HBT’s thermal impedance measurement

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Motivation

- Bipolar compact model (e.g. VBIC)
Do we really need $C_{TH}$?

Harmonic balance simulation:
HICUM with ADS
RF power transistor
Power gain as a function of input power at 2GHz

VBE=0.83V, VCE=3.5V

- Power gain (dB) @ 2GHz
- $P_{out}/P_{in}$ (2GHz - $C_{th} = 3\text{nJ/K}$)
- $P_{out}/P_{in}$ (2GHz - $C_{th} = 1\text{e-30 J/K}$)
We do really need $C_{TH}$.

- But, how to get it?
Outline

• Motivation: done

• Presentation of two methods for:
  – $Z_{TH}$ measurement
  – $C_{TH}$ extraction
  – $Z_{TH}$ modelling

• Scaling issues

• Questions
$Z_{TH}$ measurement

1. Load Pull measurement

2. Small Signal measurement
   - frequency range
     - NWA
     - Z-parameters

3. Pulsed measurement
Load Pull measurement

• Measurement equipment
• De-embedding and calibration
• Indirect extraction
  – First, full compact model parameter extraction
  – Second, $C_{TH}$ fitting
  – Third, $C_{TH}$ is in general not very sensitive

• => For instance, not the best choice
Small Signal measurement

• Frequency range: first order guess
  – Standard transistor:
    • Deep trench isolation
    • $0.25 \mu m \times 12.8 \mu m$
    • $R_{TH} = 1000 \text{ K/W}$
    • $C_{TH} = 0.5 \text{ nJ/K}$
    • $f_{TH} = 1/(2\pi R_{TH} C_{TH}) \approx 300 \text{ kHz}$
  – Out of the range of standard NWA
Measurement setup: AC

• Base: $I_B$ constant
• Collector: $V_{DC} + V_{AC}$
• $I_C$ through $R_C$
• $Z_{CE} = V_C/I_C$ (complex)
• frequency range
  – Theory: $0 \rightarrow \infty$
  – $0.1$Hz$\rightarrow 10$ MHz
Measurement results: AC

- Real Part of $Z_{CE}$
Modelling: AC

• Hicum compact model: $R_{TH}$
  – Real part of $Z_{CE}$ at low frequencies
Modelling: AC

- Hicum compact model: $C_{TH}$
  - Phase of $Z_{CE}$
Measurement setup: pulse

- Base: $I_B$ constant
- Collector: $V_{CE1} \rightarrow V_{CE2}$
- Measure $V_B$
- Calibration $V_B \rightarrow T$
- Time range
  - Theory: $0 \rightarrow \infty$
  - 10ns → 10s
Measurement results: pulse

- $V_{BE}(t) \rightarrow T(t)$
Modelling: pulse

- $R_{TH} - C_{TH}$ cell:
  - \text{lin}
  - \text{log}
Modelling pulse: recursive network

- Recursive network
Recursive network: toolkit & results
Scaling issues
Why does the dynamic behaviour change for small devices?
Measurement problem

- Small transistors, small $I_B$, high $Z_{in}$
- New current source: new dynamic behaviour !!!

• Solution : ?
Discussion

- Pulse and AC method for $C_{TH}$ determination
  - Both methods give similar results
  - Both methods need similar equipment
  - AC: a full parameter extraction has to be performed for $R_{TH}$ and $C_{TH}$ determination
  - Pulse: $R_{TH}$ and $C_{TH}$ can be directly determined, but a $V_{BE}$-T calibration is necessary

- Recursive network for accurate modelling
- Limits for small transistors
• Thanks for your attention