – no native implementation

Example: Leakage I_{off} in ultra low-power digital design

- accurate I_{off} model is important
- synthesis of digital block - minimizing I_{leak}
- 100kgates ~ 10-20nA (0.18µm/FLASH)

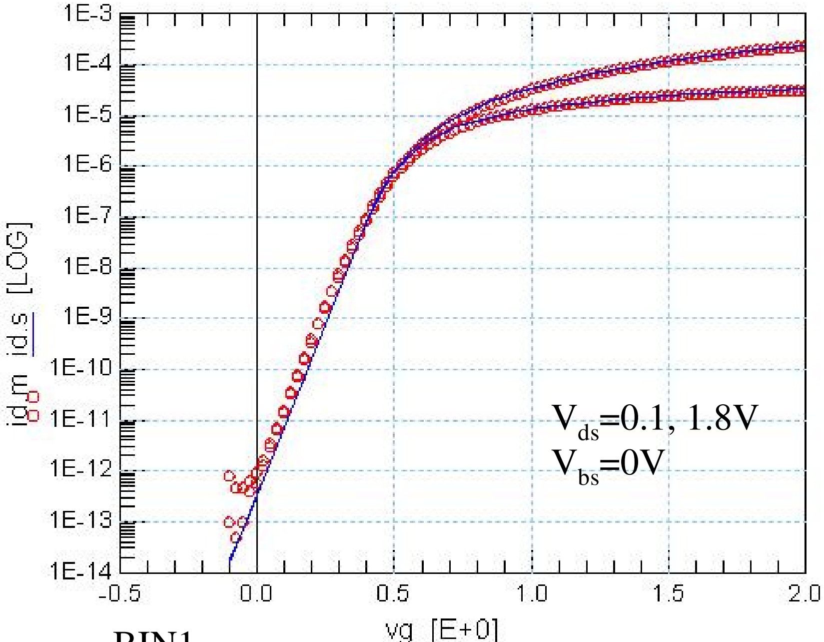




EKV2.6 for advanced processes: need compromises between I_{off} and weak-inv. accuracy

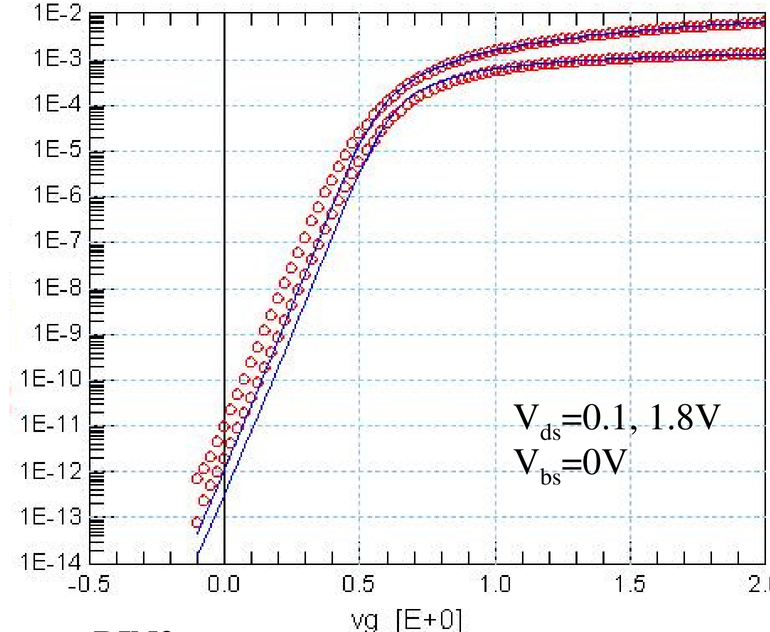
0.18μm FLASH experimental lot: LV NMOST (25°C)

10/10



BIN1

10/0.18

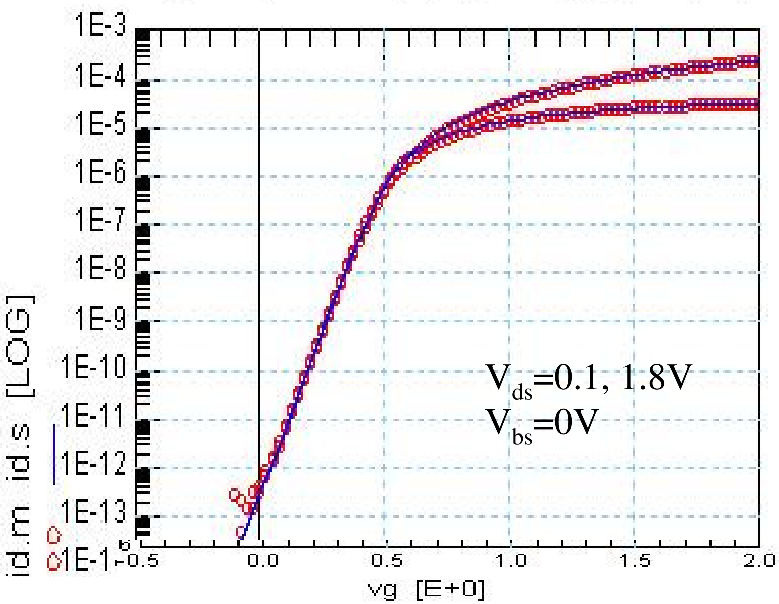


BIN2

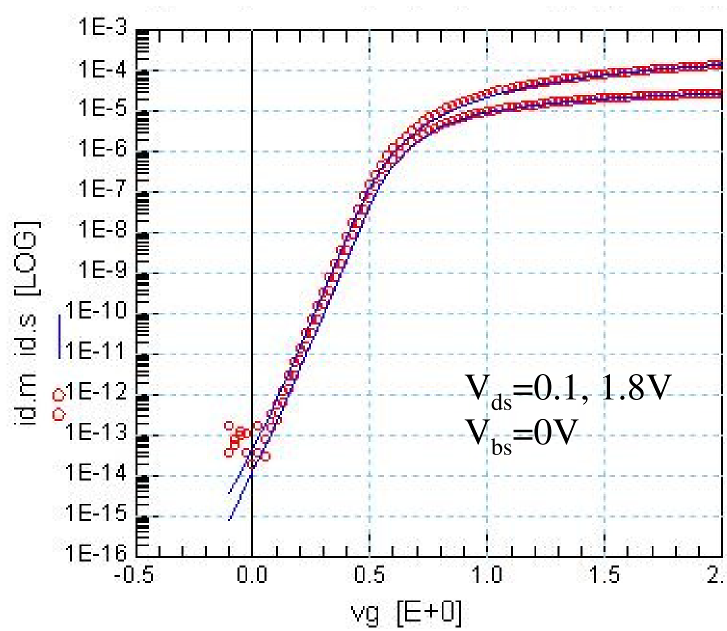
EKV 2.6

0.18µm FLASH: LV NMOST (25°C)

10/10

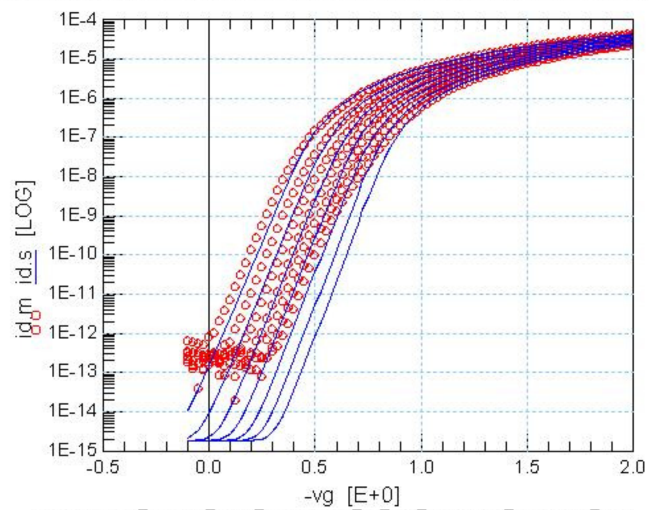


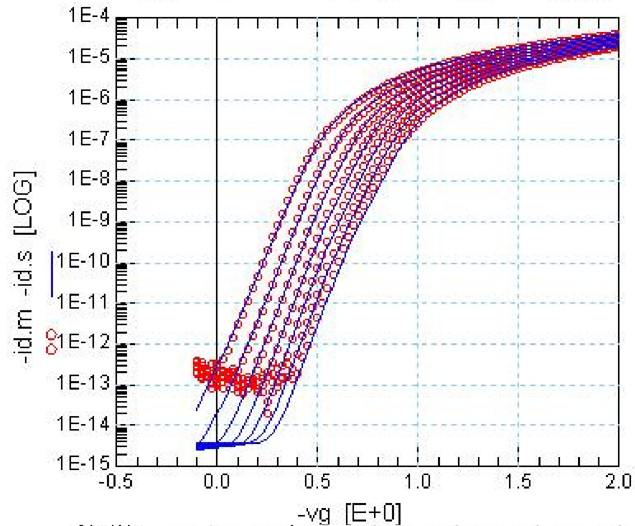
0.22/0.18



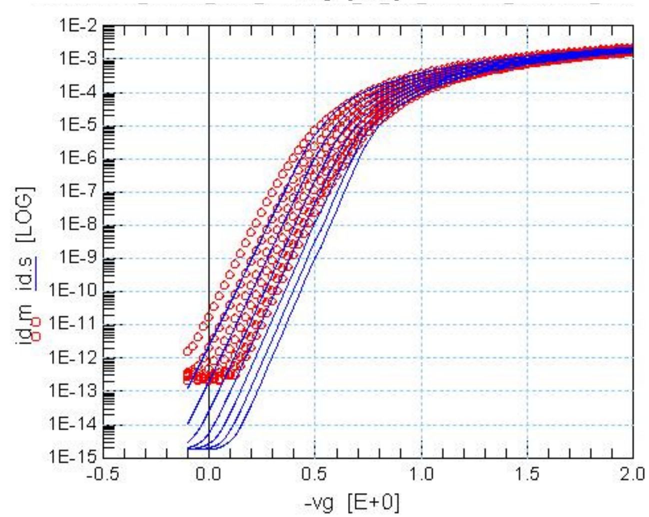
unique parameter set

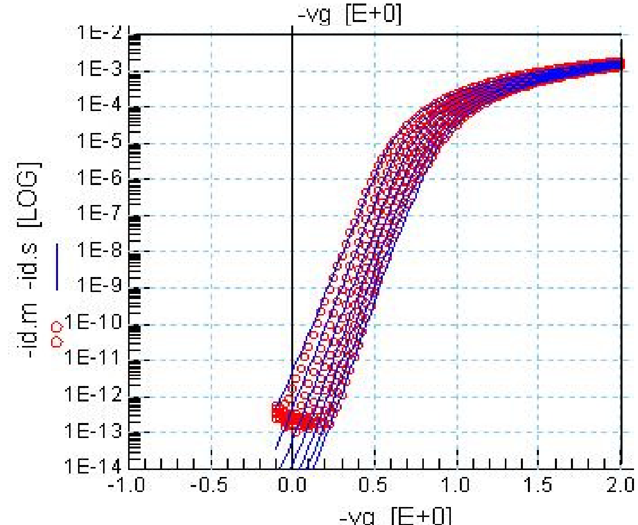
EKV 3





10/10





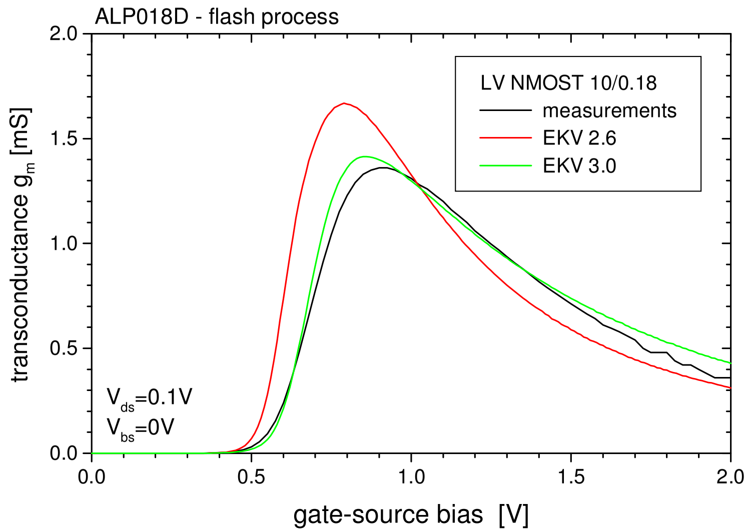
10/0.18

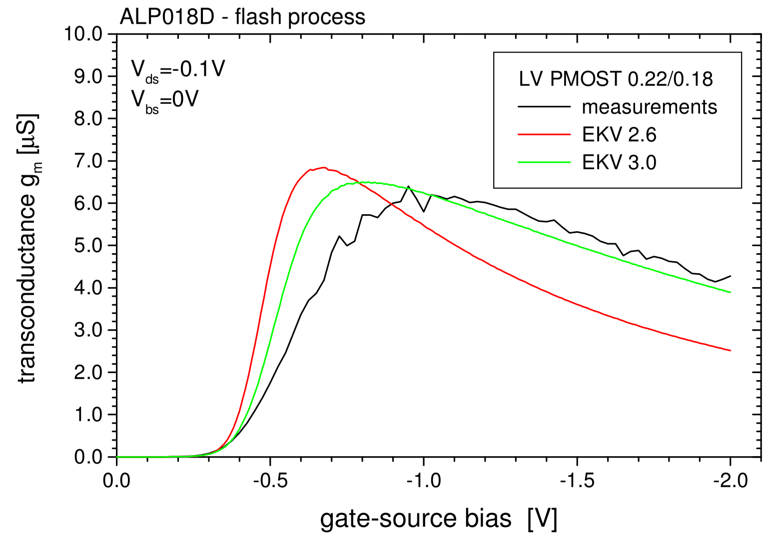
V_{ds} = -1.8V
V_{bs}=0, 0.3, 0.6, 0.9, 1.2, 1.5, 1.8V

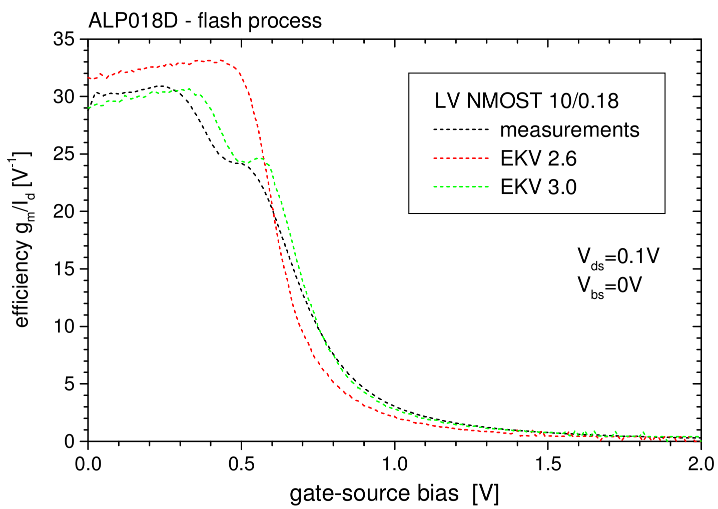
EKV2.6 **EKV3**

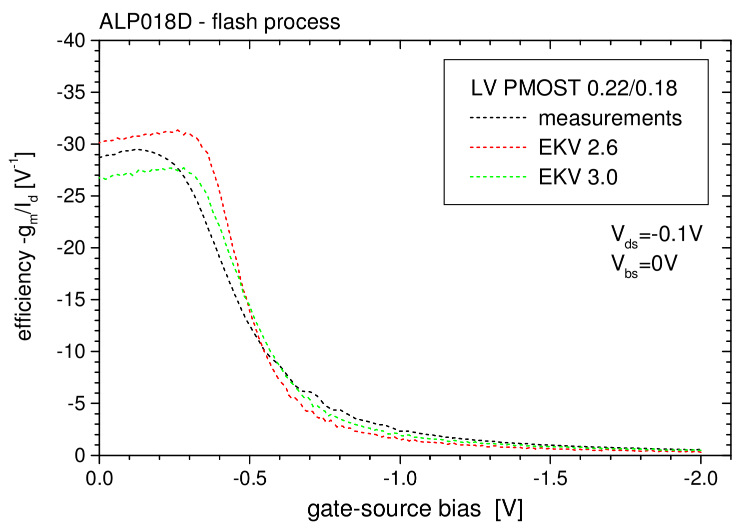
0.18μm FLASH: LV PMOST (25°C)

Example: Accuracy of analog parameters around V_{th}









Example: good model of output conductance

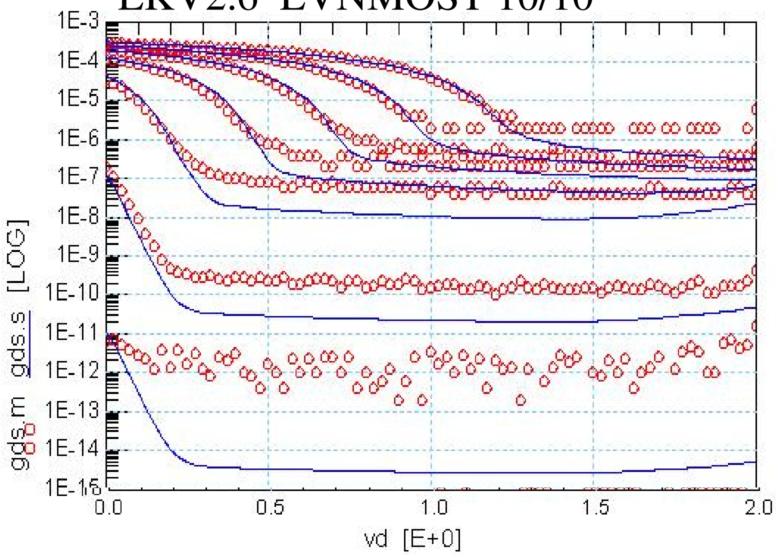
- design of low-noise amplifier in 0.18µm logic process
- long-channel MOST (> 10µm)

Conductance g_{ds} degrades in long-channel (of 0.18µm EM processes)

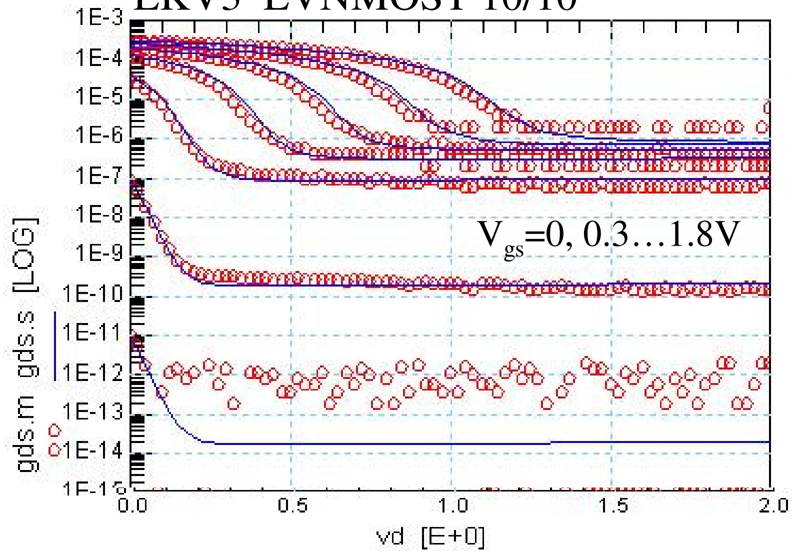
a) LV MOST 1.8V (HALO implant)

b) MV MOST 3.3V

EKV2.6 LVNMOST 10/10



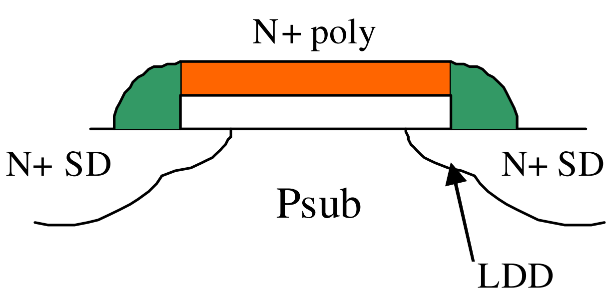
EKV3 LVNMOST 10/10



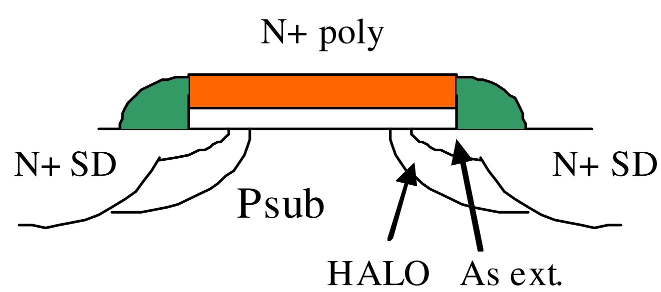
EKV2.6: parameters tuned for g_{ds} of short L_G $\Rightarrow$ g_{ds} strongly underestimated in long L_G in analog circuits
Practical solution for EKV2.6: separate BIN for g_{ds} tuning of desired long L_G

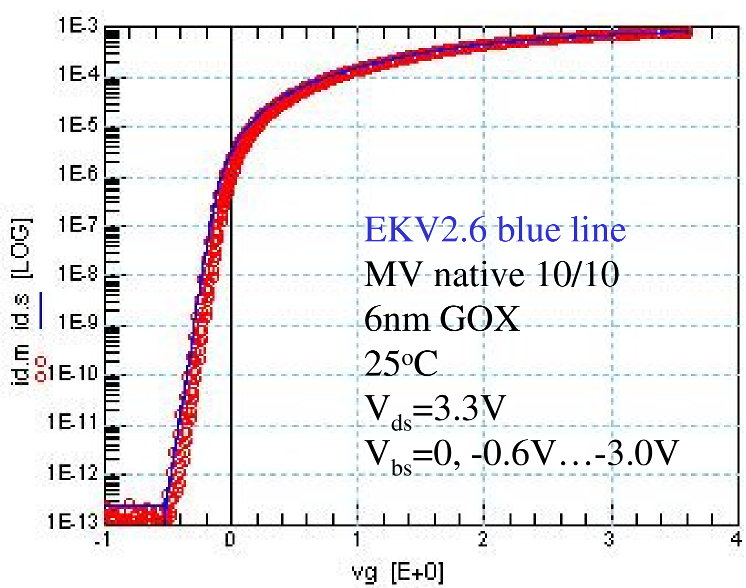
Example: Model of native MOST

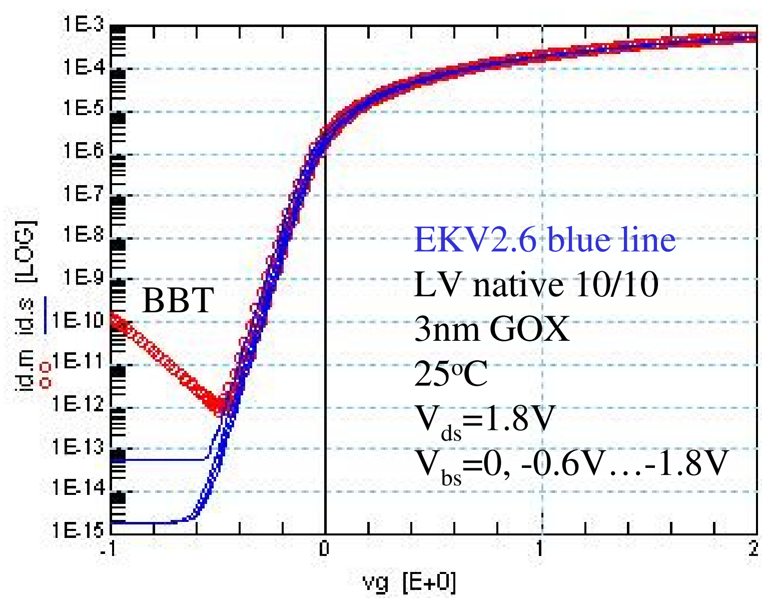
MV native 10/10



LV native 10/10

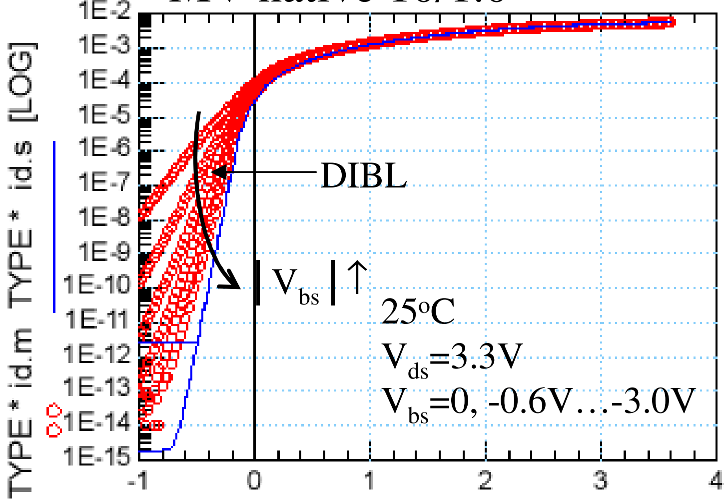






0.18µm logic process

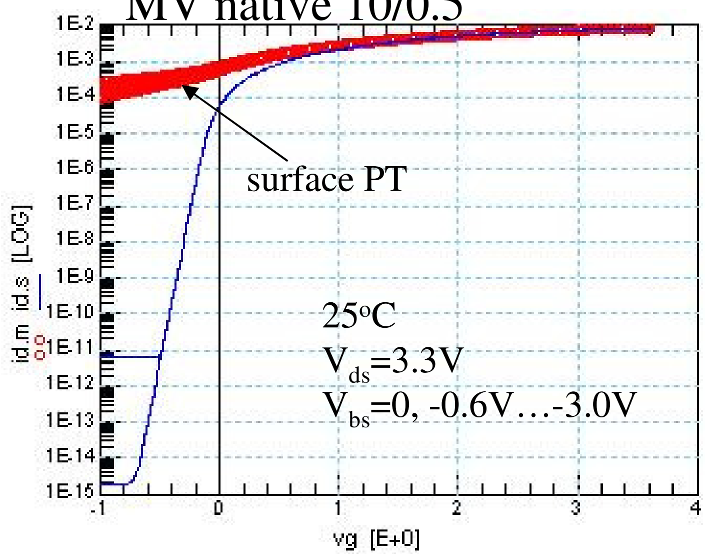
MV native 10/1.0



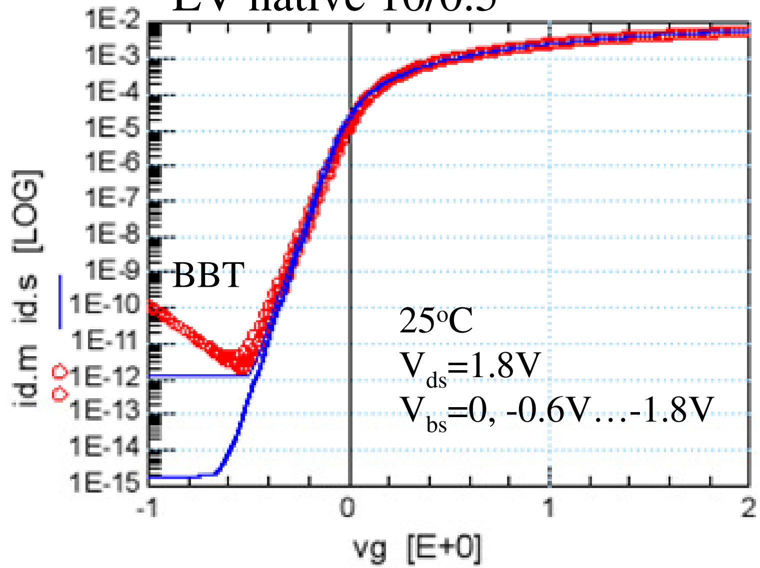
EKV2.6 blue lines

For short native at moderate/high V_{ds}
Model EKV 2.6 fails due to:
- DIBL effect
- BBT

MV native 10/0.5

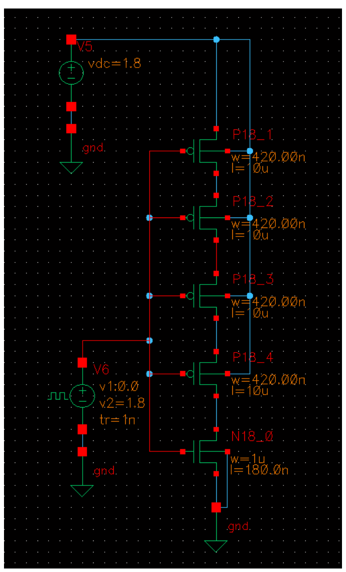


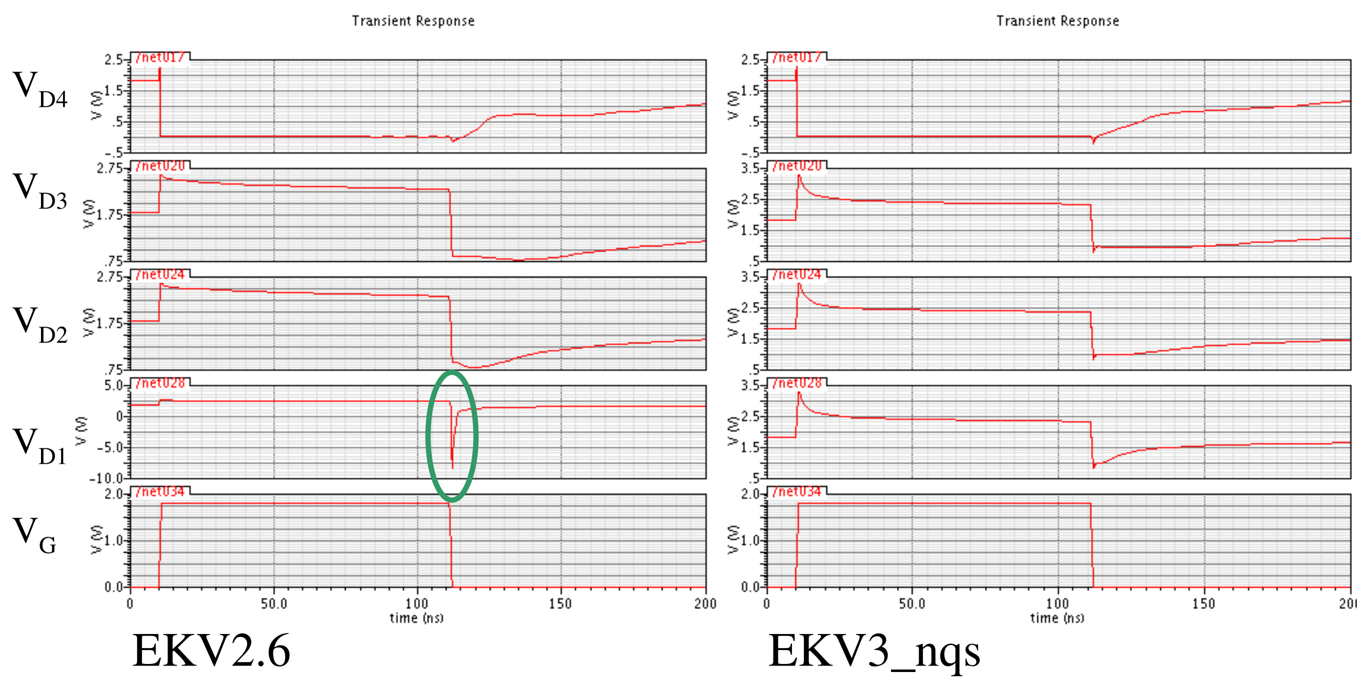
LV native 10/0.5



Example: Non-quasi-static effect in long MOST

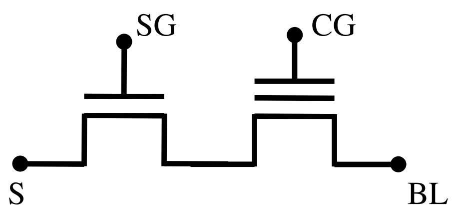
- Known artefact of negative drain/source current spikes
- Fast switching of long MOST
- In EM practical design:
  - → Turn-ON simulation of IC blocks
  - → Control of analog part working in DC by core logic
- Artefact in MOST models that apply QS charge conservation





Example: Model of 2T-flash cell

Model of select MOST – 0.18µm with embedded FLASH



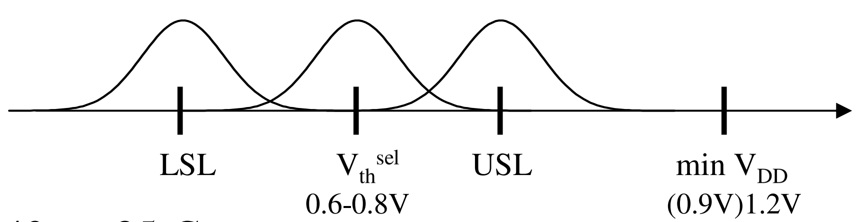
Select MOST: tunnel oxide 8nm

typical size 220/220 ÷ 400/300

V_{th} tradeoff:

1) V_{th} too low ⇒ I_{off} leakage, leakage on inhibited cells
→ program disturb
→ HV charge-pump load

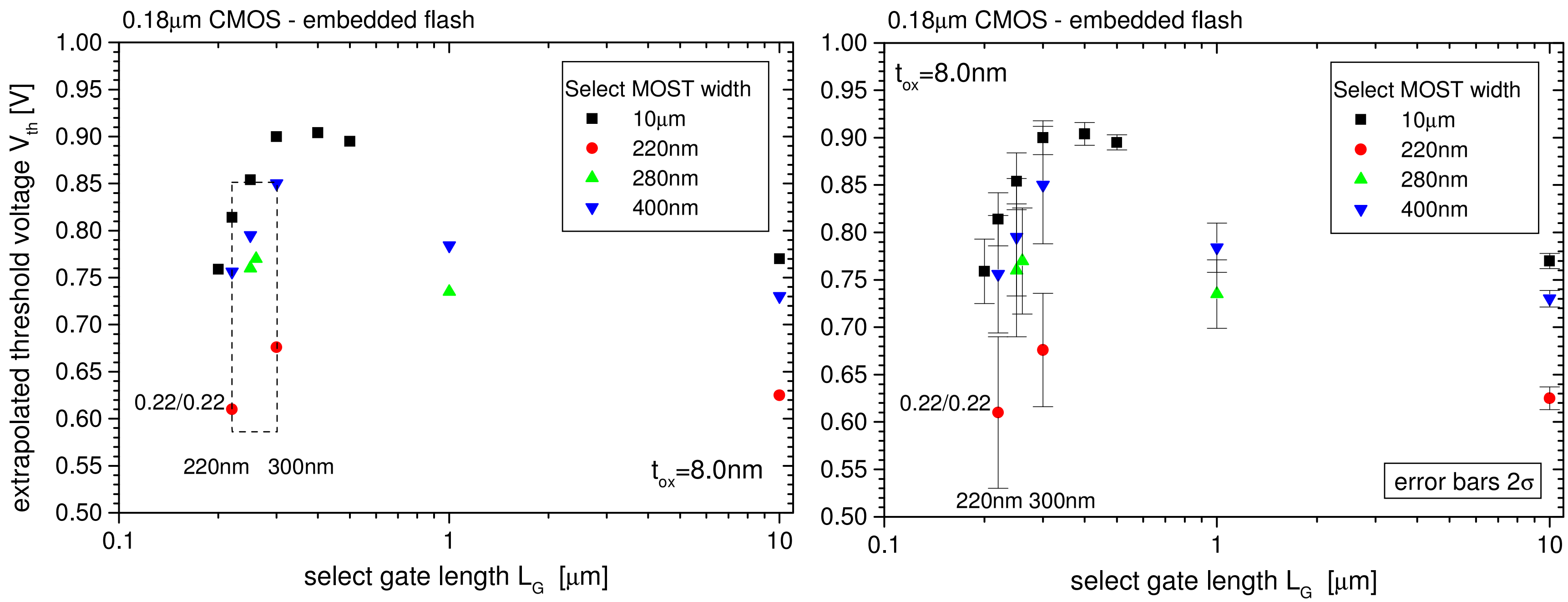
2) V_{th} too high ⇒ inability to operate with low V_{dd}



-40 ÷ +85°C

(a) V_{dd}=1.2V end-of-life of 1.5V battery

(b) Future ICs: down to 0.9V



Small size select MOST → V_{th} spread

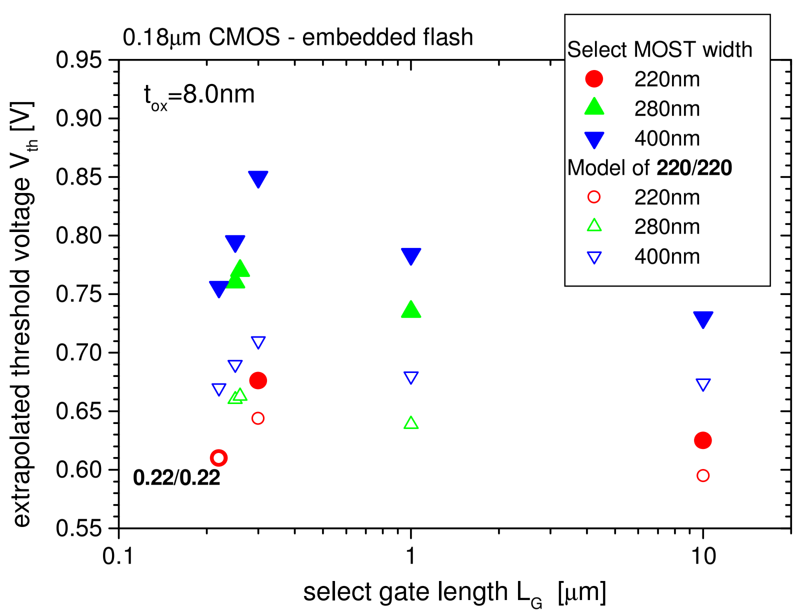
Larger cell W/L → smaller V_{th} spread, but larger FLASH memory area

Note: V_{th} may be adjusted by process

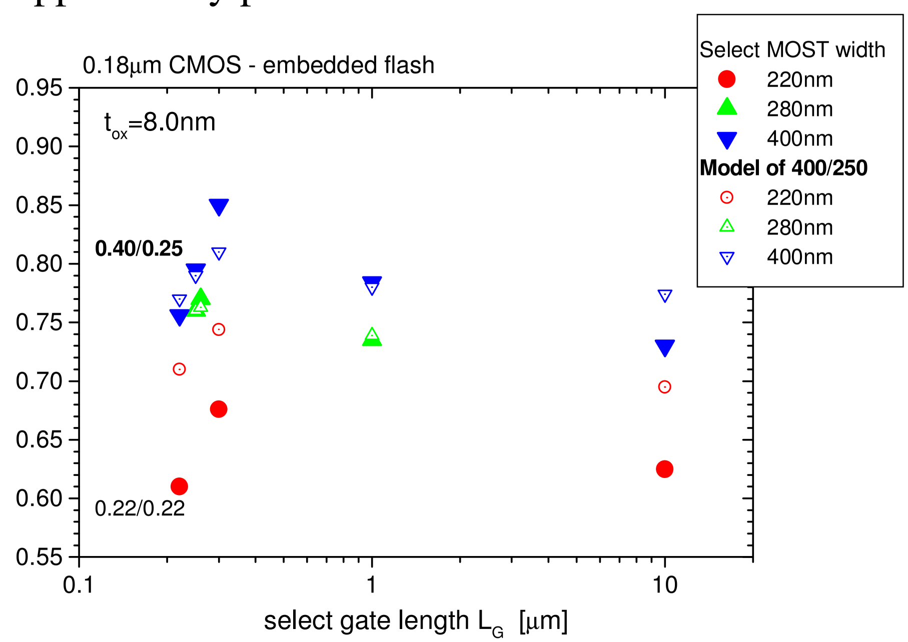
Accurate select MOST model with
- W/L dependence
- T-dependence
- matching parameters

exceeds EKV 2.6 model capability.

⇒ Models for specific sizes W/L, with limited applicability possible:



dedicated 0.22/0.22 model



dedicated 0.4/0.25 model

Conclusion:

- Some challenges in EKV2.6 MOSFET modelling in low-power circuit design are reviewed.

- EKV3.0 behaves correctly and shows good accuracy in solving the reviewed problems.

- EKV2.6 → EKV3.0
  for current most advanced and future EMM technologies.