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

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

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

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

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).

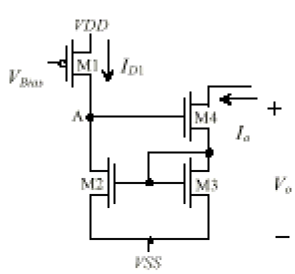

Figure 20.19 Wilson current mirror.

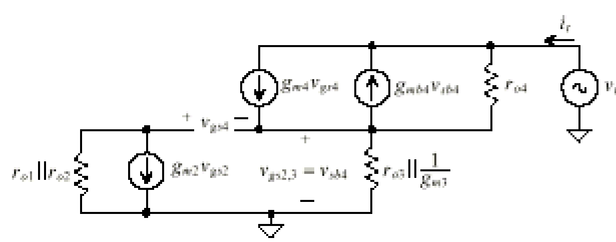

Figure 20.20 Small signal model of the Wilson current mirror used to determine output resistance.

The output voltage requirements for the Wilson current sink is described by

$$V_{o,\min} = V_{GS3} + V_{DS4,sat} = V_{GS3} + V_{GS4} - V_{THN4}$$

Alternately, in terms of output current,

$$V_{o,\min} = \sqrt{\frac{2I_o}{\beta_3}} + V_{THN3} + \sqrt{\frac{2I_o}{\beta_4}}$$

Hence, increasing I_o causes $V_{o,\min}$ 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

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

$$R_{out} \approx g_{m2} g_{m4}\left(r_{o1} \parallel r_{o2}\right) r_{o3} r_{o4} \approx \frac{g_m^2 r_o^3}{2}$$

10's of GΩ to 100's of GΩ of output resistance can be readily achieved!

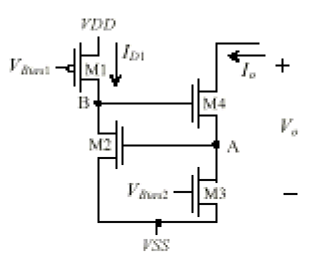

Figure 20.21 Regulated cascode current sink.

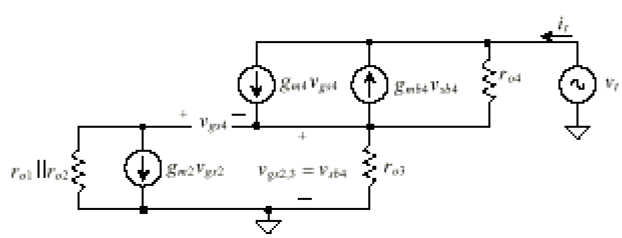

Figure 20.22 Small-signal model of the regulated cascode current mirror used to determine output resistance.

The output voltage requirement of the regulated cascode to maintain maximum output resistance is given by

$$V_{o,\min} = V_{GS2} + \left(V_{DS,sat}\right)_4$$

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

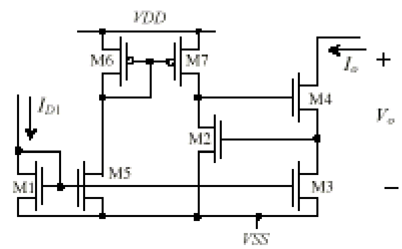

Figure 20.23 Regulated cascode current mirror.

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).

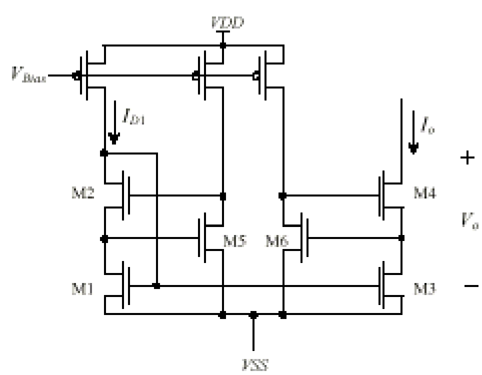

Figure 20.25 Improved regulated cascode current mirror.

The wide-swing cascode current mirror provides an output resistance of approximately $g_m r_o^2$ and an output voltage requirement of only $2V_{DS,sat}$ ($2\Delta V$).

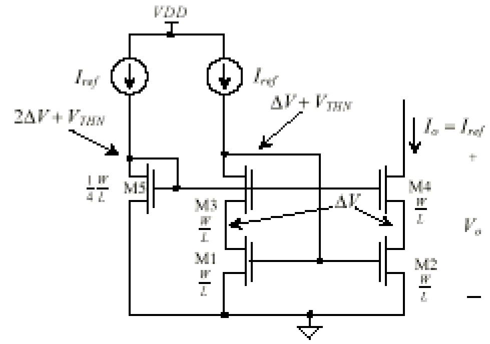

Figure 20.26 A high-swing cascode current mirror.

A practical implementation of this current mirror is shown below.

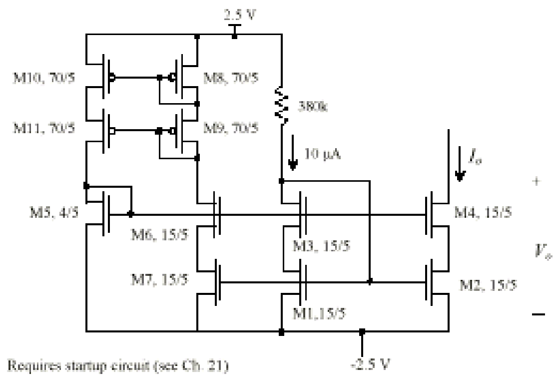

Figure 20.27 A 10 µA wide-swing current sink.

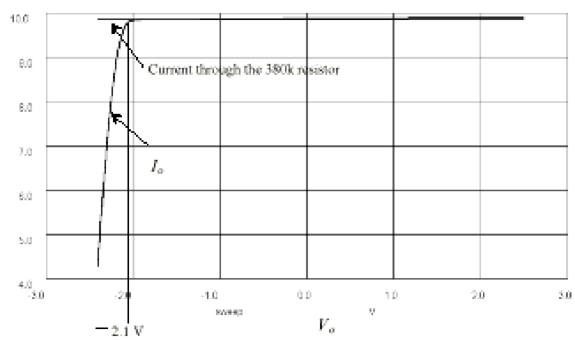

Figure 20.28 Simulation results for the current mirror of Fig. 20.27.