TECHNISCHE UNIVERSITÄT DRESDEN

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Scalable Compact Modeling for SiGe HBTs suitable for Microwave Radar Applications

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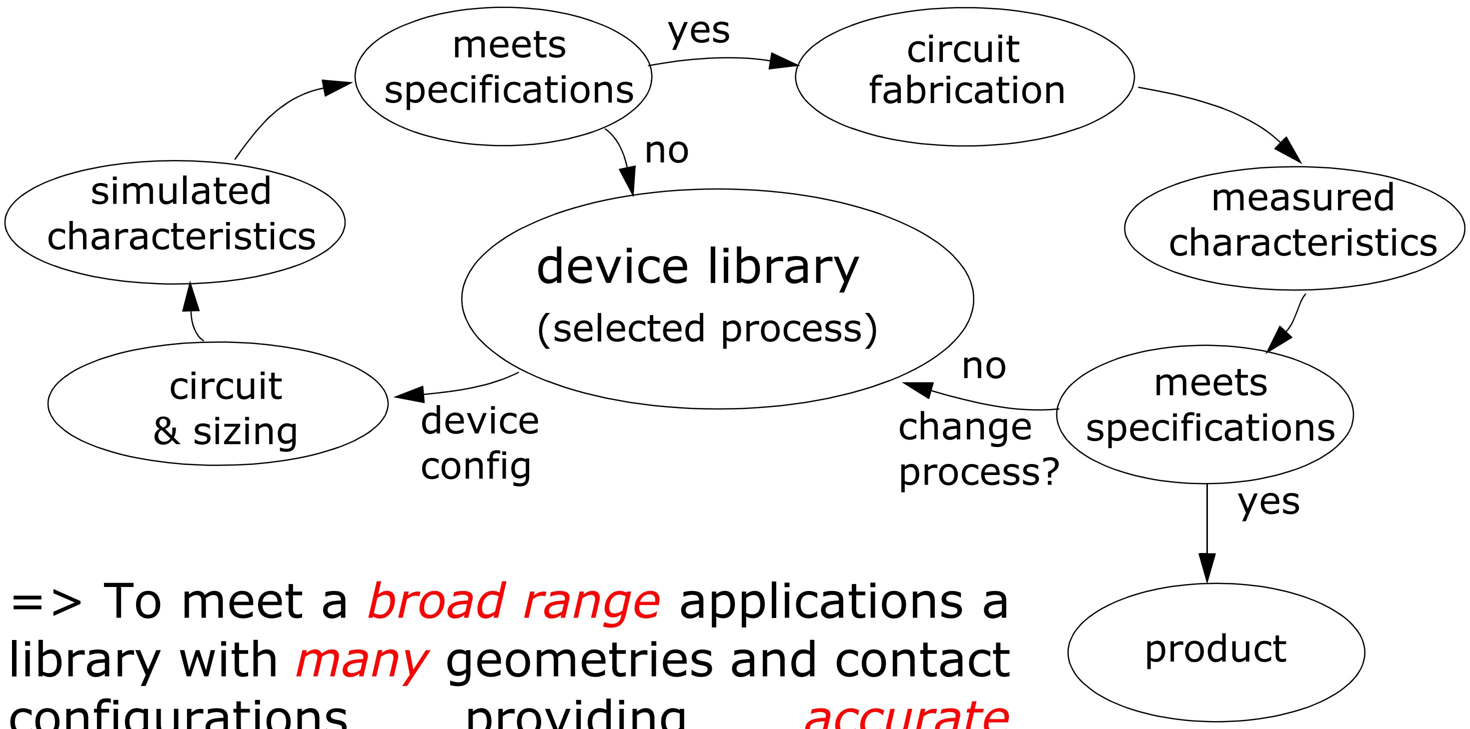
Outline

- Motivation
- Extraction of electrical parameters
- Thermal characterization approach
- Standard characteristics
- Scalability of standard characteristics
- Summary and Outlook

1 Motivation

Reduction of circuit optimization cycles



=> To meet a *broad range* applications a library with *many* geometries and contact configurations providing *accurate* compact models is required

Motivation (cont'd)

The modeler's view - optimization of characterization effort

Single device extraction

- Measure few available devices
- Extract device model parameters
- Model characteristics of only the measured devices
- In case of process drift/variations all devices have to re-measured and parameter extraction has to be repeated
- circuit optimization by sizing not possible

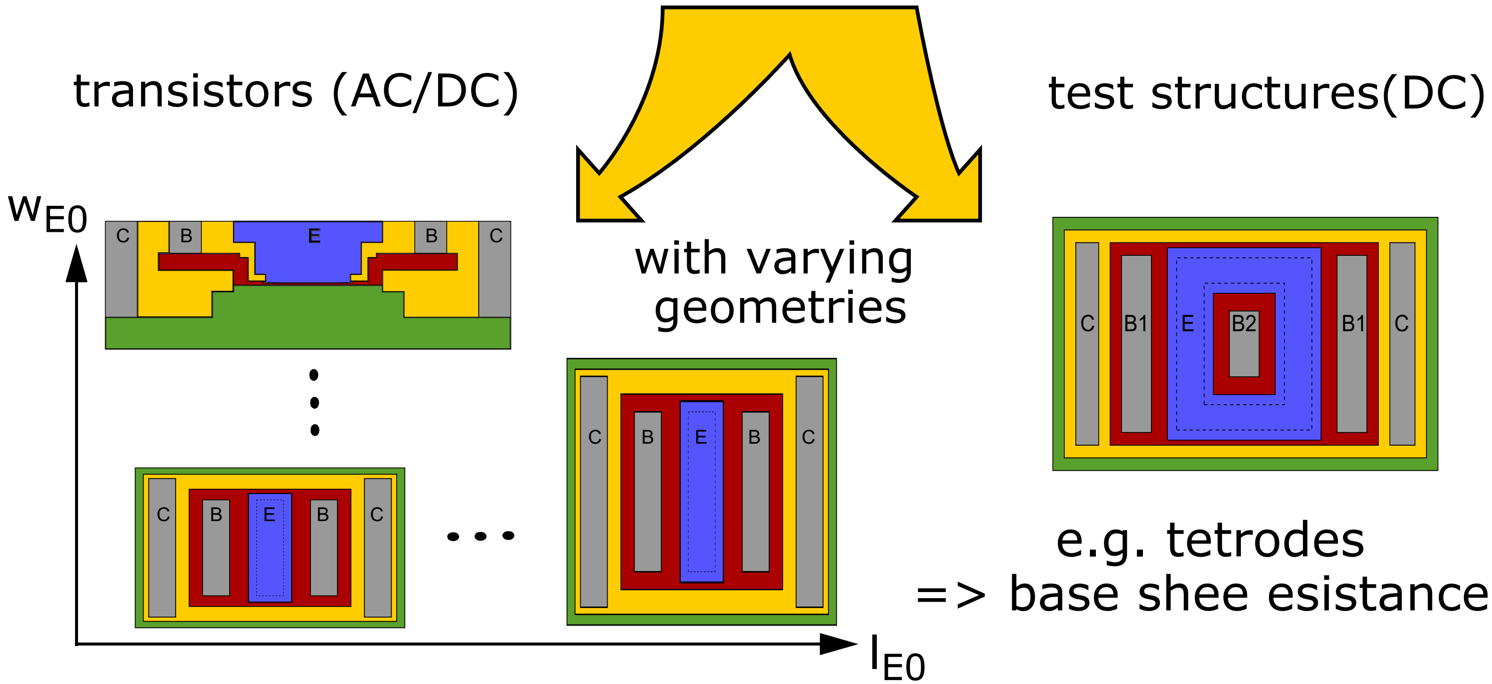
Scalable approach

- Measure selected devices (inc. PCMs)
- Extract scalable parameters
- Model characteristics of ALL devices required by the designer
- In case of process drift/variations a parameter drift can be estimated with reduced effort, if the model is physics-based

=> Only scalable approach meets requirements for foundry and broad range of circuit applications

2 Extraction of electrical parameters

- External series resistances
- Area/perimeter specific parameters for junction capacitances, diode currents and transit time related charges
- HICUM-specific model parameters, thermal dependencies, impact ionization, NQS effects, special effects



3 Thermal characterization approach

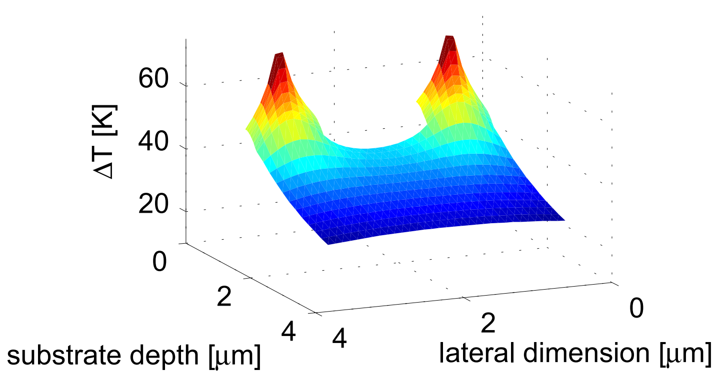
Self-heating for two-emitter finger device

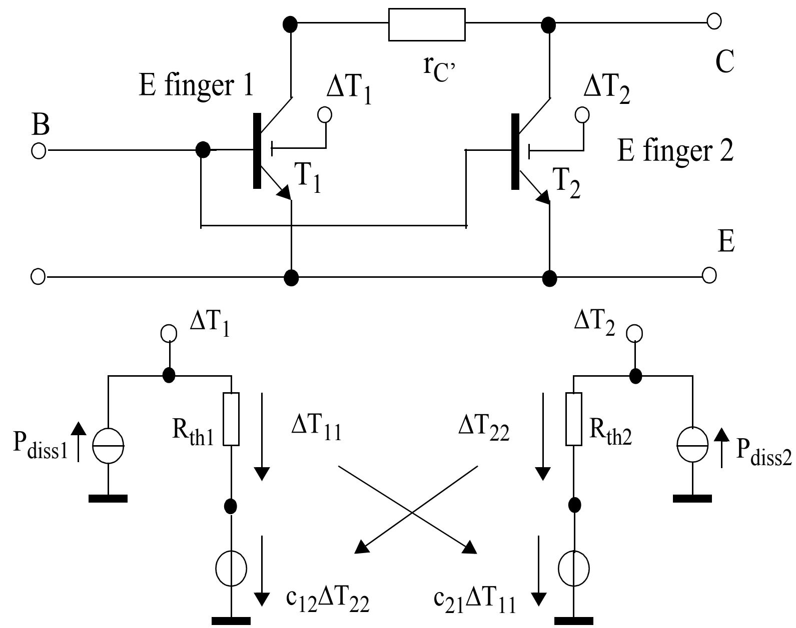
=> Temperature increase at the BE junction calculated by solving the heat equation based on Green's function

=> Approach allows a direct determination of coupling factors required for a thermal equivalent network

$$\Delta T_1 = \Delta T_{11} + c_{12}\Delta T_{22}$$

$$\Delta T_2 = \Delta T_{22} + c_{21}\Delta T_{11}$$





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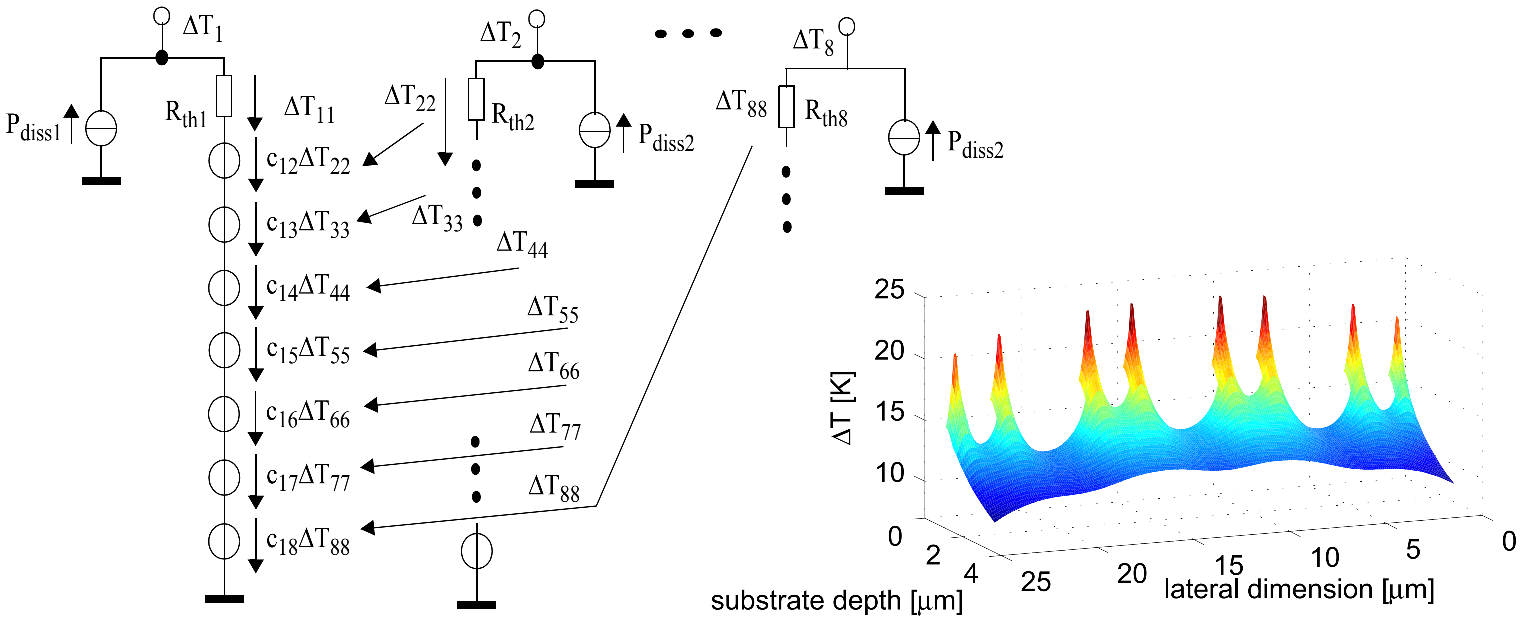
Thermal characterization approach (cont'd)

equivalent coupled thermal network for a 4-cell CBEBEBC HBT



Complete network allows:

- determination of maximum finger temperature
- derivation of single equivalent lumped thermal resistance (which is larger than $R_{th1}||R_{th2}||..||R_{th8}$!)

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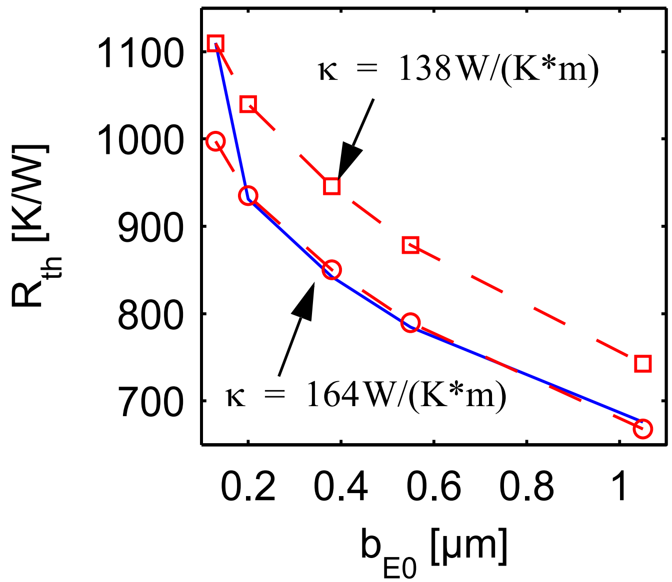
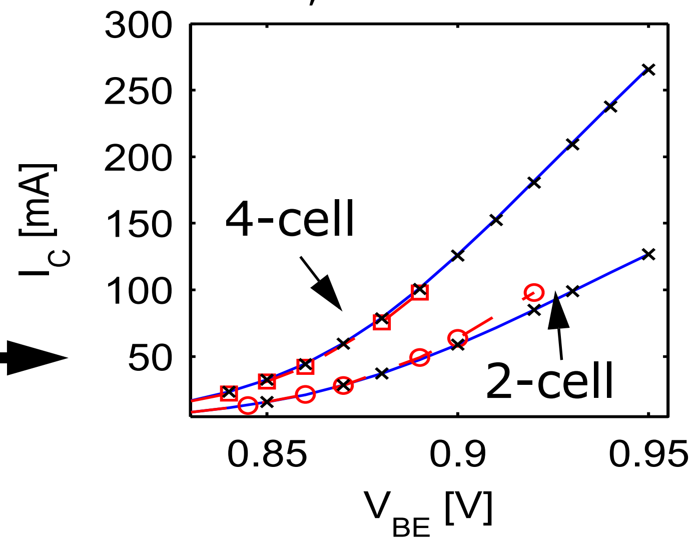
Thermal characterization approach (cont'd)

- Determination of R_{th} for standard transistors with different emitter widths (solid)
- Calibration of GF approach by experim. thermal conductivity



parallel $R_{th,4\text{-}cell}$=178K/W
derived $R_{th,4\text{-}cell}$=254K/W

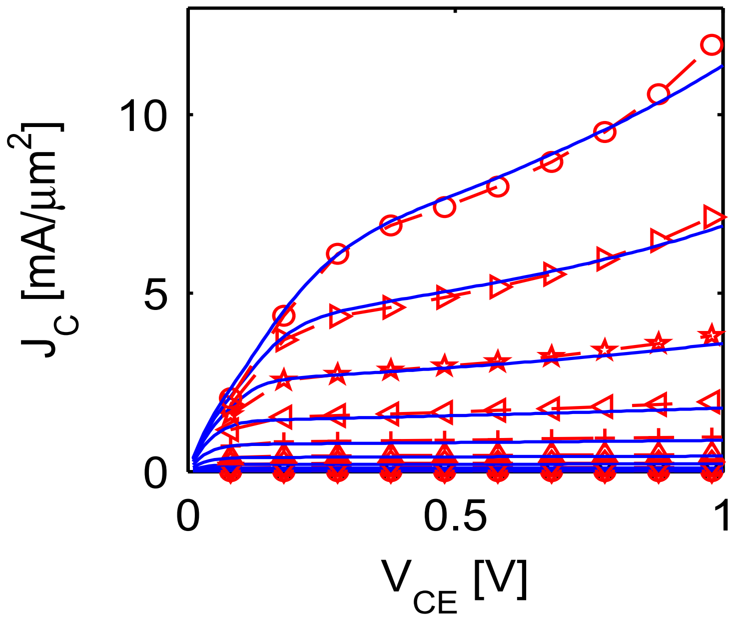


Excellent match for coupled thermal network (crosses) and *derived* lumped thermal resistance (solid line) for 2-cell and 4-cell transistor

4 Standard characteristics

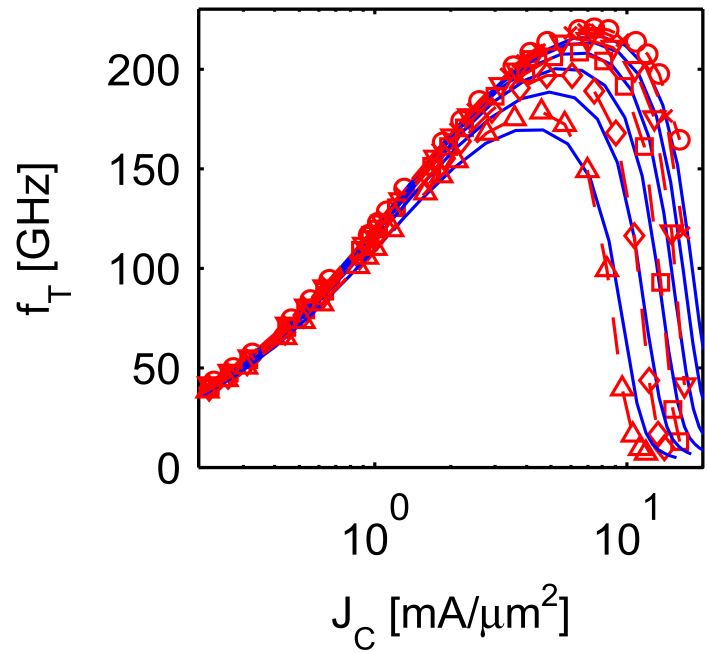
Example: CBEBC HBT with A_{E0}=0.53x9.45µm^2

output characteristics



V_{BE} = {0.78, 0.8, 0.82, 0.84, 0.86, 0.88, 0.9}V

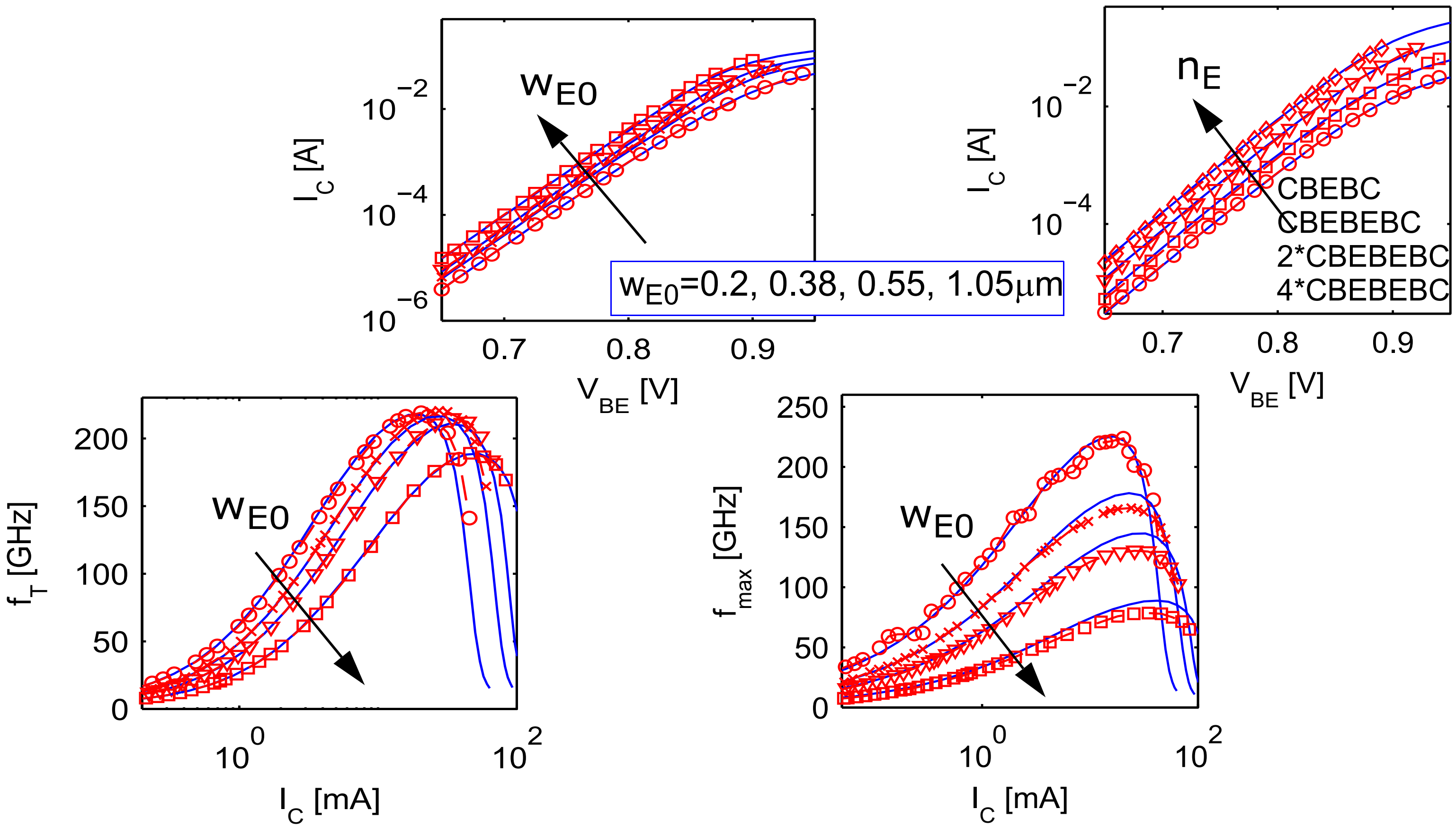
transit frequency



V_{BC} = {0.5, 0.4, 0.3, 0.2, 0.1, 0.0}V

=> Excellent agreement for bias dependence

Scalability of standard characteristics



=> Excellent agreement for geometry scaling

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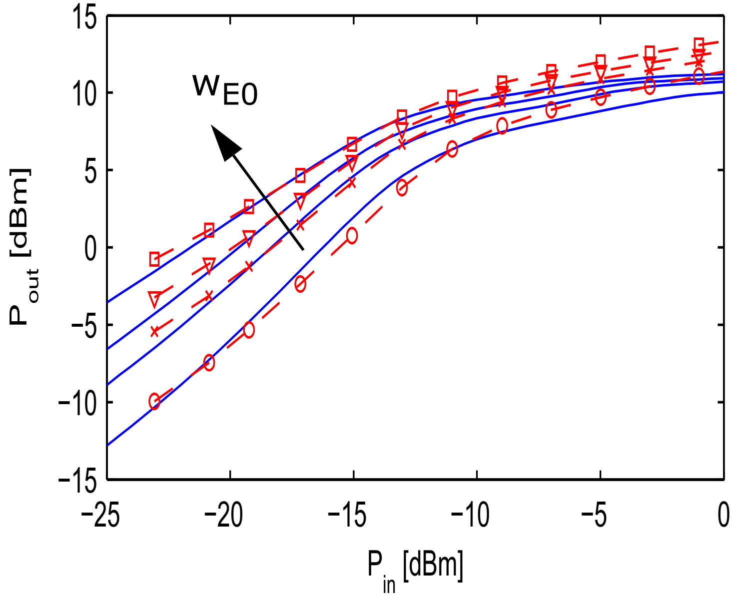
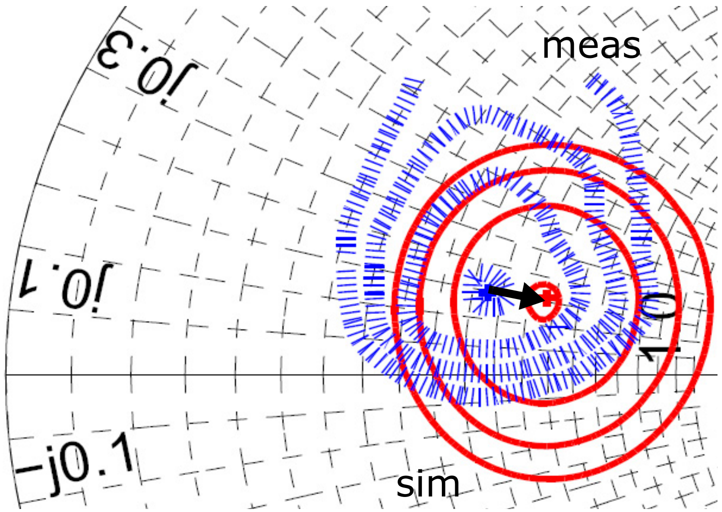
5 Large-signal results

single-tone single-E transistor with different emitter widths

P_{in} vs. P_{out} f = 2.5 GHz P_{out} contours





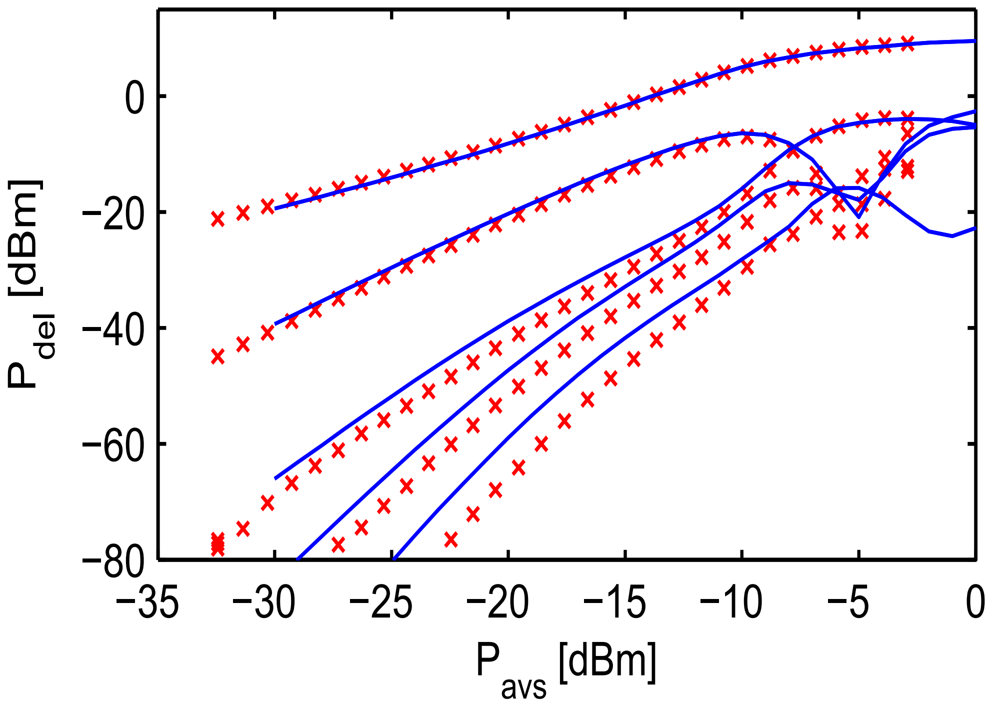
$P_{out,max}$(meas/sim) = (11.2/10.7)dBm
P_{in} = -14dBm

- J_C=0.54mA/μm^2 (V_{BE}=0.8V), V_{CE}=1V, Z_S=Z_L=50Ω

=> Excellent agreement and scalability with thermal coupling

Large-signal results (cont'd)

P_{in} vs. P_{out} for single-tone analysis with Agilent's PNA-X at f = 10GHz and V_{BE}=0.8V, V_{CE}=1V, Z_S=Z_L=50Ω.

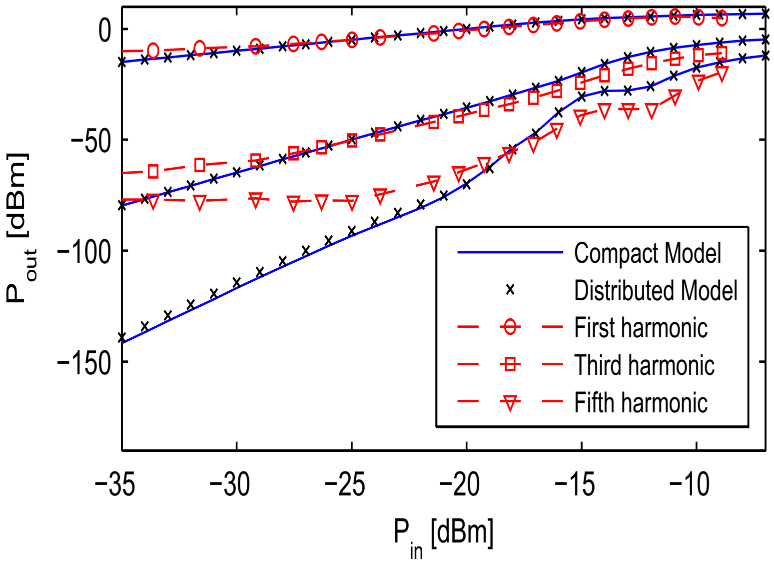


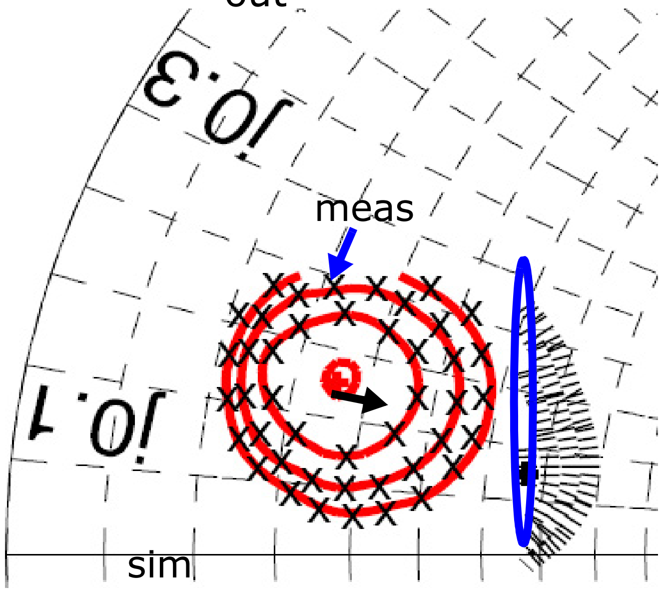
=> Good agreement up to fifth harmonic

Large-signal results (cont'd)

two-tone (with 5MHz tone spacing) 4-cell transistor

P_{in} vs. P_{out} f = 2.5 GHz P_{out} contours





P_{in} = -14dBm

- J_C=0.54mA/μm^2 (V_{BE}=0.8V), V_{CE}=1V, Z_S=Z_L=50Ω

=> Good agreement of power device with thermal coupling

6 Summary and Outlook

- Application and verification of a scalable electro-thermal modeling approach
  => Slightly higher extraction effort but more physical parameters

- For multi-emitter finger devices with a larger number of fingers a single lumped thermal resistance may be insufficient
  => Extension to suitable distributed equivalent thermal network (should be automated approach)

- Thermal approach can be applied for developing optimized layout for power applications
  => Adapt emitter finger distance or length for *equalizing* temperature