The current source

- Minimum noise equals: \( \frac{4kT}{R} \)
- DC current through resistor gives an increase of 1/f noise (granular structure)
- Accuracy of source also determined by the accuracy of \( R \)
- Output impedance mostly too low

Use active \( \text{V} \to \text{I} \) converter

The Active Current Source

- Output impedance is ………
- What about the noise?
Nullor implemented by one CE stage

- \[ I = -(V_{\text{ref}} - V_{\text{BE}})/R \]
- Temperature behavior \( V_{\text{BE}} \) found in I (how to solve?)
- Output impedance:
  \[ r_{\text{out}} = r_0 + R + R \cdot \frac{\beta_f r_o - R}{r_b + r_o + R} \]
- If \( R \gg r_\pi \) and \( R \gg r_b \)
  \[ r_{\text{out}} = (\beta_f + 1)r_0 \]

Plot of the output impedance vs \( R \)

- \[ V_R = I \cdot R = I \cdot 2r_\pi = 2\beta \frac{kT}{q} \]
- \[ \beta_f = 100, \quad \frac{kT}{q} = 25 \text{ mV} \]
- Lower \( \beta_f \) reduces \( V_R \) but also \( r_{\text{out}} \)
- Better nullor approximation helps (\( r_o \) must be increased)
Noise behavior of active current source

\[ S_{\text{out}} = \frac{2qI_C}{(1+\frac{\beta_R}{r_\pi})^2} + \frac{2qI_B}{(1+\frac{r_\pi}{\beta_I R})^2} + 4kT \left( \frac{1}{R} + \frac{r_h}{R^2} \right) \]

I \quad II \quad III

- I \quad \rightarrow \quad 0
- II \quad \rightarrow \quad 2qI_B
- III \quad \rightarrow \quad 0 \quad (4kT/R)

R \rightarrow \text{infinite}

Only base shot noise remains

Plot of noise vs R

If contribution of \(2qI_C\) plus \(4kT/R\) equals \(2qI_B\), then

\[ R = \frac{2\beta_I}{g_m} \quad \Rightarrow \quad V_R = 5 \text{ V} \quad \text{and} \quad S_{\text{out}} = 4qI_B = 2.2qI_B \]

Lowering \(\beta_I\) for reducing \(V_R\) does not help also, as:

\[ S_{\text{out}} = 8kT \frac{I}{V_R} \quad \Rightarrow \quad \text{The lower} \quad V_R \quad \text{the higher the noise} \]
**Current source demo**

Switch open:

\[ S_{\text{out}} = 4kT \frac{R_2^2}{R_1} + 4kT R_2 + 2qI_R R_2 \]

\[ v_{n,\text{out}} \approx 22 \, \text{nV} / \sqrt{\text{Hz}} = -33 \, \text{dB} \mu \text{V} \]

Switch closed:

\[ S_{\text{out}} = 0 + 4kT R_2 + 2qI_R R_2 \]

\[ v_{n,\text{out}} \approx nV / \sqrt{\text{Hz}} = dB \mu \text{V} \]

**Current sources in 1V circuits**

Output impedance:

- \( V_R \) relatively small \( \Rightarrow r_{\text{out}} = \frac{V_{\text{AF}}}{I_C} \)
  - Reduction of the DC loop gain
  - Accuracy
  - Does not need to cost bandwidth as pole also shifts

Noise:

- Noise of the active part approximately doubles
**Saturating transistors**

- Transistor saturates if $I_C/I_B < \beta_F$
- Collector-emitter voltage is the difference of $V_{BE}$ and $V_{BC}$

$$V_{CE} = kT \ln \left[ \frac{1 + \frac{1}{\beta_f} \left(1 + \frac{I_C}{I_B}\right)}{1 - \frac{I_C}{I_B \beta_f}} \right]$$

- For $I_C/I_B = \beta_f$ denominator equals zero $\Rightarrow V_{CE}$ not determined
- $V_{CE}$ reduces for larger $\beta_f$ (saturation voltage reduces)
- $V_{CE}$ reduces for larger $I_C/I_B$ (deeper saturation)

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**Influence of layout on $V_{saturation}$ (I)**

- Electron at I has a larger chance on recombination than electron at II
  $\Rightarrow$ Bad for $\beta_f$
  
  **Take care of a large $\beta_f$**

- Most of the electrons have a short way to go
  $\Rightarrow$ Less recombination
  $\Rightarrow$ $\beta_f$ increases

General: Collector and emitter overlap should be as large as possible
The current mirror

Mirror used for:
• biasing purposes
• current-gain stages
• buffering (cascode)

Transfer: \[ \frac{I_{\text{in}}}{I_{\text{out}}} = \frac{m}{n} \]

Again nullor can be implemented by wire ⇒ standard current mirror

Signal-to-noise ratio and dynamic range of a current mirror

• SNR is the ratio of smallest and largest signal that can be processed at the same time
• DR is ratio of smallest and largest signal that can be processed, not necessarily at the same time
• Noise power proportional to collector current \((2qI_c)\)
• Signal power proportional to the square of IC \((I_c^2)\)

For \(I_c=1\) nA and \(B=10\) kHz

\[ \text{SNR} = 52\text{dB} \]
\[ \text{DR} \rightarrow \infty \]
**Peaking current source**

Derived from current mirror

\[
\ln\left(\frac{I_2}{I_{S2}}\right) = \ln\left(\frac{I_1}{I_{S1}}\right) - \frac{I_1R_1}{kT/q}
\]

\[
\frac{dI_{C2}}{dI_{C1}} = 0 \quad \text{for} \quad R \cdot I_{C1} = \frac{kT}{q}
\]

- Source \(I_1\) can be implemented by a resistor
- \(R_1\) relatively low ohmic and accurate ➔ a broad resistor
- \(R_2\) relatively high ohmic and not very accurate ➔ a small resistor
- What about PSSR?

Reference Sources

A. van Staveren and W.A. Serdijn
Peaking current source vs Current mirror

- 50 must be accurate
- 8kΩ does not need to be accurate
- 21kΩ must be accurate

Reference Sources
A. van Staveren and W.A. Serdijn
Conclusion/Summary

- Several configurations of voltage and current sources discussed
- Current level is the performance determining quality, not a 1V constraint
- Circuit design is hampered by 1V criterion ➔ other topologies