Chapter 20

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**Current Mirrors - Basics**

![Current Mirror Diagram](image)

**LONG CHANNEL DERIVATION**

- **IDEAL OUTPUT RESISTANCE=∞**
  - OUTPUT CURRENT INDEPENDENT OF VOLTAGE ACROSS SOURCE
- **ASSUME M1, M2 SAME W, L**
- **D1 SHORTED TO G1**
- **V_{GS1}=V_{DS1}=V_{GS2}**
- **DUE TO SAME Vgs, SAME Ids**
- **IF RES EQUAL, M2 VD=M1 VD**
- **THEREFORE: V_{GS1}=V_{DS1}=V_{GS2}=V_{DS2}**

- **CURRENT IN M1:**
  - \( I_{REF} = I_{D1} = (K_P N / 2) (W_1/L_1) (V_{GS1} - V_{tn})^2 \)
  - **KNOWN:**
    - \( V_{GS1} = V_{GS2} \)
    - \( V_{DS1, SAT} = V_{GS1} - V_{tn} \) (WHERE \( V_{DG}=V_{tn} \))

- **CURRENT IN M2:**
  - \( I_O = I_{D2} = (K_P N / 2) (W_2/L_2) (V_{GS1} - V_{tn})^2 \)

- **RATIO OF THE CURRENTS:**
  - \( I_O / I_{REF} = (W_2/L_2) / (W_1/L_1) \)

- **IF L_1=L_2, THEN:**
  - \( I_O / I_{REF} = W_2 / W_1 \)
**Current Mirrors - Basics**

Current Mirrors - Basics

- \( I_O / I_{REF} = W_2 / W_1 \)
  - SCALE \( W \) TO GET VARIOUS \( I_O \)
- WHAT IS THE RESISTOR VALUE?
  - FOR \( I_{REF} = 20 \mu A \),
    \( I_{REF} = (VDD - V_{GS1}) / R \rightarrow R = (5 - 1.05) / 20 \mu A \)
    \( R = 200k \) OHMS
- HOW IS \( V_{GS1} = 1.05 \) FOUND?
  - SWEEP \( V_O \) TO FIND WHERE \( I_{REF} = I_O \)
  - SOLVE THE EQUATION:
    - \( I_{REF} = I_{D1} = (KP_N / 2) (W_1 / L_1) (V_{GS1} - V_t)^2 \)
    - KNOW \( I_{REF}, KP, W, L, V_t \)
- WHY DOES \( I_O \) DROP BELOW 250 mV?
- CURRENT SOURCE RANGE:
  - \( V_{DS, SAT} < V_O < VDD \)
- IMPORTANT IDEAS:
  - \( I_O = I_{REF} \) WHEN \( V_O = V_{DS1} = V_{GS1} \)
  - \( I_{REF}, V_{GS1} \) NOT DEPENDENT ON \( V_O \)
**Current Mirrors - Basics**

- **PROCESS CAUSE**
  - **FIRST-ORDER PROCESS ISSUES:**
    - GATE OXIDE THICKNESS
    - LATERAL DIFFUSION
    - OXIDE ENCROACHMENT
    - OXIDE CHARGE DENSITY

- **THRESHOLD MISMATCH**
  - MISMATCH IN $\Delta V_t$ LEADS TO:
    - $I_0/I_{\text{REF}} \approx 1 - \left[ \frac{2 \Delta V_t}{V_{GS}-V_t} \right] = 1 - \left[ \frac{2 \Delta V_t}{V_{DS,SAT}} \right]$
    - WANT LARGE $V_{GS}$
    - REDUCES MISMATCH

- **TRANSCONDUCTANCE MISMATCH**
  - MISMATCH IN $\Delta K_P$ LEADS TO:
    - $I_0/I_{\text{REF}} \approx 1 + \left[ \frac{\Delta K_P}{K_P} \frac{N}{N} \right]$
    - WANT LARGE AREA, $K_P$ INCR

- **$V_{DS}$ MISMATCH**
  - $I_0/I_{\text{REF}} \approx \frac{[1 + \lambda_2 V_0]}{[1 + \lambda_1 V_{DS1}]}$
  - $V_{DS}$ VARIES W/ RESISTANCE
  - DO NOT USE SHORT CHANNEL

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**Figure 20.5** (a) Large device with a single contact and (b) its equivalent circuit. (c) Adding more contacts to reduce parasitic resistance.

**Figure 20.6** (a) A parallel device with dummy strips, (b) the equivalent circuit, and (c) undercutting.

**Note:** Cap reduced by $(n+1)/2n$
CURRENT MIRRORS - BASICS

- **LAYOUT CONSIDERATIONS**
  - DO NOT CHANGE ORIENTATION
    - IMPLANTS ARE ORIENTED
  - INTERDIGITIZE FINGERS
    - AVERAGES PROCESS VARIATIONS

- **DIFFERING WIDTHS ISSUES**
  - LATERAL DIFFUSION \( L_{\text{DIFF}} \)
  - OXIDE ENCROACHMENT \( W_{\text{ENC}} \)
    - \( \frac{I_o}{I_{\text{REF}}} = \frac{(W_{2,\text{DRAWN}}-2W_{\text{ENC}})(L_{1,\text{DRAWN}}-2L_{\text{DIFF}})}{(W_{1,\text{DRAWN}}-2W_{\text{ENC}})(L_{2,\text{DRAWN}}-2L_{\text{DIFF}})} \)
    - FIX \( L_1 = L_2 \), MINIMIZE MISMATCH
    - WIDTHS DETERMINE OFFSET

**Figure 20.9** Layout of a current mirror (a) without width correction and (b) with width correction.
Current Mirrors - Basics

BIASING

- DO NOT WANT TO USE RES
  - VARIES WITH TEMPERATURE
- WANT \( I_{\text{REF}} \) VDD-INDEPENDENT
- REPLACE RES WITH XTOR
  - USE EITHER M1 OR M3
  - WANT VDS IND OF VDD, GND
- EXAMPLE CHANGE VS. VDD:
  - \( I_O \sim 8\text{nA} / \text{mV} \)
  - \( I_{\text{REF}} \) (XTOR) \( \sim 12\text{nA} / \text{mV} \)
  - \( I_{\text{REF}} \) (RES) \( \sim 5\text{nA} / \text{mV} \)

Figure 20.10 How reference and output current vary with VDD.

Figure 20.12 A MOSFET-only bias circuit.

Figure 20.13 Behavior of MOSFET-only bias circuits with changes in VDD.
Current Mirrors - Basics

- **SUPPLY INDEPENDENT BIAS**
  - WANT $I_{\text{REF}}$ VDD-INDEPENDENT
    - LAST EXAMPLES 5-12nA/mV
  - MOVE RESISTOR FROM $D \rightarrow S$
    - DRAWBACK: $V_{GS2} \neq V_{GS5}$
    - CAN USE M1 AS DIODE
    - MIRROR M1 CURRENT TO M5
  - NEED M2=M1 CURRENT
    - ADD PMOS CURRENT MIRROR
  - DERIVE $I_{\text{REF}}$ AS A FUNCTION OF VDD
    - $V_{GS1} = V_{GS2} + (I_{\text{REF}})(R)$
    - MAKES SENSE IF $V_{GS1} > V_{GS2}$
    - DONE BY MAKING $W_2 > W_1$
    - RESULT:
      - $I_{\text{REF}} = \frac{2}{R_2K_{PN}W_1L_1} \left[ 1 - \frac{1}{(K^{1/2})^2} \right]^2$
      - $I_{\text{REF}}$ INDEPENDENT OF VDD
  - CONSTANT-GM BIAS CIRCUIT
    - $K=4$, EVALUATE EQUATION
    - $g_m = \left[ 2K_{PN}(W/L) I_{\text{REF}} \right]^{1/2} = 1/R$

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Figure 20.1 A basic current mirror.

Figure 20.4 Developing the Beta-multiplier reference.
**Current Mirrors - Basics**

- **BIASING- USING STARTUP**
  - UNWANTED STATE
    - M1, M2 GATES AT GND
    - M3, M4 GATES AT VDD
    - NO CURRENT FLOWS
    - NEED STARTUP
  - IN THE ZERO-CURRENT STATE
    - MSU1 VG=0
    - MSU2 VG>=VDD-Vtp
    - MSU3 TURNS ON
      - VDD @ M3/4 → M1/2
    - M1/2 RISE, CIRCUIT WORKS
    - MSU3 GATE GOES TO GND
  - POSITIVE FEEDBACK ISSUES
    - STABLE IF GAIN < 1
    - RESISTOR SMALL, GAIN>1
    - M2 PARASITIC CAP, R→0
    - CIRCUIT WILL OSCILLATE
  - RESULTS
    - \( V_{DD_{MIN}} = V_{DS3,SAT} + V_{GS1} \approx 1.3V \)
    - \( \Delta I_{REF} / \Delta VDD \approx 800\text{pA} / \text{mV} \)
    - COMPARE TO 5-12nA / mV

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**Figure 20.15** Beta-multiplier reference for biasing in the long-channel process described in Table 9.1.

**Figure 20.16** The reference currents through M1 and M2 in the Beta-multiplier.