Low-Frequency Noise Modeling at Low Temperature with the EKV3 Compact Model

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Outline

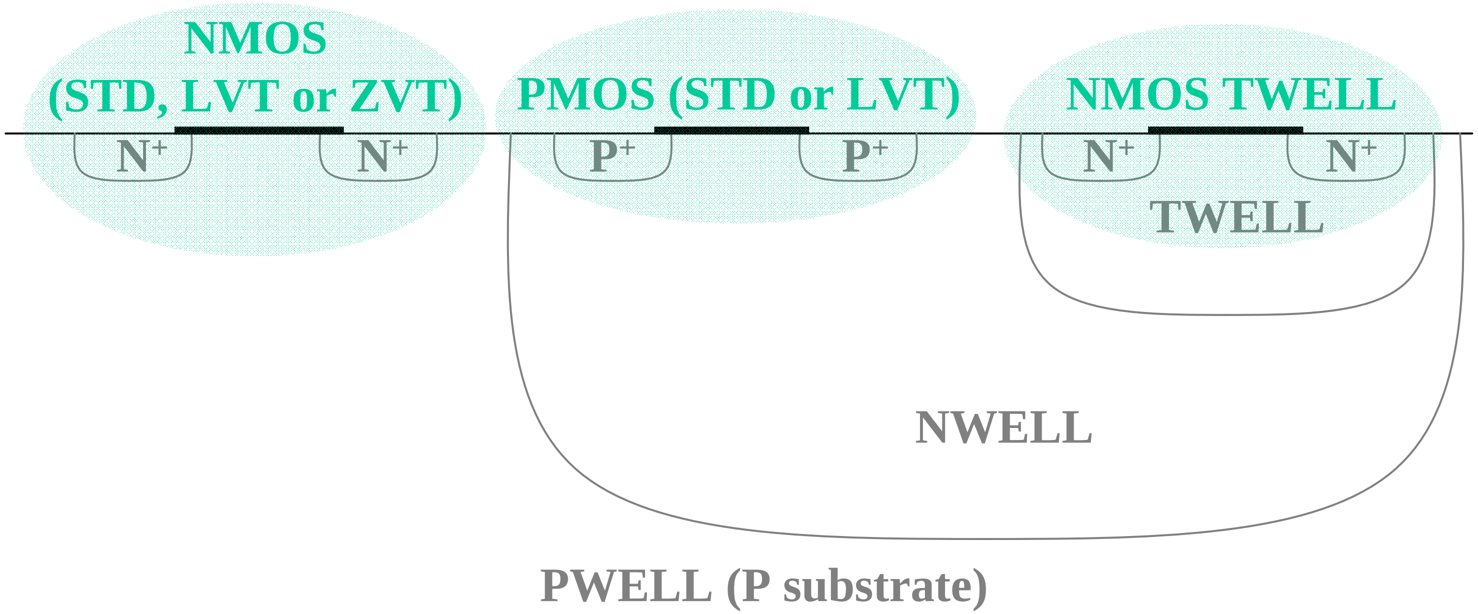
- **Introduction**
- **CMOS process and characterization**
- **Low frequency (LF) noise measurements at room & low temperature and physical models**
- **Compact modeling of LF noise with EKV3**
- **Conclusion**

Introduction: aim of this work

- **Design of hybrid CMOS read-out circuits for night vision using high performance infrared (IR) detectors**
- **IR detectors and CMOS circuits cooled down to 77 K**
- **Difficulties: low temperature (LT) & analog circuits (weak/moderate inversion)**
- **IC design with 0.8, 0.5 and 0.35 µm CMOS and circuit simulation with the EKV2.6 compact model**
- **More and more transistors in the pixel, need for more and more advanced CMOS processes**
- **0.18 µm process: new effects, e.g. INWE (STI), DITS (pockets)**
- **EKV3 is an accurate compact model for LT analog circuits design, Cryogenics, in press, 2009**
- **This work: evaluation of the EKV3 LF noise model**

CMOS process

- **Commercial process for Analog / Digital / RF applications**
- **Not optimized for LT operation**
- **Dual gate:**
  - ✓ **0.18 µm - 1.8 V - Tox=3.3 nm**
  - ✓ **0.35 µm - 3.3 V - Tox=6.5 nm**
- **Multi-Vt: standard (STD), low Vth (LVT), zero Vth (ZVT)**
- **Triple well**
- **Twelve MOSFET**



DC characterization and LFN measurements

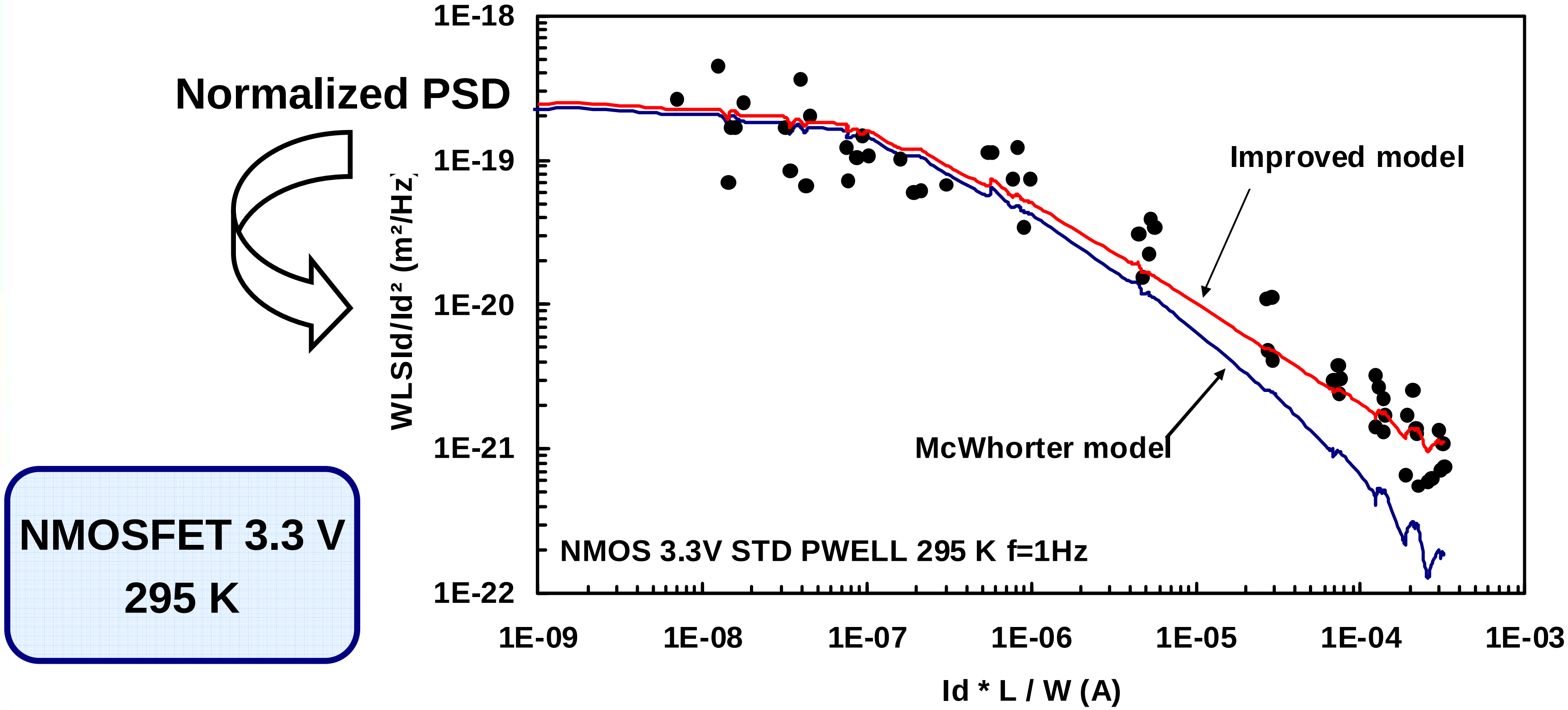
DC characterization

- 1^{st} step before LF noise measurements
- Standard and specific effects
- Id, Gm, Gmb, Gds
- Temperature range: 77 K - 300 K

LF noise measurements

- Automatic current fluctuations meas. on up to 6 devices inside a cryostat
- Specific computer-controlled system with programmable biasing amplifiers
- Transistors biased in saturation: Vds=VDD as in analog circuits
- L=Lmin - 20 µm ; W=Wmin - 20 µm
- $1/f^{\gamma}$ noise with $\gamma = 1.0 \pm 0.1$

Noise measurements at room temperature: Hooge, standard or improved McWhorter's model?



- Plateau in weak inversion: Hooge mobility fluctuation model not applicable
- McWhorter's carrier number model applicable, but has to be improved in strong inversion
- Same model applies experimentally for PMOSFET

The improved McWhorter's LF noise model

1 - Standard McWhorter carrier number fluctuations (ΔN)

$$SI_d = [1 + \alpha \mu C_{ox} \frac{I_d}{G_m}]^2 G_m^2 S_{Vfb}(f)$$

[A^2/Hz]

2 - Correlated mobility fluctuations (Δμ) at high current

$$S_{Vfb}(f) = \frac{kT q^2 \lambda N_t(E_F)}{WL C_{ox}^2} \frac{1}{f^{\gamma}}$$

[V^2/Hz]

S_{Vfb}: flat-band voltage fluctuations

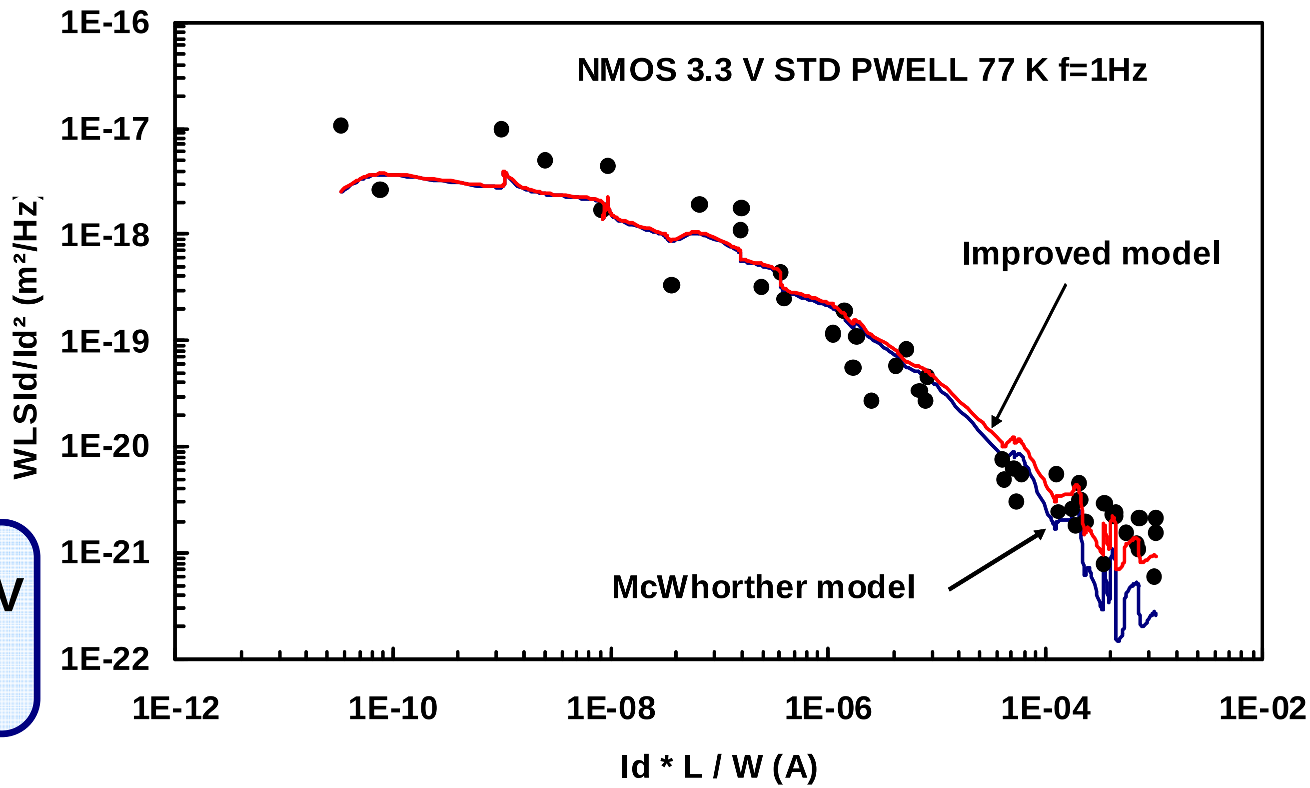
N_t: oxide trap volume density per unit energy at E_F (eV^{-1} cm^{-3})

λ: tunnel attenuation distance (0.1 nm)

α: Coulomb scattering coefficient at RT (V s/C) ~ 10^4 for electrons, 10^5 for holes

(3.3 V STD n-MOSFETs: $\alpha = 7 \times 10^3$ at 295 K)

Noise measurements at 77 K



NMOSFET 3.3 V
77 K

- **Improved McWhorter's model still applicable at low temperature**
- **Lower α Coulomb scattering coefficient at LT ($9x10^2$ at 77 K)**
- **Same result for PMOSFET, but different Coulomb scattering coefficient**

LFN model in EKV2.6 and EKV3

in EKV2.6:

$$S_{Id} = \frac{KF\, G_m^{2}}{C_{ox}\, W_{eff}\, L_{eff}\, f^{AF}}$$

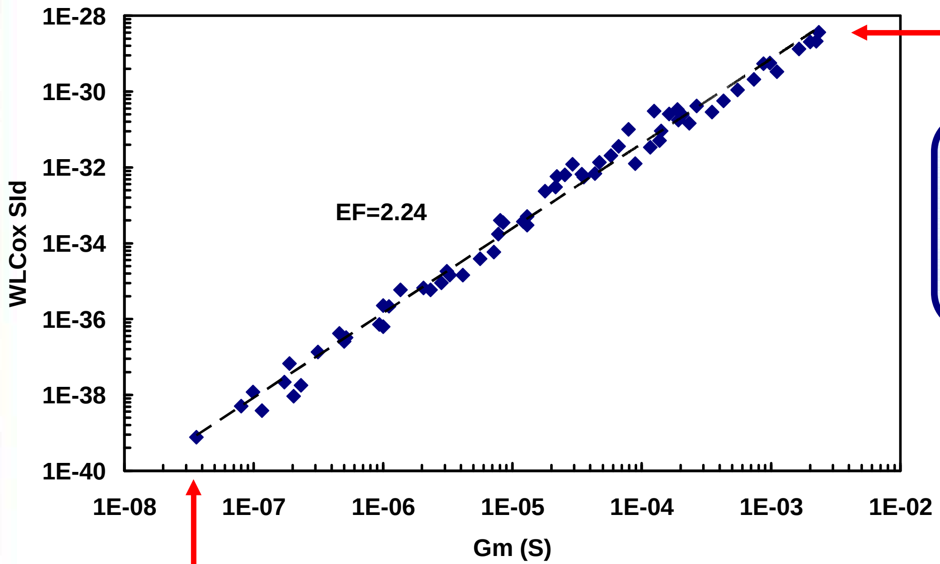
in EKV3:

$$S_{Id} = \frac{KF\, G_m^{EF}}{C_{ox}\, W_{eff}\, L_{eff}\, f^{AF}}$$

Three parameters: KF, AF, EF ≠ 2

- **Only Gm, the gate transconductance**
- **Simple but efficient model? Valid only in weak inversion? Also valid in moderate and strong inversion?**

Test of the EKV3 LFN model at RT

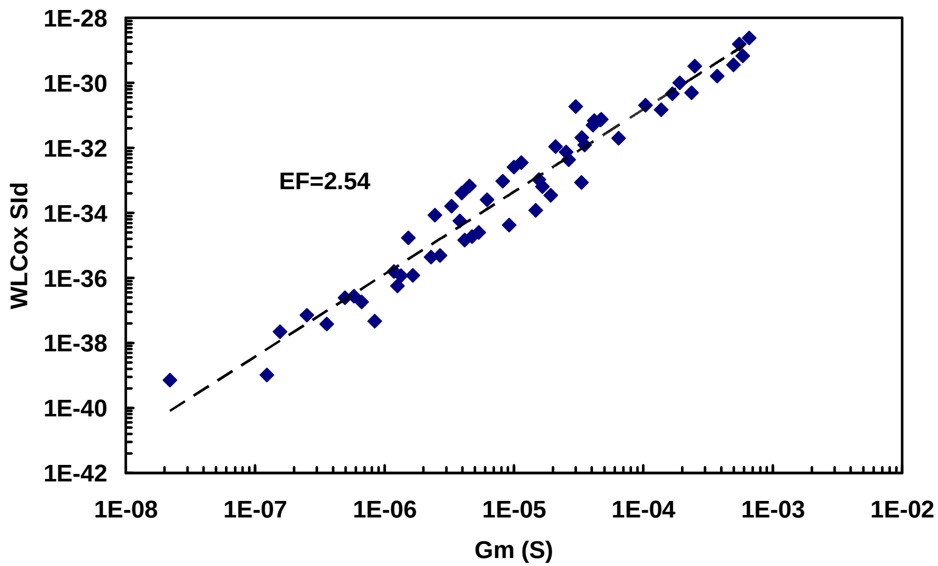


strong inversion

NMOSFET STD 3.3 V P-WELL

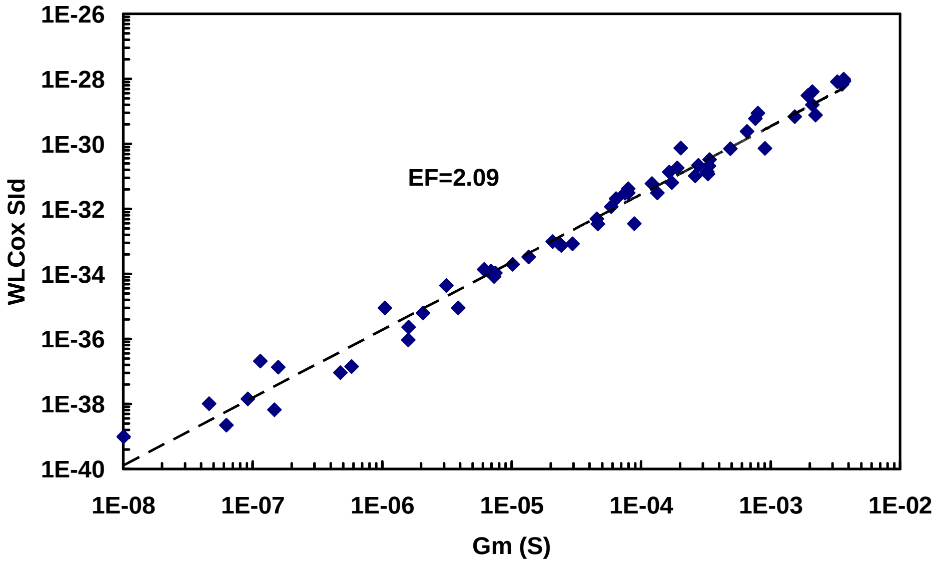
Tox=6.5 nm f=1 Hz

weak inversion

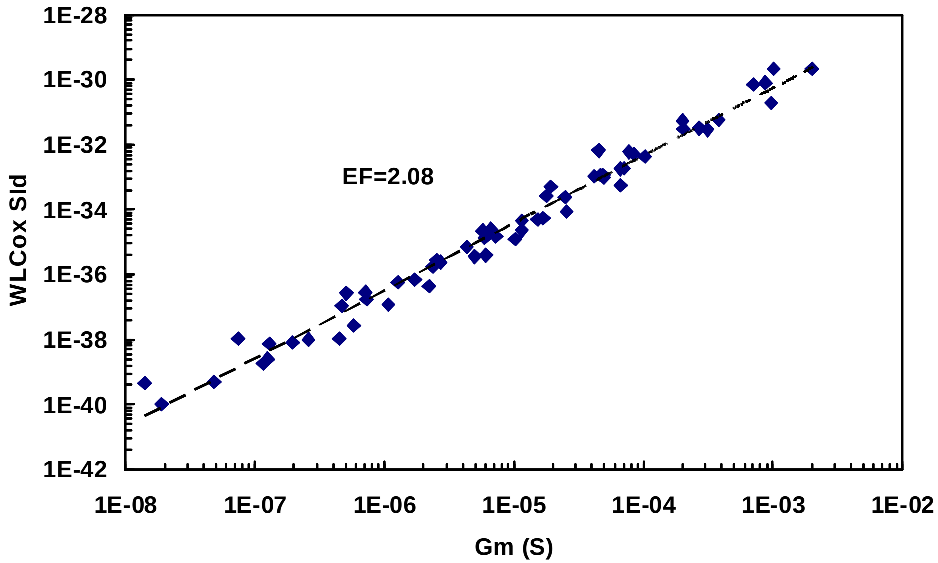


PMOSFET STD 3.3 V N-WELL

Test of the EKV3 LFN model at 77 K



NMOSFET STD 3.3 V P-WELL



PMOSFET STD 3.3 V N-WELL

Conclusion

- **Measurements of LFN in a 0.18 µm mixed-mode / RF CMOS process at room and low temperature**
- **1/f noise is well described by the ΔN - Δµ (improved McWhorter's) model**
- **The Coulomb scattering coefficient is lower at 77 K than at RT**
- **The LF noise model implemented in EKV3 is simple but valid at low temperature in a very wide range of inversion: weak, moderate and strong inversion**
- **Measured EF parameter values are <> 2 and are device- and technology-dependent**

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