Generation of distributed electrical and electro-thermal networks with TRADICA

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OUTLINE

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Introduction

- Shrinking device sizes lead to increased influence of parasitic effects on electrical behavior.
- Deep trenches confine the heat flow resulting in higher operating temperatures.
- Multi-dimensional effects like avalanche breakdown are difficult to implement in compact models.
- Need for accurate models for critical circuits and single devices

Electro-thermal Characteristics

- Distinguish two different effects:

  1. Self-heating (temperature rise due to power dissipation of a single heat source) and
  2. Thermal coupling (temperature rise due to thermal interaction between several heat sources).

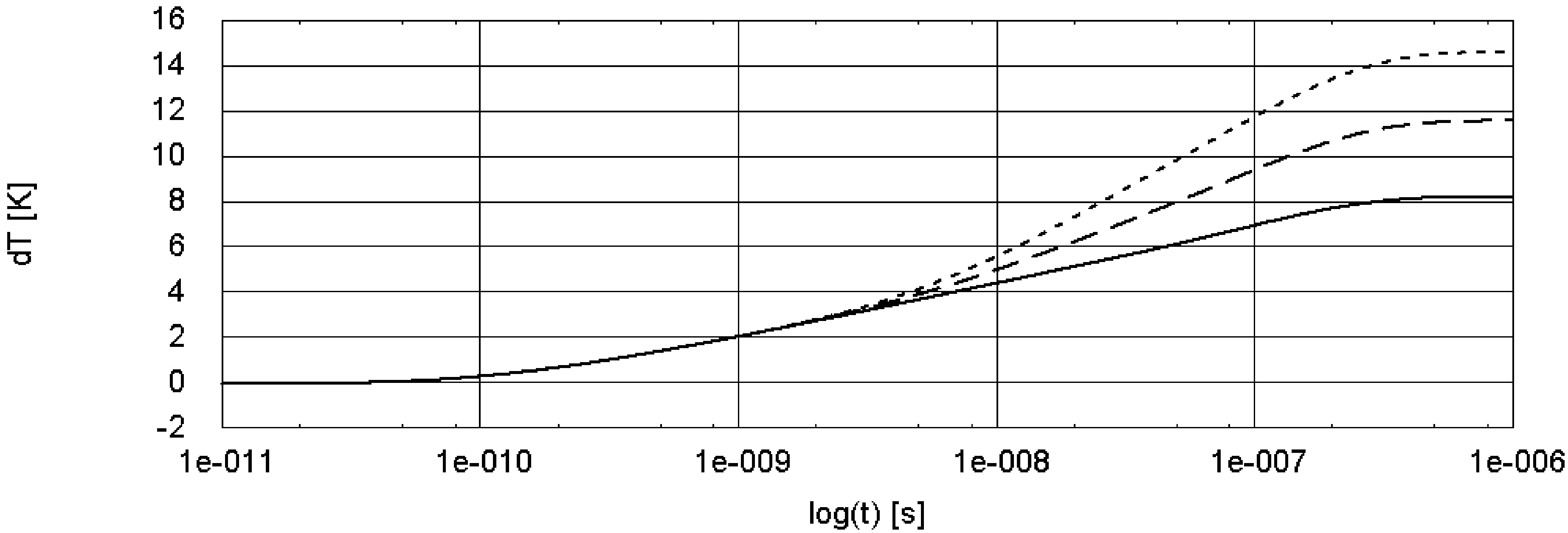
- Heat source definition:

  Characteristic volume of integrated devices where heat is generated (e.g. BC-SCR of BJTs)

PROBLEM-I

- Transient thermal characteristic is of complex exponential nature and varies with emitter contact configuration (CBEBC (solid), CBEBEBC (dashed), CBEBEBEC (dotted)).

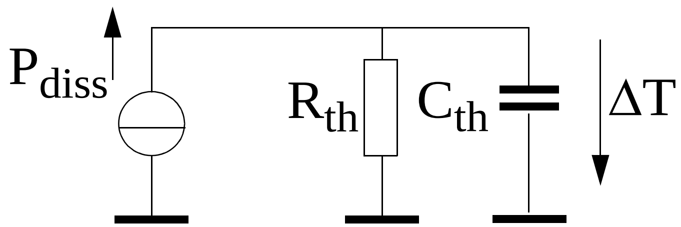
BUT: Compact models use only simple thermal networks (parallel thermal resistance R_{th} and capacitance C_{th})!!!



Self-heating Networks

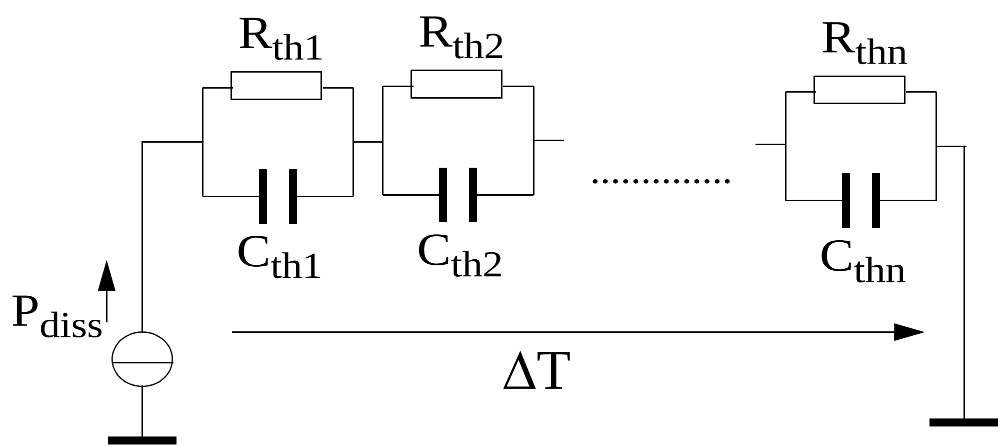
- Common simple „built-in“ network (single RC-element):

$$\Delta T(t) = P_{diss} \cdot R_{th}\left(1 - \exp\left(\frac{-t}{R_{th} \cdot C_{th}}\right)\right)$$



- Extended network (multiple RC-elements):

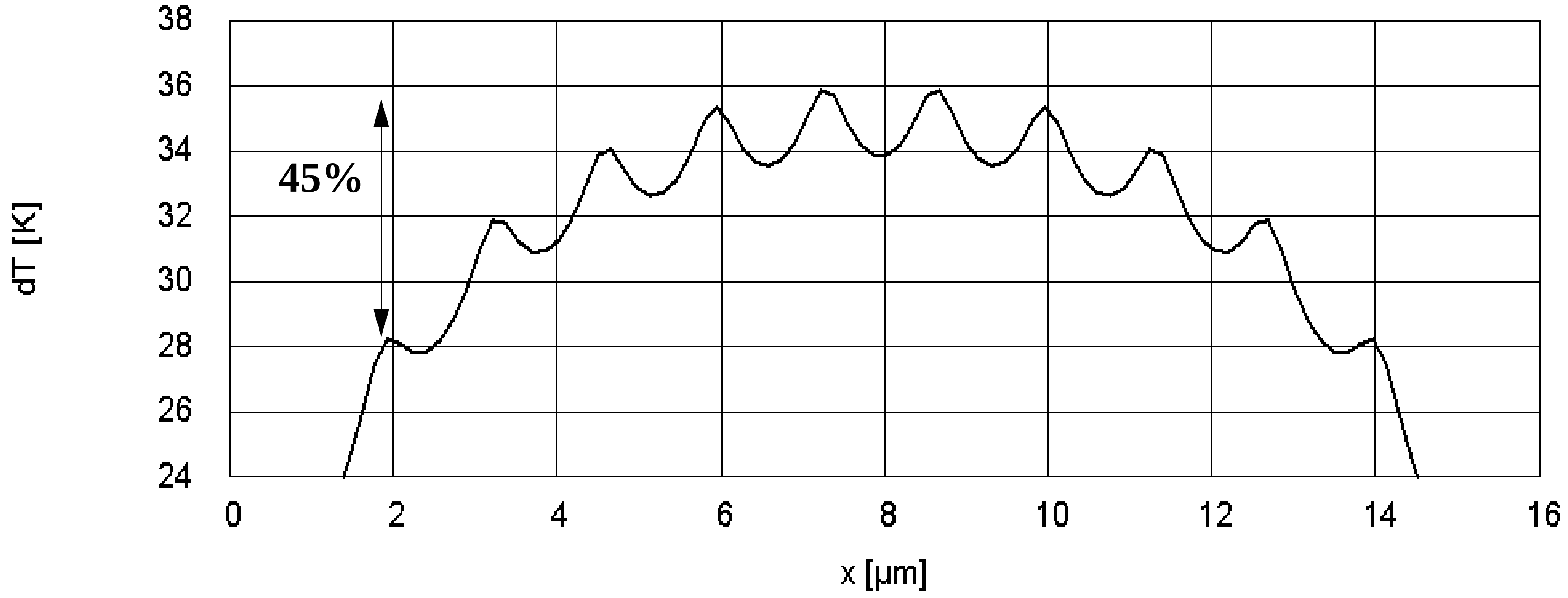
$$\Delta T(t) = P_{diss} \cdot \sum_{i=1}^{n} R_{thi}\left(1 - \exp\left(\frac{-t}{R_{thi} \cdot C_{thi}}\right)\right)$$



PROBLEM-II

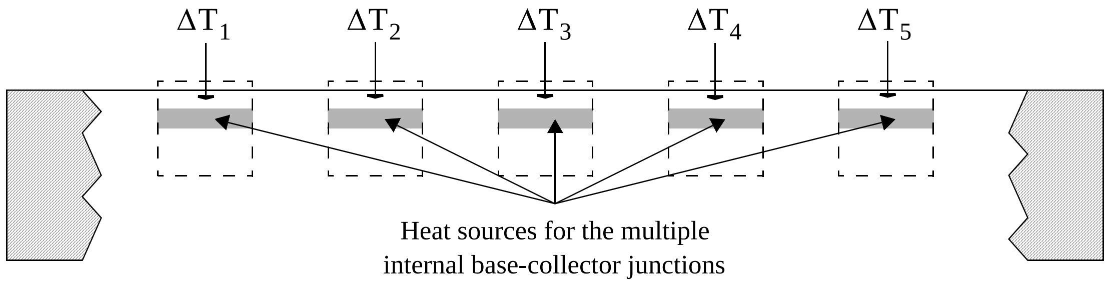
- Multi-emitter BJTs consist of several characteristic heat sources (one per emitter finger).
- Temperature distribution across the devices is **NOT** homogeneous due to thermal coupling resulting in different operating temperatures at the fingers.

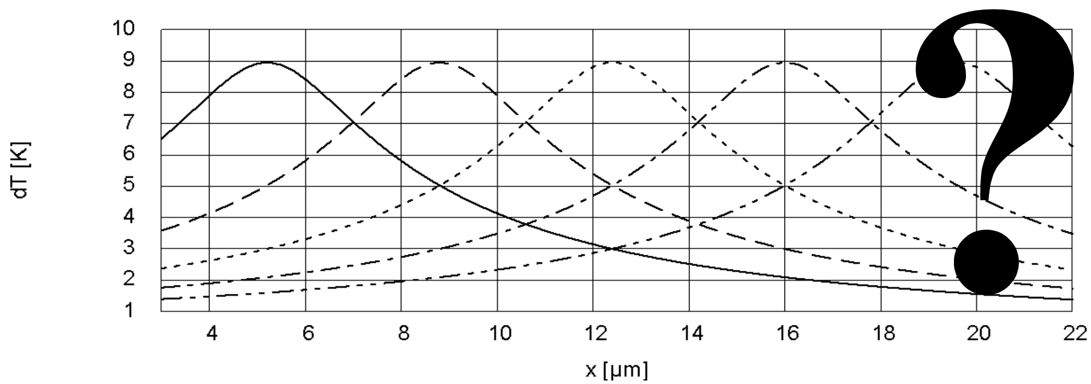
BUT: Compact models use only **ONE** ΔT for whole structure!!!

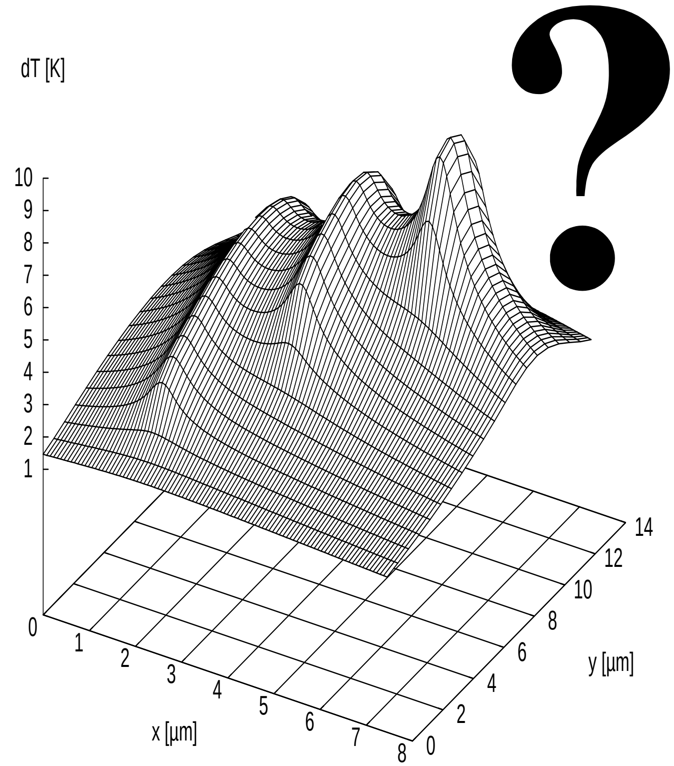


PROBLEM-II

- Thermal coupling (intra- and inter-device) characteristic is **NOT** covered by compact models.





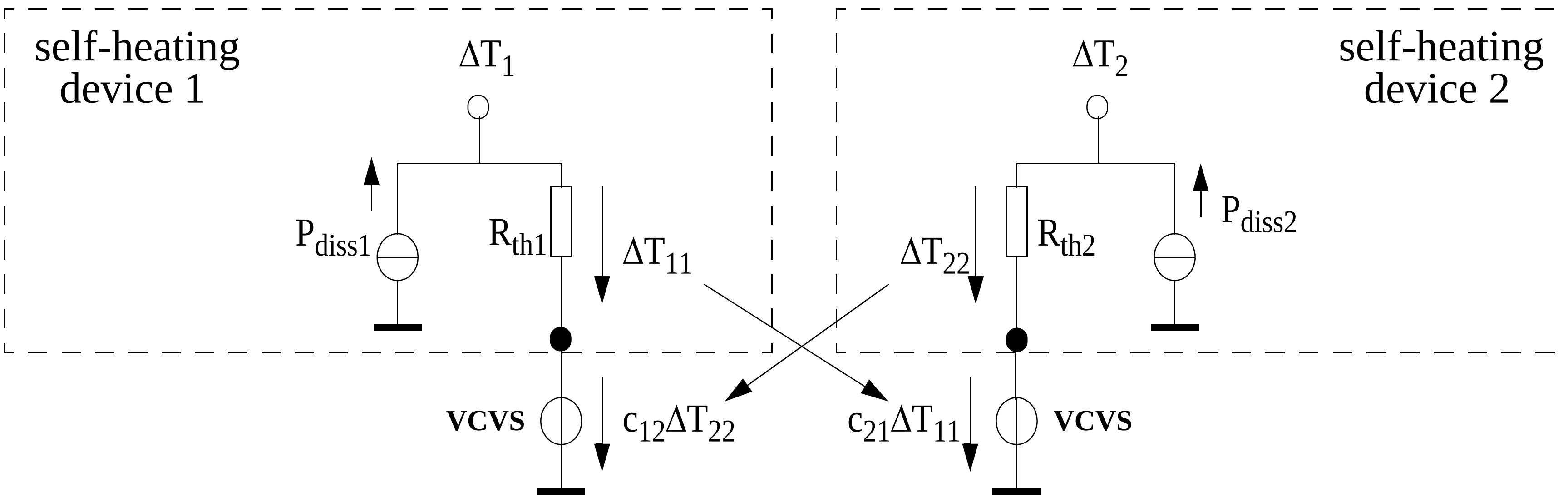


Static Thermal Coupling

- Total temperature rises (ΔT_1, ΔT_2) of two interacting sources can be expressed as a sum of both self-heating contributions (ΔT_{11}, ΔT_{22}) using thermal coupling coefficients (c_{21}, c_{12}):

$$\Delta T_1 = \Delta T_{11} + c_{21}\Delta T_{22} \qquad \Delta T_2 = \Delta T_{22} + c_{12}\Delta T_{11}$$

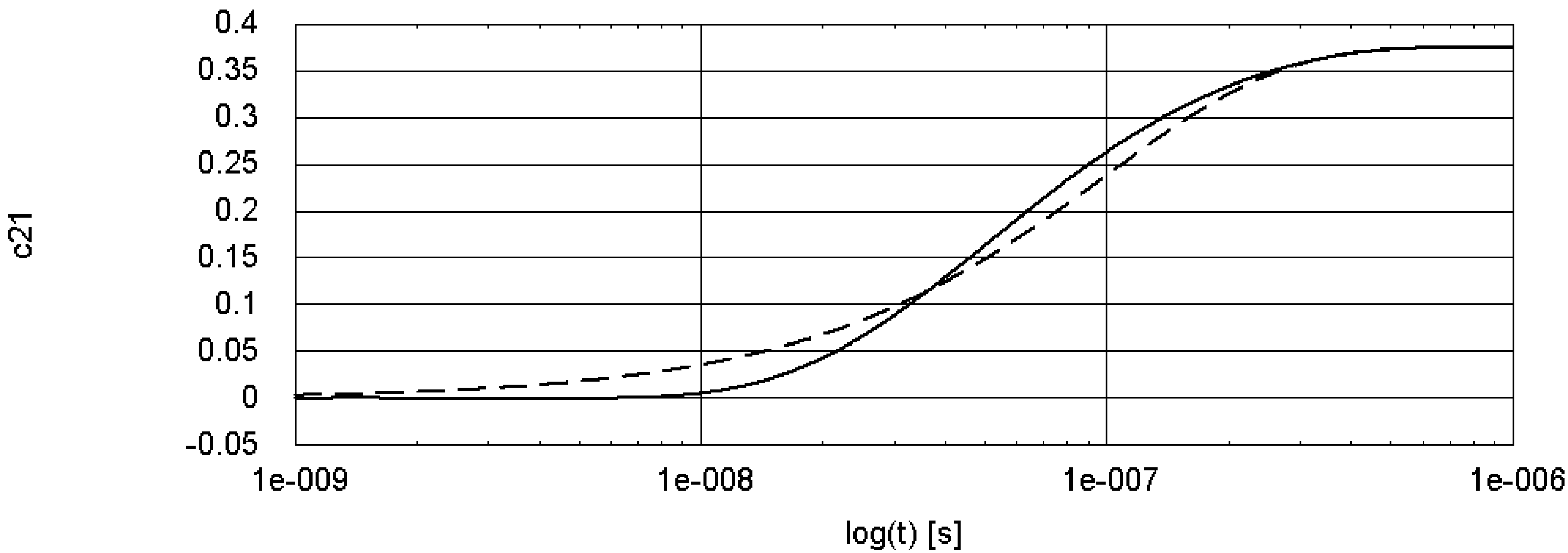
- Representation using voltage controlled voltage sources (VCVS) [D.J.Walkey]:



Transient Thermal Coupling

- Time-dependence of coupling coefficient (solid line) is of exponential nature and can be represented using one or multiple RC-elements (dashed line).

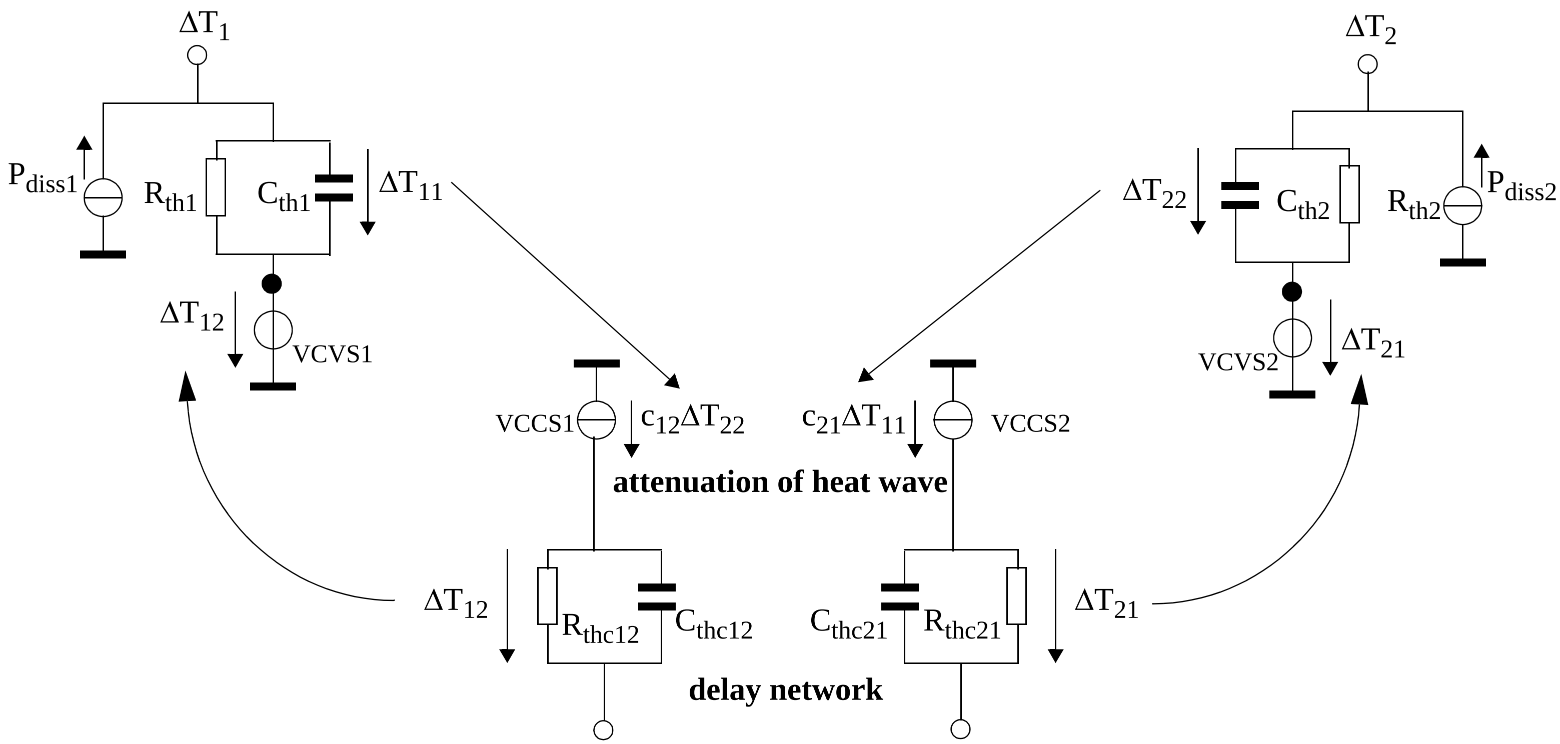
$$c_{21c}(t) = \frac{\Delta T_{21}(t)}{\Delta T_{11}(t)} = c_{21}\left(1 - \exp\left(\frac{-t}{R_{thc21} \cdot C_{thc21}}\right)\right)$$



Transient Thermal Coupling

- Voltage controlled current sources (VCCS) drive the delay networks for the coupling coefficients. VCVSs add the coupled temperatures to the respective self-heating contributions.

$$\Delta T_{12}(t) = \Delta T_{22}(t) \cdot c_{12}\left(1 - \exp\left(\frac{-t}{R_{thc12} \cdot C_{thc12}}\right)\right) \qquad \Delta T_{21}(t) = \Delta T_{11}(t) \cdot c_{21}\left(1 - \exp\left(\frac{-t}{R_{thc21} \cdot C_{thc21}}\right)\right)$$

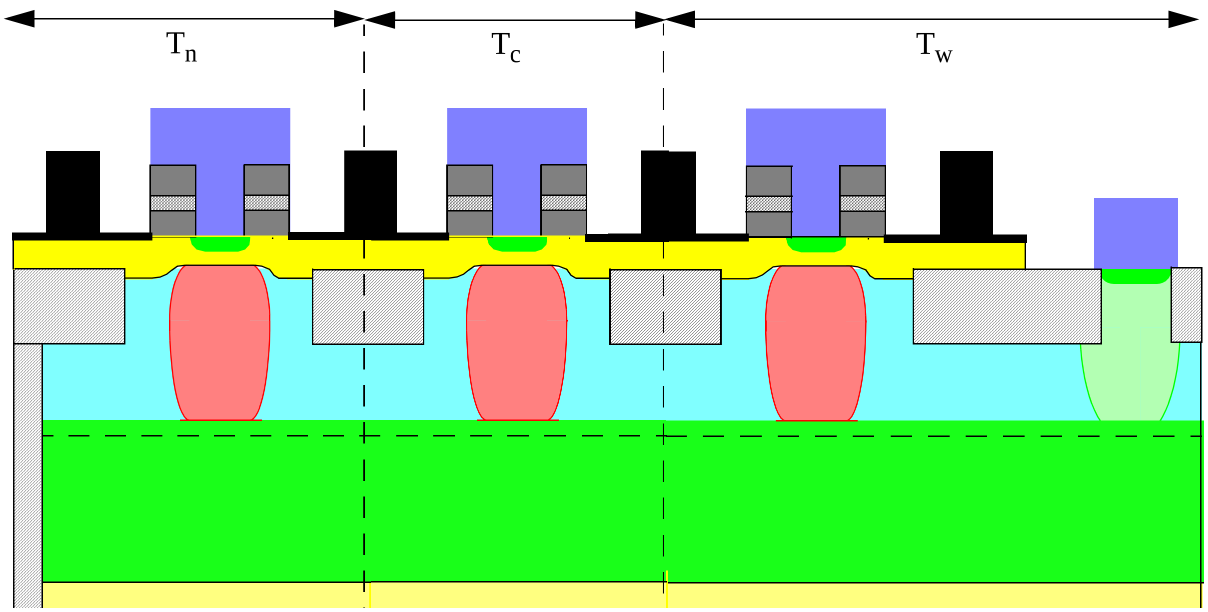


Distributed electrical network

Finger-partitioning

- Every finger is represented by one transistor model.
- Distinguish three different types of transistor elements:

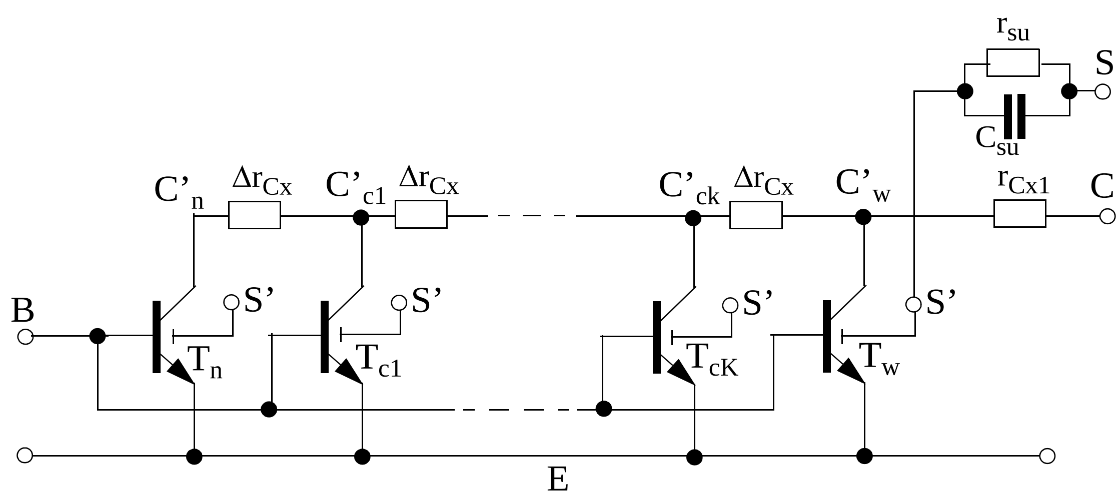
1. an outer element T_w containing the collector region
2. a center element T_c bounded by base contacts at each side (does not contain collector region)
3. an outer element T_n bounded by a base contact at one side (does not contain collector region)



Distributed electrical network

Finger-partitioning

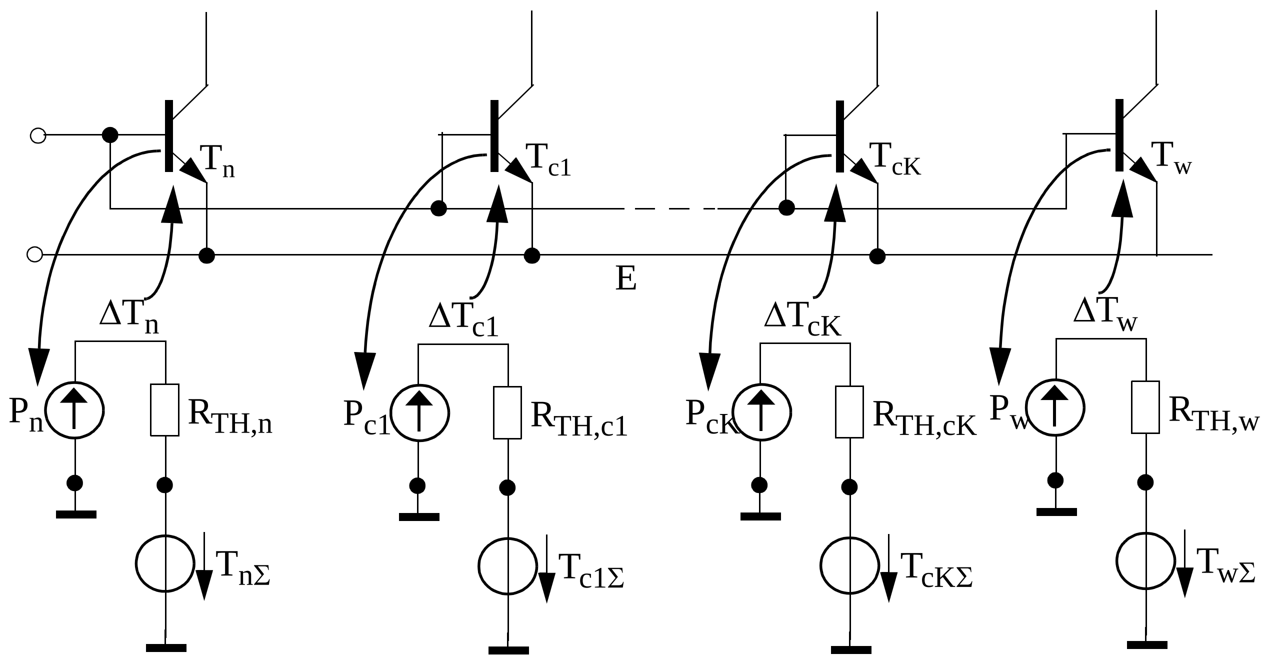
- External collector resistance is partitioned and pulled out of the transistor elements.
- Transistor model parameters are calculated from technology data using the respective emitter area portion.



Distributed electrical network

Finger-partitioning

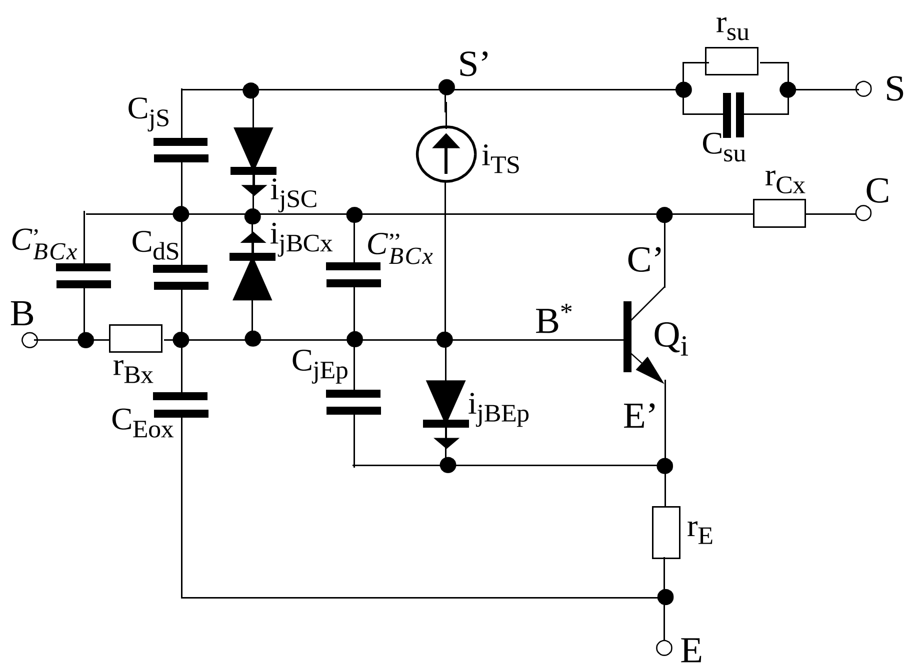
- External access to the thermal nodes ΔT enables contacting thermal (coupling) networks of arbitrary complexity.



Distributed electrical network

Emitter-partitioning

- The equivalent circuit of one emitter is split into external elements and an internal transistor Q_i, which is represented by a distributed network



Distributed electrical network

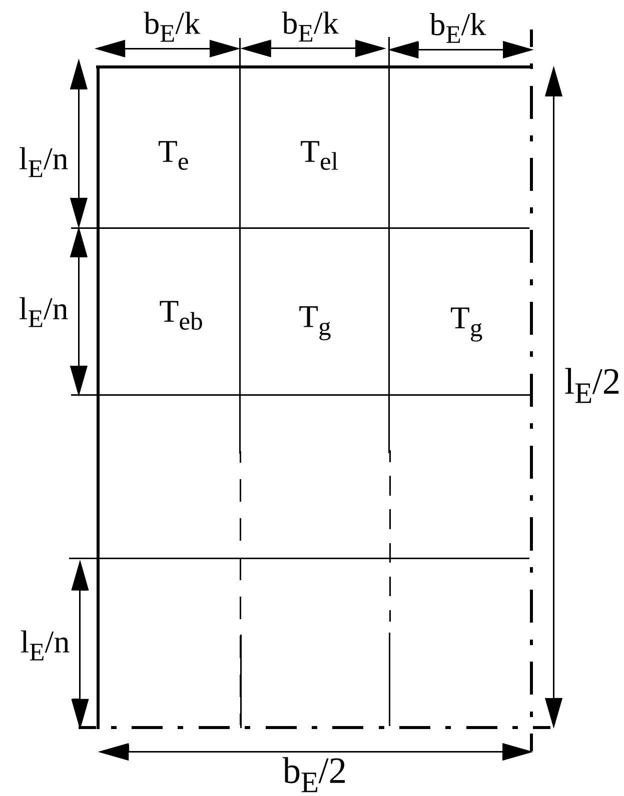
Emitter-partitioning

- The finger (internal transistor Q_i) is partitioned and represented by several transistor models.
- Distinguish three different types of transistor elements:

1. a generic element T_g bounded by another element in each direction

2. an edge element T_e bounding to other elements on 2 sides

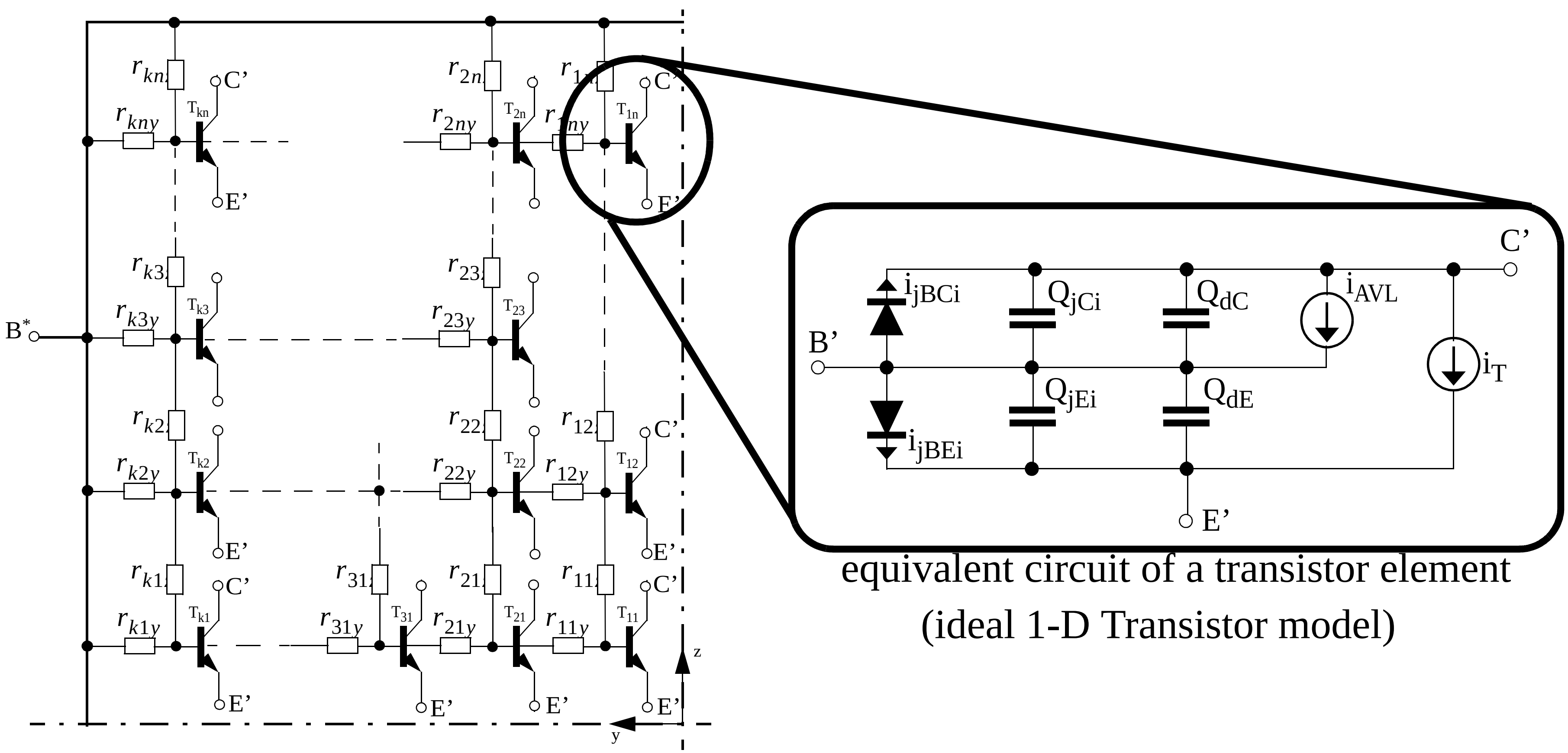
3. edge elements T_{el} and T_{eb} bounding to other elements on 3 sides



Distributed electrical network

Emitter-partitioning

- The internal base resistance is partitioned and pulled out of the transistor element model.
- Thermal (coupling) networks can be contacted through access to the thermal nodes ΔT.



equivalent circuit of a transistor element
(ideal 1-D Transistor model)

Available Model Complexities

	electrical representation	self-heating („built-in“)	self-heating (improved external)	thermal coupling (inter-device)	thermal coupling (intra-device)
HICUM/L2 Cell/Device	1 TM per Device/ Cell	X	X		
HICUM/L4 Cell	1 TM per Device	X	X	X	
HICUM/L4 Finger	1 TM per Finger	X	X	X	X
HICUM /L4 Emitter	1 TM per Finger- sub-element	X	X	X	X

(TM = transistor model)

Conclusion

- Partitioning of emitter fingers enables better simulation of avalanche breakdown.
- Derived distributed models covering self-heating and thermal coupling effects.
- Implemented scaling equations and extraction routines for the respective parameters.
- The approach is based on „fast“ analytic expressions enabling efficient parameter generation.
- Established automated network generation of different model complexities.

Planned Activities - Outlook

- Verification of distributed electrical and electro-thermal networks.
- Development of scaling equations for substrate coupling.
- Automated generation of distributed models covering substrate coupling.
- Development of scaling equations for backend parasitics.
- Implementation into existing model generation procedures.
- Test and Verification.