Other Current Sources/Sinks or Mirrors

Negative feedback is an effective technique for providing enhanced output impedance for current sources and sinks. Two circuits that demonstrate this are the Wilson current mirror and the regulated cascode.

Negative feedback action within the Wilson current sink ⇒ Suppose $V_o$ increases while $I_{D1}$ is constant. Then $I_{D4}$ would increase causing $V_{GS3}$ ($= V_{GS2}$) to increase which in turn tries to force $I_{D2}$ to increase. But if $I_{D1}$ is constant, then the voltage at node A must decrease since $I_{D2} = I_{D1}$ ($V_{DS2}$ must decrease to accommodate increasing $V_{GS2}$ while under constant current conditions). As a result, $V_{GS4}$ would decrease, thus stabilizing $I_{D4}$.

The Wilson current sink’s output resistance is given by

$$R_{out} = \frac{V_L}{I_t} = r_{o4} \left[ 1 + g_{m4} \left( r_{o3} \parallel \frac{1}{g_{m3}} \left( 1 + g_{m2} (r_{o1} \parallel r_{o2}) \right) \right) \right] + g_{mb4} \left[ r_{o3} \parallel \frac{1}{g_{m3}} + \frac{1}{g_{o4}} \left( r_{o3} \parallel \frac{1}{g_{m3}} \right) \right]$$

$$R_{out} \approx r_{o4} \left[ 1 + g_{m2} (r_{o1} \parallel r_{o2}) + g_{mb4} \left( \frac{1}{g_{m3}} + \frac{1}{r_{o4} g_{m3}} \right) \right]$$

$$R_{out} \approx r_o + g_{m2} \left( \frac{r_o^2}{2} \right)$$

The small-signal analysis for obtaining this result included the application of Ohm’s Law (Eq. 20.42), KVL (Eq. 20.43), and KCL (Eq. 20.44).

![Figure 20.19 Wilson current mirror.](image)

![Figure 20.20 Small signal model of the Wilson current mirror used to determine output resistance.](image)
The output voltage requirements for the Wilson current sink is described by

\[ V_{o,\text{min}} = V_{GS3} + V_{DS4,\text{sat}} = V_{GS3} + V_{GS4} - V_{THN4} \]

Alternately, in terms of output current,

\[ V_{o,\text{min}} = \frac{2I_o}{\beta_3} + V_{THN3} + \frac{2I_o}{\beta_4} \]

Hence, increasing \( I_o \) causes \( V_{o,\text{min}} \) to increase by twice the square root of \( I_o \) if \( \beta_3 = \beta_4 \). This is an unattractive characteristic of the Wilson current sink.

The regulated cascode current sink’s negative feedback is as follows. Observe that \( V_{SG1} \) and \( V_{GS3} \) are constant (DC bias voltages). If \( I_o \) attempts to increase, the voltage at node A will rise, inducing an increase in \( I_{D2} \). Then the voltage at node B must decrease since \( I_{D1} \) is constant. This reduction in \( V_{GS4} \) counters any increase in \( I_o \). Subsequently, \( I_o \) is stabilized.

The regulated cascode current sink’s output resistance is given by

\[ R_{out} = \frac{v_l}{i_t} = r_o4 \left[ 1 + g_m r_o3 \left( 1 + g_m (r_{o1} || r_{o2}) \right) + g_m b_4 r_o3 + \frac{r_o3}{r_o4} \right] \]

\[ R_{out} \approx g_m b_2 g_m b_4 \left( r_{o1} || r_{o2} \right) r_o3 r_o4 \approx \frac{g_m b_o^3}{2} \]

10’s of G\( \Omega \) to 100’s of G\( \Omega \) of output resistance can be readily achieved!
The output voltage requirement of the regulated cascode to maintain maximum output resistance is given by

\[ V_{o, \text{min}} = V_{GS2} + (V_{DS, sat})_4 \]

An example of a “simple” regulated cascode current mirror is shown below.

Unfortunately, this implementation does not provide \( V_{DS1} = V_{DS3} \), resulting in current mismatch.

The implementation shown below, however, provides improved current matching since (by design) \( V_{DS1} = V_{DS3} \) (when all the transistors are matched).
The wide-swing cascode current mirror provides an output resistance of approximately \( g_m r_o^2 \) and an output voltage requirement of only \( 2V_{DS,sat} (2\Delta V) \).

![Figure 20.24: A high-swing cascode current mirror.](image)

A practical implementation of this current mirror is shown below.

![Figure 20.27: A 10 \( \mu A \) wide-swing current unit.](image)

![Figure 20.28: Simulation results for the current mirror of Fig. 20.27.](image)