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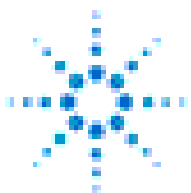
Thomas Gneiting (ADMOS)

LARGE-SIGNAL NETWORK ANALYZER MEASUREMENTS AND THEIR USE IN DEVICE MODELLING



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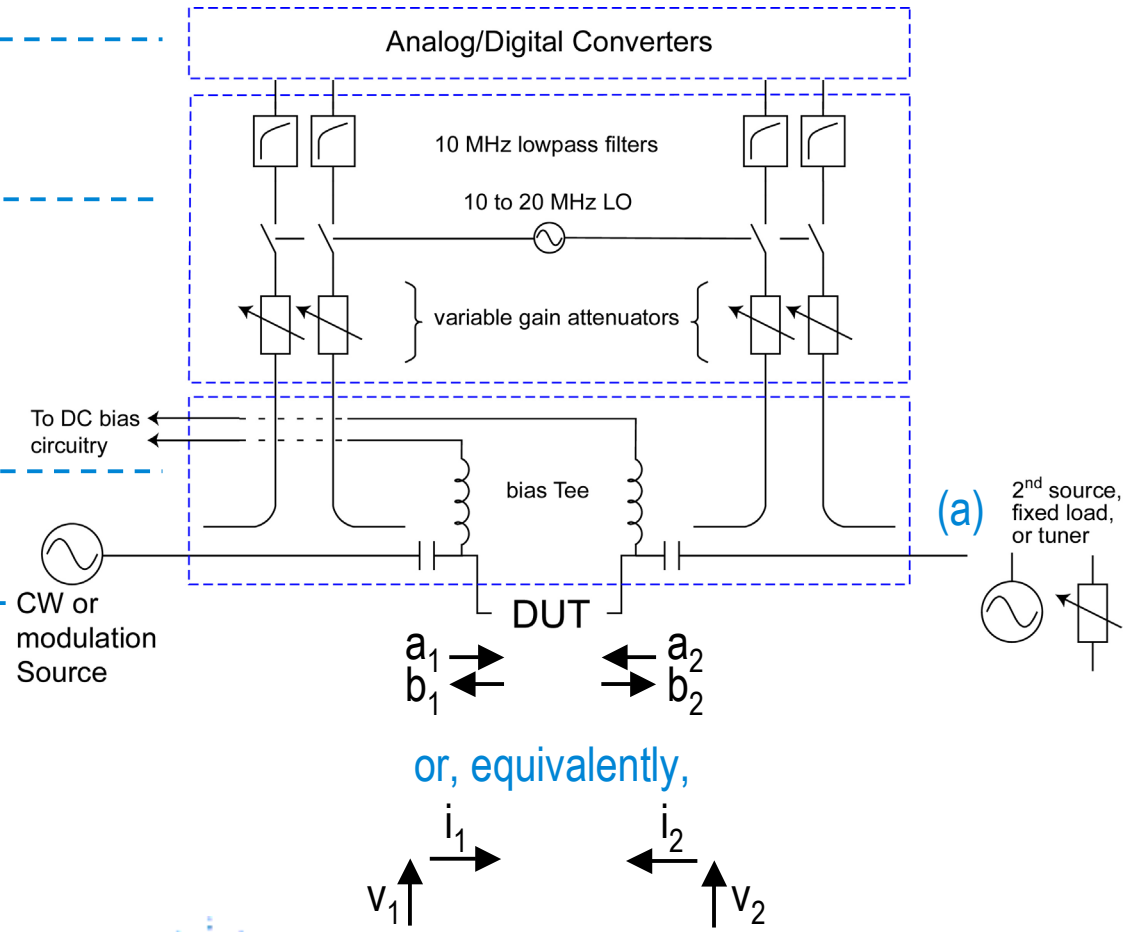
Outline

- Large-Signal Network Analyzer (LSNA) technology
- Advantages of using LSNA for device modelling engineers
- LSNA measurements
  - de-embedding
  - implementation in CAE tool (iccap)
  - measurement and simulation results
  - tuning of model parameter to LSNA measurements
- Conclusions

Agilent's Large-Signal Network Analyzer technology

- RF bandwidth: 600 MHz - 20 GHz
- max RF power: 10 Watt
- IF bandwidth: 8 MHz
- Needs CW or periodic modulation



Calibration Standards:

Cal Kit,
e.g. LOS, LRRM, etc.

Power Std

Phase Std

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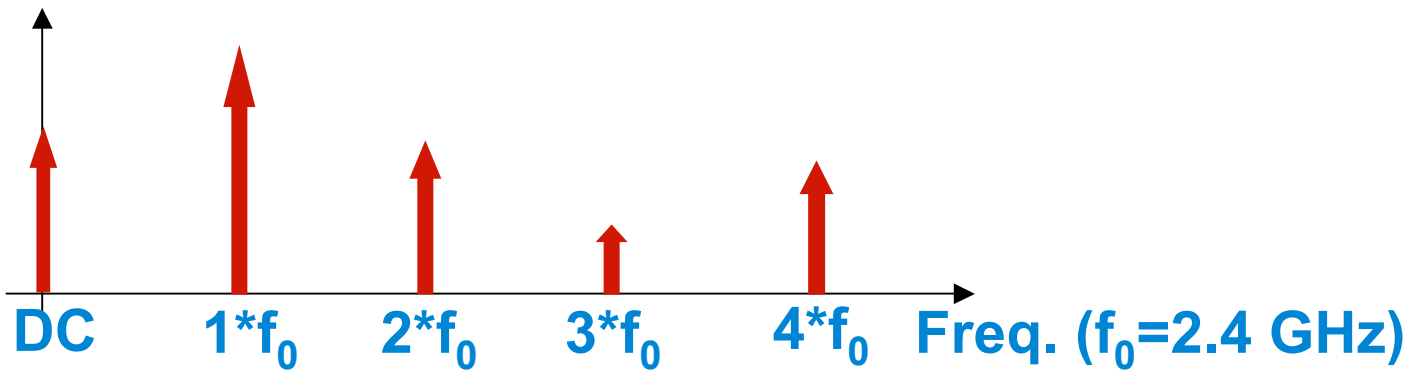
CW class of signals measured with LSNA

- 2-port Device-Under-Test (DUT) under periodic excitation
  - e.g. transistor excited by a 2.4 GHz tone with an arbitrary output termination
- All current and voltage waveforms are represented by a fundamental and harmonics



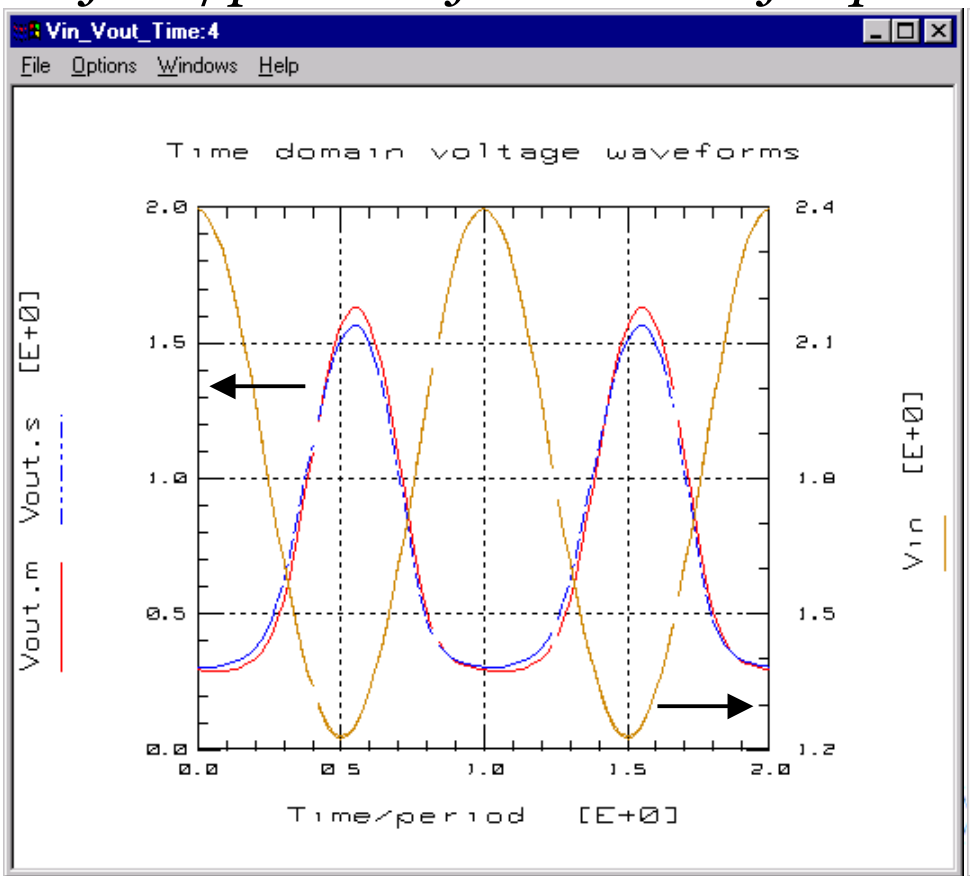
- Spectral components X_h = complex Fourier Series coefficients of the waveforms

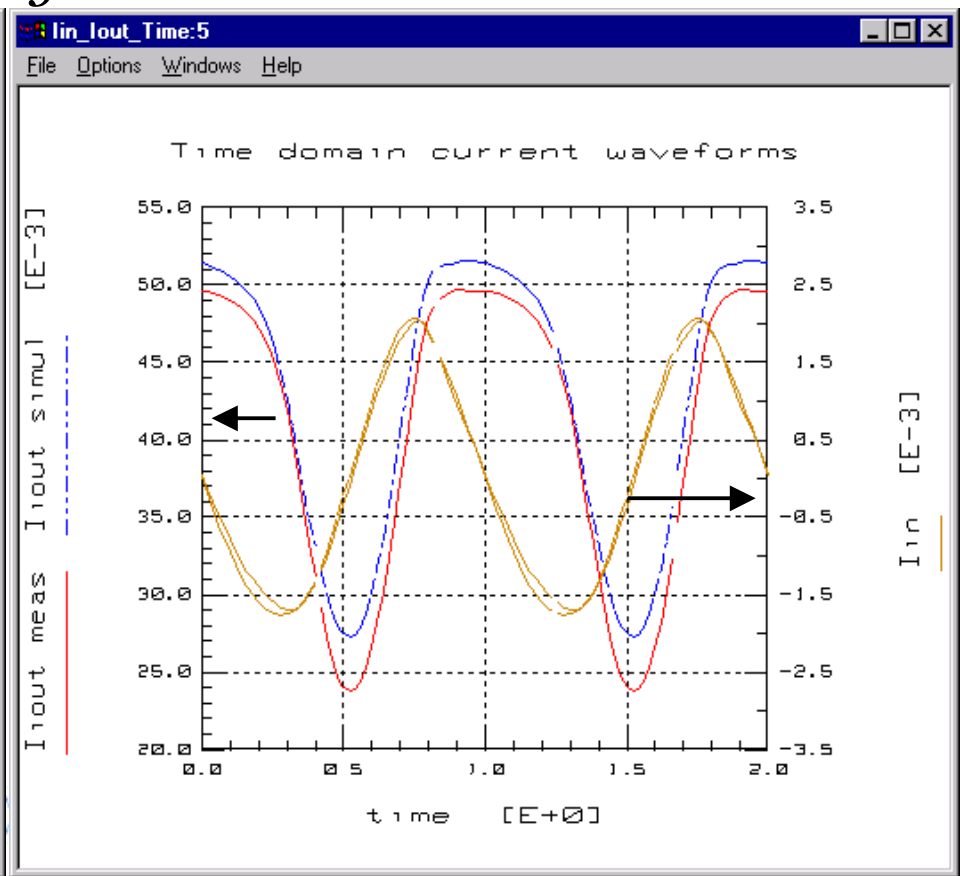
LSNA measurements: time domain, frequency domain or combination of both (e.g. envelope in modulation)

$$x(t) = \mathrm{Re}\left(\sum_{h=0}^{H} X_h \, e^{j\,2\pi\, h f\, t} \right)$$

$$X_h = 2f \int_0^{f^{-1}} x(t) e^{-j\,2\pi\, h f\, t} dt$$

$$f = 1/period = fundamental frequency$$



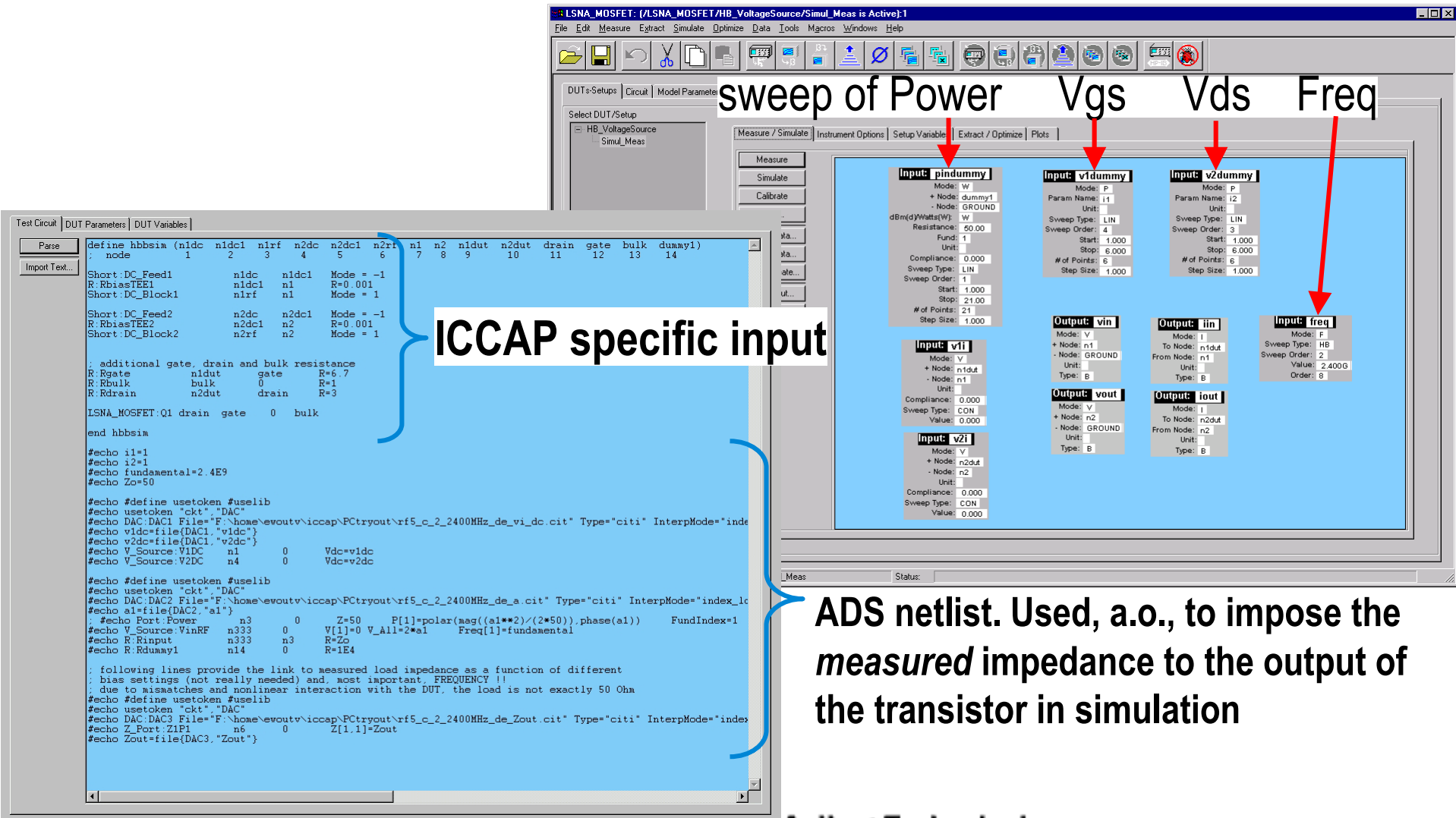


Advantages of using the LSNA in device modelling

- Measure the following characteristics of your DUT making a ***single*** connection, using *one* measurement setup (the LSNA)
  - DC,
  - Small-signal (Scattering parameters), and
  - Large-signal behaviour
- Verify the model accuracy of your device under ***realistic*** operation conditions
  - power amplification
  - high-speed switching
- Identify modelling problems at a ***single*** glance
  - LSNA measurements, e.g., immediately reveal weaknesses in capacitance and charge models

Use of LSNA measurements in CAE tool (iccap)

⇒ model *verification, optimisation (and extraction)*



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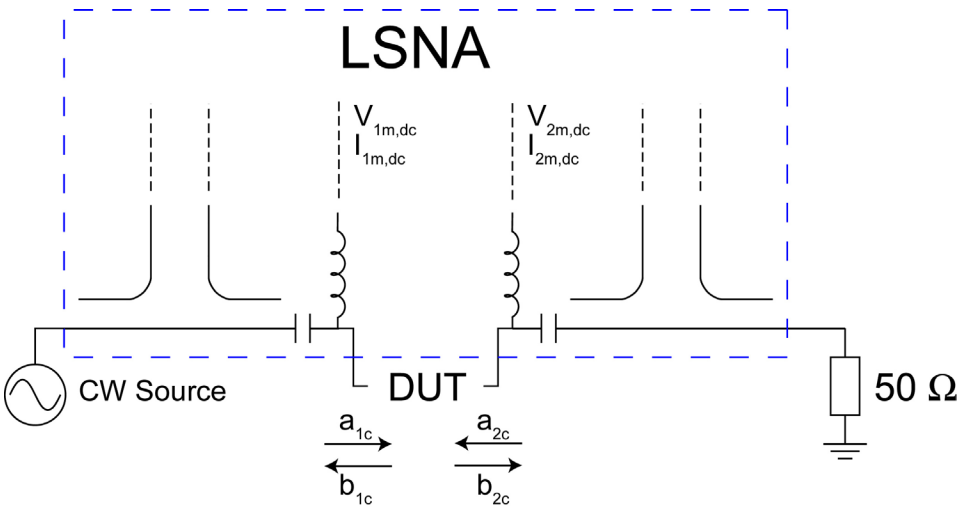
Use of LSNA measurements for simulation (1/2)

Measurements ⟹ RF de-embedding

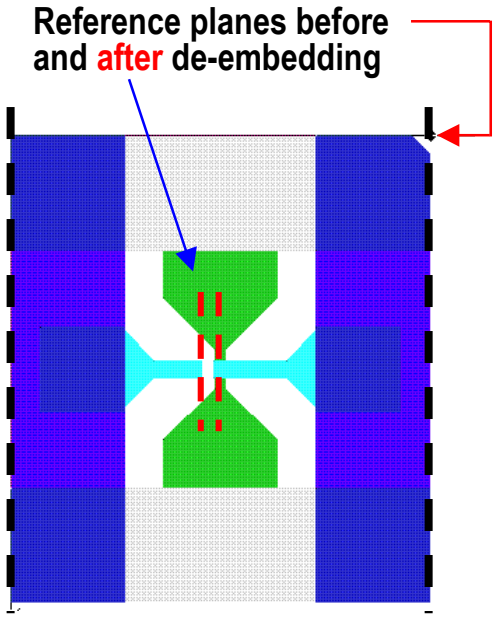


$$\begin{matrix} a_{1c} & b_{1c} \\ a_{2c} & b_{2c} \end{matrix} \Leftrightarrow \begin{matrix} v_{1c} & i_{1c} \\ v_{2c} & i_{2c} \end{matrix} \} \text{ @ } f_0, 2*f_0, \ldots$$

calibrated

$$\begin{matrix} V_{1m,dc} & I_{1m,dc} \\ V_{2m,dc} & I_{2m,dc} \end{matrix} \Rightarrow \begin{matrix} V_{1,dc} & I_{1,dc} \\ V_{2,dc} & I_{2,dc} \end{matrix}$$

LSNA accounts for cable resistances



$$\begin{matrix} v_{1c} & i_{1c} \\ v_{2c} & i_{2c} \end{matrix} \Rightarrow \begin{matrix} v_{1d} & i_{1d} \\ v_{2d} & i_{2d} \end{matrix}$$

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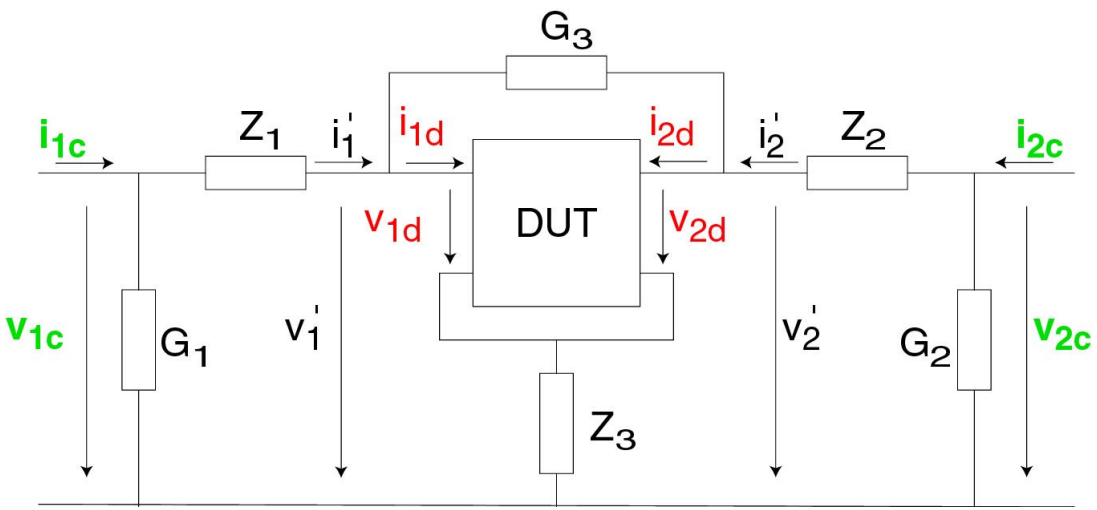
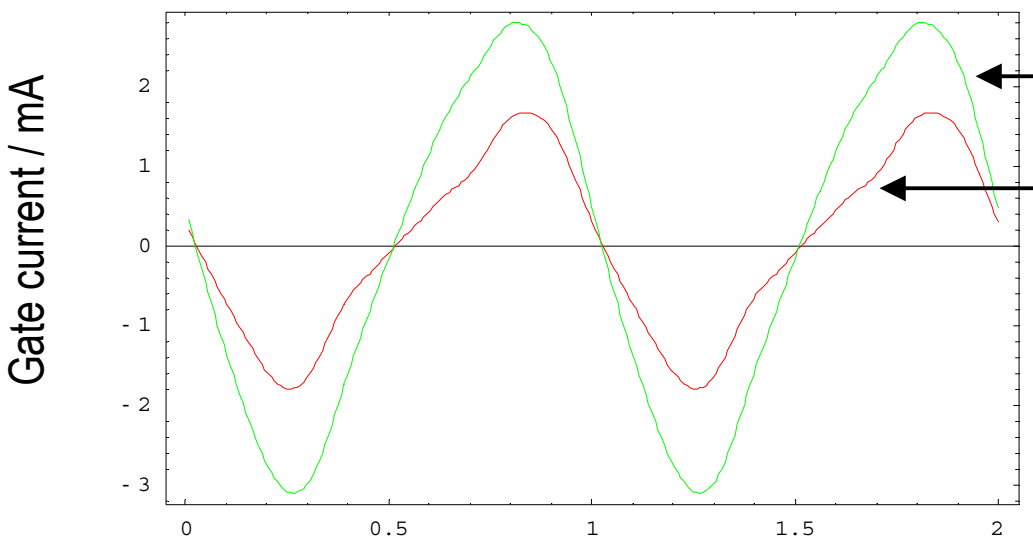
De-embedding intermezzo (1/2)



Equivalent circuit of the RF test-structure, including the DUT and layout parasitics



before
after
de-embedding

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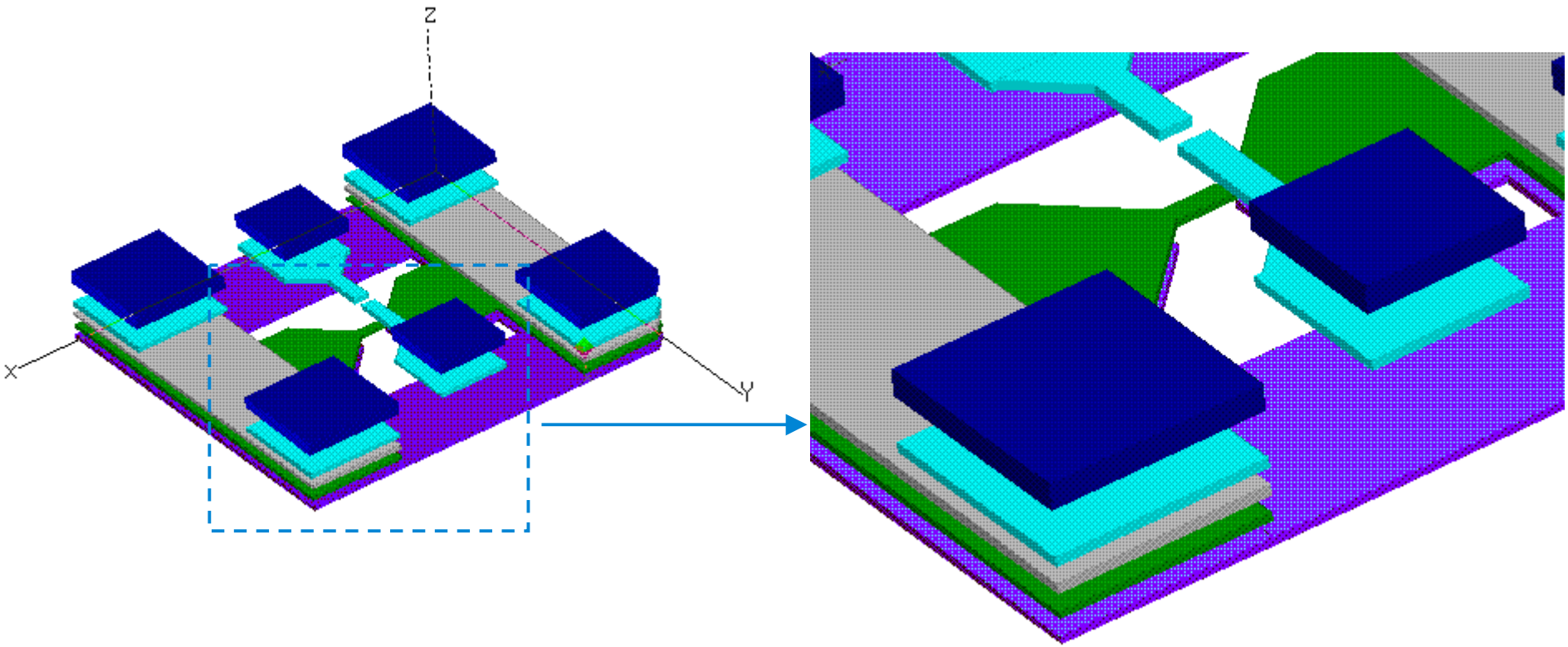
De-embedding intermezzo (2/2)



Detailed view on the layout of the RF MOSFET

for minimum influence of pad parasitics

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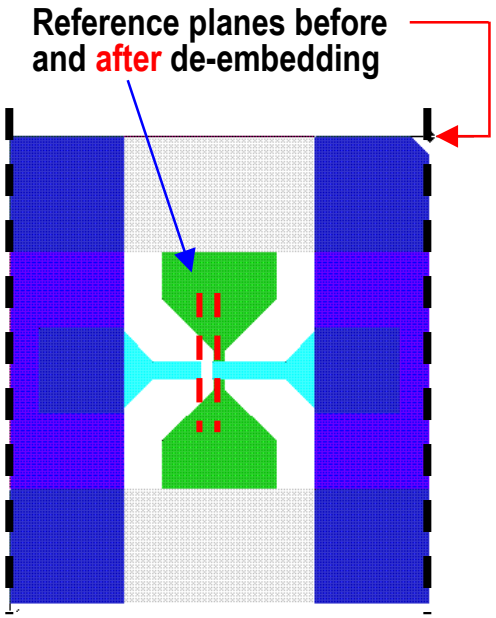
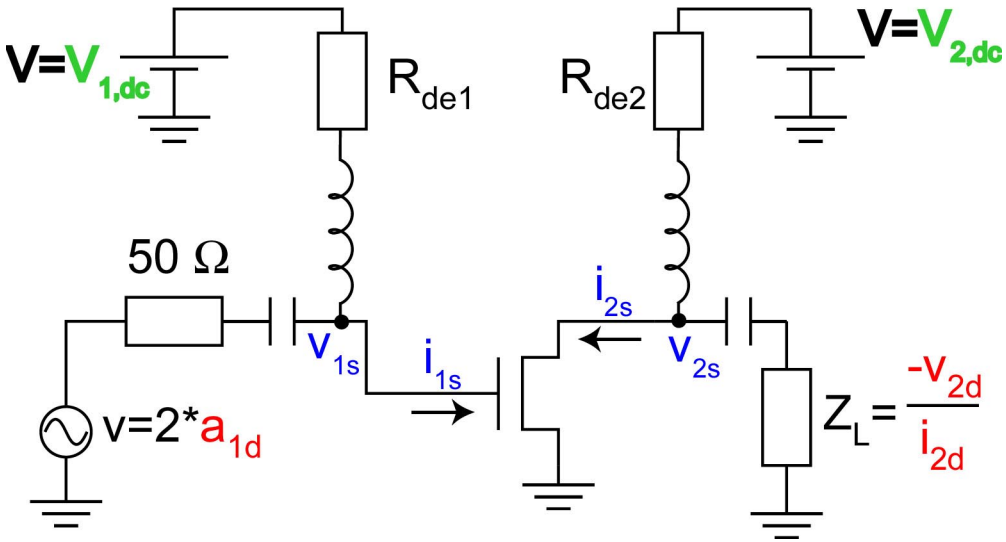
Use of LSNA measurements for simulation (2/2)

RF de-embedding ⇒ Simulations



V_{1c} I_{1c} ⇒ V_{1d} I_{1d}

V_{2c} I_{2c} V_{2d} I_{2d}



Compare measurements: V_{1d} I_{1d} V_{2d} I_{2d}

with simulations: V_{1s} I_{1s} V_{2s} I_{2s}

R_{de1} and R_{de2} are de-embedding resistances (in dc path)

The load impedance Z_L at $f=n*f_0$ equals 50 Ω if a_{2n}<-50 dBm

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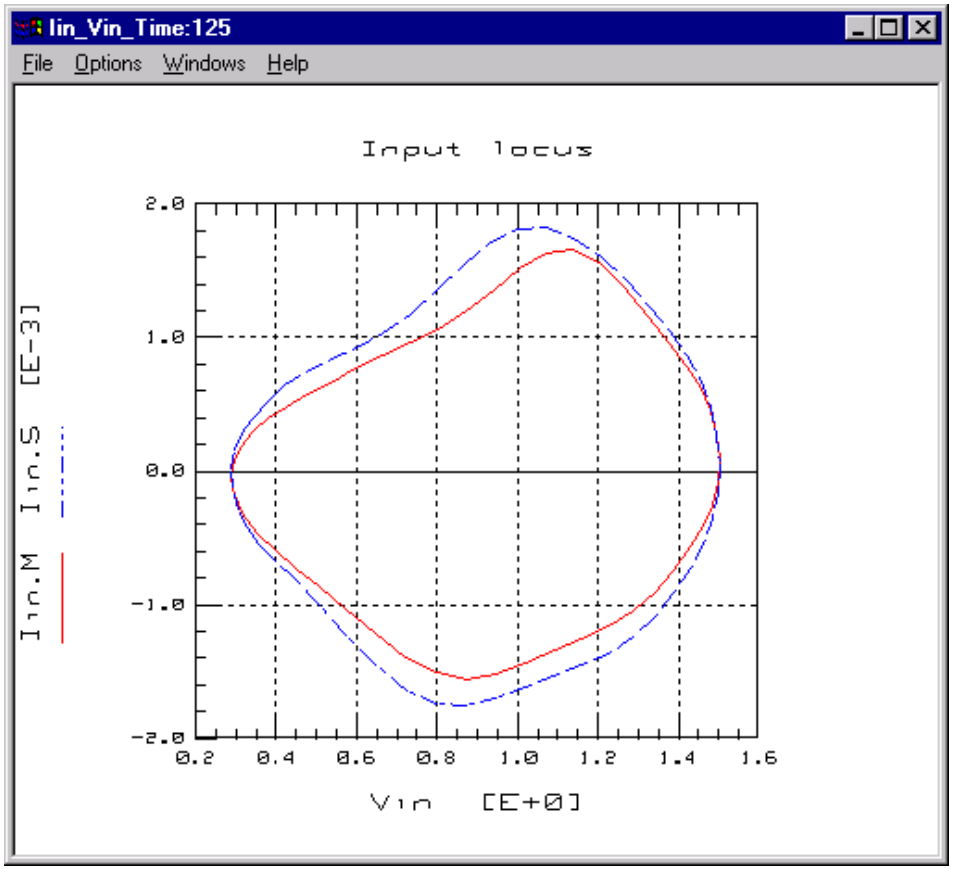
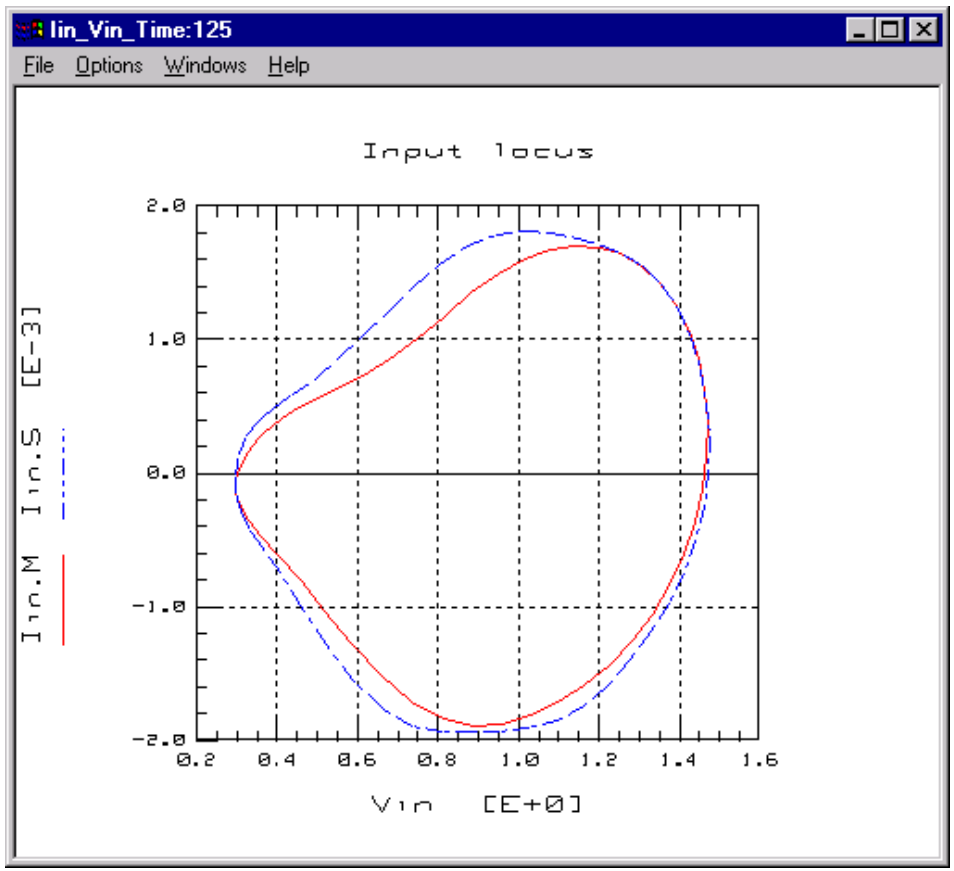
Input capacitance behaviour

$V_{ds,dc}$=0.3 V $V_{gs,dc}$=0.9 V $V_{ds,dc}$=1.8 V





Input loci turn clockwise, conform i=C*dv/dt

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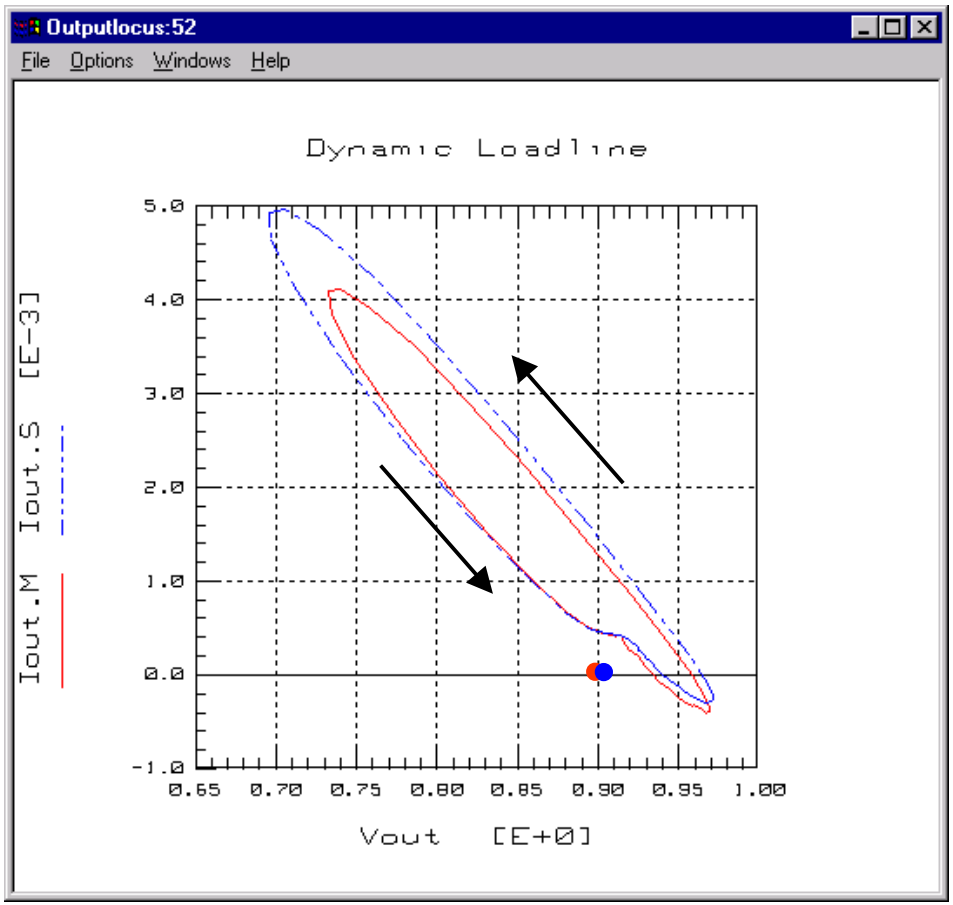
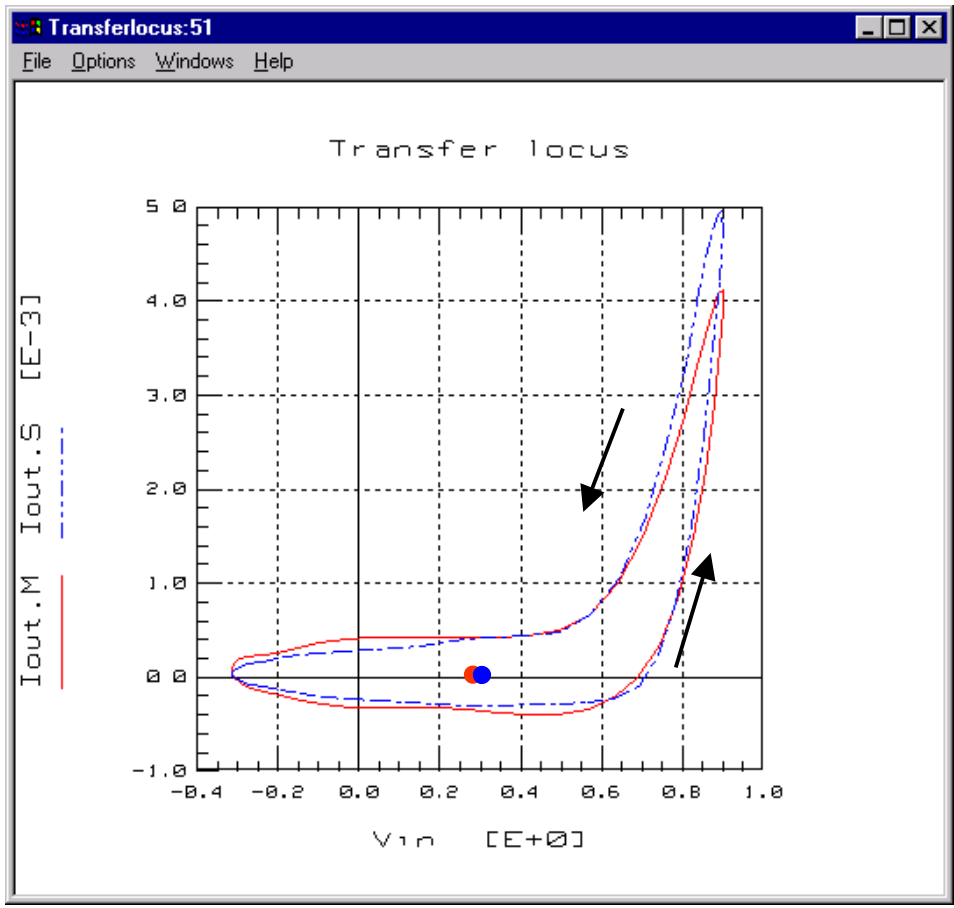
Dynamic loadline & transfer characteristic

$V_{ds,dc}$=0.9 V $V_{gs,dc}$=0.3 V





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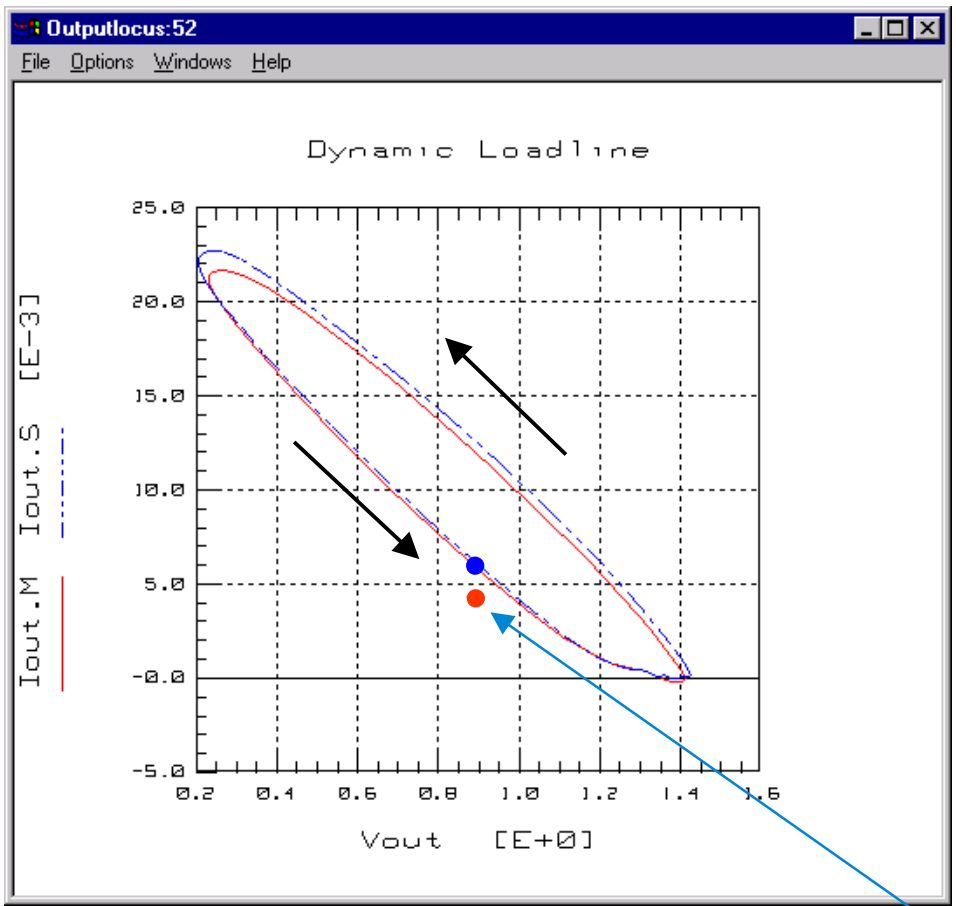
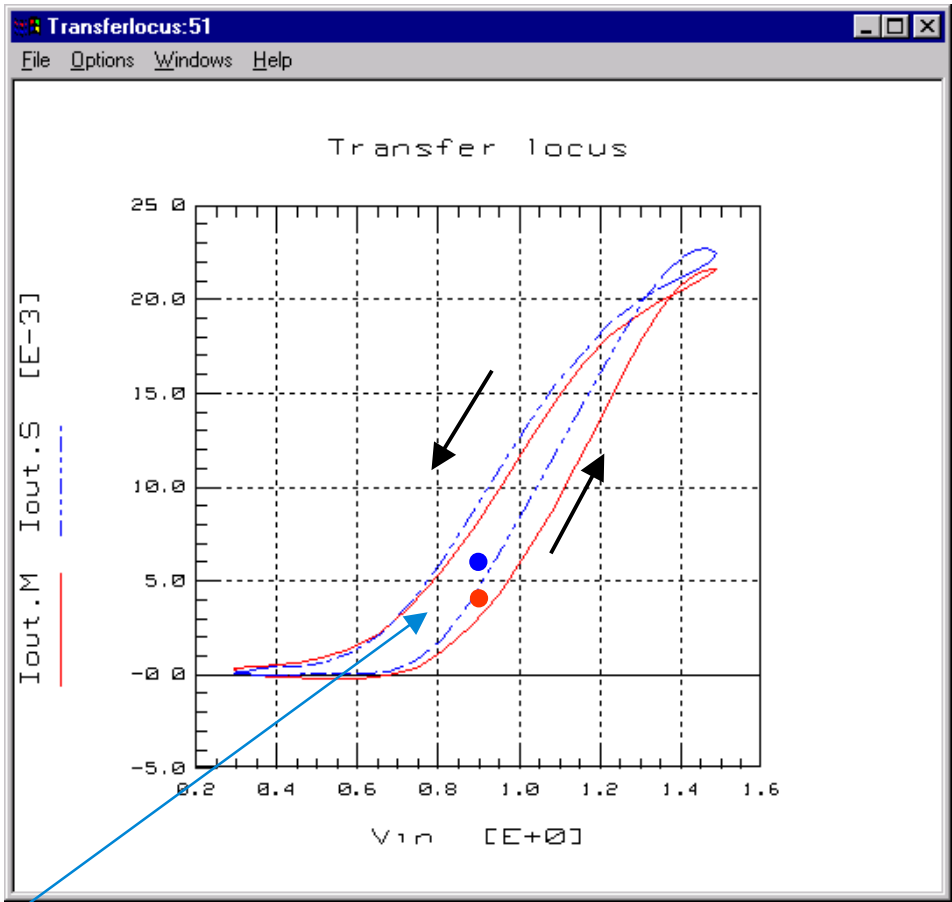
Dynamic loadline & transfer characteristic

$V_{ds,dc}$=0.9 V $V_{gs,dc}$=0.9 V





DC operating point if RF *not* present ⇒ self-biasing

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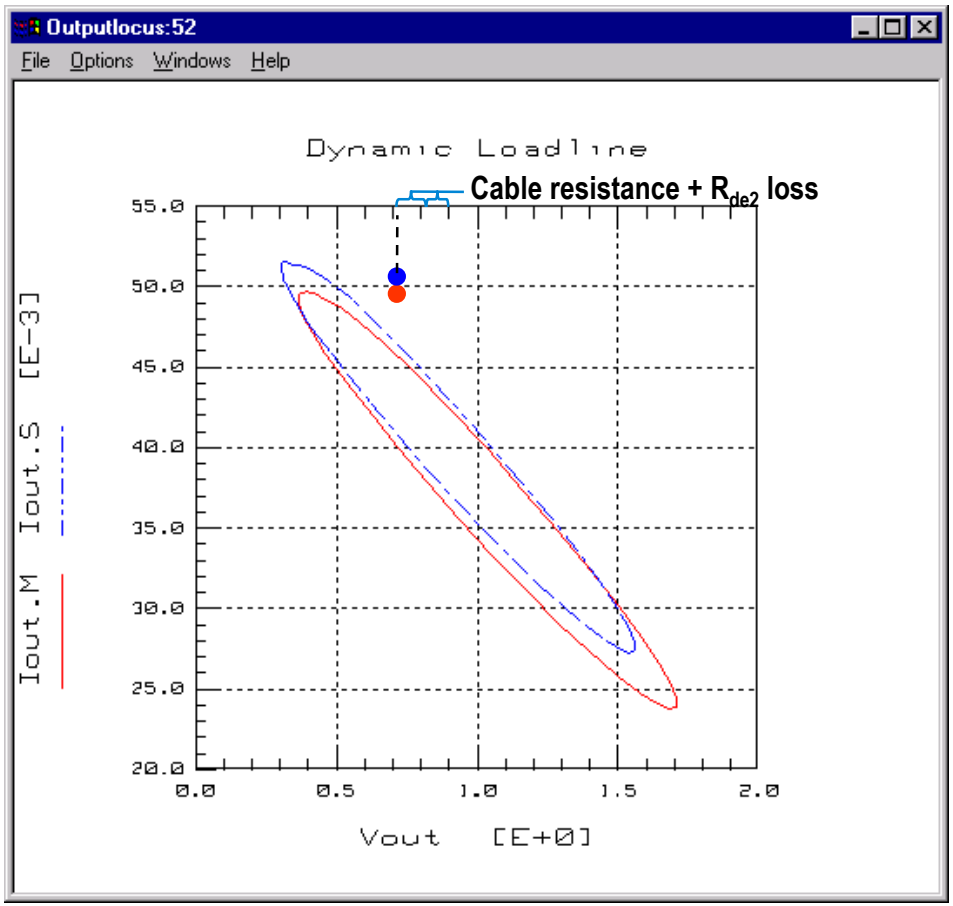
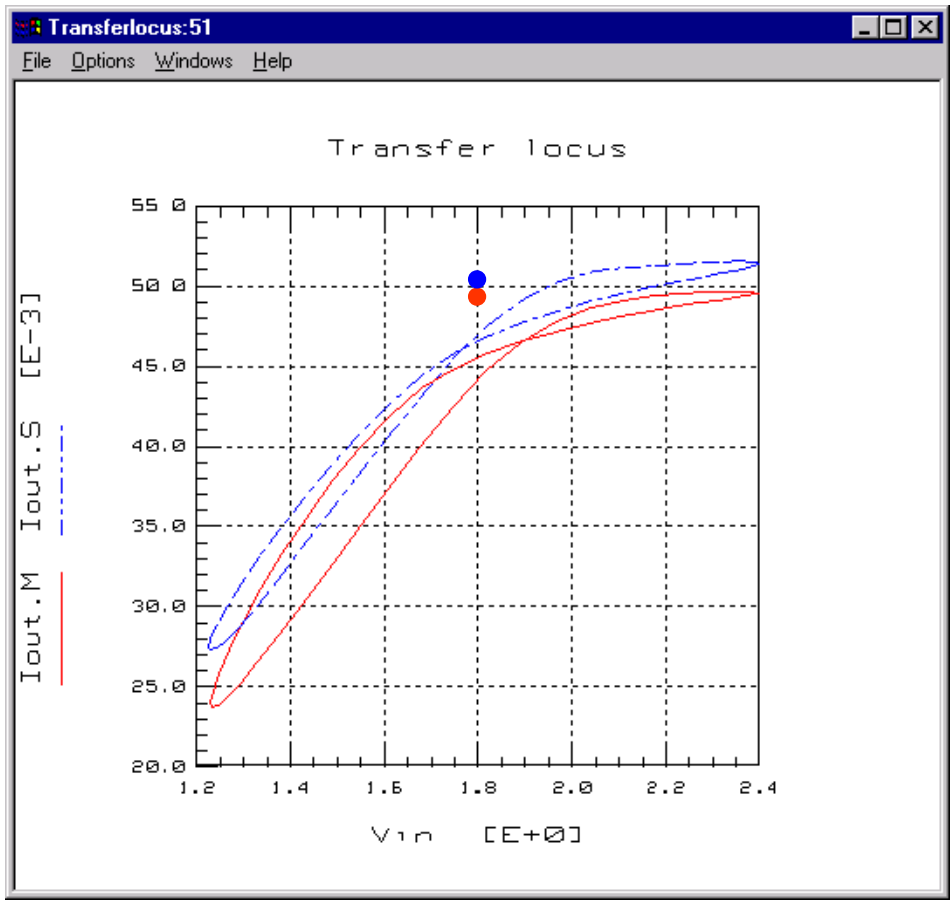
Dynamic loadline & transfer characteristic

$V_{ds,dc}$=0.9 V $V_{gs,dc}$=1.8 V





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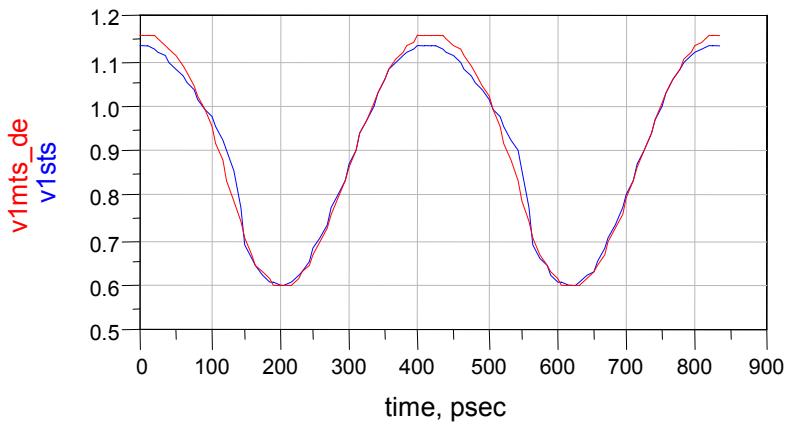
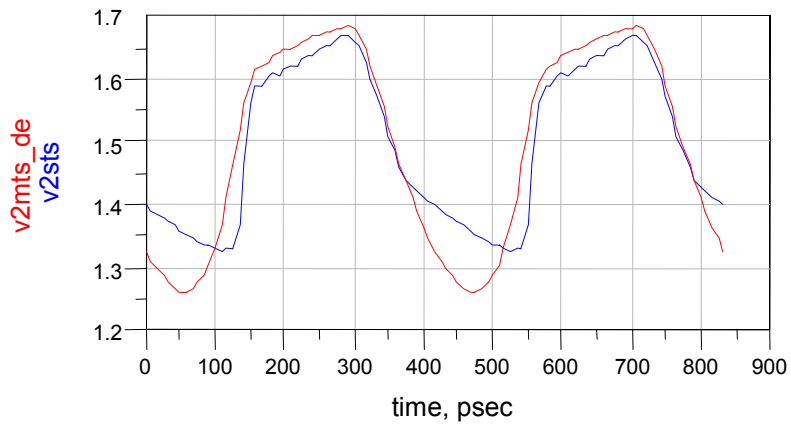
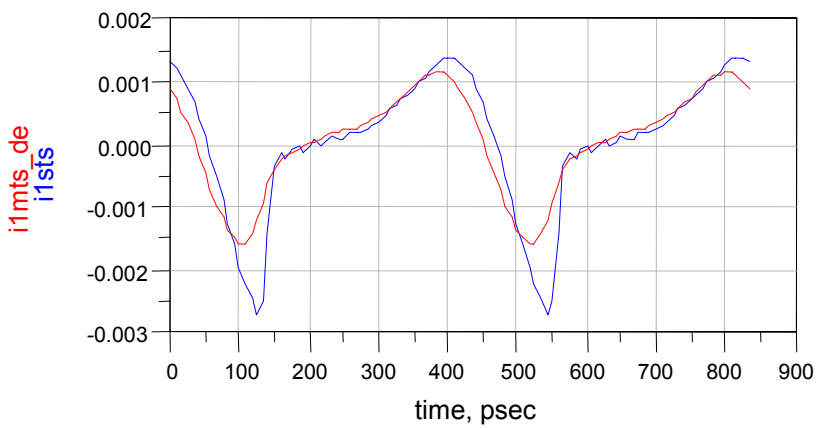
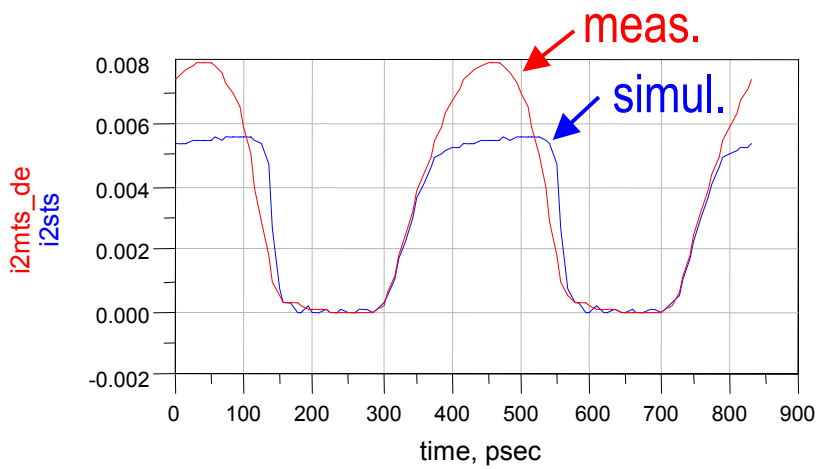
Intermezzo (1/2): extrapolation example SiGe HBT

Model parameters extracted using DC measurements up to 1 V









SiGe HBT

V_{be}= 0.9 V; V_{ce}=1.5 V; P_{in}= - 6 dBm; f_0= 2.4 GHz

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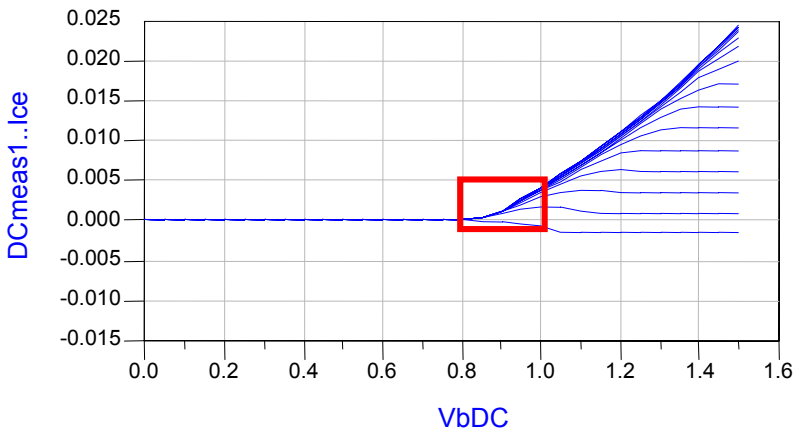
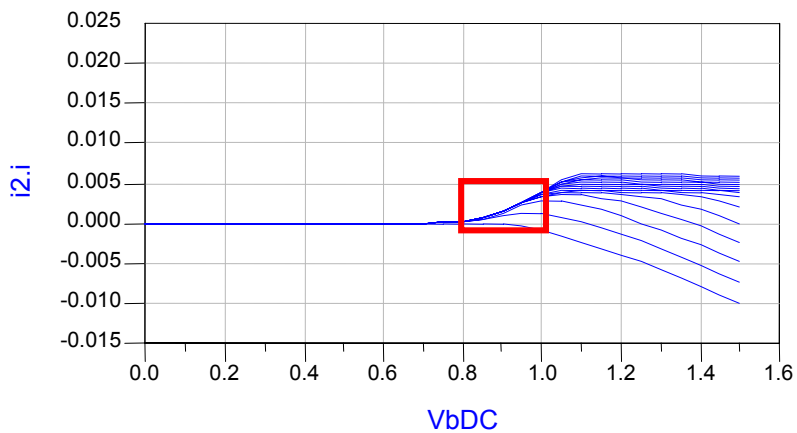
Intermezzo (2/2): extrapolation example SiGe HBT

Measured and simulated DC characteristics

SiGe HBT - DC characteristics





Measurement **Simulation**

Alcatel Microelectronics and the Alcatel SEL Stuttgart Research Center teams are acknowledged for providing these data.

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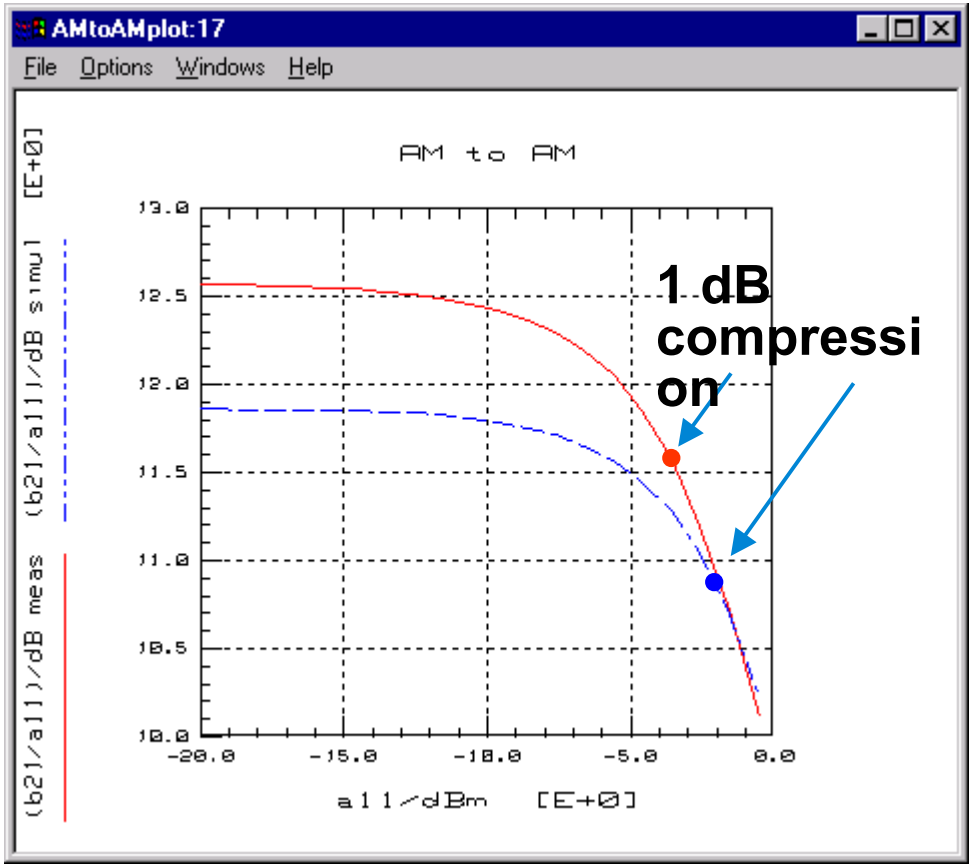
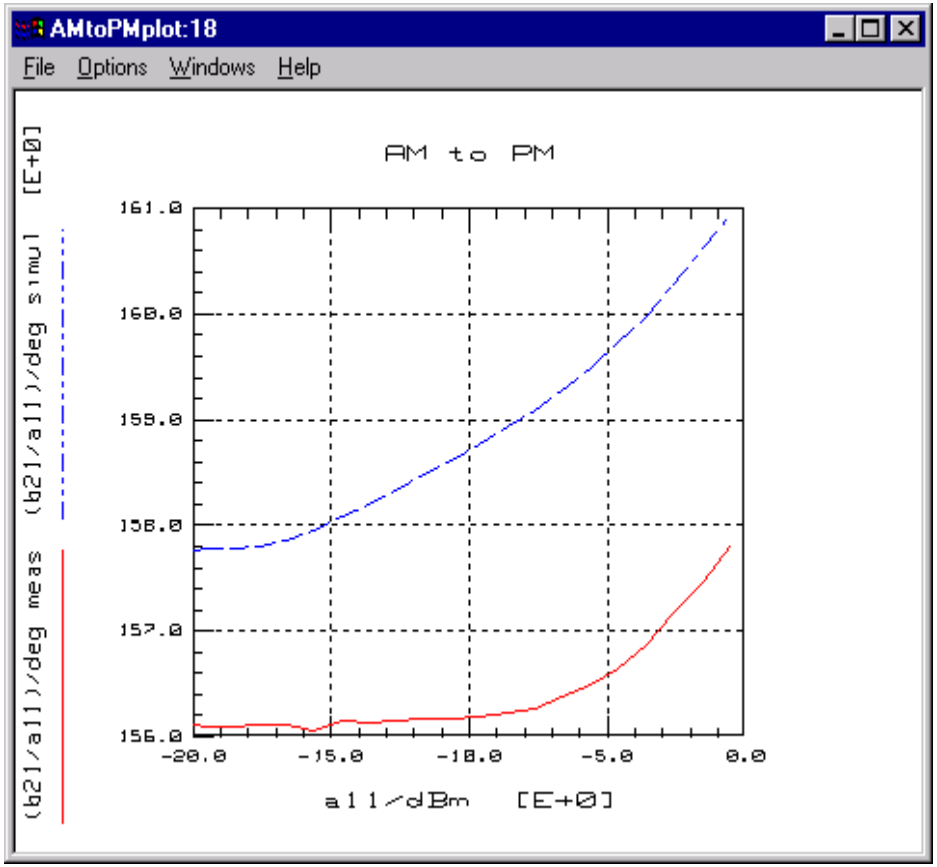
AM to AM (gain) and AM to PM versus input power





$V_{ds,dc}=V_{gs,dc}=1.2$ V

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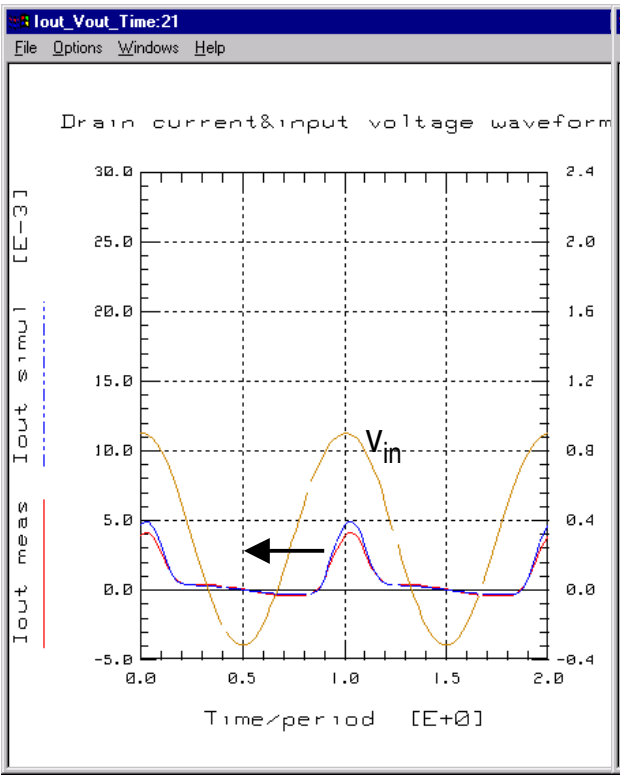
Drain current & gate voltage time domain waveforms

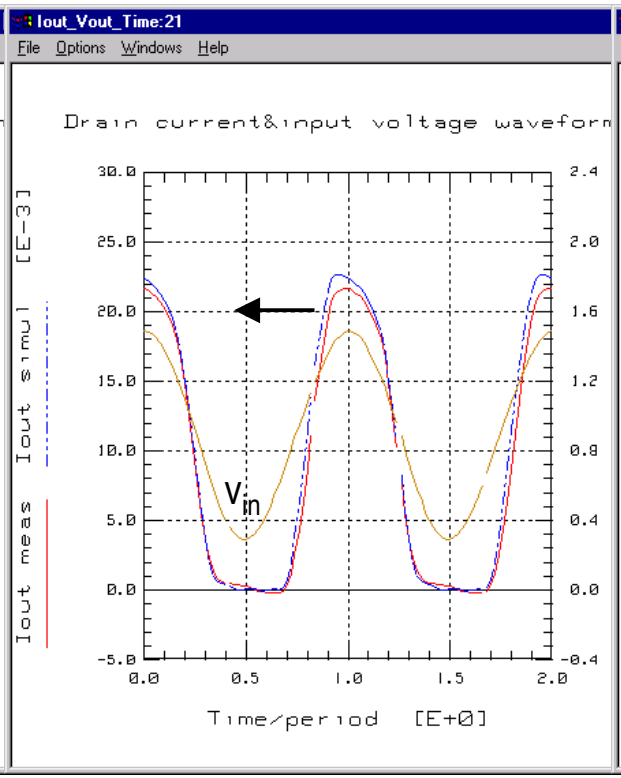
“Class C”



$V_{gs,dc}$=0.3 V

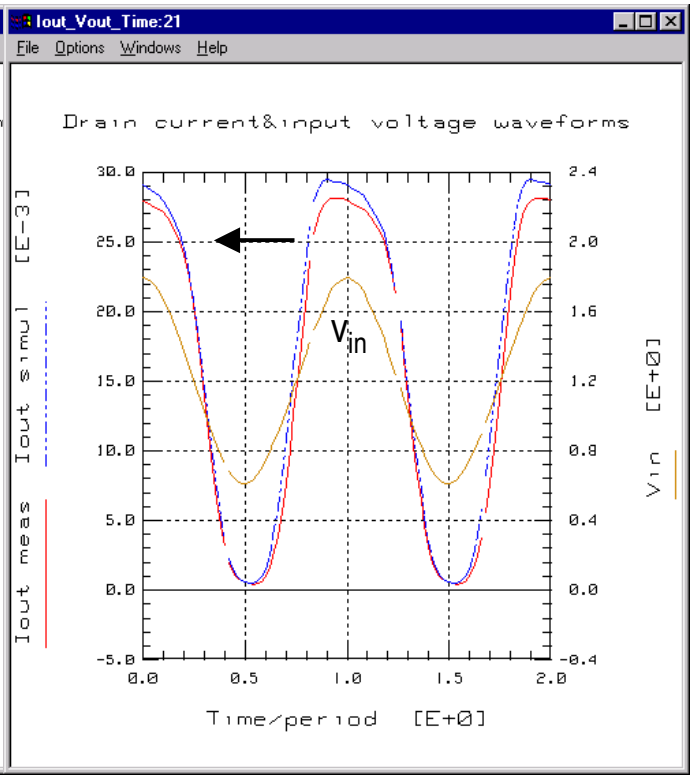
$V_{ds,dc}$=0.9 V

Class AB



$V_{gs,dc}$=0.9 V

Class A



$V_{gs,dc}$=1.2 V

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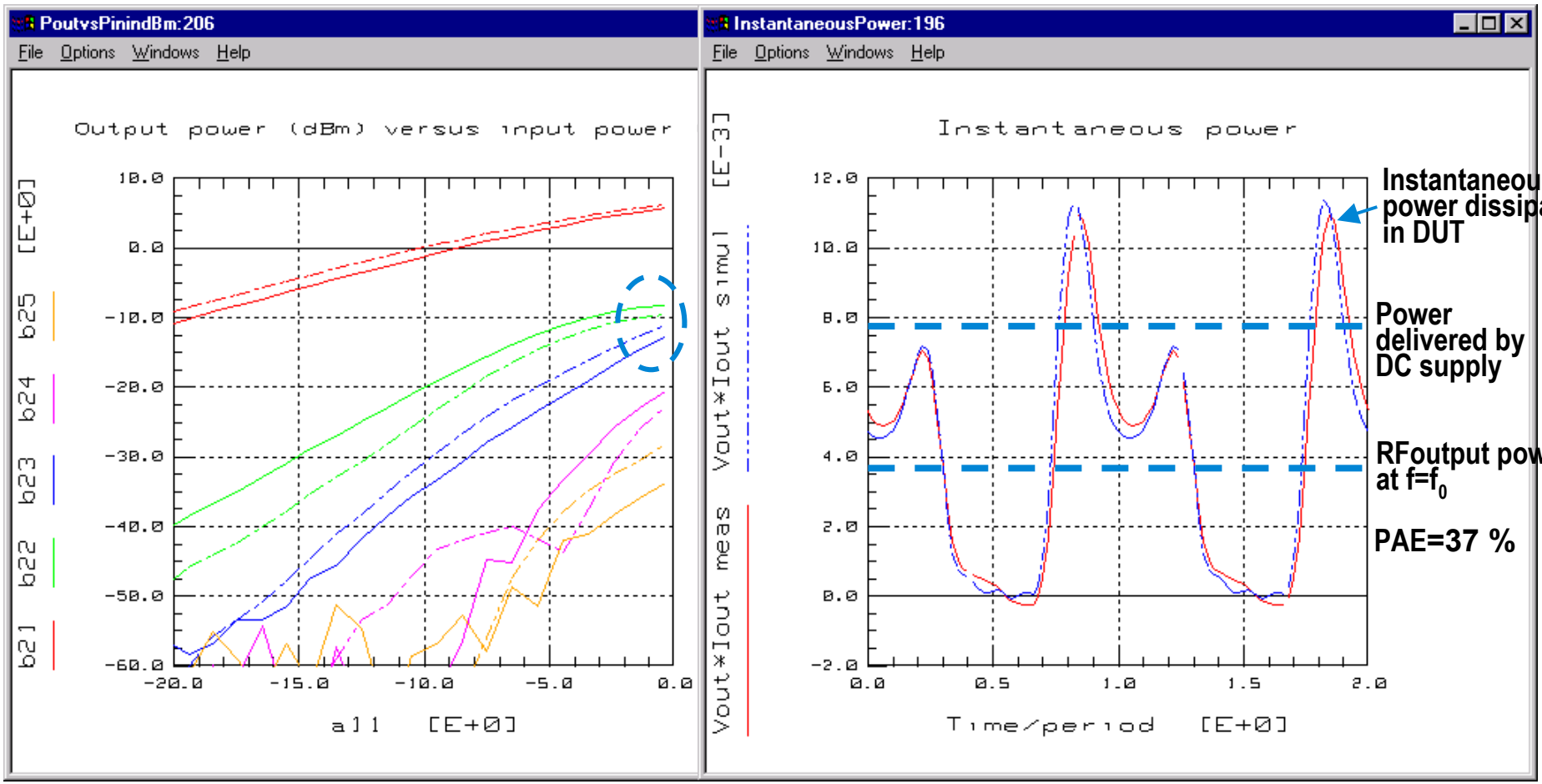
Effect of operating regime on dissipated power in the DUT, load, and DC power supply — class AB



$V_{ds,dc}$=0.9 V, $V_{gs,dc}$=0.9 V

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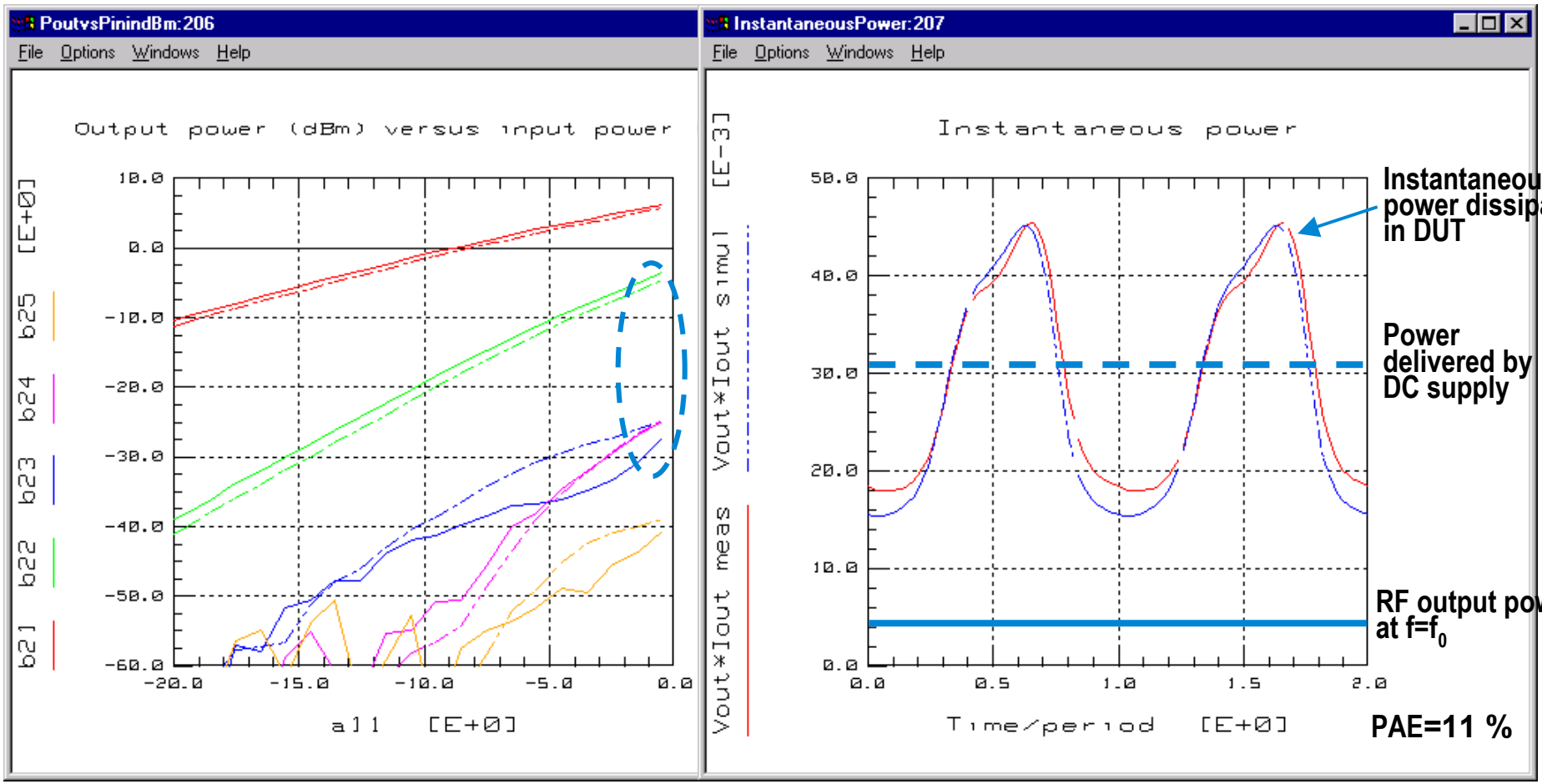
Effect of operating regime on dissipated power in the DUT, load, and DC power supply — “class A”



$V_{ds,dc}$=0.9 V, $V_{gs,dc}$=1.8 V

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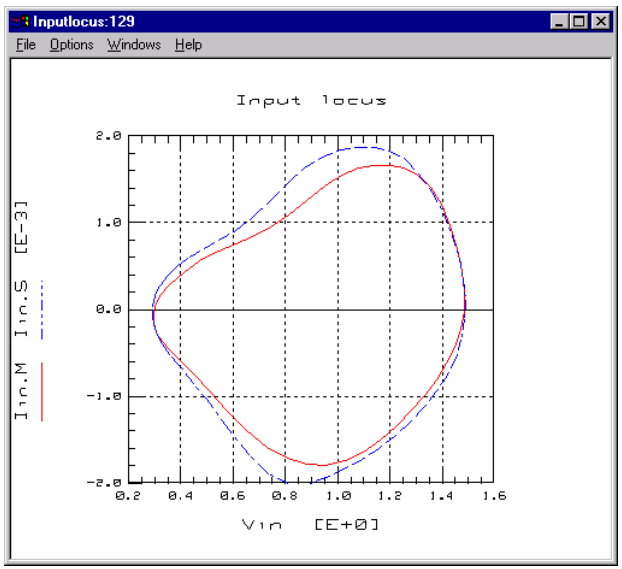
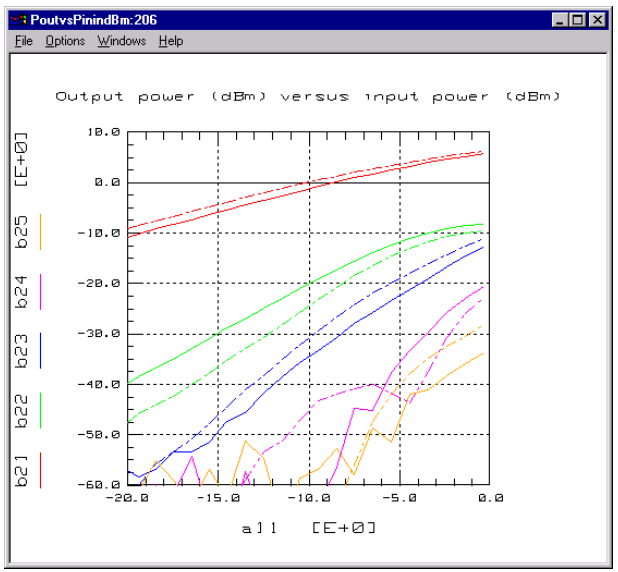
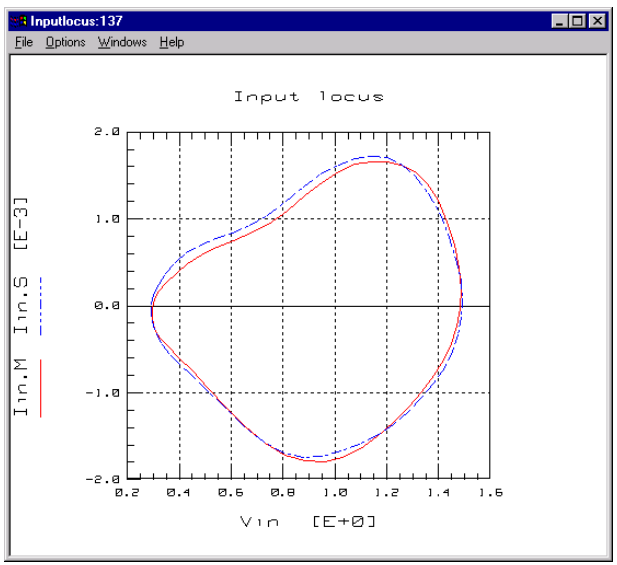
Tuning of model parameters to LSNA measurements

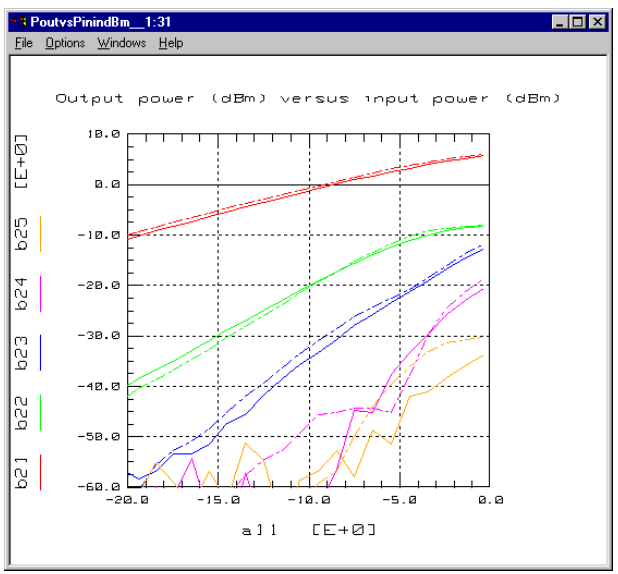


before





after



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LSNA measurements in device modelling Conclusions:

- Unique tool for *complete* large-signal model accuracy assessment under *realistic* RF or microwave signals
  - information on amplitude and phase
- Reduce number of design cycles and reduce manufacturing costs through *better* device models, thus more optimal designs
- *Optimize* model parameters to LSNA measurements
- *Benchmark* various device models, e.g.,
  - BSIM, MM11, EKV, …
  - Gummel-Poon, VBIC, MEXTRAM, HICUM, ...
- Build *confidence* in your model

Contact

- For info on LSNA technology, visit
  http://www.agilent.com/find/lsna

- Soon, a measurement and consulting service related to Large-Signal Network Analyzer Technology will be available through the 'NMDG' group in Belgium. For info, you need to contact NMDG directly at
  email: Marcus_Vandenbossche@agilent.com, or
  tel.: +32 - 3 - 890 46 16