Structured Electronic Design

Analysis and budgeting of biasing errors

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Modeling and analysis of biasing errors

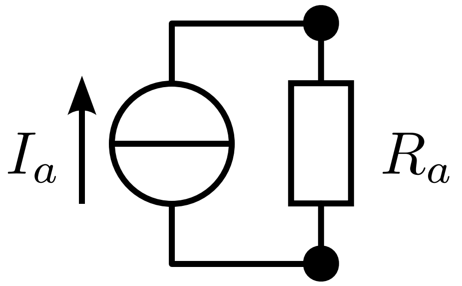
1. Worst-case analysis
   Too pessimistic; results in too tight error budgets
2. Monte-Carlo analysis
   Only numeric; not useful for error budgeting
3. Symbolic statistical analysis
   Too complex; PDF of the sum of two random variables is found from the convolution of the PDFs of these random variables
4. Simplified symbolic statistical analysis
   Has been implemented in SLiCAP as
   DC variance analysis

   Simplifications: $\frac{1}{1+\delta} \approx 1-\delta;\ \delta \ll 1$

   $(1+\delta)(1+\epsilon) \approx 1+\delta+\epsilon;\ \delta \ll 1, \epsilon \ll 1$

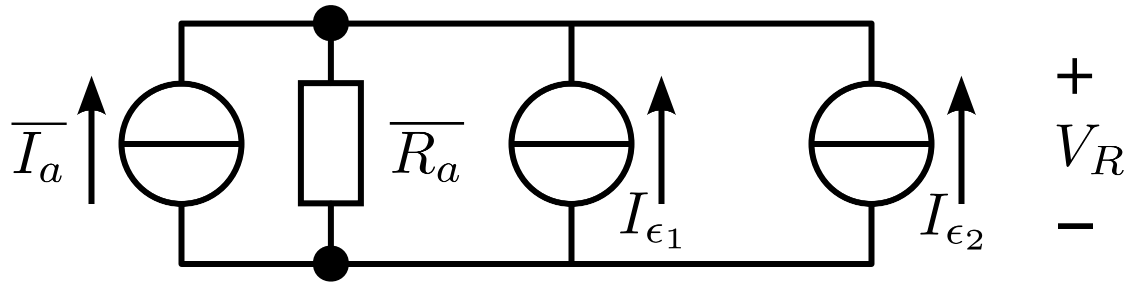
   SLiCAP replaces resistor tolerances with error currents

Circuit with uncorrelated device tolerances:



mean value:	$\overline{I_a}$	$\overline{R_a}$
variance:	$\sigma^2_{I_a}$	$\sigma^2_{R_a}$
std. deviation:	σ_{I_a}	σ_{R_a}

Equivalent circuit using the above approximations:



two uncorrelated error sources:

$$\mathrm{var}(I_{\epsilon_1}) = \sigma^2_{I_a}$$

$$\mathrm{var}(I_{\epsilon_2}) = \left(\frac{\sigma_{R_a}}{\overline{R_a}}\right)^2 \overline{I_a}^2$$

Calculation of the variance of the voltage across the resistor:

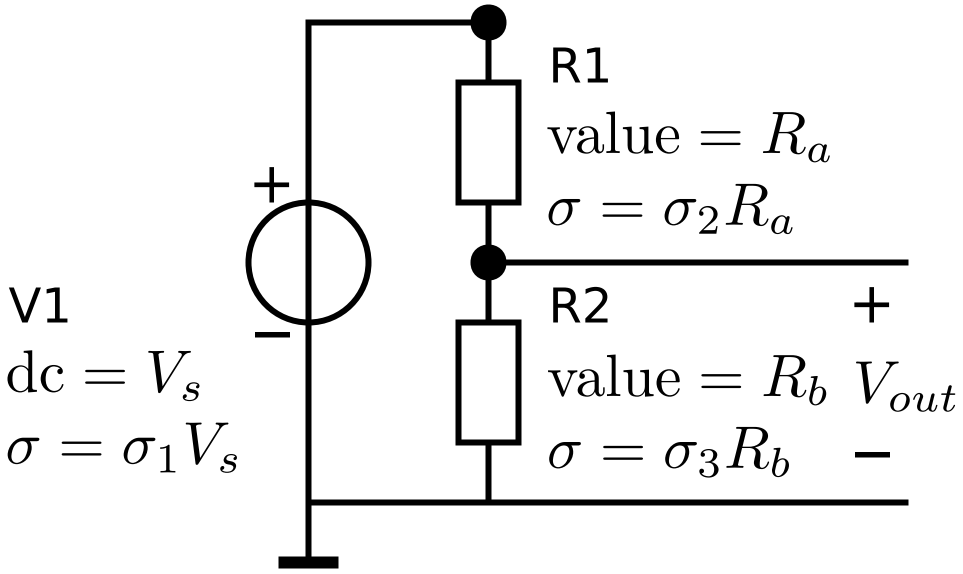
Add their uncorrelated contributions:

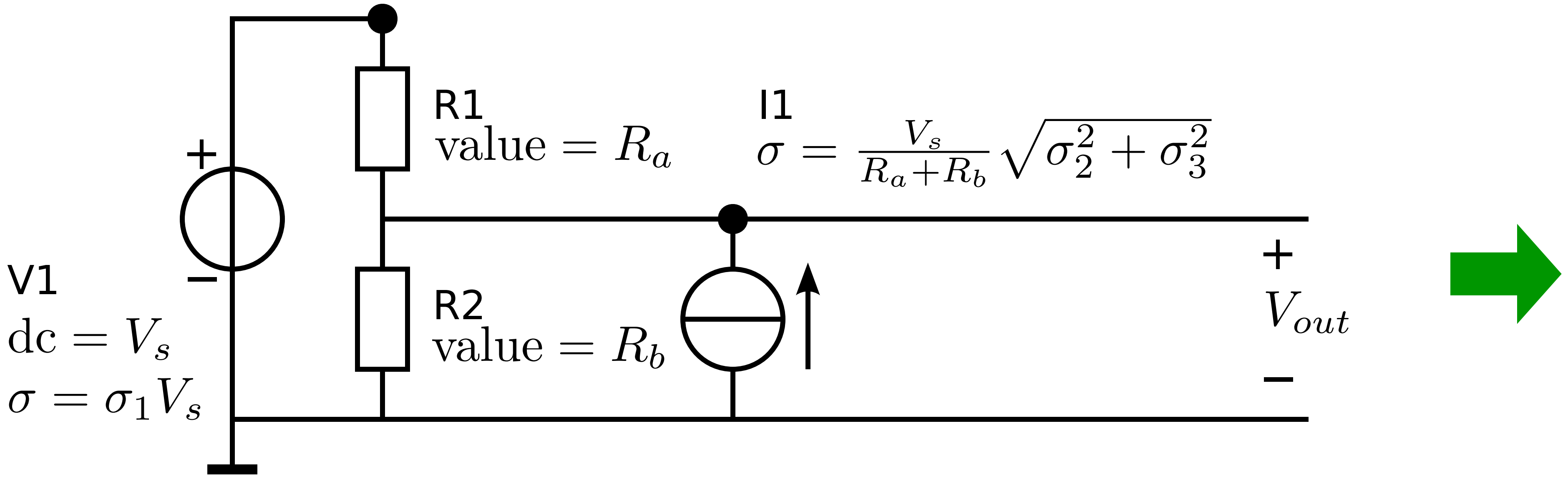
$$\mathrm{var}(V_R) = \overline{R_a}^2 \sigma^2_{I_a} + \overline{I_a}^2 \sigma^2_{R_a}$$

Standard deviation of the voltage across the resistor:

$$\sigma_{V_R} = \sqrt{\overline{R_a}^2 \sigma^2_{I_a} + \overline{I_a}^2 \sigma^2_{R_a}}$$

Influence of supply and resistor tolerances





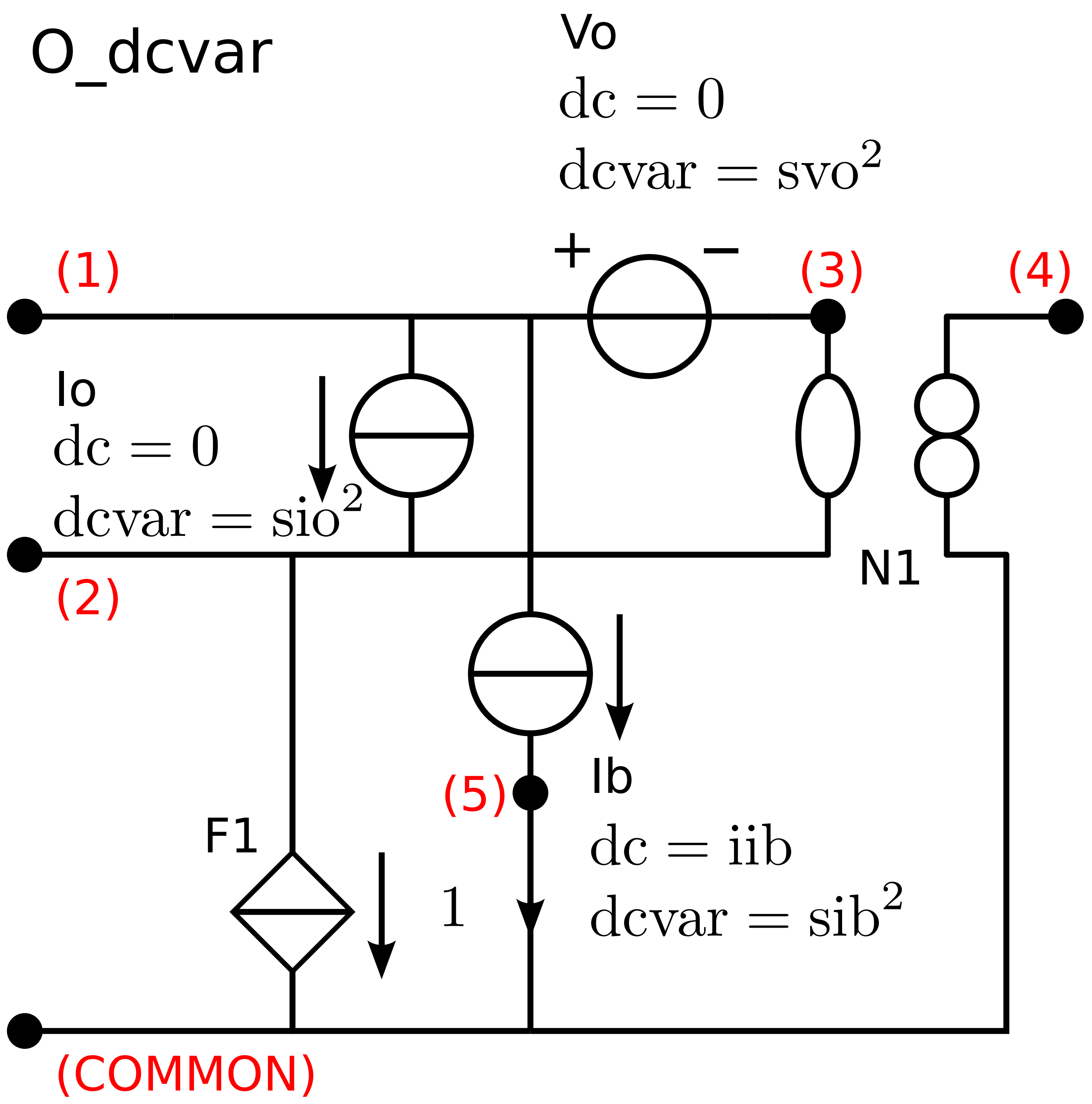
$$\overline{V_{out}} = V_s \frac{R_b}{R_a+R_b}$$

$$\frac{\sigma_{V_{out}}}{\overline{V_{out}}} = \sqrt{\left(\frac{R_a}{R_a+R_b}\right)^2 (\sigma_2^2+\sigma_3^2)+\sigma_1^2}$$

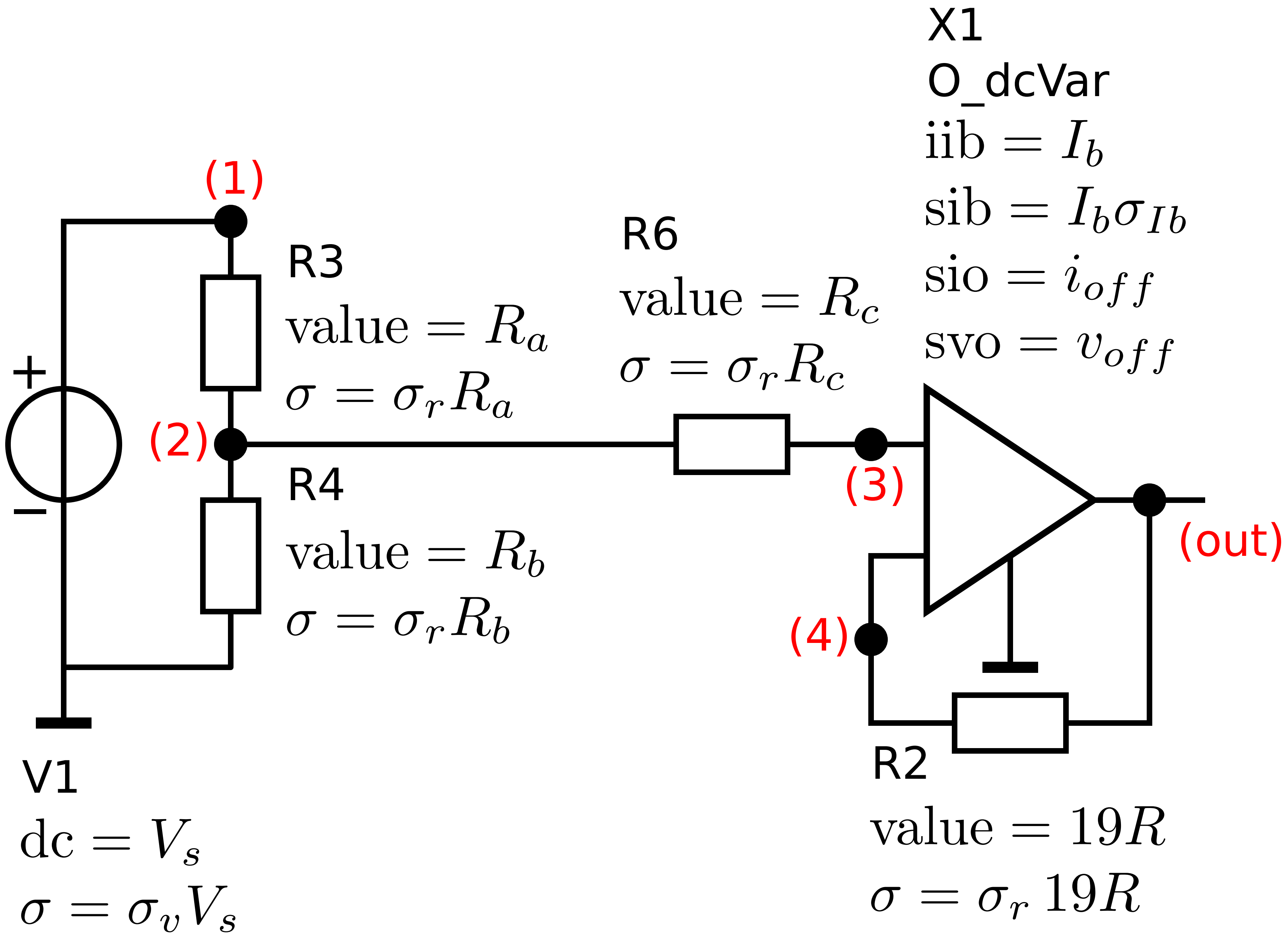
Influence of controller biasing errors

SLiCAP model of ideal OpAmp with bias errors

- Correlated bias currents
- Uncorrelated offsets



Total bias errors



Simplified result: $R_c \gg \frac{R_a R_b}{R_a + R_b}$

$$
\begin{aligned}
\sigma^2_{Vout} = {} & 2\sigma_r^2 \left(\frac{V_s}{R_a + R_b}\right)^2 \left(\frac{R_a R_b}{R_a + R_b}\right)^2 \\
& + \sigma_v^2 V_s^2 \left(\frac{R_b}{R_a + R_b}\right)^2 \\
& + v_{off}^2 \\
& + i_{off}^2 \left(R_c + 19R\right)^2 \\
& + \sigma_{Ib}^2 I_b^2 \left(R_c - 19R\right)^2 \\
& + \sigma_r^2 I_b^2 \left(R_c^2 + (19R)^2\right)
\end{aligned}
$$

