Chapter 7
Building Blocks of Integrated Circuit Amplifiers:

Part D: Advanced Current Mirrors
Current Mirror Example

Two Stage Op Amp (MOSFET)
Current Mirror Example

Three Stage 741 Opamp (BJT)
Advanced Current Mirrors

Goals:
1) Learn how basic CM is improved
2) Learn the effect of advanced CM on the amplifier
3) Learn how to analyze and design an advanced CM
Cascode MOS CM

- Cascoding of transistors can be used to increase gain and improve performance
- Very popular biasing circuit in IC design

Q4 and Q1 are always in saturation

Design Equations?
Wilson Current Mirror (BJT based)

- Addition of a diode-connected transistor in series with Q2 can reduce the effect of $\beta$ on output resistance.

Basic Current Mirror

Wilson Current Mirror

Design Equations?
Wilson Current Mirror (MOSFET based)

- Wilson current mirror can be used to increase output resistance and gain
Widlar Current Mirror

- A resistor $R_E$ is included in the emitter of $Q_2$

1) This CM can provide very small $I_o$
2) The output resistance can be very high (an ideal current source has infinite resistance)

Design Equations?
In Class Practice Problems
Example 7.6

The two circuits for generating a constant current $I_o = 10 \mu A$ shown in Fig. 7.37 operate from a 10-V supply. Determine the values of the required resistors, assuming that $V_{BE}$ is 0.7 V at a current of 1 mA and neglecting the effect of finite $\beta$.

7.22 Find the output resistance of each of the two current sources designed in Example 7.6. Let $V_A = 100$ V and $\beta = 100$.

Ans. 10 MΩ; 54 MΩ
In a particular cascoded current mirror, such as that shown in Fig. 7.32, all transistors have $V_t = 0.6$ V, $\mu_n C_{ox} = 160 \mu A/V^2$, $L = 1 \mu m$, and $V_D = 10$ V. Width $W_1 = W_4 = 4 \mu m$, and $W_2 = W_3 = 40 \mu m$. The reference current $I_{\text{REF}}$ is 20 $\mu A$. What output current results? What are the voltages at the gates of $Q_2$ and $Q_3$? What is the lowest voltage at the output for which current-source operation is possible? What are the values of $g_m$ and $r_o$ of $Q_2$ and $Q_3$? What is the output resistance of the mirror?

Also calculate change in current given change in $V_o=10V$

**Simulate**

**Q:** How to provide $I_{\text{ref}}$?

**A:** $I_{\text{ref}} = (V_{DD} - 2V_{GS})/R$
Ch7 Summary

- An overriding concern for IC designers is the minimization of chip area or “silicon real estate.” As a result, large-valued resistors and capacitors are avoided.

- We can use an active load instead of passive resistors.

- The basic gain cell of IC amplifier is the CS (CE) amplifier with a current-source load. For an ideal current-source load (i.e. one with infinite output resistance), the transistor operates in an open-circuit fashion and thus provides the maximum gain possible:
\[ A_{vo} = -g_m r_o = -A_0. \]
Simple current-source loads reduce the gain realized in the basic gain cell because of their finite resistance (usually comparable to the value of $r_o$ of the amplifying transistor).

To raise the output resistance of the CS or CE transistor, we stack a CG or CB transistor on top. This is called cascoding. The CG or CB transistor in the cascode passes the current $g_{m1}v_i$ provided by the CS or CE transistor.

Double cascoding is possible in the MOS case only. However, the large number of transistors in the stack between the power-supply rails results in the disadvantages of a severely limited output-signal swing. The folded-cascode configuration helps to resolve this issue.
Biasing in integrated circuits utilizes current sources. Current sources are used as load devices. Typically an accurate and stable reference current is generated and then replicated to provide bias current for the various amplifier stages on the chip. The heart of the current-steering circuitry utilized to perform this function is the current mirror.

- The MOS current mirror has a current transfer ratio of \((W/L)_2/(W/L)_1\). For a bipolar mirror, the ratio is \(I_{S2}/I_{S1}\).
Summary

- Bipolar mirrors suffer from the finite $\beta$, which reduces the accuracy of the current transfer ratio

- Both BJT and MOS mirrors of the basic type have a finite output resistance equal to $r_o$ of the output device. Also, for proper operation, a voltage of at least 0.3V is required across the output transistor of a simple BJT mirror ($|V_{OV}|$ for the MOS case)

- Cascoding can be applied to current mirrors to increase their output resistances

- Widlar CM can be used to provide very small output current and very large output resistance.