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# Extraction of CTH with pulsed measurements

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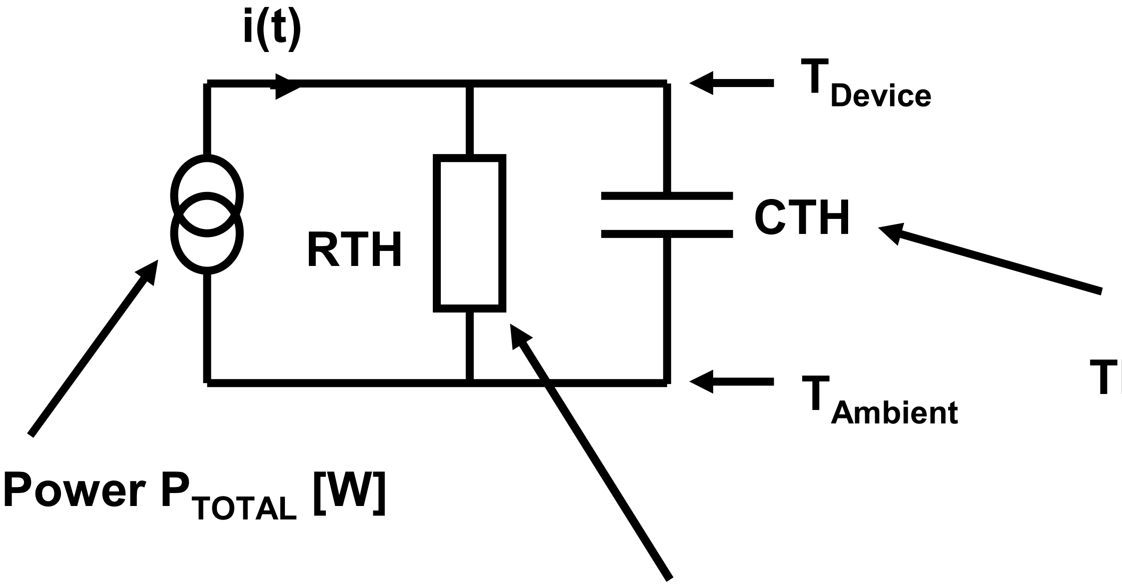
# Overview

- **Thermal network**
- **Measurement equipment**
- **Results**
- **Summary**

# Simple Thermal network



**Thermal capacitance [J/K]**

**Dissipated Power $P_{TOTAL}$ [W]**

**Thermal resistance [K/W]**

**for BJT/HBT:**

$$P_{TOTAL}(t) = V_{CE}(t) \cdot I_C(t) + V_{BE}(t) \cdot I_B(t)$$

# How to measure

- **Thermal resistance RTH can easily be measured with DC analyzer**
- **Thermal capacitance can be calculated from thermal time constant**
- **Thermal time constant is measurable with transient or quasi transient measurements**

$$\tau_{th} = RTH \cdot CTH$$

$$CTH = \frac{\tau_{th}}{RTH}$$

# Measurement equipment

- **DiVA 210 from Accent Opto**
- **dynamic I(V) analyzer**
- **Key features:**

  **2 pulsed channels**

  **100 ns – 1 ms pulse width**

  **500 mA $I_{max}$**

  **10 V $V_{max}$**

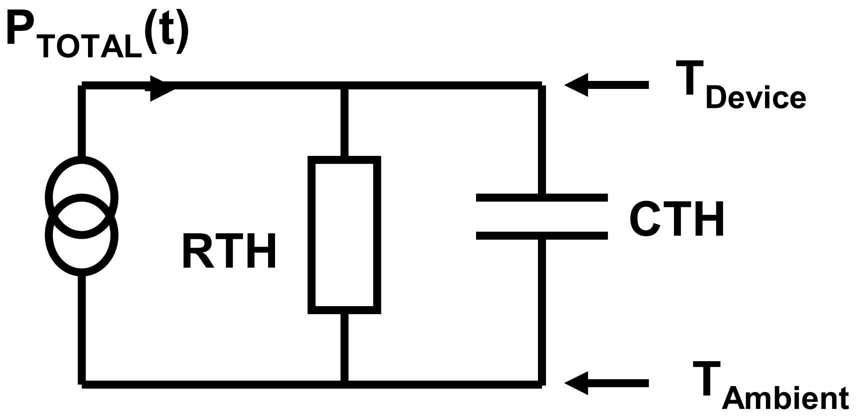
  **Pulsing from every DC BIAS point**

  **Quasi transient measurements possible**

# Assumptions

- only one thermal time constant
- only silicon has thermal capacitance
  metallization and insulation is not taken into account
- Transistor is electrical fast
  ft > 500/$t_{pulse}$ at pulsed BIAS point (5 GHz for 100 ns)
- Collector current is a linear function of temperature
- Power dissipation is constant over time
  biggest simplification

# Equations for Temperature



$$P_{TOTAL}(t) = CTH\,\frac{d\Delta T(t)}{dt} + \frac{\Delta T(t)}{RTH}$$

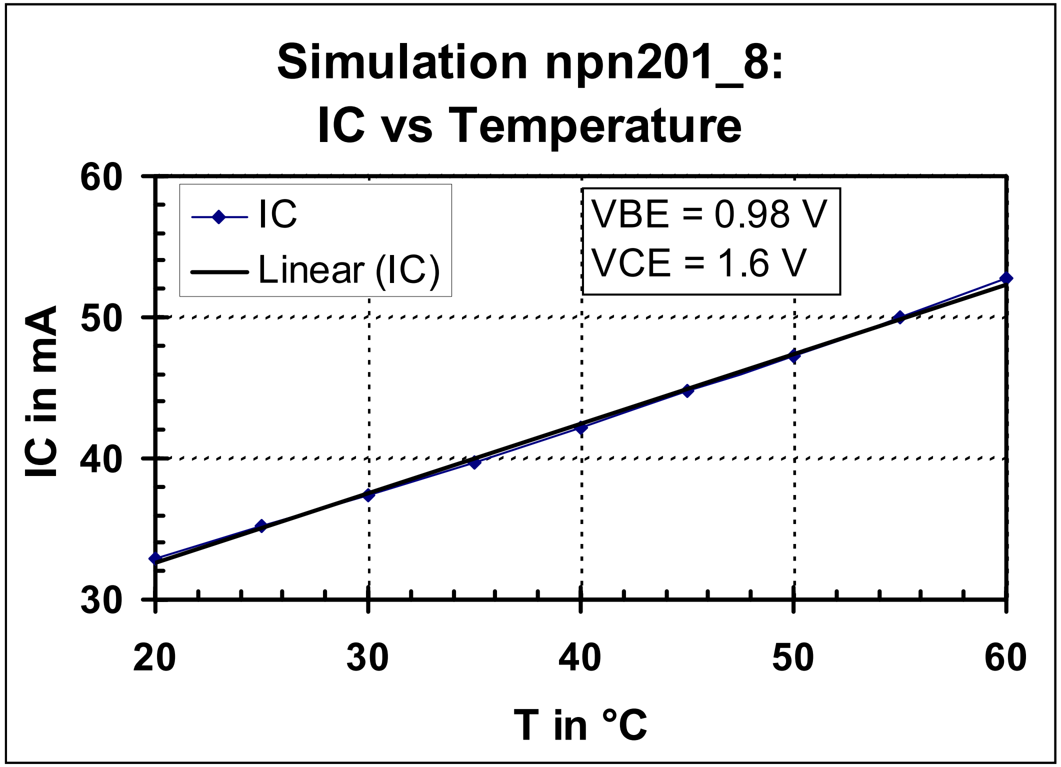
$$\Delta T(t) = P(t \to \infty) \cdot RTH \cdot \left(1 - \exp\left[-\frac{t}{\tau_{th}}\right]\right)$$

$$\Delta T = T_{Device} - T_{Ambient}$$

$$\tau_{th} = CTH \cdot RTH$$

# Current vs. Temperature

- **Temperature at device is unknown**
  **can be measured indirectly over collector current**



**IC can be approximate as linear function of temperature:**

$$I_C(T) = I_C(T_{NOM}) \cdot [1 + m \cdot (T - T_{NOM})]$$

$$\Delta T(t) = T(t) - T_{NOM}$$

$$I_C \sim T$$

# Equations for Collector Current

- **Temperature is replaced by current**

$$I_C(t) = I_{C0} + X \cdot \left(1 - \exp\left[1 - \frac{t}{\tau_{TH}}\right]\right)$$

- **IC0 and X are unknown**

  **but IC at steady state is know**

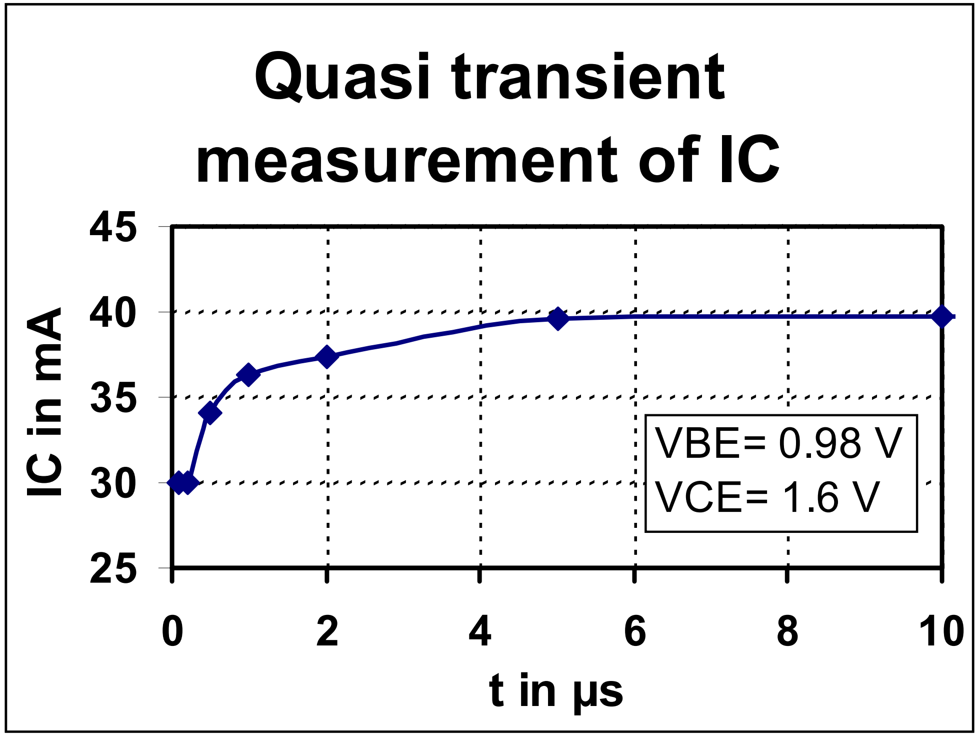
$$\ln\left(I_C(t \to \infty) - I_C(t)\right) = -\frac{1}{\tau_{TH}} \cdot t + \ln(X)$$

$$y = m \cdot x + b$$

- **The slope contains the time constant**

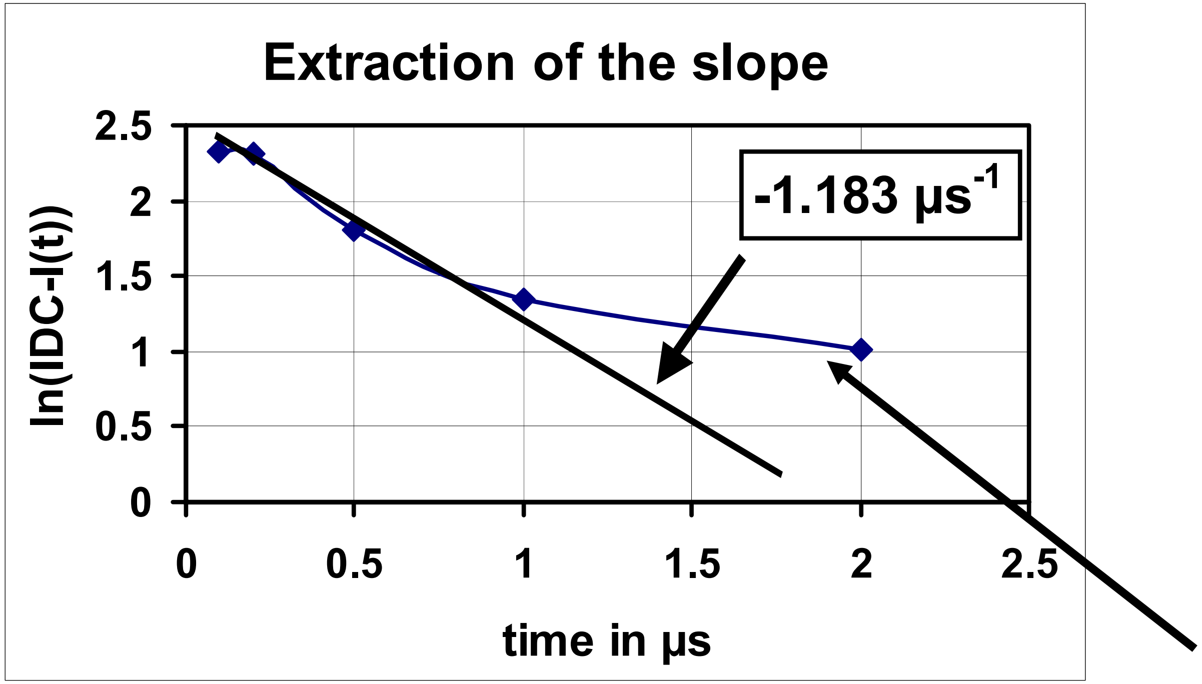
# Measurement Results – IC

- **Quasi transient measurement of an 8 emitter HBT**
  **pulse condutions: VBE = 0.98 V, VCE = 1.6 V**



# Measurement Results – time constant

- **Applying previous equations**



**second time constant is visible**

$$\tau_{TH} = -\frac{1}{m} \approx 0.85\mu s$$

# Measurement Results - CTH

- **RTH of the transistor is known**

  **CTH can be calculated**

$$RTH = 1980 \frac{K}{W}$$

$$\tau_{TH} \approx 0.85 \mu s$$

$$CTH \approx 430 \frac{pJ}{K}$$

# Confidence check

- **Specific heat capacity and density of silicon are known**

  **calculate the heated volume**

$$\sigma_{Si} = 2330 \frac{kg}{m^3} \qquad c_{Si} = 700 \frac{J}{kg \cdot K}$$

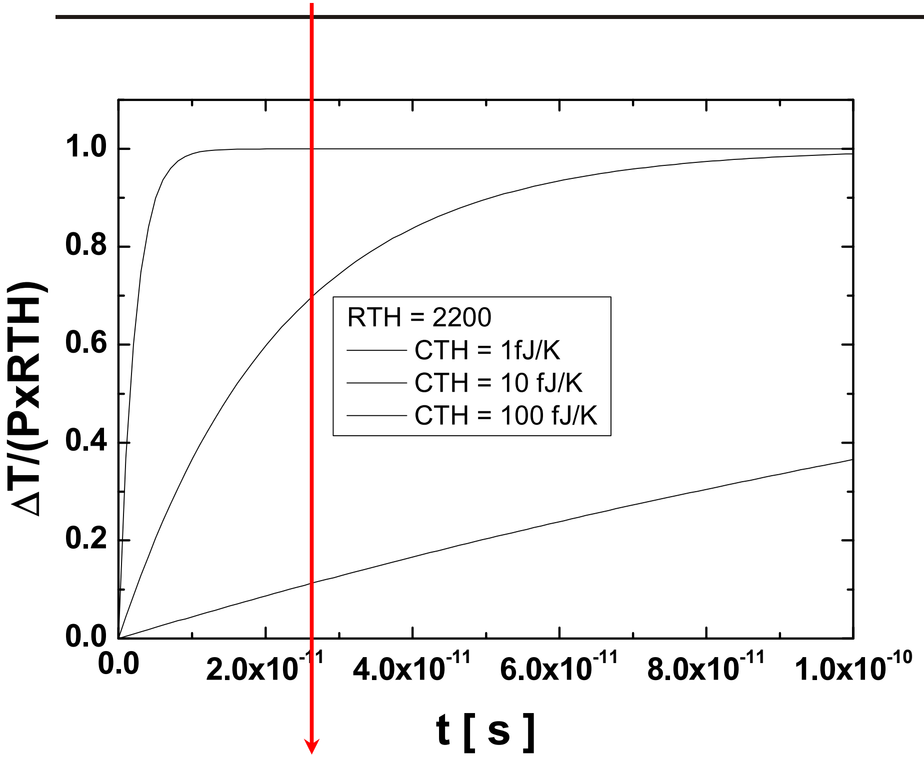
$$V_{heated} = \frac{CTH}{\sigma \cdot c}$$

$$V_{heated} = 2.64 \cdot 10^{-16} m^3$$

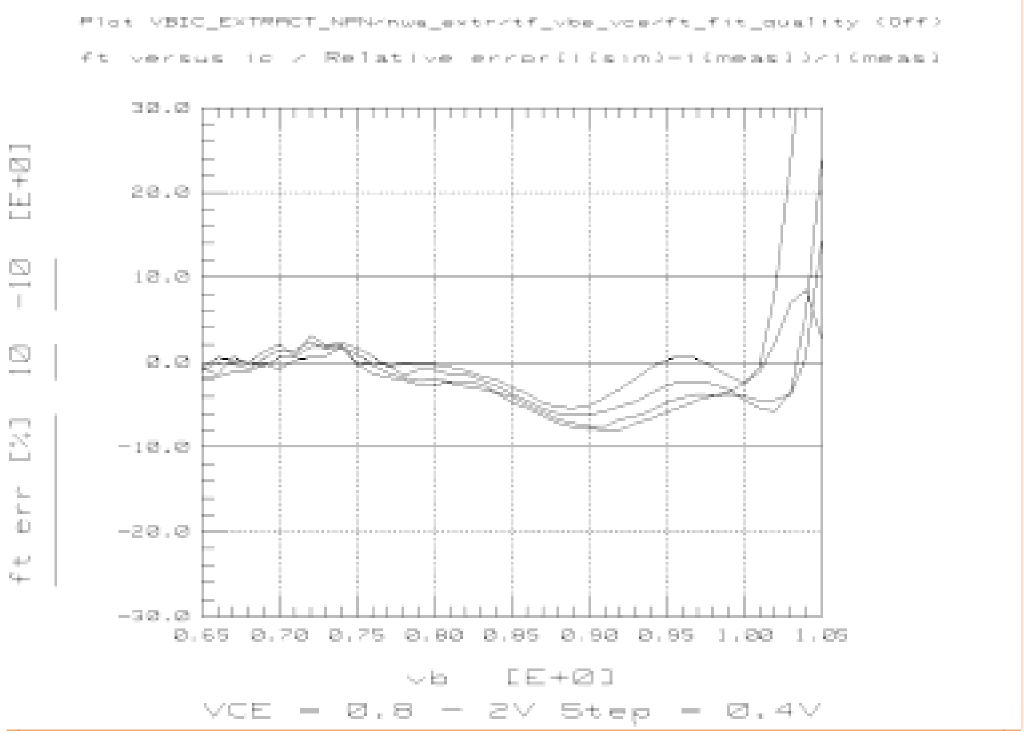
$$= 264 \mu m^3$$

**corresponds to a cube with 6.4µm long sides:**
**reasonable result**

# Influence of CTH on simulation



**Influence of CTH on fT simulation:**

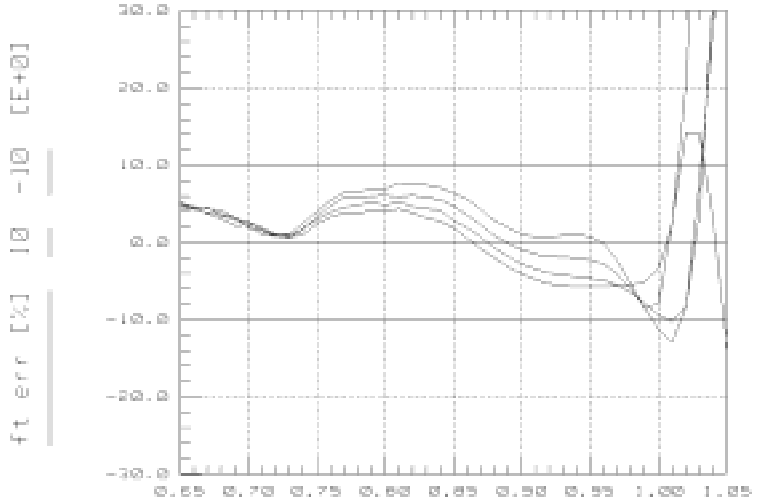


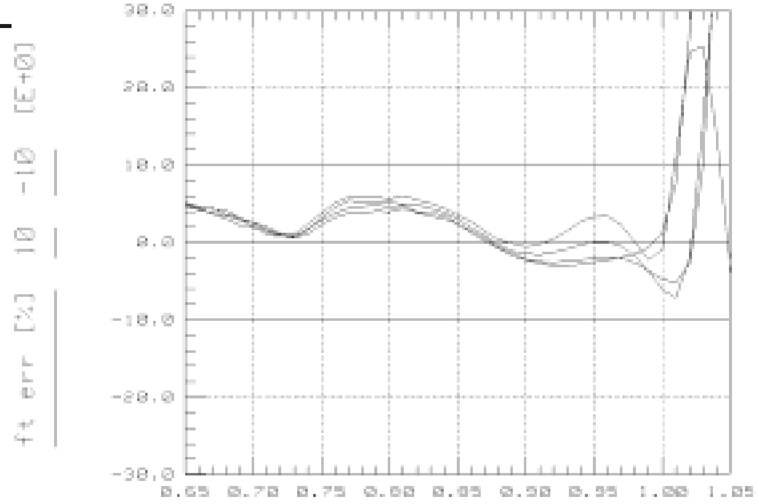
**Measurement at 10 GHz, biggest influence on simulation if CTH ~ 5 – 20 fJ/K.**

**A CTH in pJ/K range influences the 100MHz frequency range**

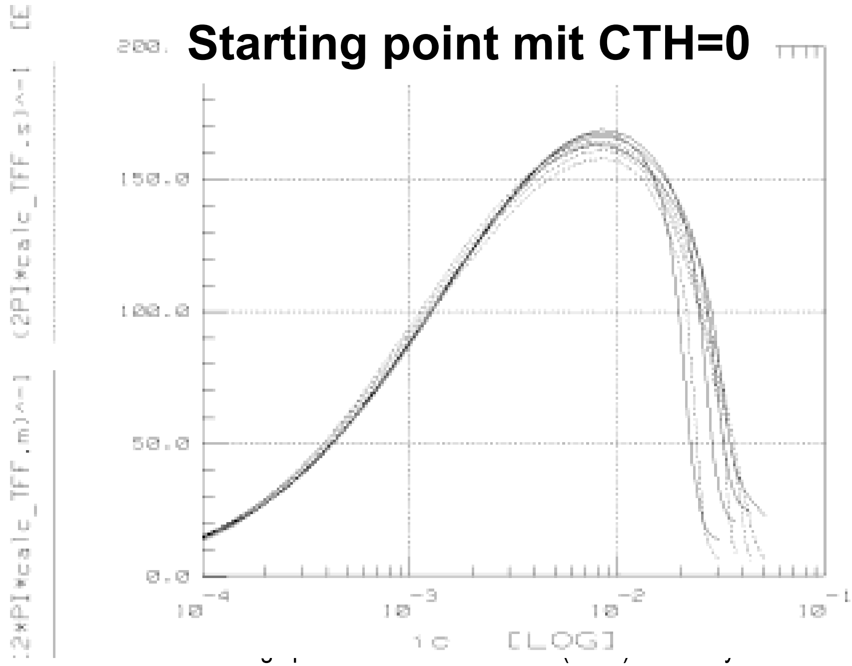
**CTH = 430p**

# Optimization of npn201 with CTH = 430p

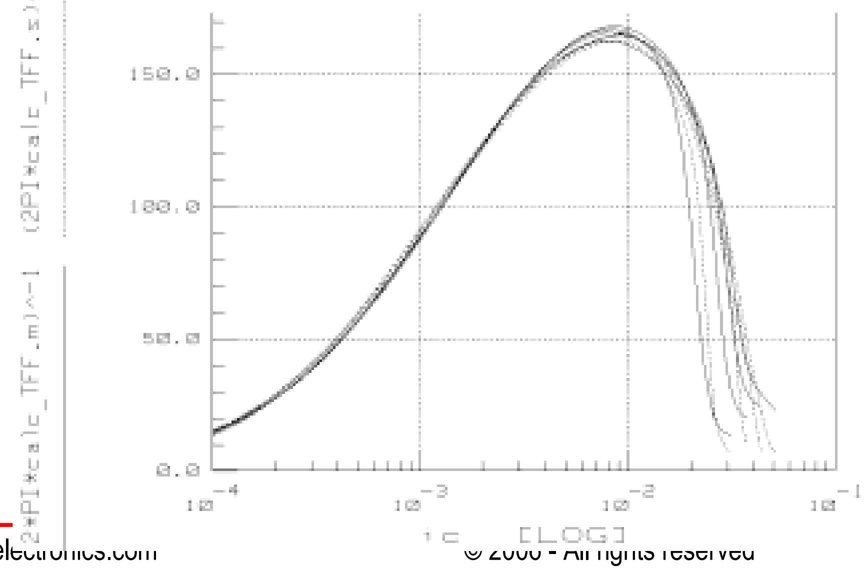




**Starting point mit CTH=0**



**With CTH=430p and changing TFNOM from 660f to 615f**



# Summary

- **Simple thermal network with corresponding equations was presented**
- **Results of quasi transient measurements were shown**
- **Step by step extraction of CTH including confidence check**
- **Influence of CTH on simulation was shown**