Current Mirrors Revisited
Basic Current Mirror

- Fast and small
- High output voltage swing
- But: low output impedance $r_{out} \approx r_{ds2}$
  $\Rightarrow$ bad PSRR, high systematic error
Operation principle:
Negative feedback by $R_S$ improves output impedance, $1/f$ noise and matching by $\frac{1}{1 + R \cdot g_m} \Rightarrow R \cdot g_m > 1$

- Needs same voltage drop on both sides
  $\Rightarrow \frac{W(Q_1)}{W(Q_2)} = \frac{R_{S2}}{R_{S1}}$
- Unefficient for low $g_m$ devices (e.g. PMOS)
- Beware of resistor mismatch: additional mismatch term!

\[
\sigma^2 \left( \frac{\Delta R}{R} \right) \cdot \frac{Rg_m^2}{1 + Rg_m}
\]
Improved Wilson Current Mirror

Operation Principle:
Q₂ senses output current, mirrors it to Q₁, V₆₄ changes if Iᵢₙ ≠ Iᵦₜ → Feedback Loop!
Note: Q₃ helps to make Vᵦ₂ = Vᵦ₁ ("improved")

- Similar performance and headroom as stacked cascode
- Stability? Speed?
  ⇒ Advantages for bipolar technologies (compensation of base currents), but not recommended for CMOS

2Vₜ⁺2Vₐfₜ
Vₜ⁺2Vₐfₜ

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Stacked Cascode Current Mirror

**Operation principle:**
Cascode transistor Q₄ decouples $V_{DS}$ of current source Q₂ from $V_{out}$ and makes $V_{DS2} = V_{DS1}$, Q₃ provides bias voltage.

- Very high output impedance
  \[ r_{out} \approx r_{ds2}r_{ds4}g_{m4} \]
- Big disadvantage is low input and output voltage headroom:
  \[ V_{out} > V_T + 2V_{eff} \]
  \[ V_{in} = 2V_T + 2V_{eff} \]
Cascodes: General Hints

- Make cascode devices as short as possible (headroom!)
- Increasing L increases output impedance somewhat
- For layout reasons, devices are usually made as wide as current source transistors
- Don’t be afraid - cascode devices don’t add noise or mismatch
- Use cascode devices for power down circuitry as well
Wide Swing Cascode Current Mirror (1)

**Operation principle:**
Generate a lower bias voltage for cascode transistor $M_3$ by subtracting one $V_T$ using a source follower

- Large output headroom $V_{out} > 2 \, V_{eff}$
- Low input headroom: $V_{in} = 2V_T + 3V_{eff}$
- Difficult to dimension: $M_3$ and $M_2$ need to stay in saturation, $V_X = V_Y$ for good matching
  \[ \Rightarrow \text{not recommended due to lack of robustness!} \]
Wide Swing Cascode Current Mirror (2)

Operation principle:
Generate a lower bias voltage for cascode transistor M₃ by using a second reference path with a smaller transistor

- Large output headroom $V_{out} > 2 \cdot V_{eff}$
- Large input headroom:
  $V_{in} = V_T + 2 \cdot V_{eff}$
- Systematic gain error: $V_{DS2} \neq V_{DS1}$!
  $\Rightarrow$ not recommended for high precision!

\[
\frac{W_1}{L_1} > 4 \cdot \frac{W_4}{L_4}
\]
Wide Swing Cascode Current Mirror (3)

Operation principle:
The gate potential of $Q_3$ rises until $Q_3$ can sink $I_{\text{in}}$. Size $Q_1$ and $Q_4$ such that $Q_2$ and $Q_3$ are not driven into triode region

- Large output headroom: $V_{\text{out}} > 2 \ V_{\text{eff}}$
- Large input headroom: $V_{\text{in}} = V_T + V_{\text{eff}}$
- Precise current ratio: $V_{DS2} = V_{DS1}$
- Robust: even works in triode region ⇒ recommended for high precision and low voltages
Don‘t ...  

- Saves one bias current path compared to last design \textbf{BUT} ...
- Sensitive to technology/temperature variations, voltage drop across R must be big enough to keep devices in saturation
- At least, do extensive simulations!
Do’s and Don’t’s (Design)

- Check for sufficient headroom at low supply voltages, high temperatures and increased input current
- Scale resistors / switch transistors in the source path with the transistor width
- Use wide swing cascodes instead of stacked ones
- Carefully check power-down modes for floating nodes and HCS conditions
Do's and Dont's (Layout)

- Use unity size elements with same orientation (matching!)
- Use shadow devices (matching!)
- Use common-centroid layout (matching!)
- Use star connection for source currents (voltage drop)
- Don't route Metal1 across the mirror (matching, stress)
  - if necessary, route across all devices identically
- Don't place mirrors near large poly areas, N- Wells or STI (matching, stress)
- Make current mirrors metal-programmable, add spare devices if area allows