

Tu1B-2

Temperature and Process Calibration of HBT-Based Square-Law Power Detectors for Millimeter-Wave Built-In Self-Test

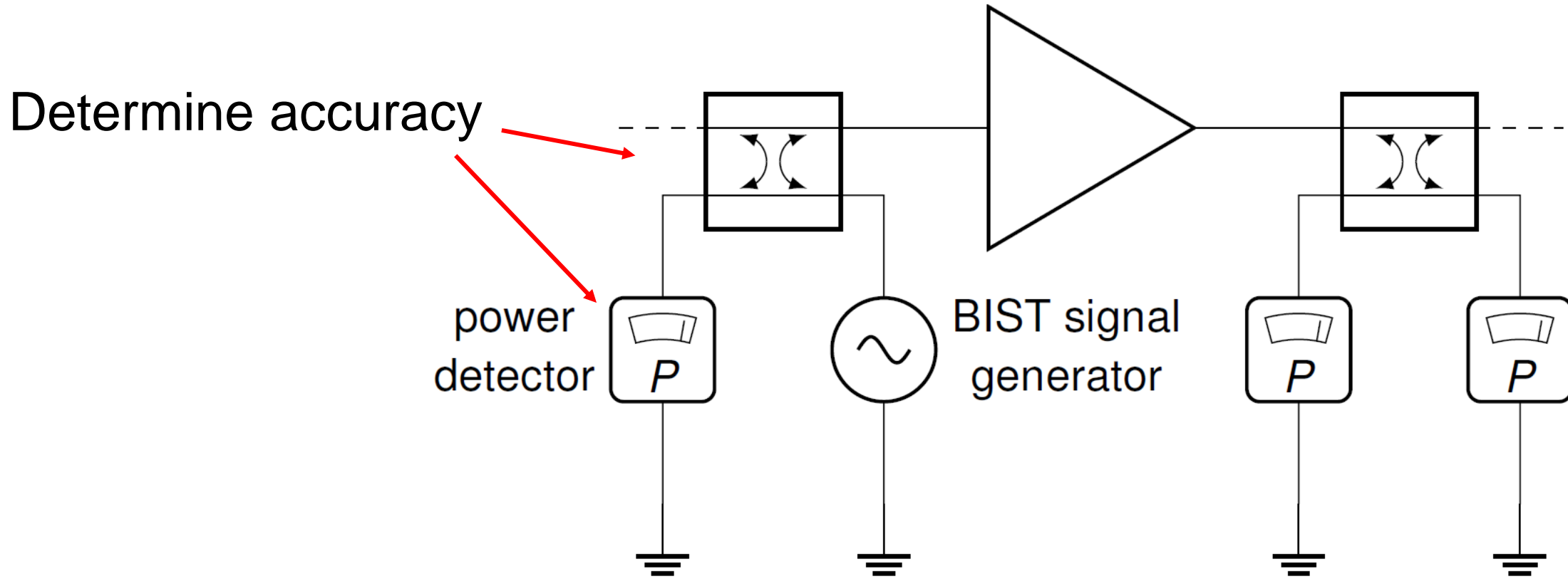
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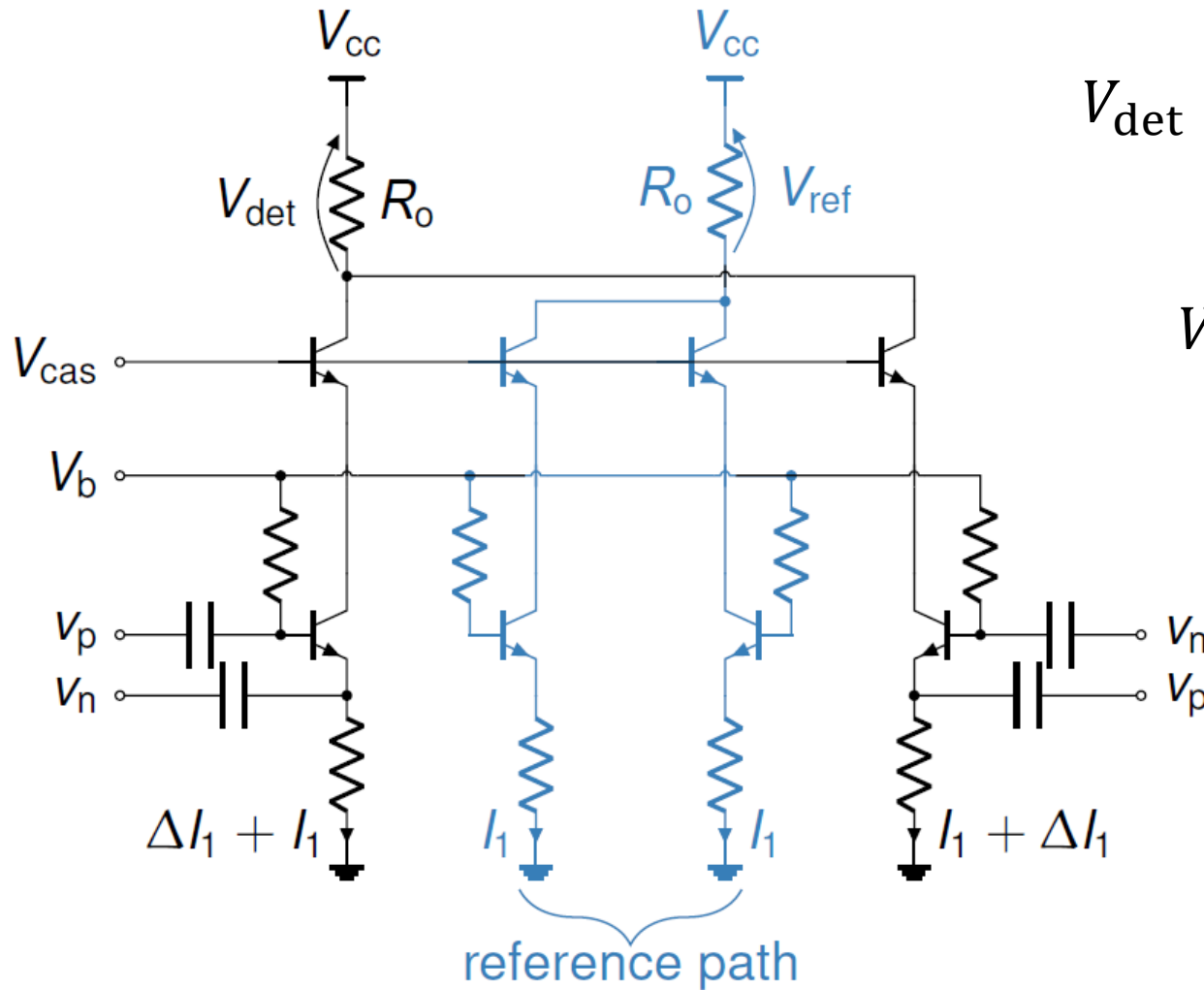
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- Millimeter-Wave Built-In Self-Test
- Process & Temperature Variation in Power Detectors
- Calibration Procedure
- Results

Typical application scenario



mm-Wave Power Detector



$$V_{\text{det}} = 2R_o(p, T) I_1(p, T) \left[1 + \frac{1}{2} \left(\frac{\hat{V}_{\text{dm}}}{V_T(T)} \right)^2 \right]$$

$$V_{\text{ref}} = 2R_o(p, T) I_1(p, T) + \Delta V_p(p, T)$$

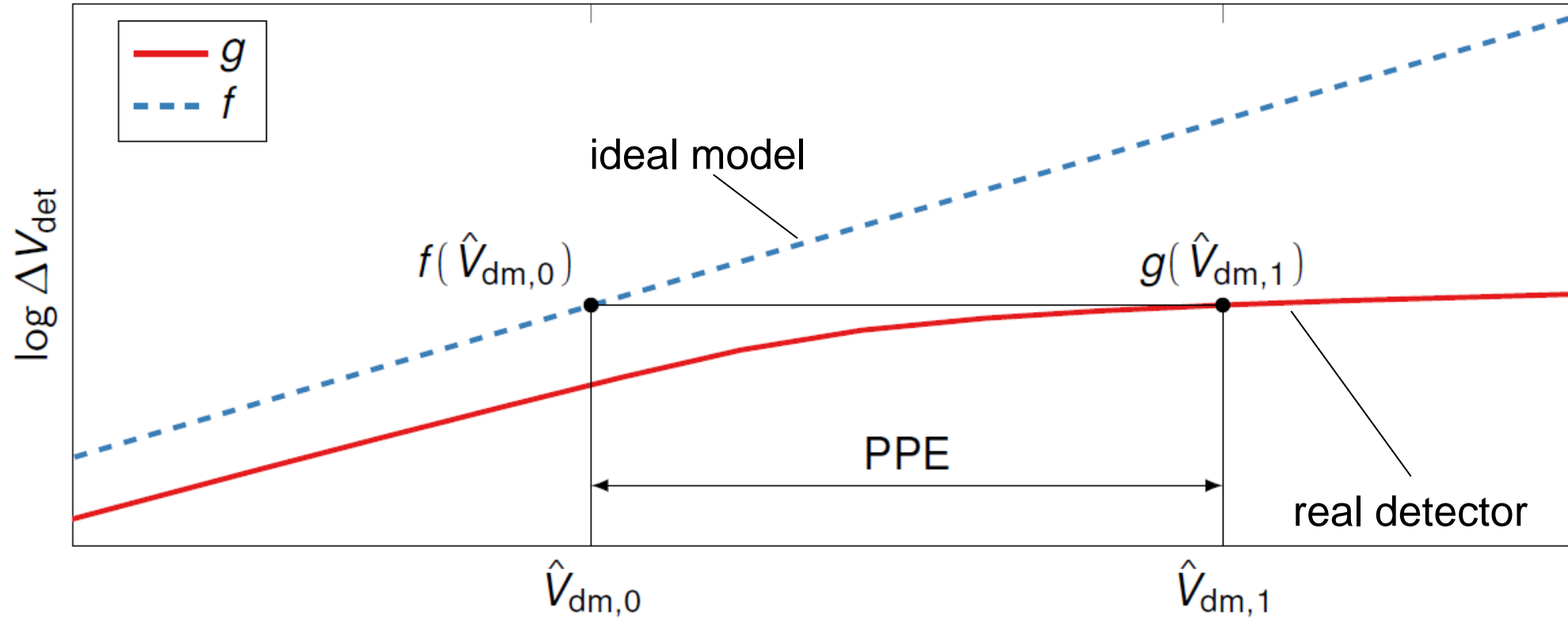
p : process dependence

T : temperature dependence

Naïve calibration:

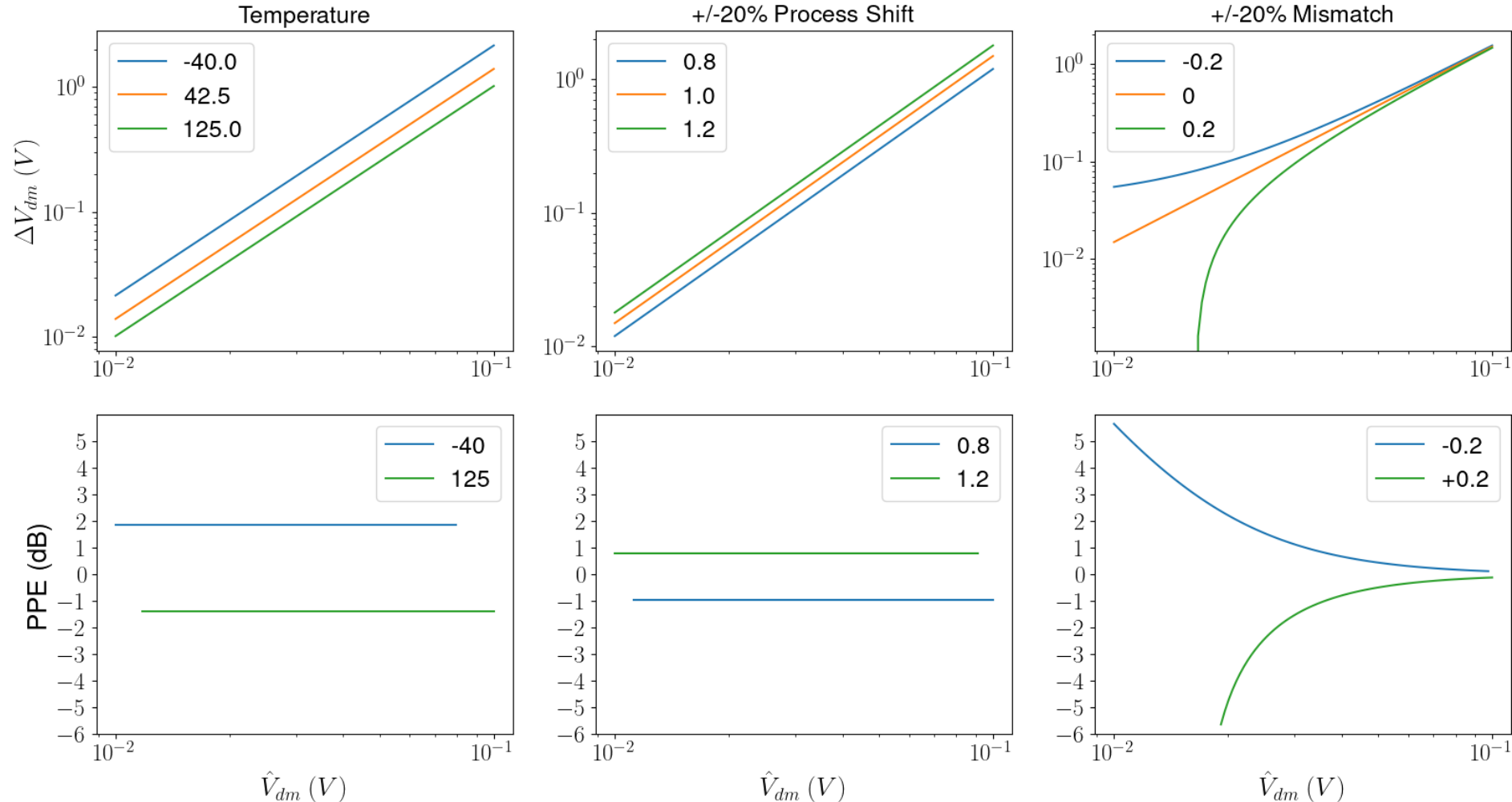
$$V_o = V_{\text{det}} - V_{\text{ref}}$$

Power Prediction Error



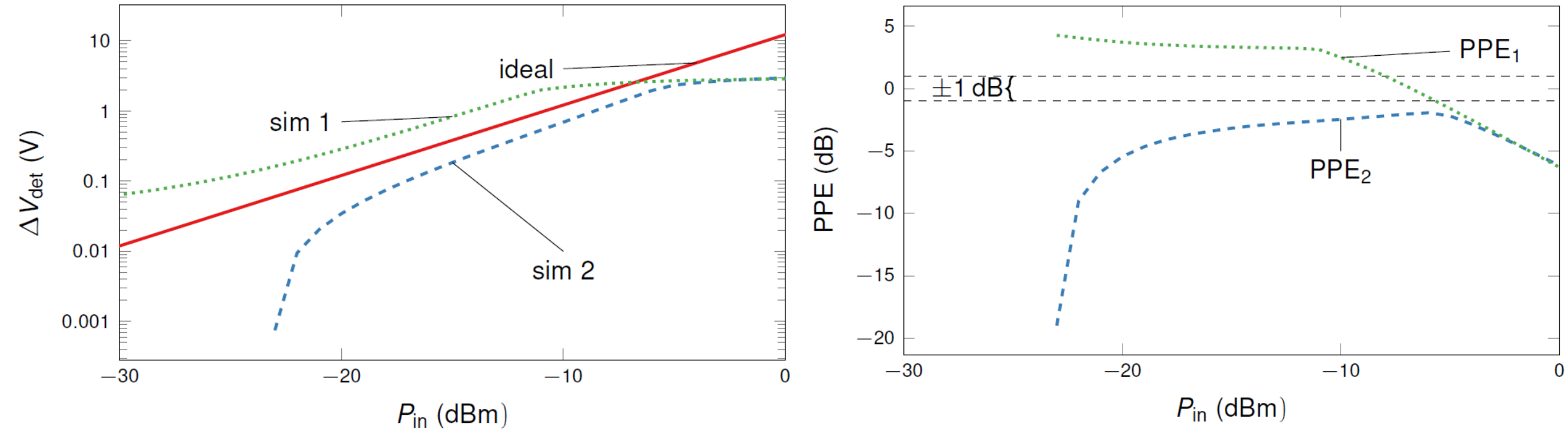
$$\text{PPE} = 20 \cdot \lg \left[\frac{f^{-1} \left(g(\hat{V}_{\text{in}}) \right)}{\hat{V}_{\text{in}}} \right] \text{ dB}$$

Process & Temperature Variation



$$\Delta V_{\text{det}} = V_{\text{det}} - V_{\text{ref}} = R_o(p, T) I_1(p, T) \left(\frac{\hat{V}_{\text{dm}}}{V_T(T)} \right)^2$$

Worst-case example from a combined Monte-Carlo simulation with -40°C to 125°C temperature sweep



For $\text{PPE} \leq \pm 1 \text{ dB}$: Dynamic range is zero in this example!

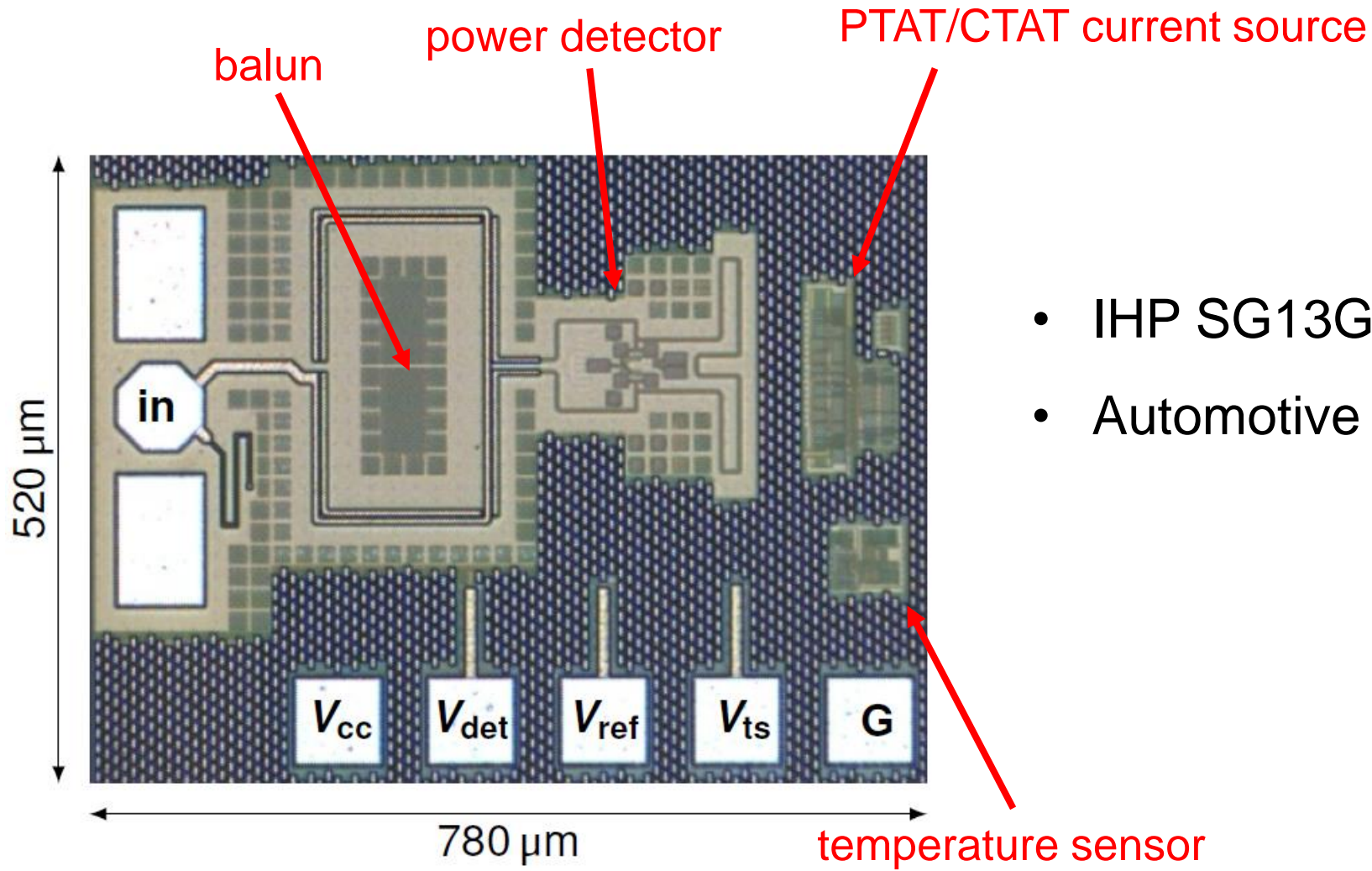
Calibration Procedure

$$V_{\text{det}} = 2R_o(p, T) I_1(p, T) \left[1 + \frac{1}{2} \left(\frac{\hat{V}_{\text{dm}}}{V_T(T)} \right)^2 \right] \quad V_{\text{ref}} = 2R_o(p, T) I_1(p, T) + \Delta V_p(p, T)$$

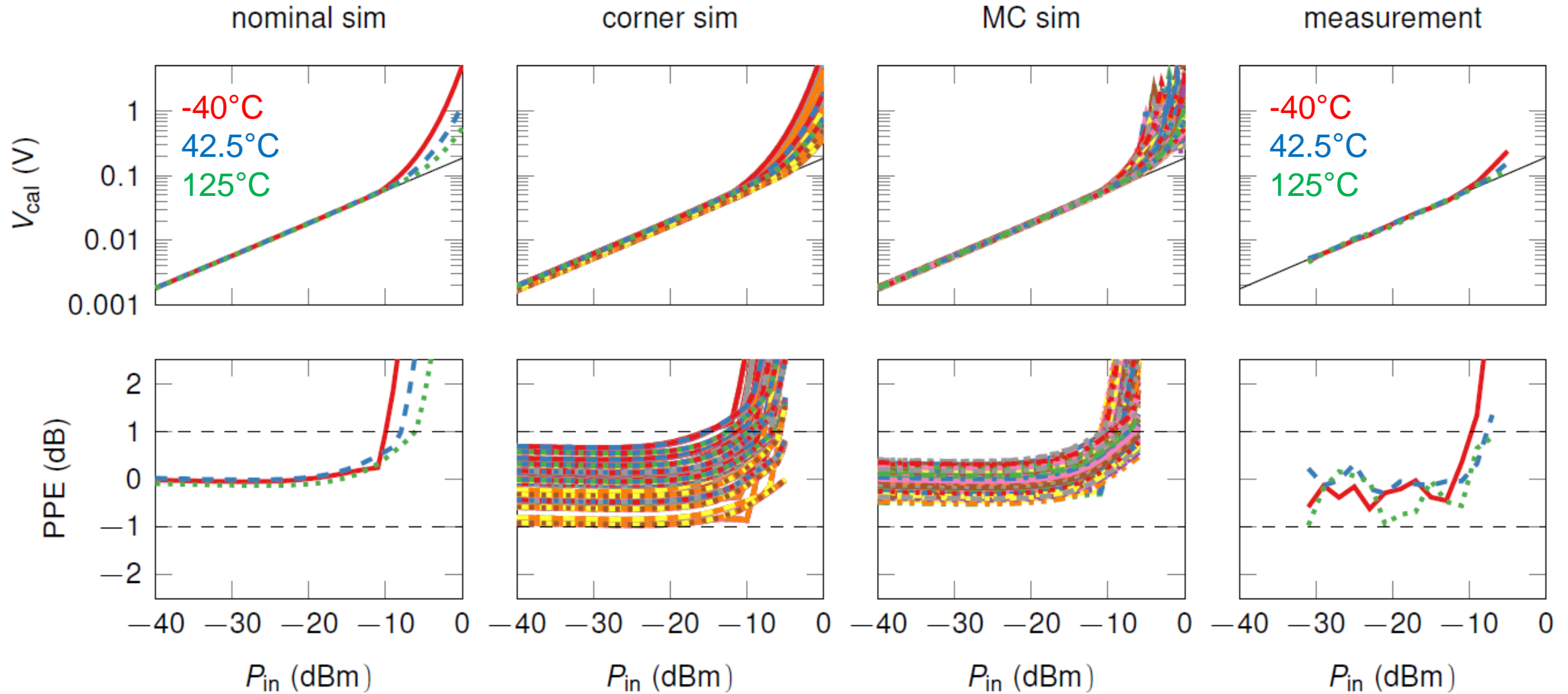
1. Determine the (temperature-dependent) mismatch between main and reference path
 - a) Minimize temperature-dependence during design (e.g. PTAT $R_o \rightarrow$ CTAT I_1)
 - b) Two-point temperature calibration
2. Divide $\frac{V_{\text{det}}}{V_{\text{ref}} - \Delta V_p} = 1 + \frac{1}{2} \left(\frac{\hat{V}_{\text{dm}}}{V_T} \right)^2$ to remove the systematic process shift
3. Multiply with V_T^2 (temperature sensor)

$$V_{\text{cal}} = \sqrt{2V_T^2} \cdot \sqrt{\frac{V_{\text{det}}}{V_{\text{ref}} - \Delta V_p(T)} - 1}$$

Test Chip



- IHP SG13G2 SiGe
- Automotive radar band (76-81 GHz)



Conclusion

- The dynamic range of HBT-based power detectors is limited by mismatch
- Temperature and process variation limit the power measurement accuracy
- Calibration based on the square-law model is able to remove these errors
- Hardware overhead: One temperature sensor (possibly: Current source with programmable PTAT slope)