ECEN4827/5827 Lecture 19

• HW6 due via D2L by 10am MT on Friday, October 11
Next topic: DC voltage and current references

**Purpose: bias and active loads**

Goals: set DC bias operating point independent of

- Component tolerances
- Supply voltages
- Temperature

Sensitivity

\[
S_{p}^{I_{ref}} = \frac{\Delta I_{ref}}{\Delta p} = \frac{p}{I_{ref}} \frac{\partial I_{ref}}{\partial p}
\]

Fractional temperature coefficient

\[
TC_{F} (I_{ref}) = \frac{\Delta I_{ref}}{\Delta T} = \frac{1}{I_{ref}} \frac{\partial I_{ref}}{\partial T} = \frac{1}{T} S_{T}^{I_{ref}}
\]
$V_t$-based current reference

\[
\text{I}_{\text{ref}} = \frac{V_{gs1}}{R_b} = \frac{V_{tn} + \sqrt{\frac{I_1}{K_1}}}{R_b} \approx \frac{V_{tn}}{R_b}
\]

\[
S_{V_{dd}} = \frac{V_{dd}}{I_{ref}} \frac{I_{ref}}{V_{dd}}
\]

\[
\frac{I_{ref}}{I_1} = \frac{\frac{V_{gs1}}{V_{dd}}}{\frac{1}{g_{m1} R_b}} = \frac{1}{g_{m1} R_b}
\]

\[
V_{gs1} = R_b I_{ref}
\]

\[
I_1 = g_{m1} V_{gs1} = g_{m1} R_b I_{ref}
\]

\[
S_{V_{dd}} = \frac{V_{dd}}{V_{tn/R_b}} \cdot \frac{1}{g_{m1} R_b} \cdot \frac{1}{R_1} = \frac{V_{dd}}{V_{tn}} \cdot \frac{1}{g_{m1} R_b} \cdot \frac{1}{R_1} \approx \frac{1}{10}
\]

$\approx \frac{1}{10}$
$V_t$-based current reference

no large resistors required!
$V_{DD}$ sensitivity in $V_t$-based current reference

$S_{V_{DD}} = \frac{\Delta I_2}{\Delta V_{DD}} = \frac{V_{DD}}{I_2} \cdot \frac{\partial I_2}{\partial V_{DD}} = \frac{I_2}{I_2} \frac{V_{DD}}{V_{DD}}$

Use self-biased.

$I_2 \approx \frac{V_{tn}}{R_b}$

$\frac{I_2}{V_{dd}} = \frac{I_2}{V_{dd}} \frac{1}{V_{dd}} = \frac{1}{g_{m1} R_b R_{out}}$

$S_{V_{DD}} = \frac{V_{DD}}{V_{tn} R_b} \frac{1}{g_{m1} R_{out} R_b} \approx \frac{1}{10}$

$\sim \frac{1}{10}$
$V_{DD}$ sensitivity in $V_t$-based current reference

\[ S_{V_{DD}} = \frac{V_{DD}}{V_{th}} \cdot \frac{1}{g_{m1}} \cdot \frac{1}{g_{m4}g_{m5}} \approx \frac{1}{1000} \]

How low can $V_{DD}$ be?

$(V_{DD})_{\text{min}}$ so that all devices are AS

Triode mode of $M_2$:

$V_{G_{S1}} + V_{G_{S2}} = V_{th} + V_{G_{S3}} + V_{G_{S5}} = (V_{DD})_{\text{min}}$

Triode mode of $M_4$:

$(V_{DD})_{\text{min}} - V_{S_{G6}} - V_{S_{G4}} + |V_{th}| - V_{G_{S2}} - V_{G_{S1}} = 0$

$(V_{DD})_{\text{min}} = V_{S_{G6}} + V_{S_{G4}} + V_{G_{S2}} + V_{G_{S1}} - |V_{th}|.$
Self-biased references: the need for a start-up ("bootstrap") circuit

\[ M_3, M_4 \text{ mirror: } I_2 = I_1 \quad (1) \]

\[ V_{G51} = R_b \cdot I_2 \]

\[ V_{t_1} + \sqrt{\frac{I_1}{K_1}} = R_b \cdot I_2 \]

\[ (2) \quad I_2 = \frac{V_{t_1}}{R_b} + \frac{1}{R_b} \sqrt{\frac{I_1}{K_1}} \approx \frac{V_{t_1}}{R_b} \]

Desirable operating point, all AS

\[ V_{extra} \]

\[ V_{2Vt_n} \]
Self-biased references: the need for a start-up ("bootstrap") circuit
Temperature dependences

Threshold voltage, $TC_F(V_t) \approx -3000$ ppm/°C

Resistors

Positive and negative TC resistors are available

Example 0.35u CMOS process: -400ppm/°C and +830ppm/°C

Mobility, and MOSFET conductance parameter $TC_F(\mu C_{ox}) \approx -5000$ ppm/°C

Forward biased pn-junction ($V_{EB}$, $V_{BE}$ or $V_D$), $-2$mV/°C

Thermal voltage $V_T = kT/q = 26$mV at 300°K,

+3300ppm/°C at room temperature