



Scalable Compact Modeling for SiGe HBTs suitable for Microwave Radar Applications

S. Lehmann, M. Weiß, Y. Zimmermann, A. Pawlak,
K. Aufinger, and M. Schröter

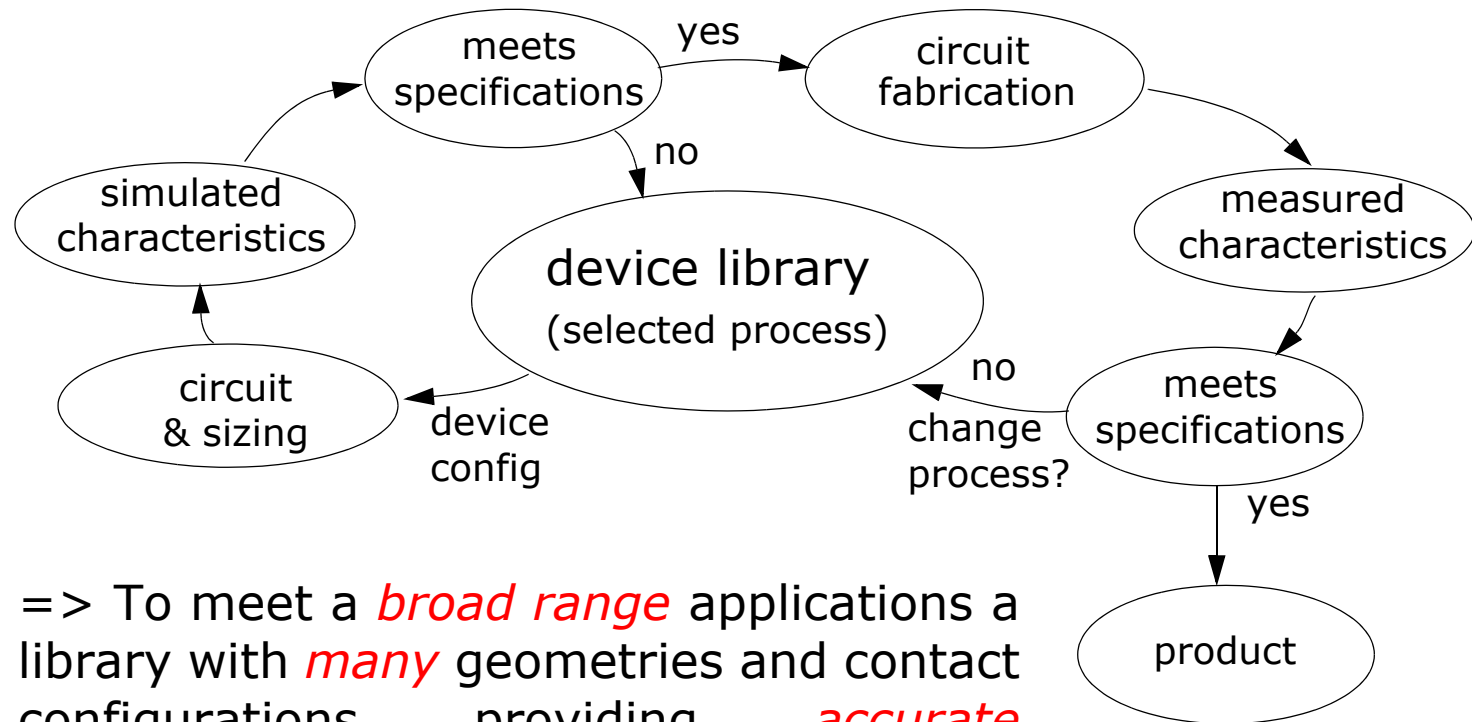
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Outline

- 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

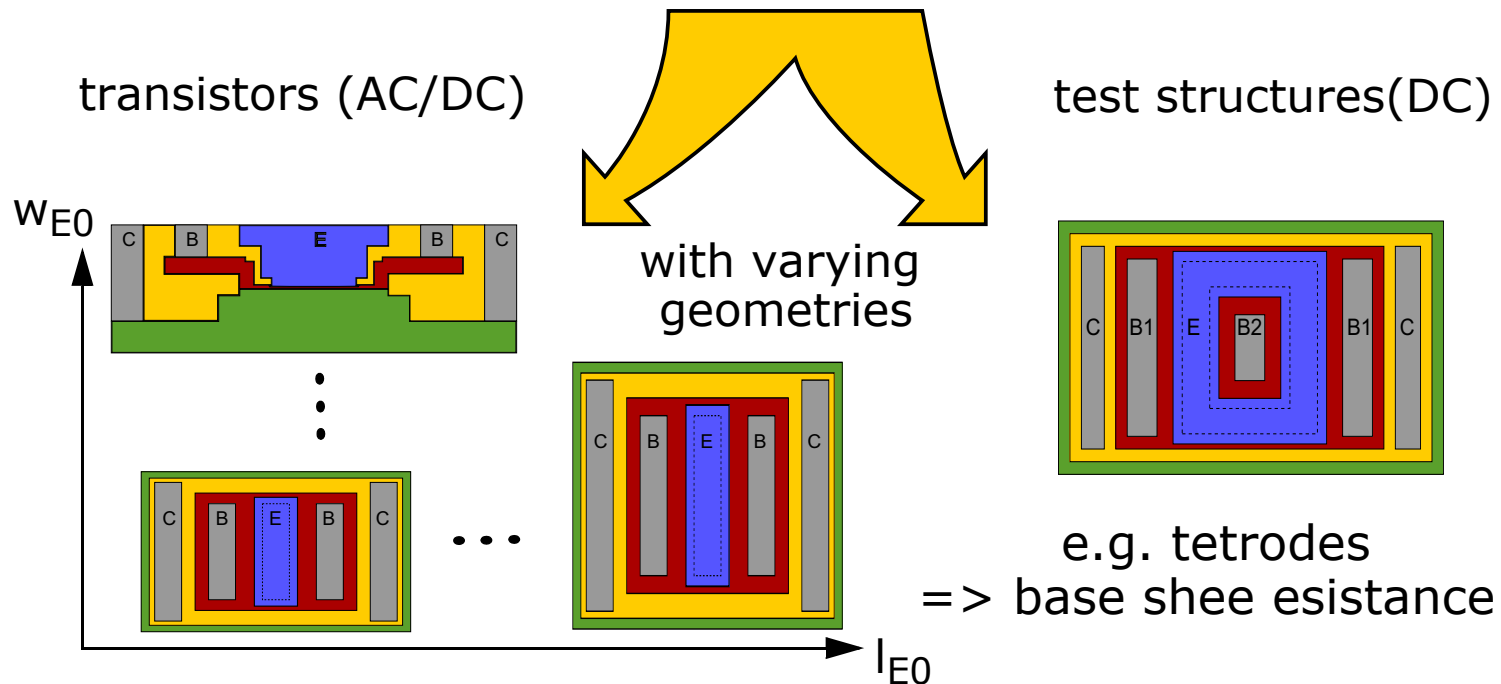
Scalable approach

- 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

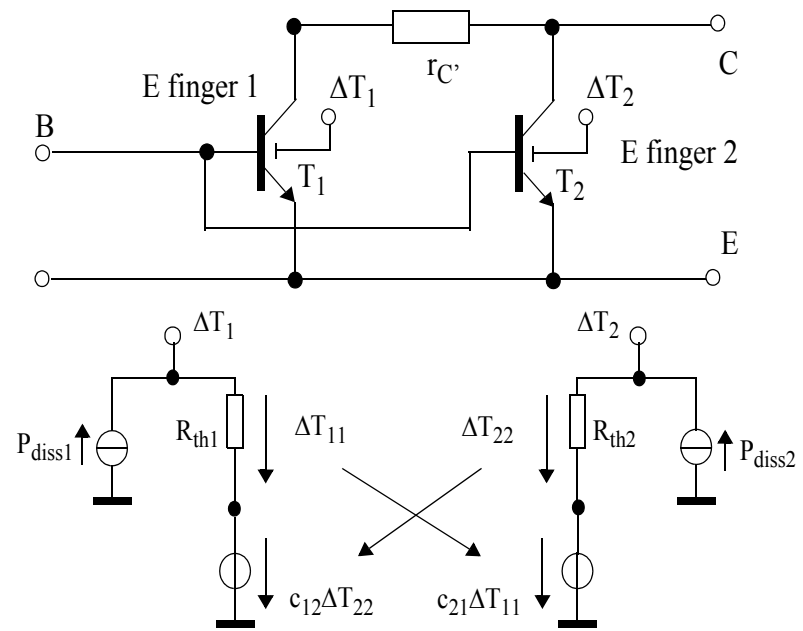
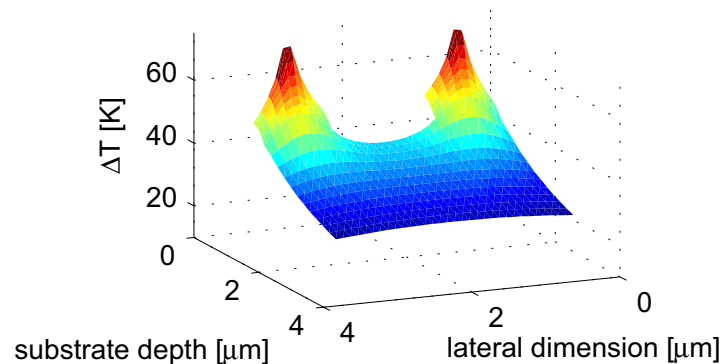
Self-heating for two-emitter finger device

=> 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

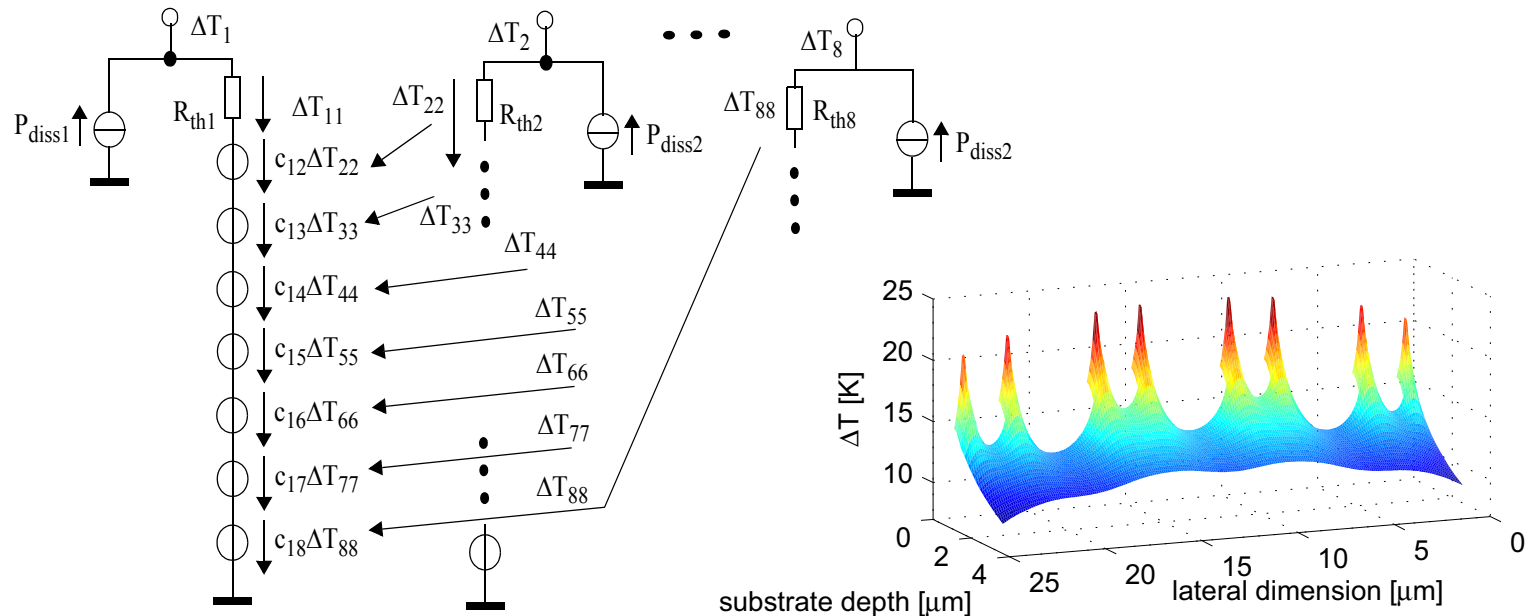
$$\Delta T_1 = \Delta T_{11} + c_{12}\Delta T_{22}$$

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



Thermal characterization approach (cont'd)

equivalent coupled thermal network for a 4-cell CBEBEBC HBT

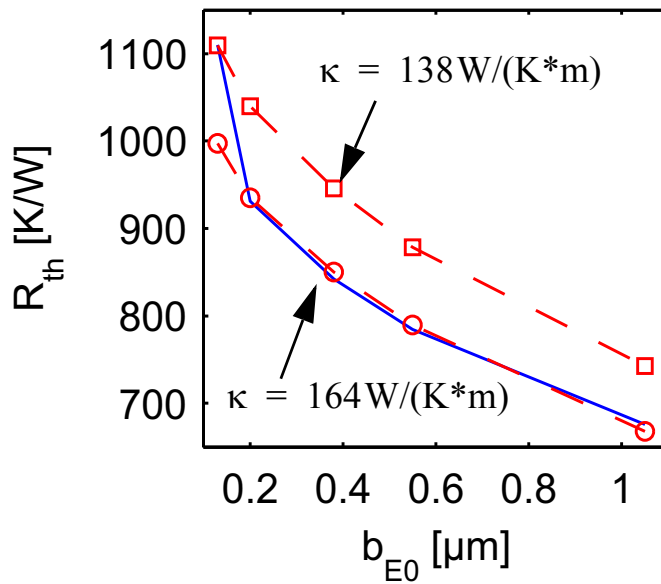


Complete network allows:

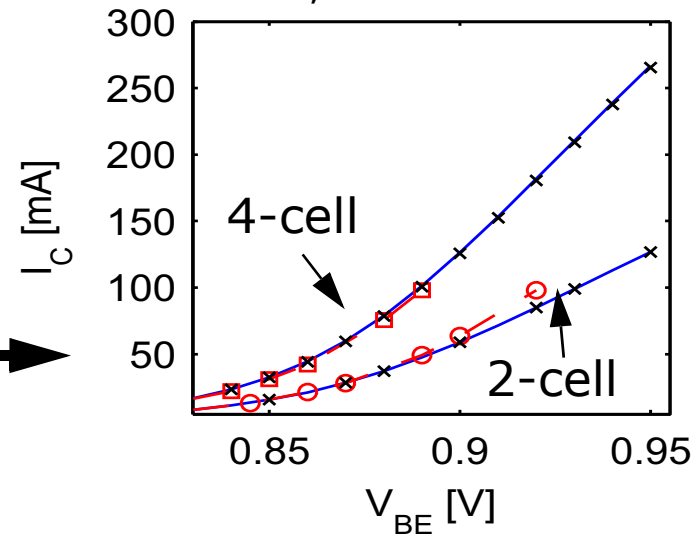
- determination of maximum finger temperature
- derivation of single equivalent lumped thermal resistance (which is larger than $R_{th1} || R_{th2} || \dots || R_{th8}$!)

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

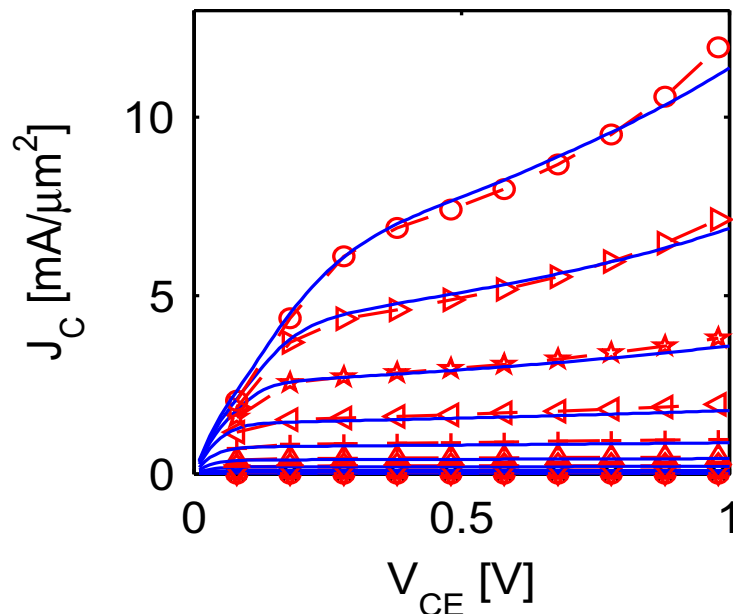


Excellent match for coupled thermal network (crosses) and *derived lumped* thermal resistance (solid line) for 2-cell and 4-cell transistor

4 Standard characteristics

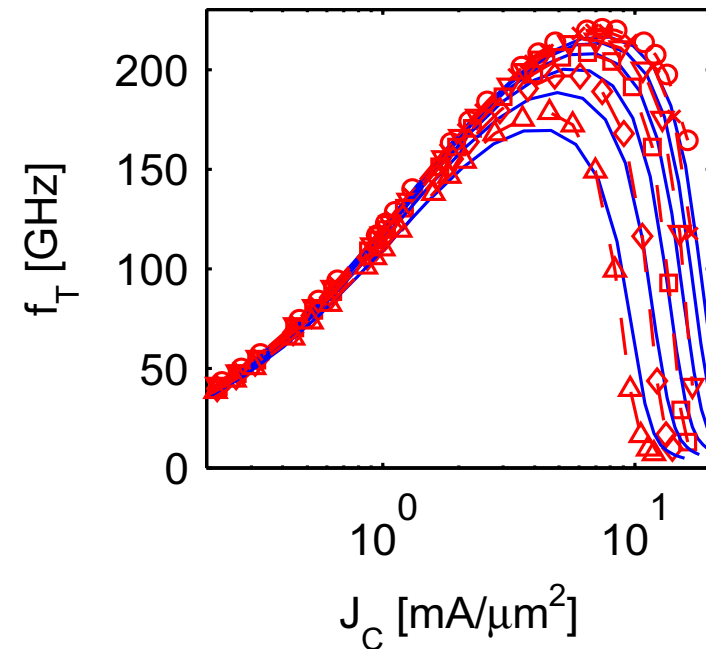
Example: CBEBC HBT with $A_{E0} = 0.53 \times 9.45 \mu\text{m}^2$

output characteristics



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

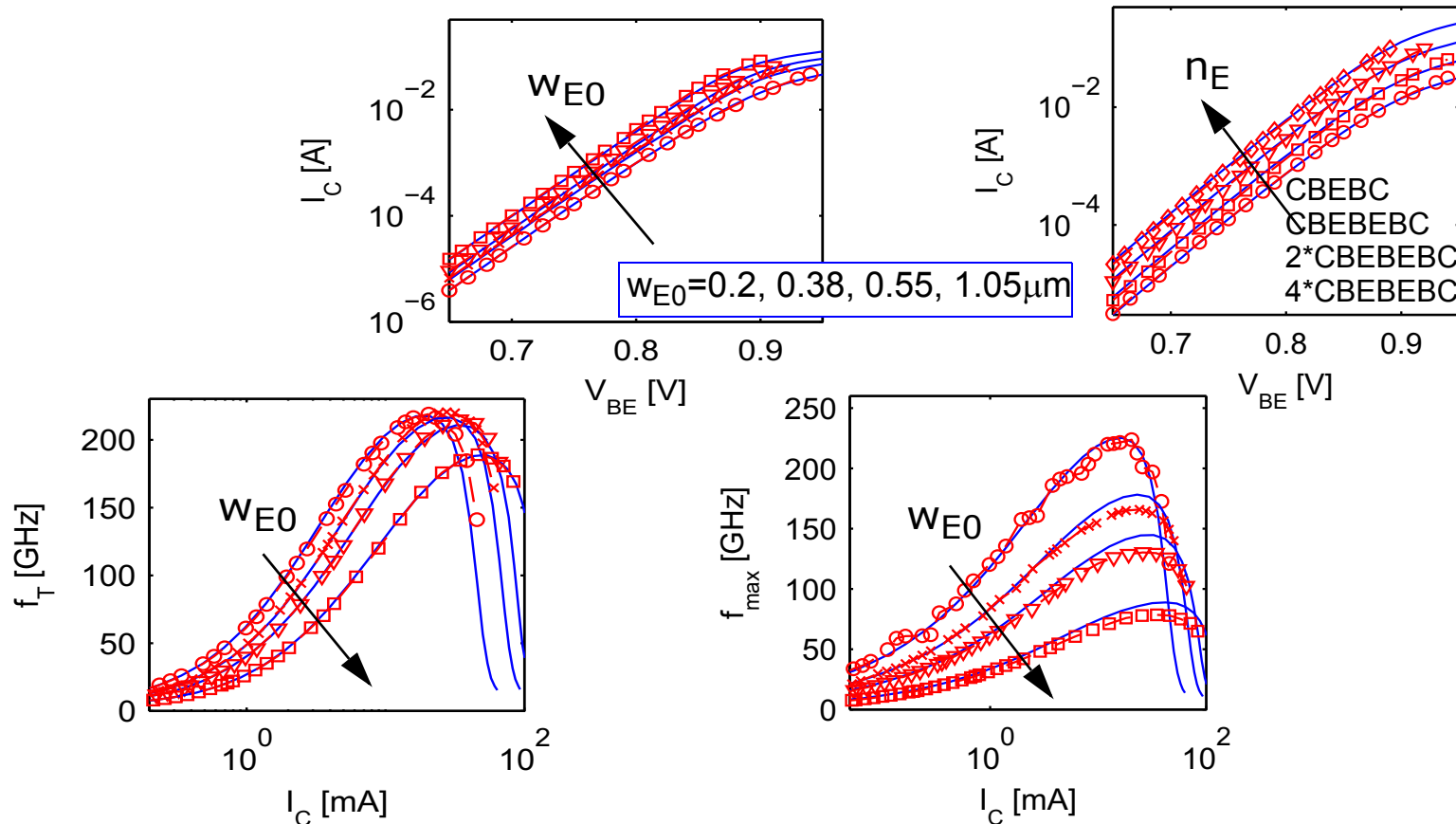
transit frequency



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

=> Excellent agreement for bias dependence

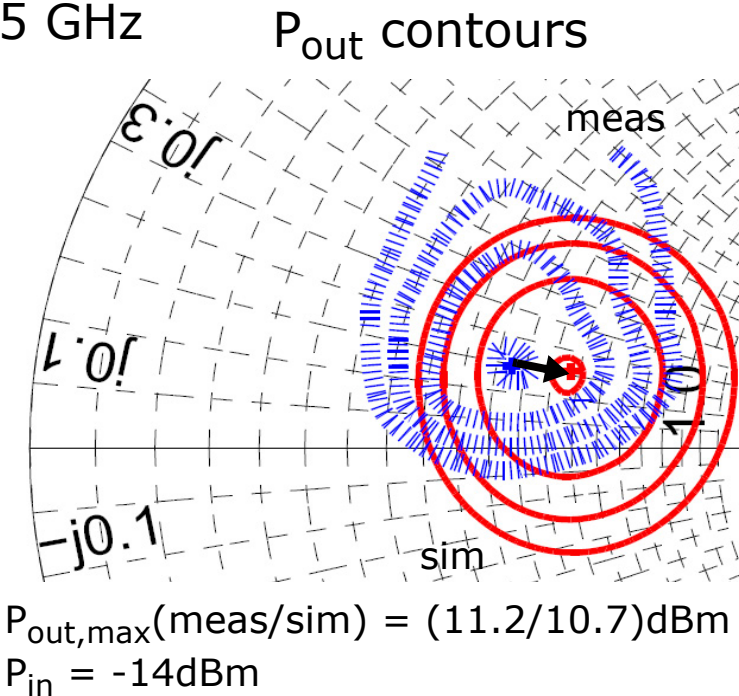
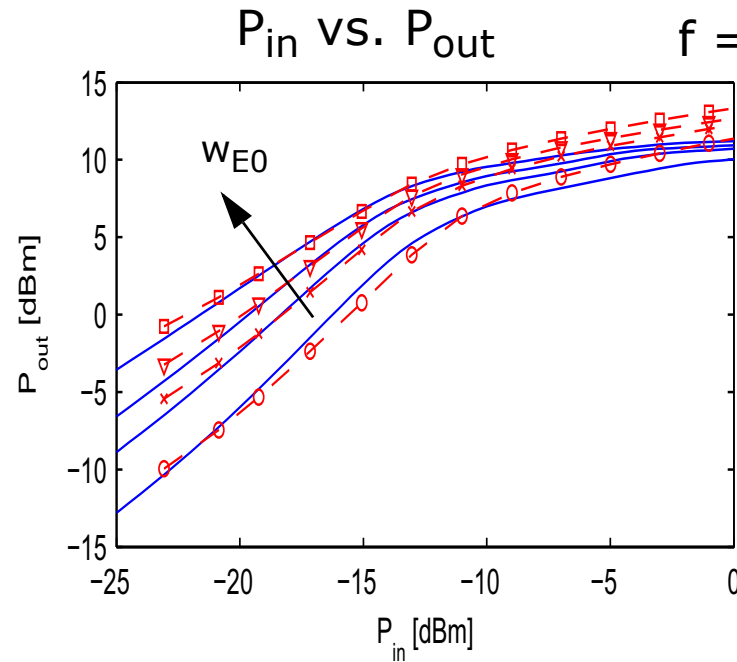
Scalability of standard characteristics



=> Excellent agreement for geometry scaling

5 Large-signal results

single-tone single-E transistor with different emitter widths

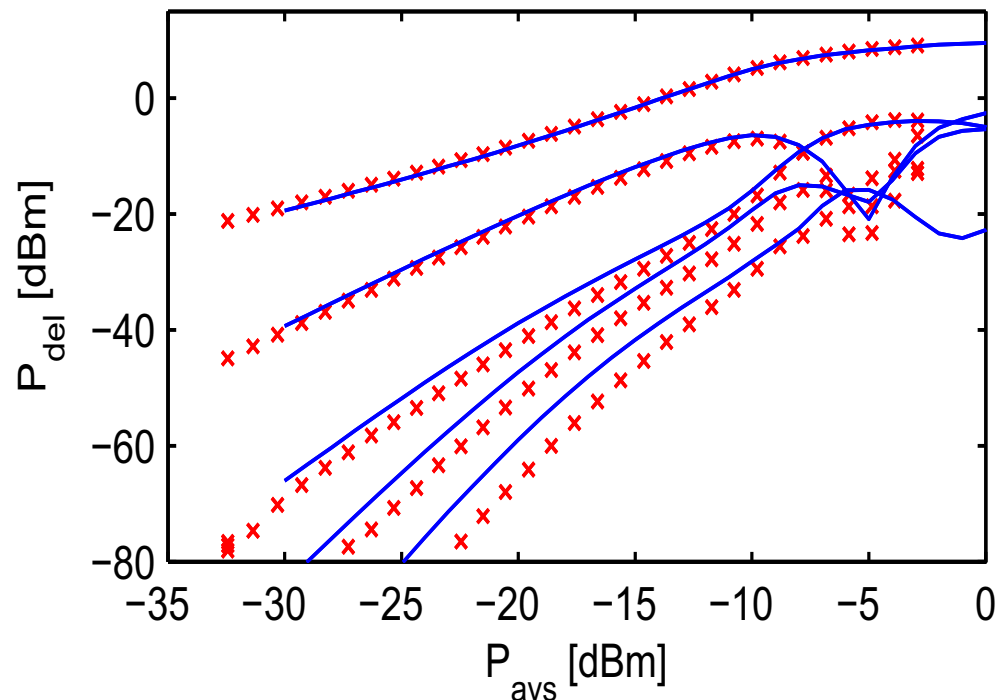


- $J_C = 0.54 \text{ mA}/\mu\text{m}^2$ ($V_{BE} = 0.8 \text{ V}$), $V_{CE} = 1 \text{ V}$, $Z_S = Z_L = 50 \Omega$

=> 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 $f = 10\text{GHz}$ and $V_{BE}=0.8\text{V}$, $V_{CE}=1\text{V}$, $Z_S=Z_L=50\Omega$.



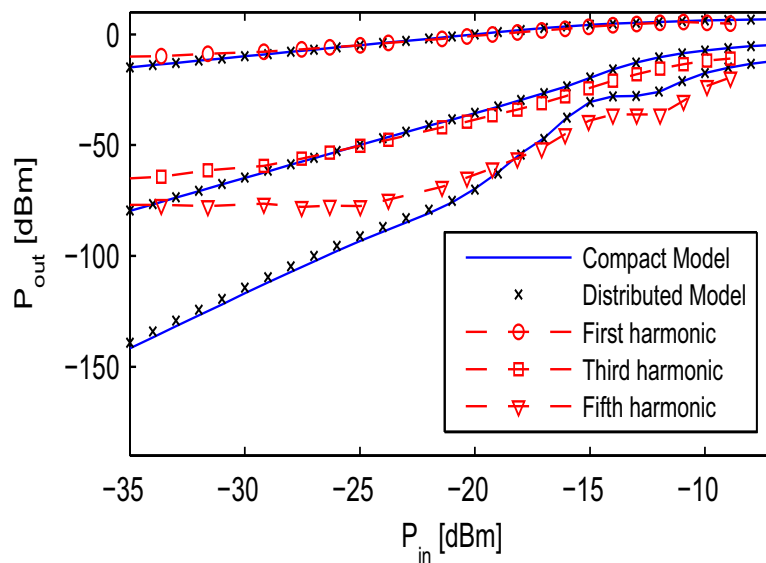
=> Good agreement up to fifth harmonic

Large-signal results (cont'd)

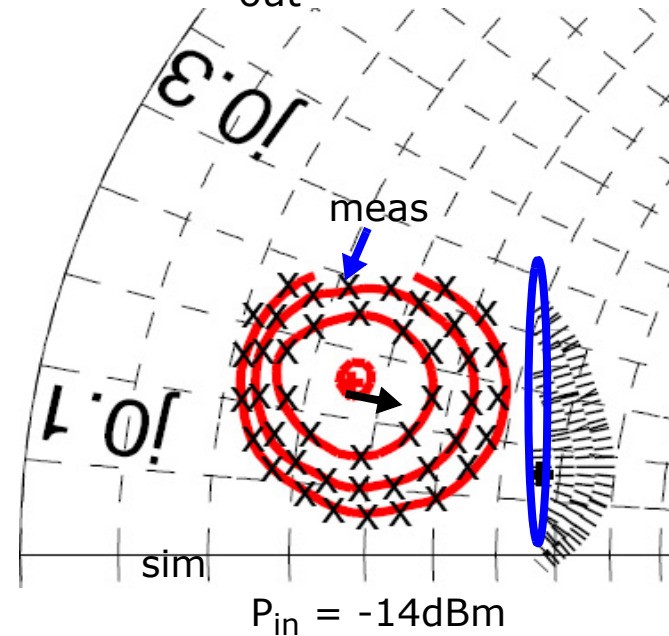
two-tone (with 5MHz tone spacing) 4-cell transistor

P_{in} vs. P_{out}

$f = 2.5$ GHz



P_{out} contours



- $J_C = 0.54 \text{ mA}/\mu\text{m}^2$ ($V_{BE} = 0.8 \text{ V}$), $V_{CE} = 1 \text{ V}$, $Z_S = Z_L = 50 \Omega$

=> 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