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Scalable high-frequency modelling with EKV3

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Outline

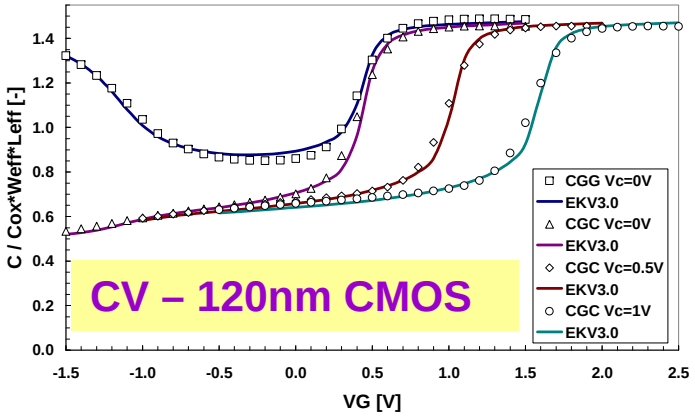
- Introduction
- EKV3 compact MOSFET model
- RF measurements in advanced RFCMOS
  - 180nm RF CMOS
  - 110nm RF CMOS
  - 90nm RF CMOS
- Conclusions

Introduction

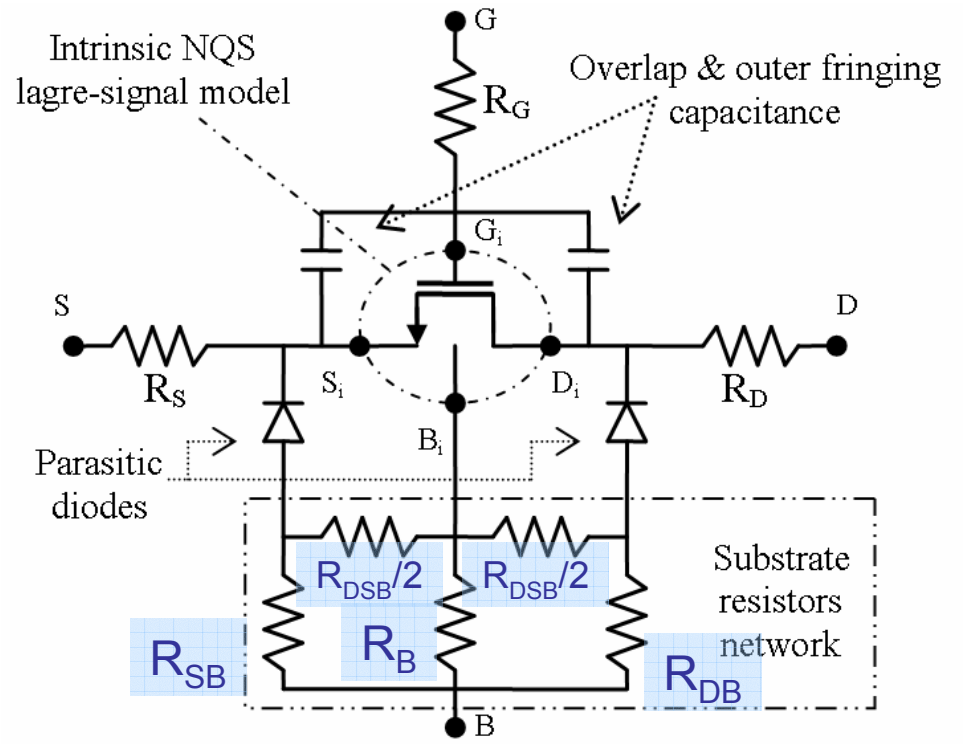
- Si CMOS is mainstream technology
  - Low-cost, “Best nano-scale technology!” (S. Cristoloveanu)
  - RF front ends compatible with large-scale digital circuits (SoC)
- Many RF applications in multi-GHz range
  - Efficient design demands efficient compact models in circuit simulators
  - High requirements in terms of RF characterization
- Analog RF design relies on compact, scalable MOSFET models
  - Physics based model
  - Covering all effects to 65nm CMOS
  - Model should cover all high-frequency aspects (RF Noise!)
  - L, W, Temperature, frequency, statistics…..
  - Multi-finger RF MOSFETs – Layout dependence
- EKV3 Compact MOSFET model for Analog/RF IC Design

EKV3 MOSFET compact model

- **Physics Based Charges Model**
  - Inversion charge linearization
  - Same parameters as surface potential model
  - Preserves the essence of a surface potential model.
- **Extensions for CV:**
  - Polydepletion, Quantum effects
  - Bias-dependent Overlap & fringing capacitance
- **Extensions of IV:**
  - DIBL, Charge sharing, RSCE, Halo doping
  - Charge-based vertical field mobility
  - Charge-based velocity saturation, CLM
  - Gate tunnelling
- **Non-quasi-static (NQS) modelling**
- **Noise modelling:**
  - 1/f noise, Induced Gate Noise, enh. Short-channel thermal noise
- **Parameter count: ca. 140**
- **Implementation: Verilog-AMS Code**
  - Available in: ELDO (Mentor) , Smash (Dolphin), Spectre (Cadence)



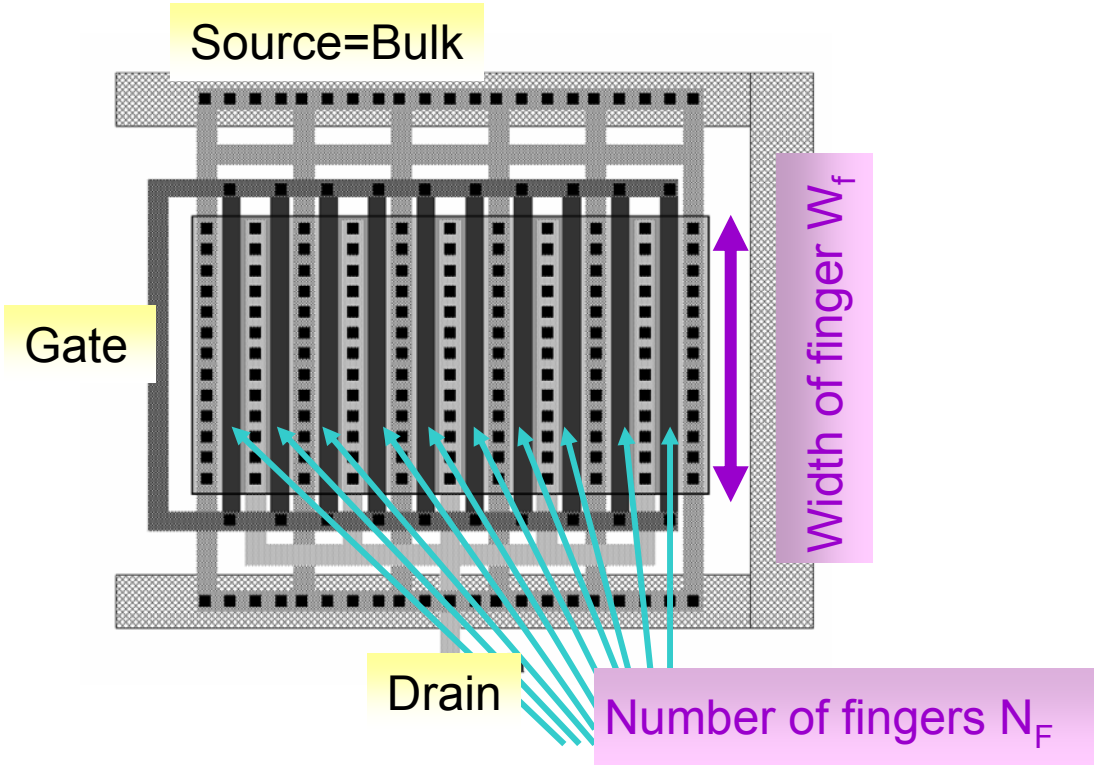
EKV3 model for RF



- Non quasi-static model (NQS)
  - channel segmentation
  - consistent AC/transient
- Gate- and substrate- parasitics scale with multi-finger layout

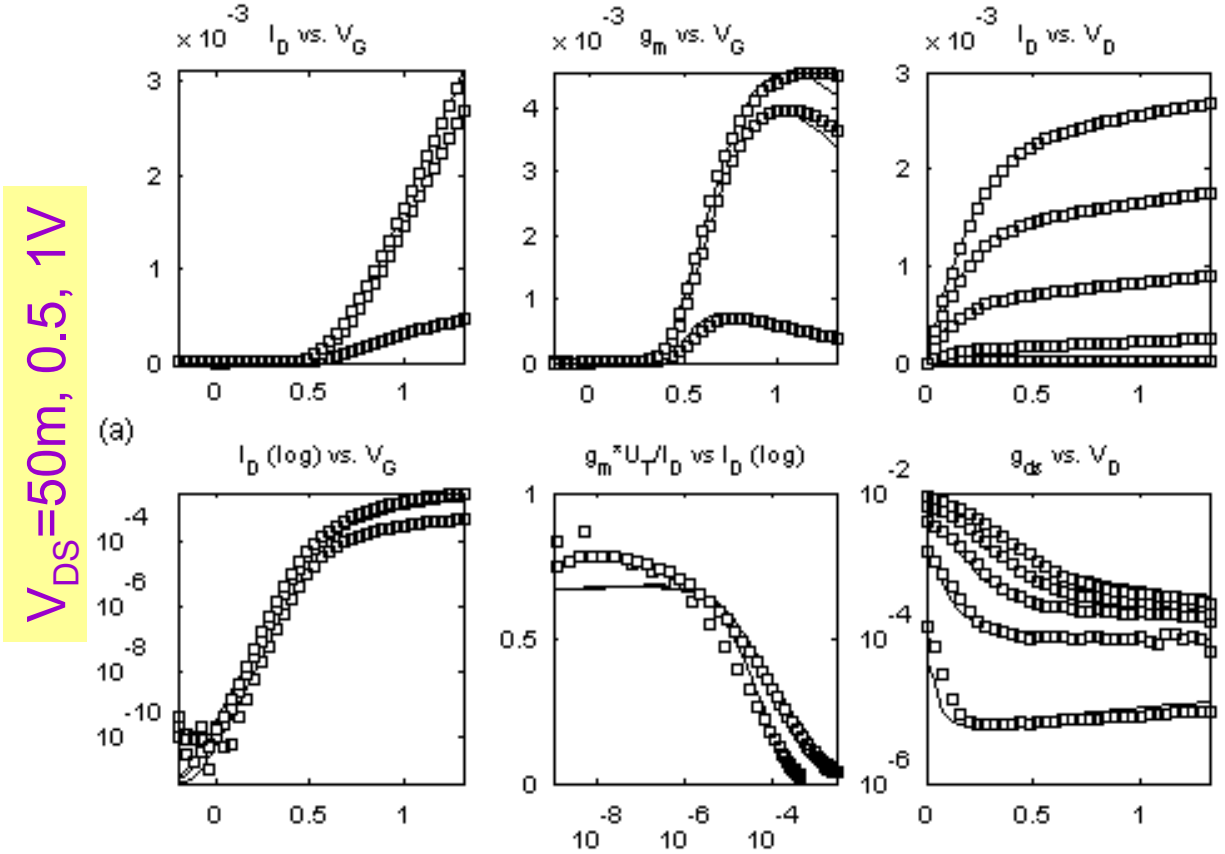
R_G	$\sim W_f/(L*N_F)$
R_{SB}, R_{DB}	$\sim 1/W_f$
R_B	$\sim 1/W_f$
R_{DSB}	$\sim L/(W_f*N_F)$

Multi-finger RF MOSFETs



- Layout of RF multi-finger MOSFET
  - Number of fingers – N_F (1-50), can be odd or even
  - Finger Width – W_f (0.5-5µm)
  - Gate Length – L
  - Single- or both-sided gate contacts
  - Layout-dependent stress: Active area to shallow trench isolation (STI)

Static characteristics – 180nm CMOS



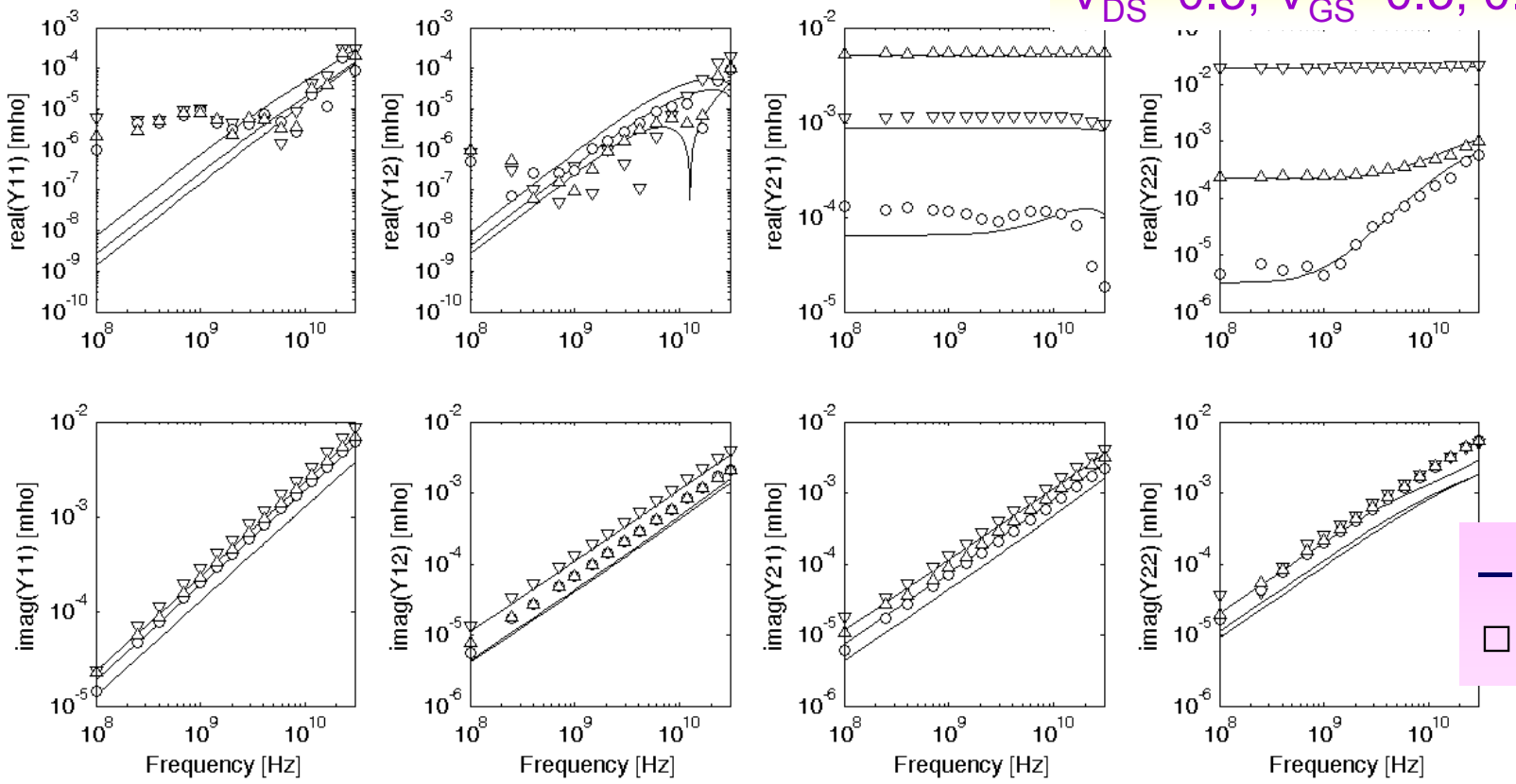
– EKV3
□ meas.

- NMOS, L=180nm, W_f=2µm, N_F=4
- I_D-V_G, g_m-V_G, $g_m.U_T/I_D$ – I_D
- I_D-V_D, g_{ds}-V_D

Bazigos e.a., Micro&Nano 2007

Y-parameters – 180nm CMOS

V_{DS}=0.3, V_{GS}=0.3, 0.6, 1.2V

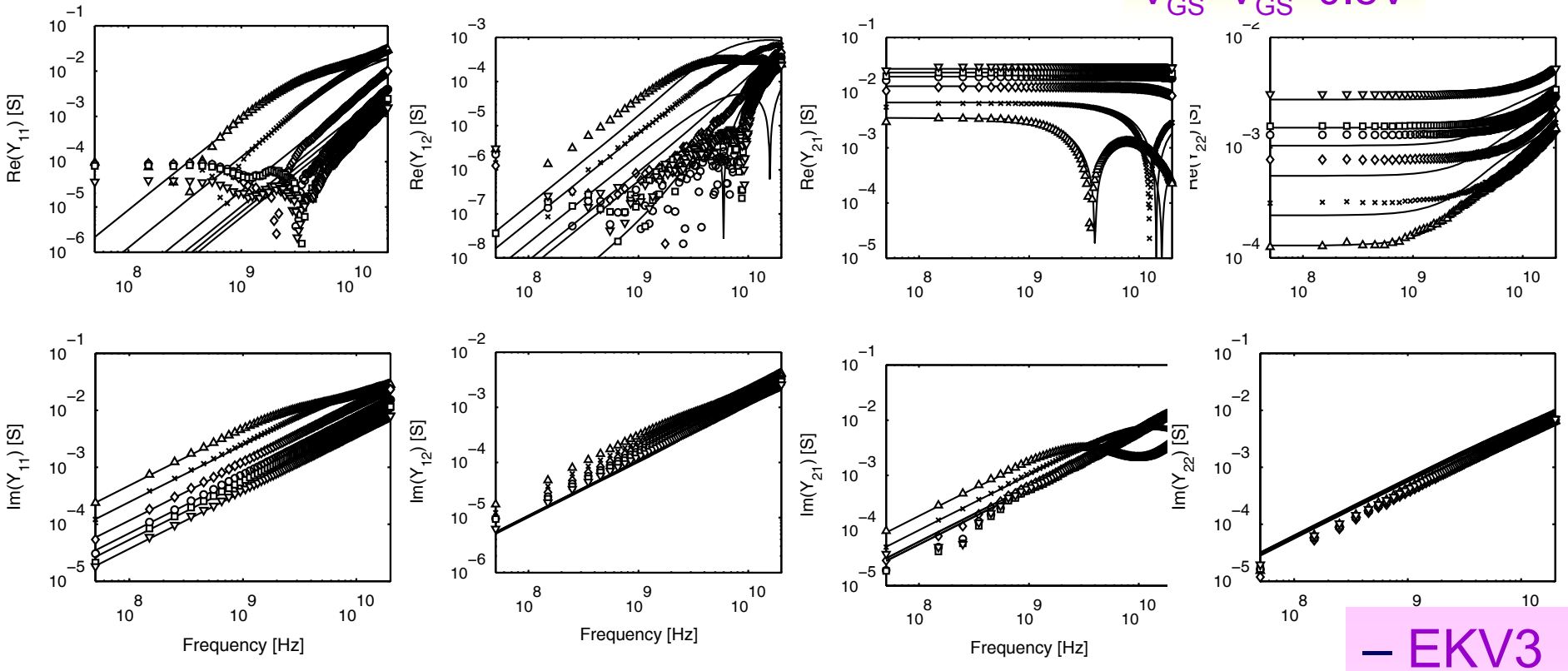


- Real & Imaginary 2-port Y-parameters up to 30GHz
- NMOS, L=180nm, W_f=2µm, N_F=9

Bazigos e.a., Micro&Nano 2007

Scaling of Y parameters vs. L – 110nm CMOS

$V_{GS}=V_{GS}=0.8V$



– EKV3

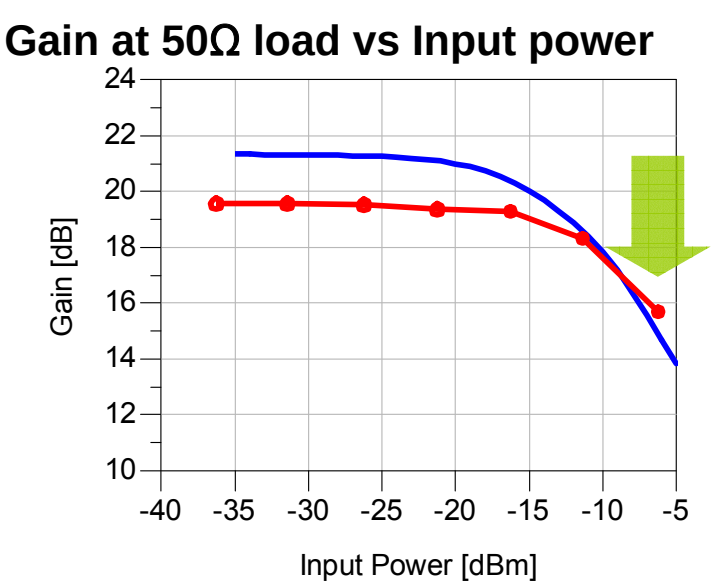
□ meas.

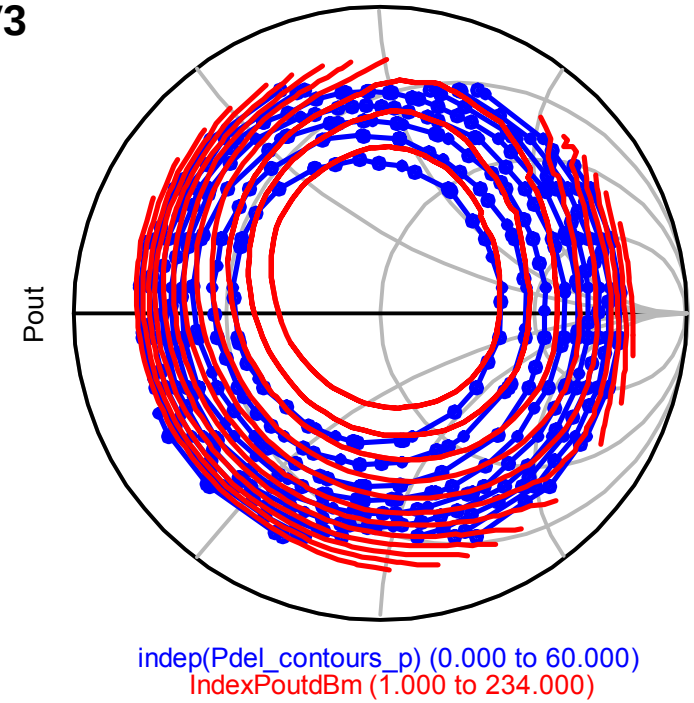
- NMOS, L=110nm ... 2um, W_f=2µm, N_F=40

Bucher e.a., RFMiCAE 2008

Large signal verification at RF – 110nm CMOS

Yoshitomi, MIXDES 2005





L_g=110nm, W_f=5.2um, N_F=12

freq = 2.45 GHz

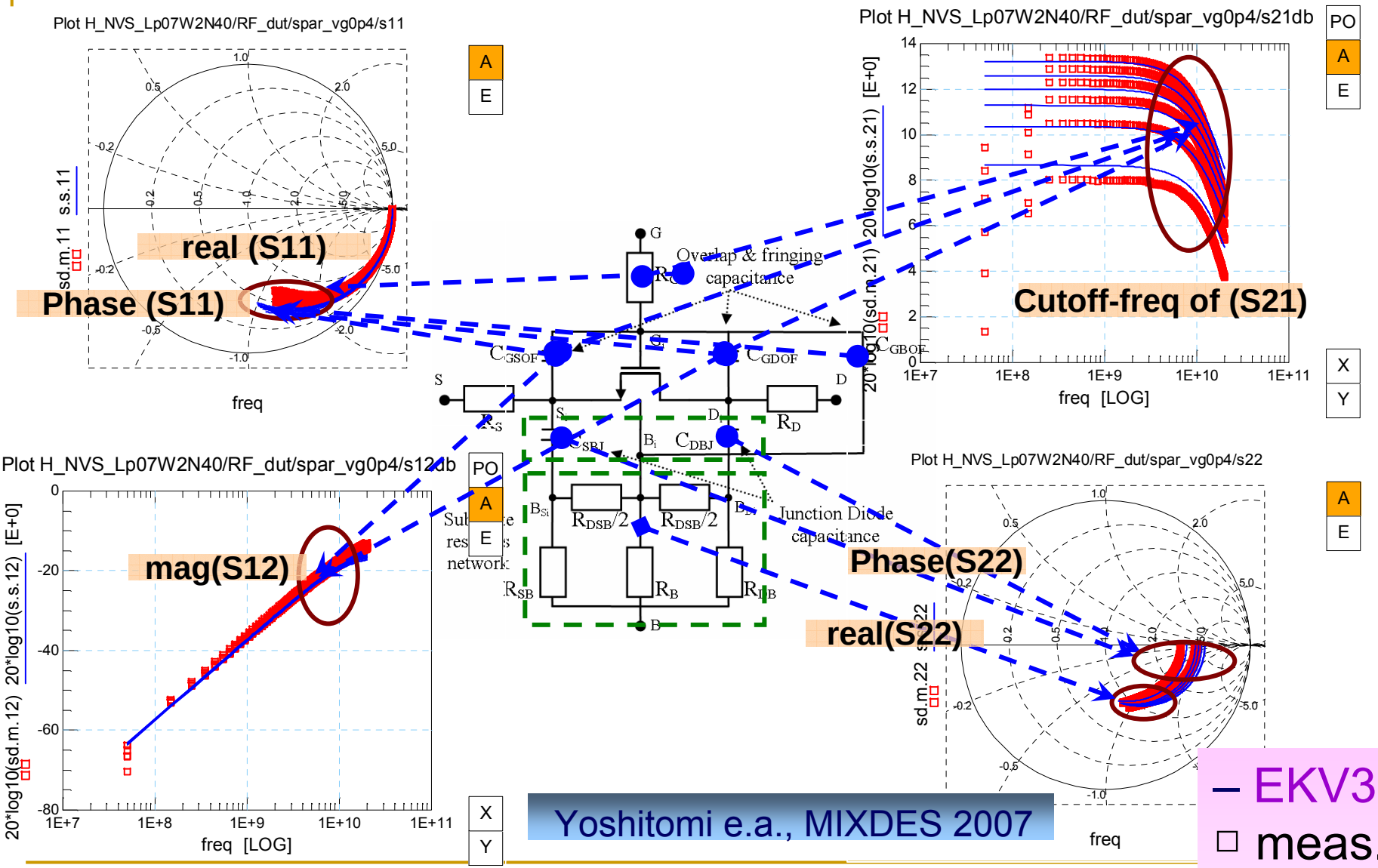
V_{GS}=0.9V, V_{DS}=1V

Gain range 3dB…8.5dB

Gain contour @ Pin = -6dBm

- Gain compression & gain contour plots at given bias & geometry

S parameters – 90nm CMOS



Yoshitomi e.a., MIXDES 2007

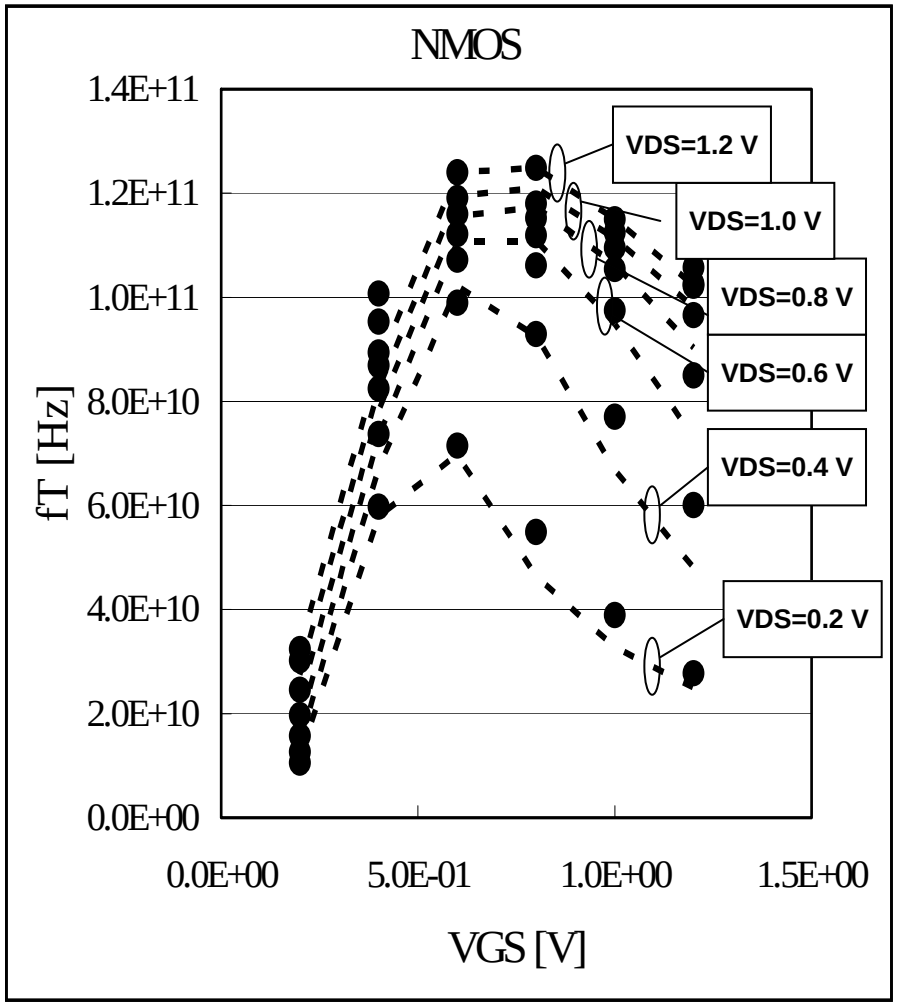
– EKV3

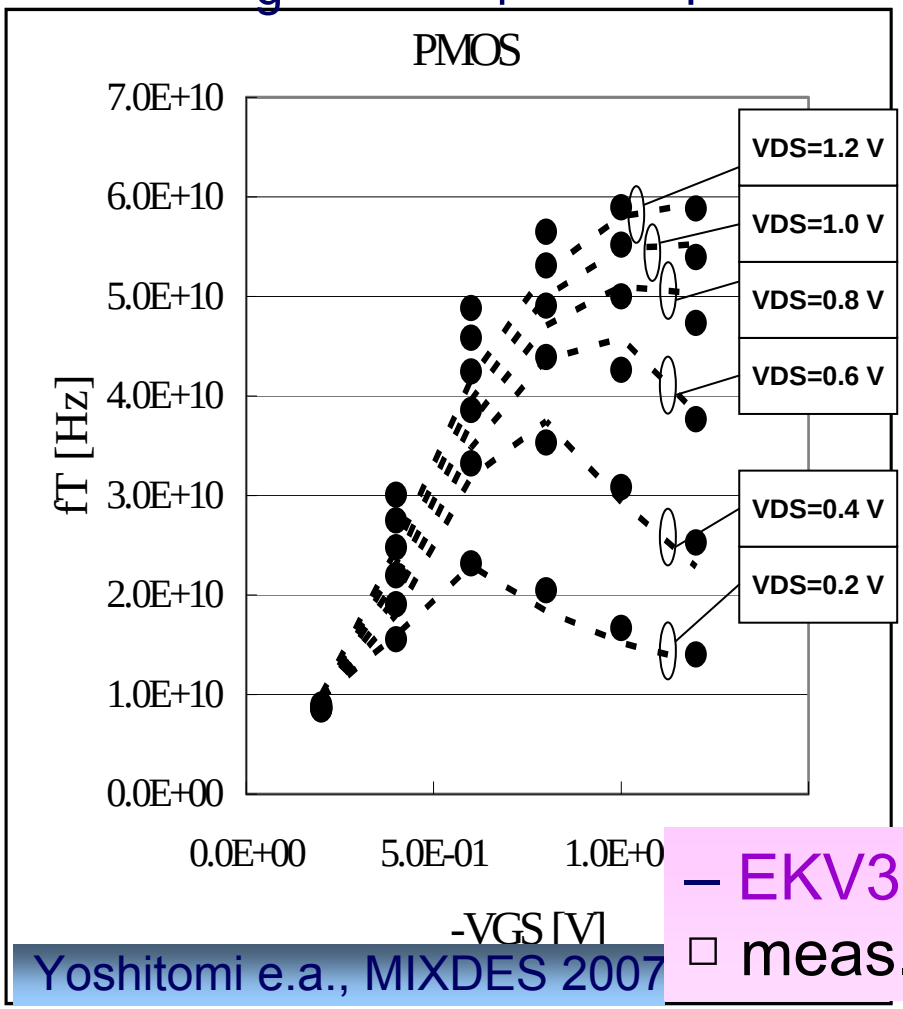
□ meas.

Transit frequency f_T vs. V_{GS}, V_{DS} – 90nm CMOS

Measurement
EKV3

L_g=70nm W_f=2um N_F=10

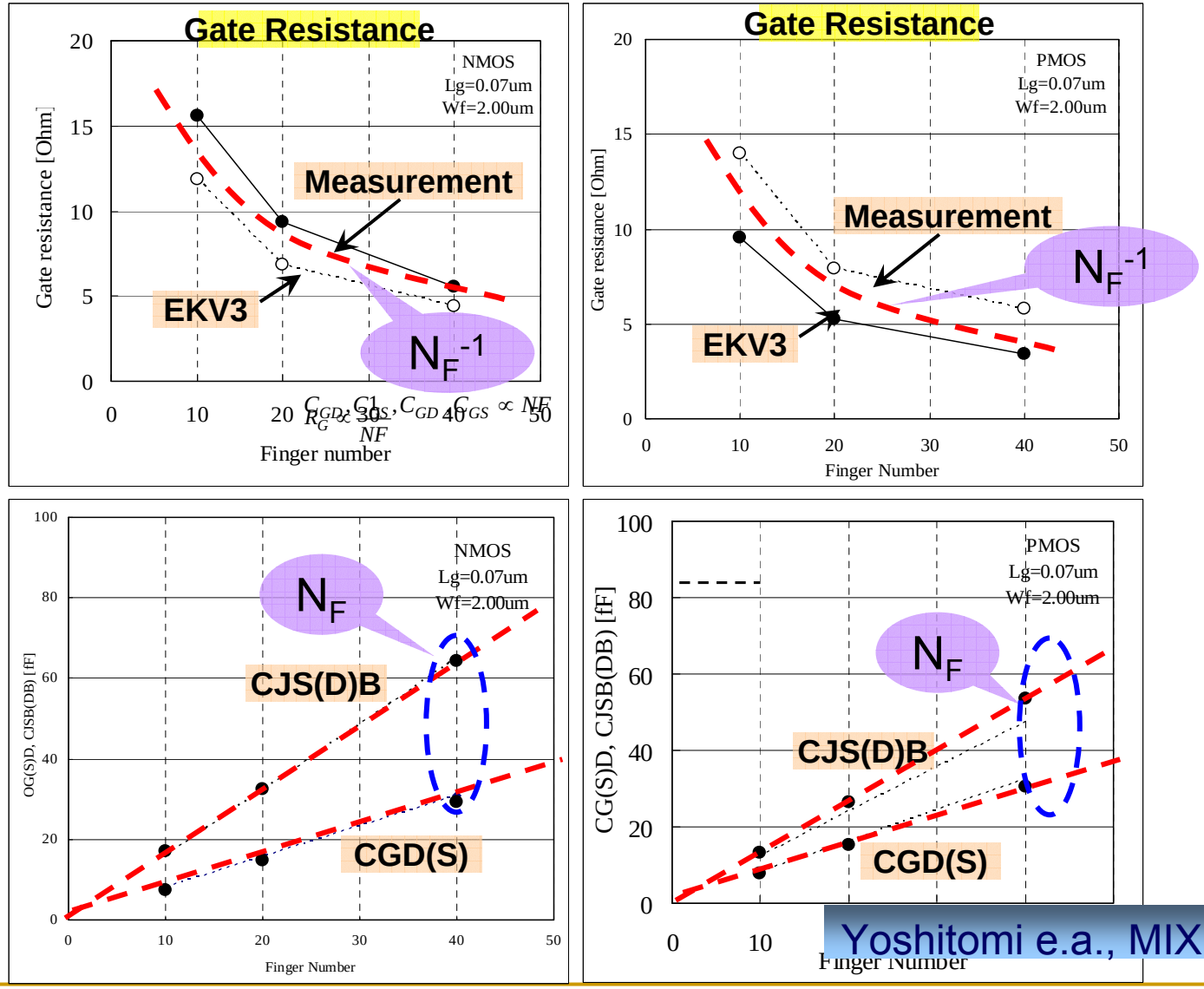




– EKV3
□ meas.

Yoshitomi e.a., MIXDES 2007

RF-Scalability vs. Number of fingers

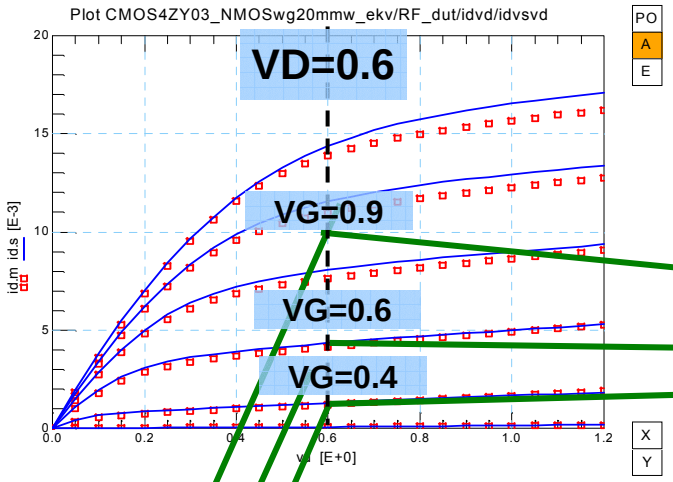


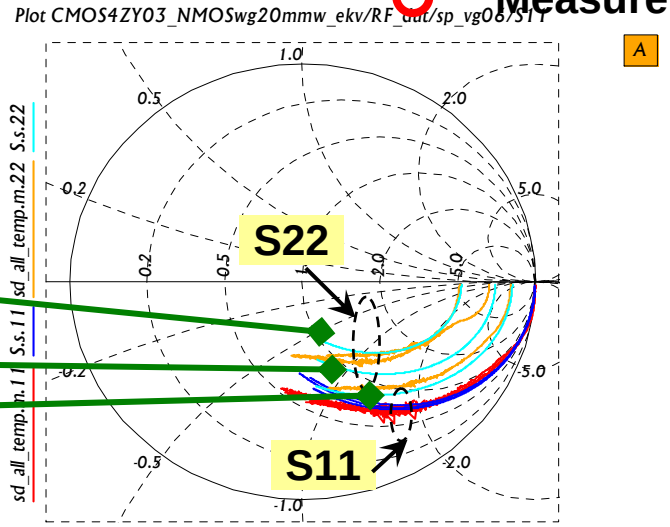
Yoshitomi e.a., MIXDES 2007

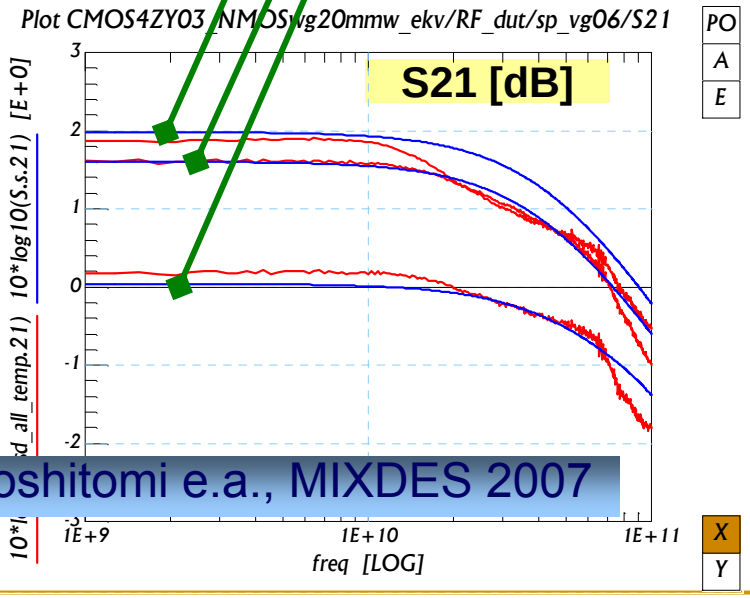
EKV3 for mm-Wave design

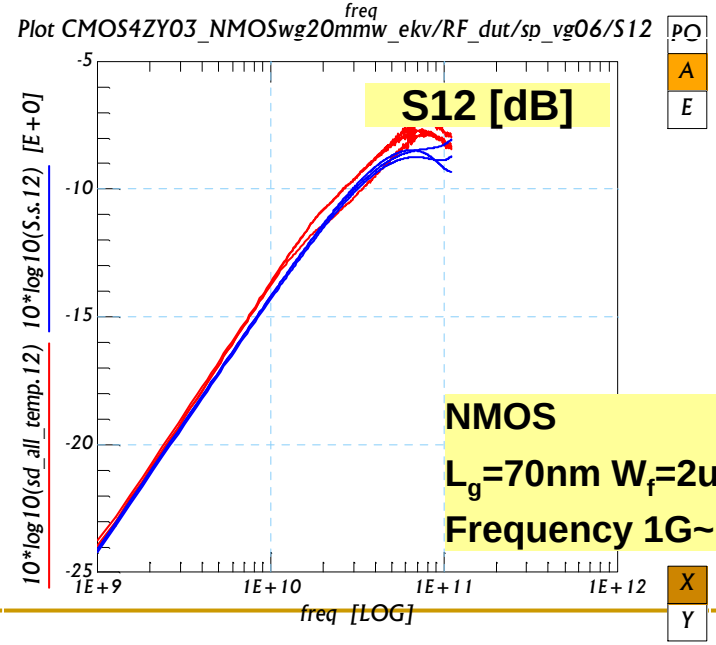
EKV3 NQS Mode

Measurement









Yoshitomi e.a., MIXDES 2007

NMOS

L_g=70nm W_f=2um N_F=10

Frequency 1G~110GHz

Conclusions

- EKV3 RF scalable model has been extensively validated
  - 180nm CMOS
  - 110nm CMOS
  - 90nm CMOS
- EKV3: a design-oriented, charge-based, compact model for analog/RF IC design.
  - EKV301.01 Verilog-AMS code released 23 November, 2007.
  - Standard model implementations
    - ELDO (Mentor)
    - Smash (Dolphin)
    - Spectre (Cadence)
  - AdMOS EKV3 parameter extraction automated toolkit for IC-CAP.
- EKV3 ongoing developments:
  - Extended 1/f noise model
  - Extended model for short-channel effects in HF noise

Reference

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