Bandgap Reference
Simulation / Measurement Comparison

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Never stop thinking

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Motivation

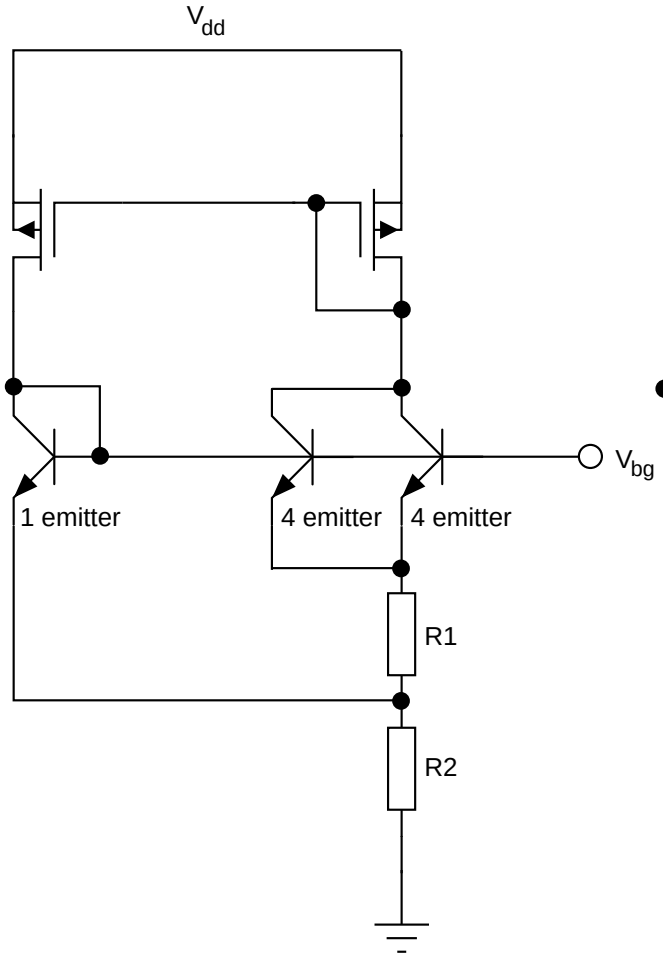
Circuit designer feedback: measured bandgap reference voltage does not match with simulated results

- Topics of investigation:
  - Influence of attached circuitry?
  - Influence of transistor configuration?
  - Influence of package?

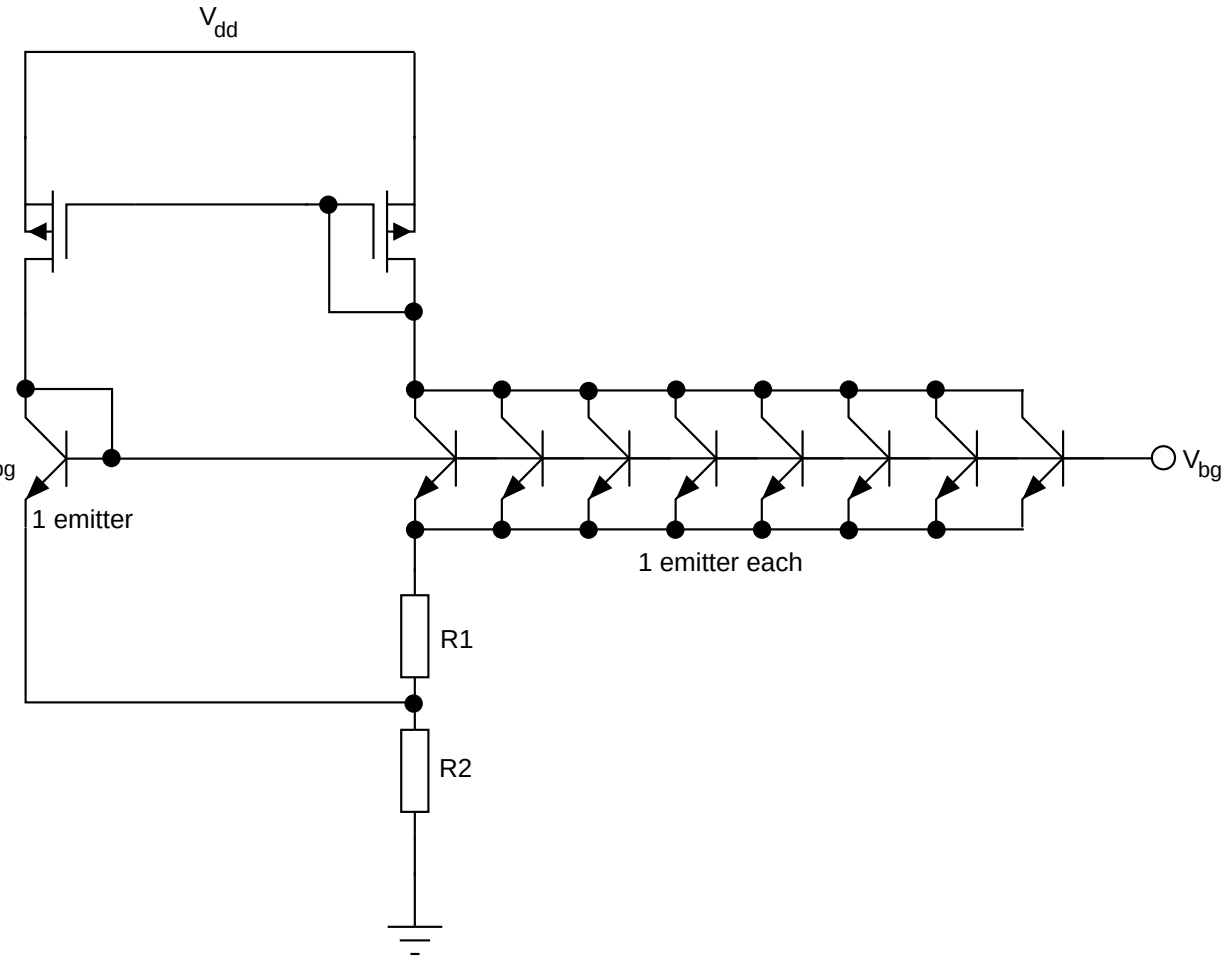
- Two bandgap reference circuits have been designed for:
  - Direct probe access to the pure bandgap circuitry
  - Evaluation of transistor configuration
  - Wafer level measurement (i. e. test chip)

Test circuits (simplified)

Brokaw cell 1:2x4

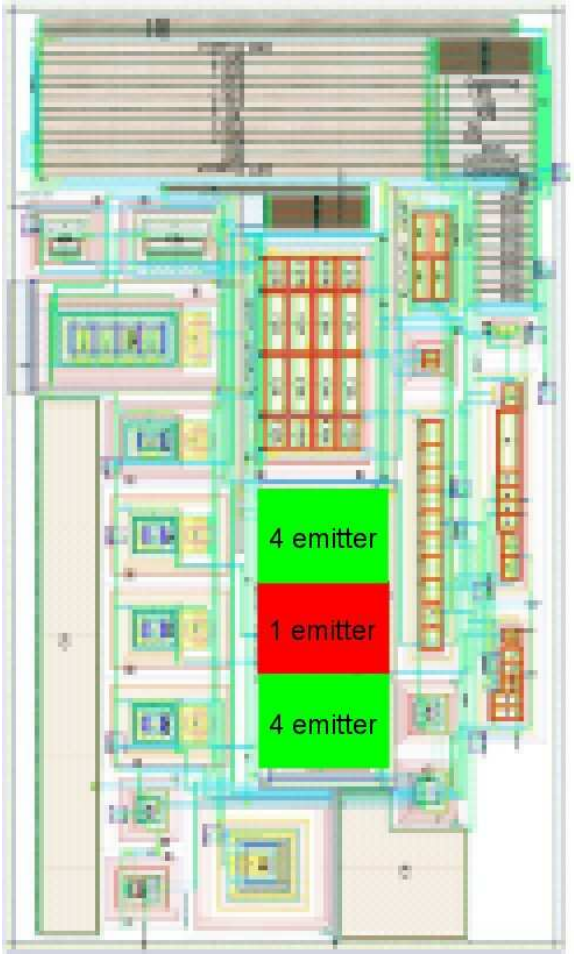


Brokaw cell 1:8

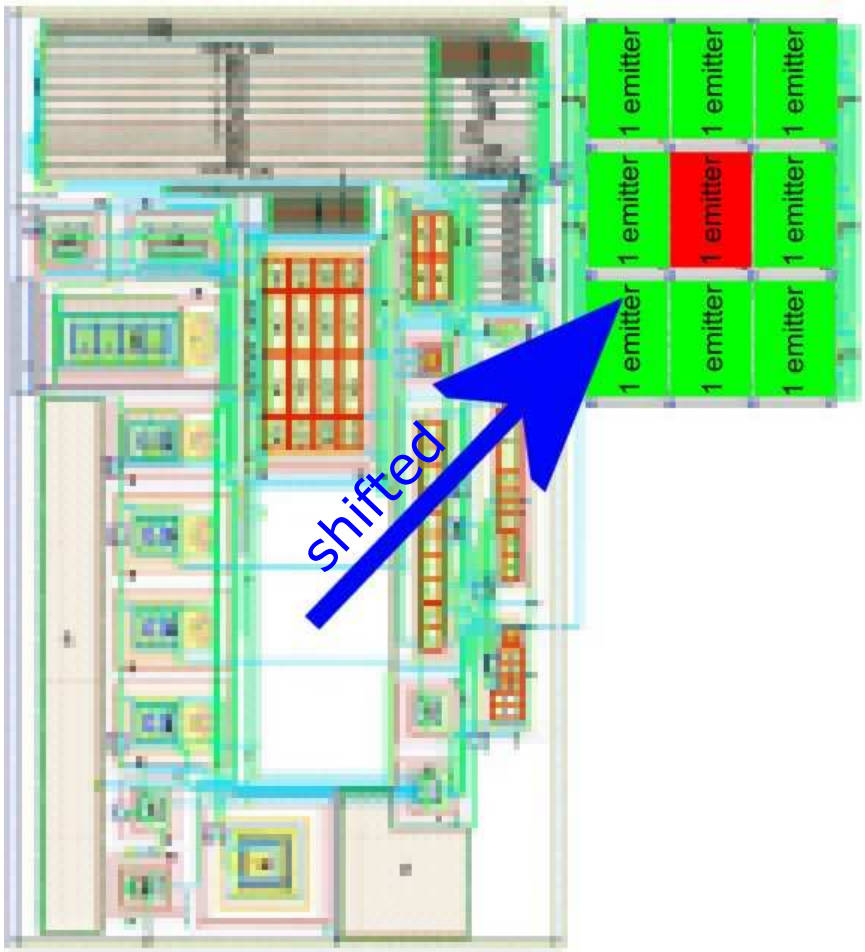


Test circuits: layouts

Brokaw cell 1:2x4

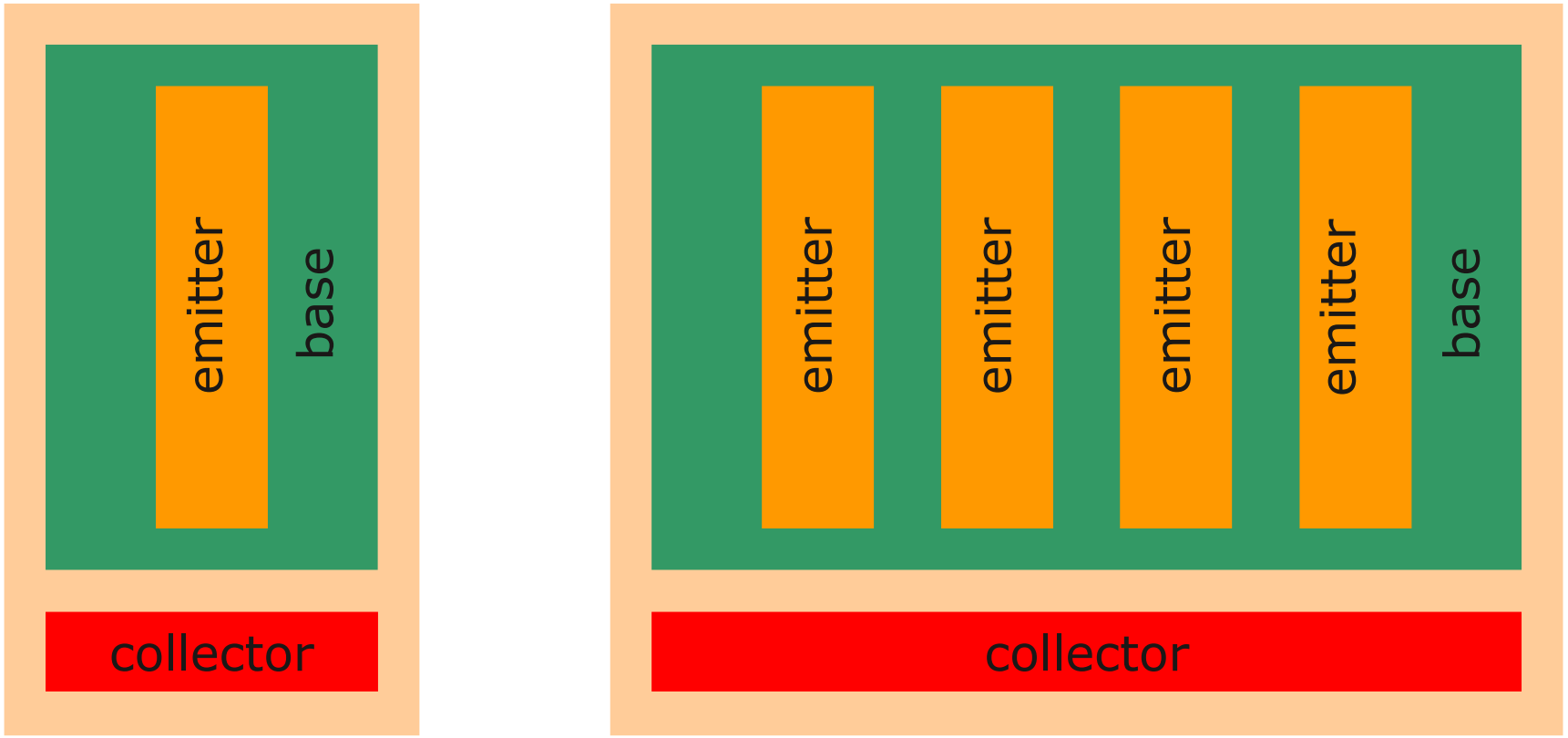


Brokaw cell 1:8



Test circuits: NPN layout

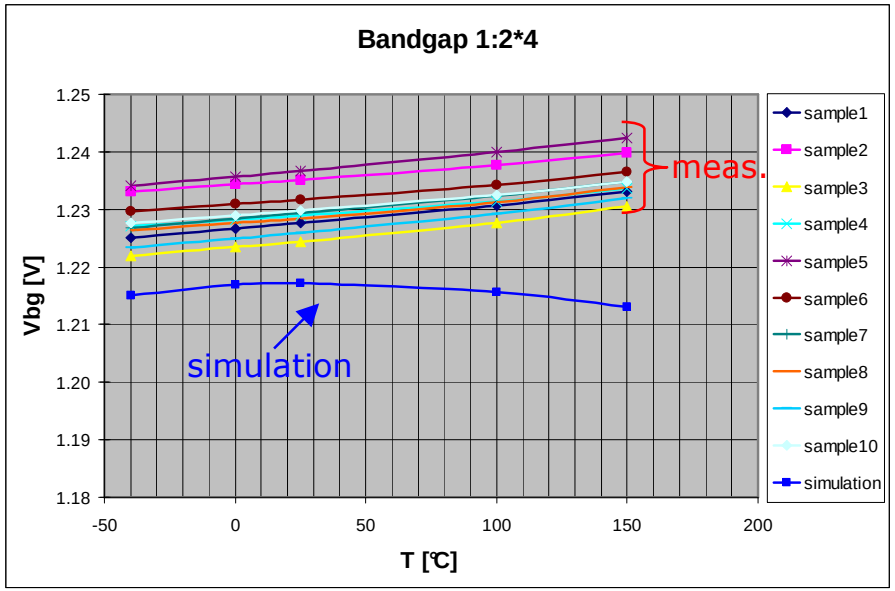
single emitter device 4 emitter device



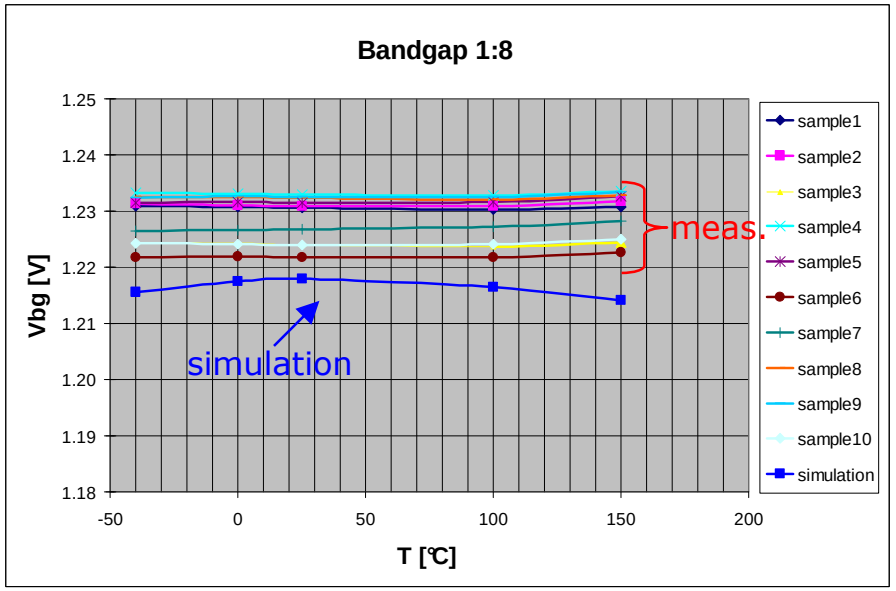
- For the multiple emitter device all emitters are located in a common base implantation

Packaged sample measurements

1:2x4 bandgap



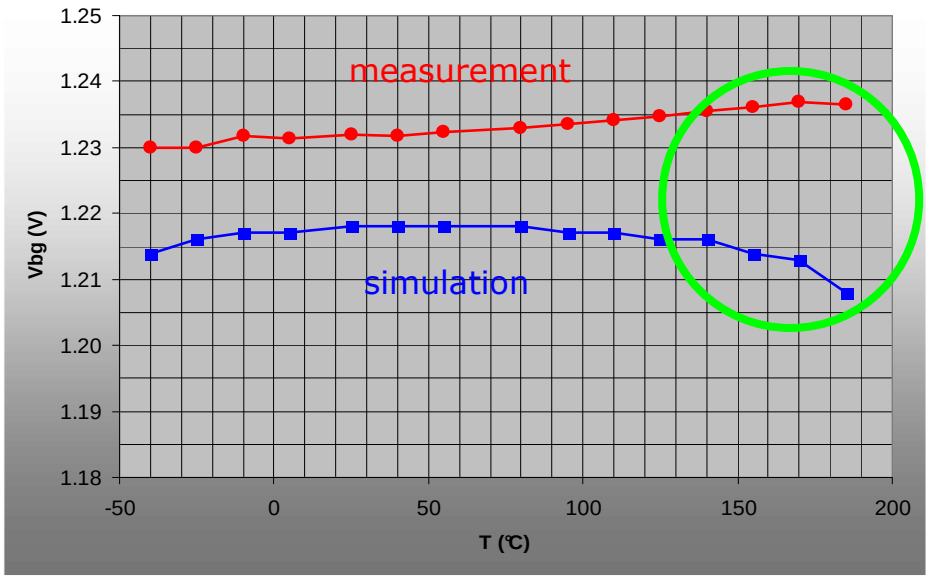
1:8 bandgap



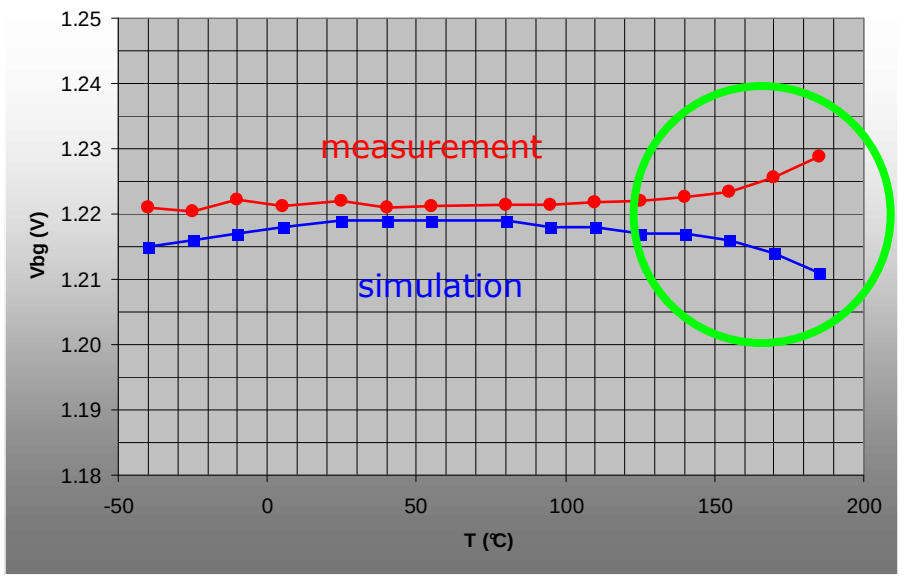
- 1:8 bandgap shows better behavior regarding temperature gradient and offset
- Tradeoff between slightly better behavior and increased area consumption

Wafer level measurements

1:2x4 bandgap



1:8 bandgap

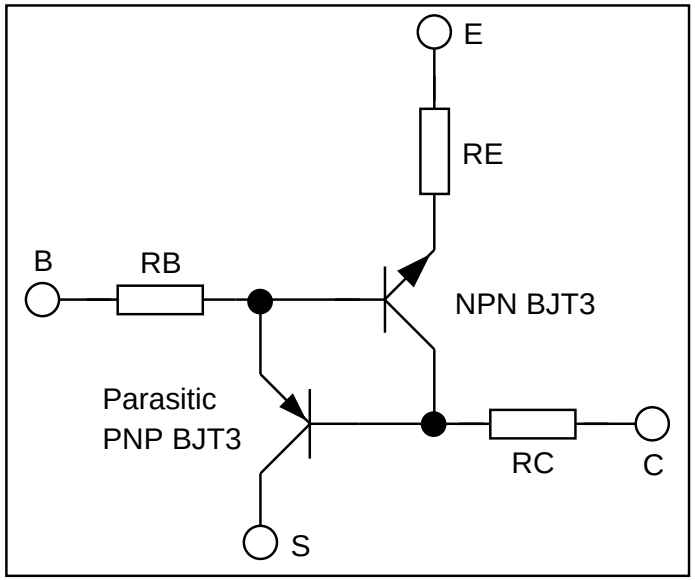


- Results from package measurements nicely confirmed
  - No negative influence of package detectable!
- Very good result for the 1:8 bandgap
- High temperature regime needs fine tuning

Parameter extraction strategy (1)

- Siemens Bipolar Junction Transistor Model BJT3 used:
  - Temperature effect parameters tuned:
    - `eg=1.11 eV` Energy gap for temperature effect on sat. current IS.
    - `tb=0` Forward and reverse beta temperature exponent.
    - `pt=3` Temperature exponent for effect on sat. current IS.
    - **`tcjbf1=0 1/C` Linear temperature coefficient for knee current Jbf.**

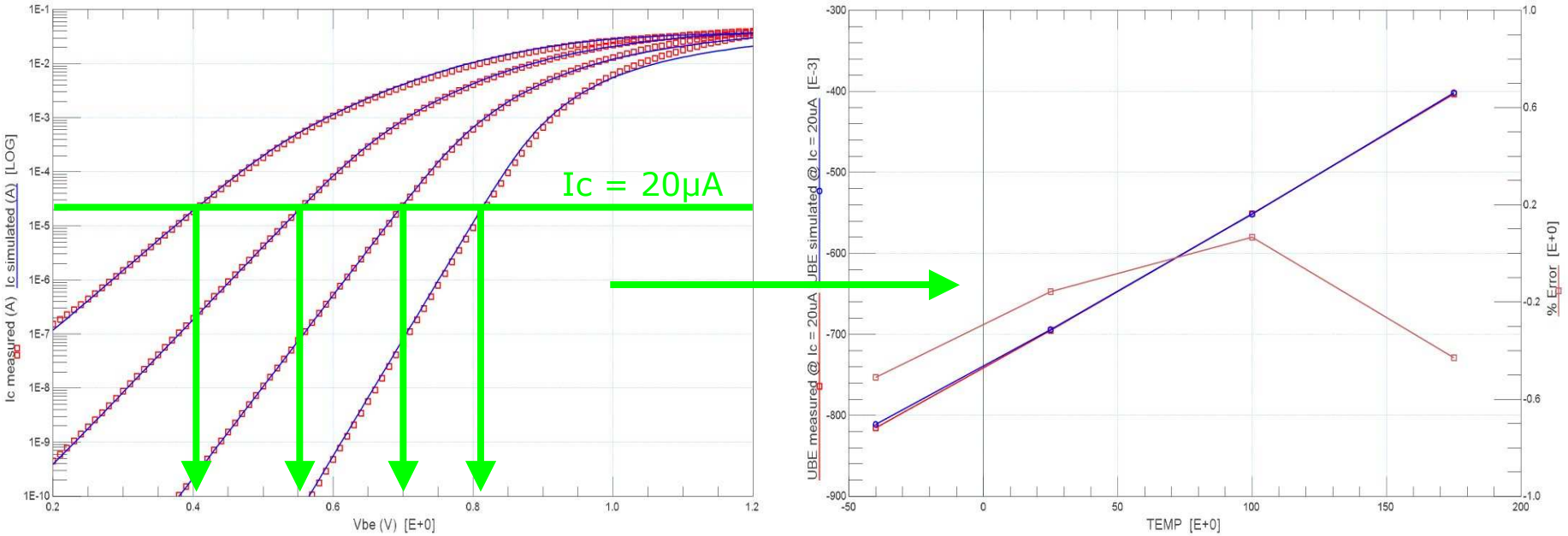
- NPN model subcircuit used:




```
eg          =  1.110
tb          =  1.645
pt          =  5.307
tcjbf1      = -0.002
```


Parameter extraction strategy (2)

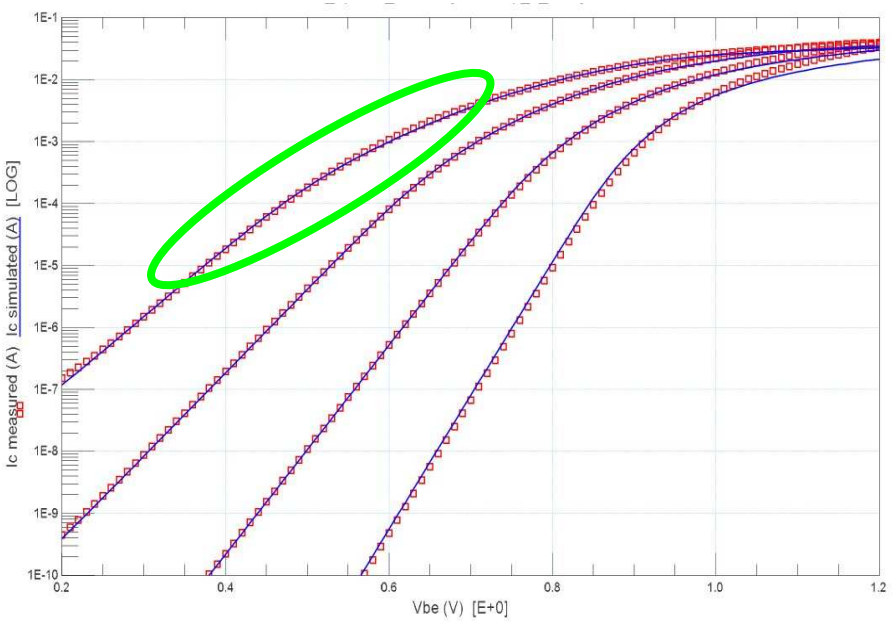
- Extraction from (T = -40°C, 25°C, 100°C, 175°C):

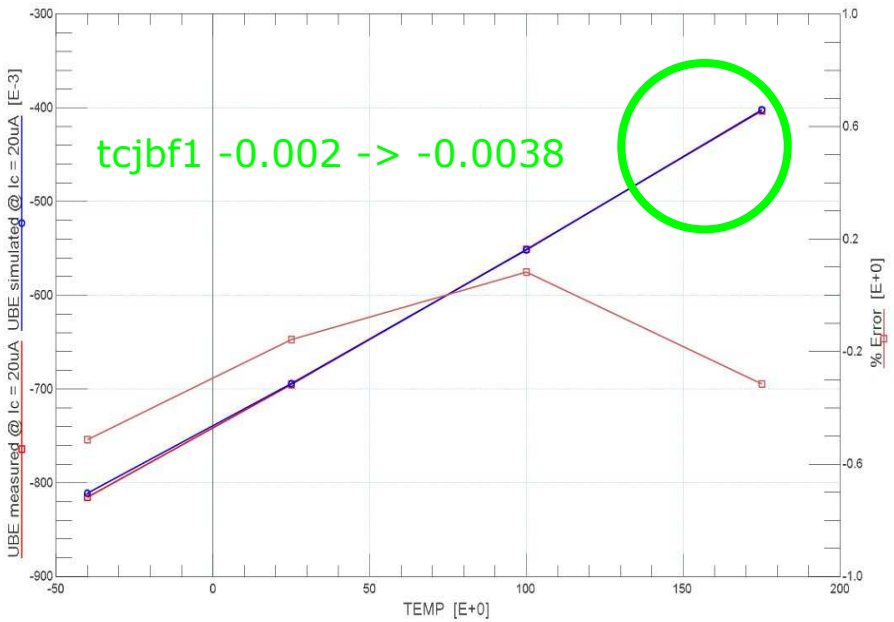


- Vbe versus temperature (calculated from Gummel Plot by interpolation) is the most sensitive plot for temperature coefficient tuning!
- Either eg or pt should be tuned, use pt and keep eg as fundamental physical constant

Parameter extraction strategy (3)

- Important for high temperature regime: tcjbf1!

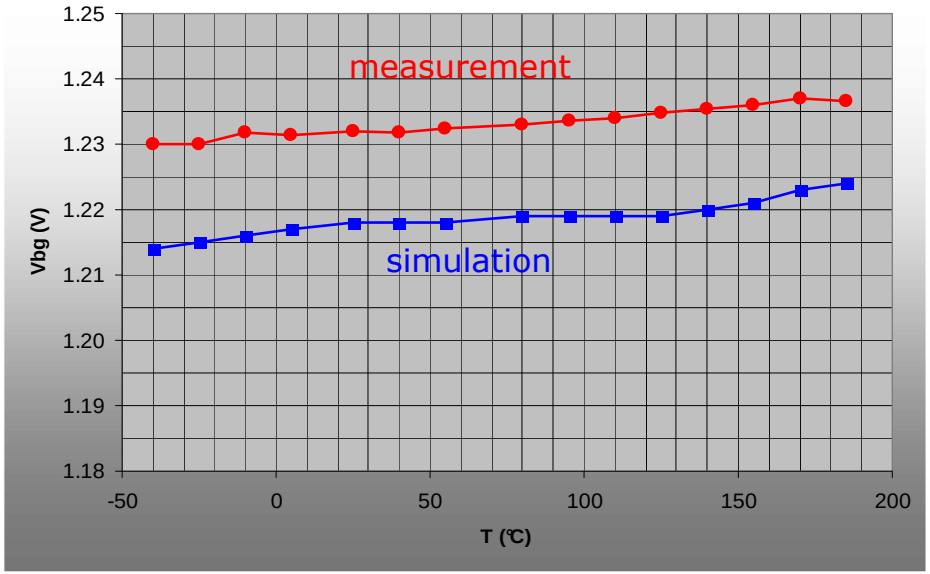




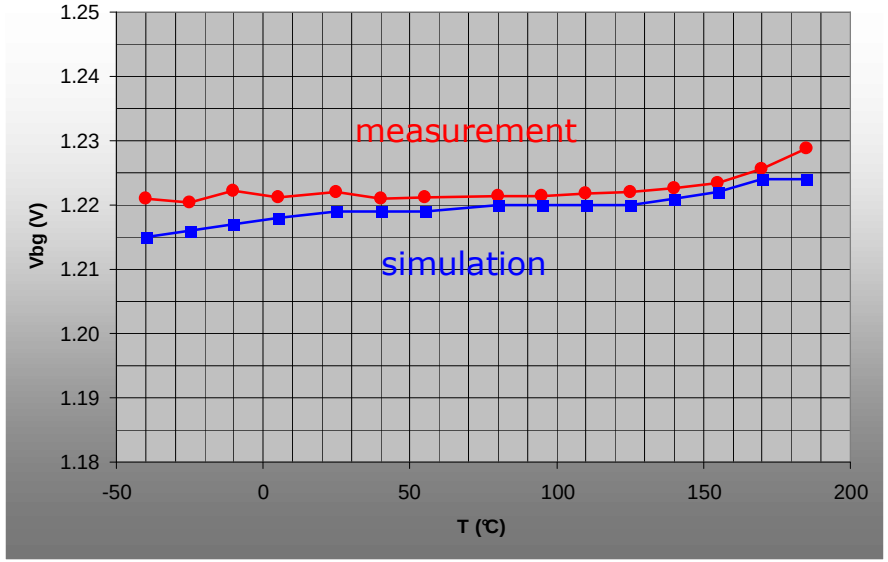
- tcjbf1 has an important influence on the bandgap temperature gradient at high temperature, although the operating currents of the bandgap transistors are far below the knee current!
- Very difficult to tune tcjbf1, almost impossible from Gummel Plot

Comparison after tcjbf1 fine tuning

1:2x4 bandgap



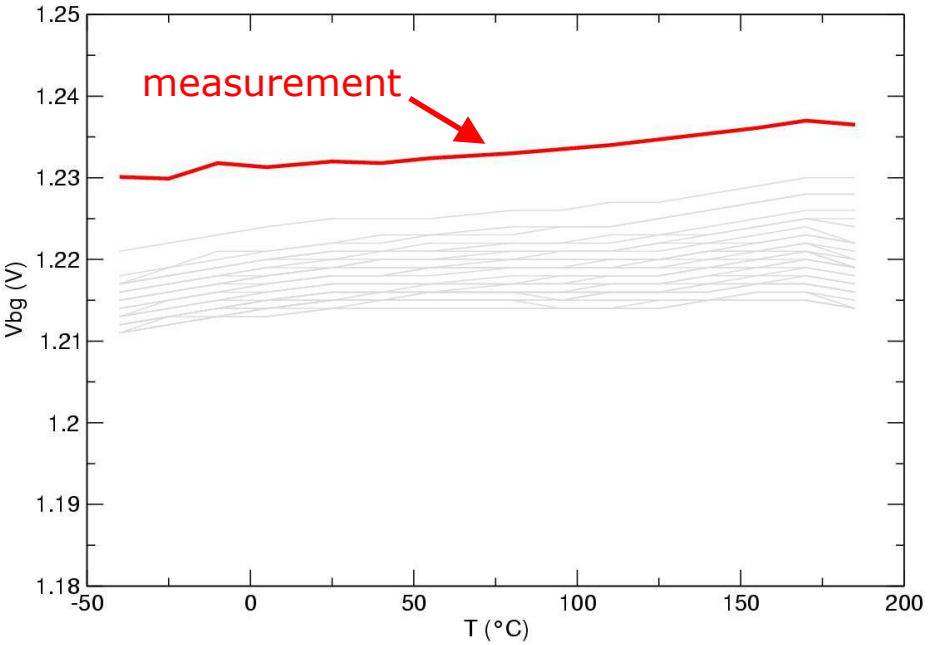
1:8 bandgap



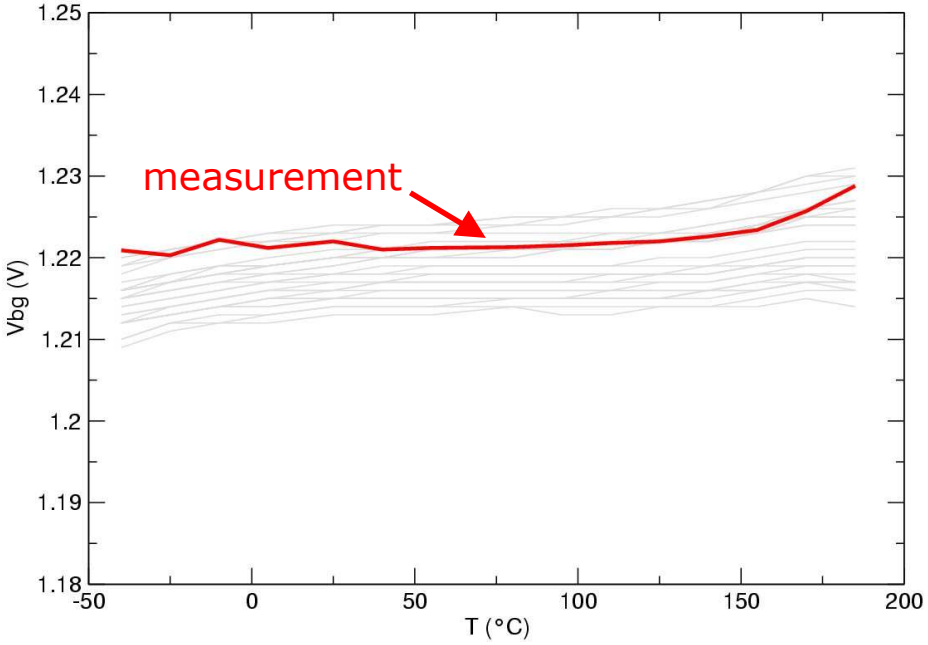
- Temperature gradient perfectly matching
- Origin of offset still not understood

Monte Carlo simulation of the bandgap references

1:2x4 bandgap



1:8 bandgap



- Relevant MC parameters: Beta, collector current, sheet resistance of poly resistors
- MC simulation of 1:8 bandgap covers measurement

Summary

- Two bandgaps differing in the arrangement of the NPNs have been investigated
- Wafer level and packaged sample measurements show a nice coincidence, no package influence detected
- Besides eg, tb and pt the temperature coefficient of the knee current tcjbf1 is an important model parameter with respect to the bandgap characteristics
- The bandgap with eight single emitter NPNs shows a better matching with simulation than the bandgap with two 4-fold emitter NPNs
- There is an offset of the absolute reference voltage between measurement and simulation in the 1:2x4 bandgap, root cause not yet understood
  - Matching of emitter currents?
  - Remaining inaccuracy in scalable transistor model?

