Discussion Outline

• Midterm 2 Solutions
  – Problem 1(b)
  – Problem 1(c)
• Diode-connected Transistors
• Current Mirrors
MT2: Problem 1(b)

- Find $R_{s2}$ to get $I_C = 100 \mu A$
- Find $R_i$
- Find an expression for $f_H$

Device Parameters:

NMOS:
- $V_{th} = 0.7 V$
- $2|\phi_b| = 0.6 V$
- $\mu n C_{ox} = 200 \mu A/V^2$
- $\lambda_n = 0.01 V^{-1}$
MT2: Problem 1(b) – Find $R_{S2}$

Given:
- $V_{DD} = 3V$
- $I_D = 100\mu A$ (given)

Device Parameters:
- NMOS:
  - $V_{th} = 0.7V$
  - $2|\phi_f| = 0.6V$
  - $\mu n C_{ox} = 200\mu A/V^2$
  - $\lambda n = 0.01 V^{-1}$

$V_{GS} = \sqrt{2I_D + V_{th0}} = 0.8V$

$R_{S2} = \frac{V_g}{I_D} = \frac{V_G - V_{GS}}{I_D} = \frac{0.7V}{100\mu A}$

$I_{S2} = I_{th} = I_D$

$R_{S2} = 7k\Omega$

$V_{bn} = V_{th0}$,

$b/c B & S$ are shorted
MT2: Problem 1(b) – Find \( R_i \)

![Circuit Diagram]

**Device Parameters:**
- NMOS:
  - \( V_{th0} = 0.7 \text{V} \)
  - \( 2|\phi| = 0.6 \text{V} \)
  - \( \mu_n C_{ox} = 200 \mu\text{A/V}^2 \)
  - \( \lambda_n = 0.01 \text{V}^{-1} \)

**BJT**
- \( \beta = g_m r_{IE} \)
- \( \beta_{eff} = g_m R_i \) => Use inspection to

\[
R_{in} = r_{IE} + (\beta_{eff} + 1) R_s
\]

**MOS**
- \( R_1 \)

\[
R_{in} = R_1 + (\beta_{eff} + 1) R_s
\]

\[
R_{in} = R_1 + (g_m R_i + 1)(R_2 \parallel R_s)\]

\[
R_{in} = 3.625 \text{ k} \Omega
\]

midband, so short large caps, open small caps, turn off DC swing
MT2: Problem 1(b) – Find $f_H(0\text{CTS})$

$C_{sb}=0$, b/c S&B shorted

$V_{DD} = 3\text{V}$

$I_{BIAS} = 0.75 \text{mA}$

NMOS:
- $V_{th0} = 0.7\text{V}$
- $2|\phi| = 0.6\text{V}$
- $\mu_nC_{ox} = 200\mu\text{A/V}^2$
- $\lambda_n = 0.01 \text{V}^{-1}$

$\tau_{gs} = C_{gs}R_{gso}$

\[ f_H = \frac{1}{2\pi \tau} \]

\[ R_{\text{rto}} = R_t \parallel \frac{R_B + R_s}{1+gmR_s} \]

\[ R_{gso} = R_1 \parallel \frac{R_3 + (R_2 \parallel R_s)}{1+gm(R_2 \parallel R_s)} \]

\[ g_m = \frac{2I_D}{V_{ov}} \]
MT2: Problem 1(b) – Find $f_H$

\[ f_H = \frac{1}{2\pi(C_{gs} + C_g + C_d)} \]

Miller equivalent:

\[ C_{gd1} = C_{gd}(1 - \frac{v_d}{v_g}) = C_{gd}(1 + G_m R_\Omega) \]

\[ C_{gd1} = (1 + \frac{g_m R_D}{1 + g_m R_\Omega}) C_{gd} \]

\[ C_{gd2} \approx C_{gd} \]

\[ C_g = C_{gd1}(R_s || R_{in}) \quad C_d = (C_{db} + C_{gd2})(R_D) \]
MT2: Problem 1(c)  

\[ V_{CC} = +8.3 \text{V} \]

\[ R_C = 4k\Omega \]

\[ R_A = 1k\Omega \]

\[ R_L = 10k\Omega \]

\[ R_S = 400\Omega \]

\[ C_C = 2\mu\text{F} \]

\[ C_E = 10\mu\text{F} \]

\[ V_{EE} = -3.7\text{V} \]

\[ f_L \approx 38 \text{Hz} \]

**Device Parameters:**

- \( \beta = 200 \)
- \( V_A = 200\text{V} \)
- \( C_\mu = 4\text{pF} \)
- \( f_T = 400\text{MHz} \)
- \( I_C = 1\text{mA} \)

- Find the source frequency: \( f_L \approx 38 \text{Hz} \)

Find \( f_L \) by applying the test source.

\[ f_L = \frac{1}{2\pi \sqrt{C_{CE}(R_S + R_E \parallel R_C)}} \]

\[ f_L = \frac{1}{2\pi \sqrt{C_{CC}(R_L + R_F \parallel R_C)}} \]
Diode Connected Transistors

\[ V_B = V_C = V_E + V_{BE(on)} \]

\[ V_{CE} = V_C - V_E = V_E + V_{BE(on)} - V_E \]

\[ V_{CE} = V_{BE(on)} \geq V_{CE, sat} \]

\[ \sim 0.7 \quad \sim 0.2 \]

Won't go into saturation!
Diode Connected Transistors

What’s happening?

Normal BJTs are actually voltage-controlled current sources \( I_c = I_S e^{\frac{v_{BE}}{V_T}} \), where we approximate \( v_{BE} \) as constant.

To set a specific \( I_c \), we need to choose \( V_B, V_E, R_E, R_t \) carefully.

Diode-connected BJTs allow us to set \( I_C \) with a single resistor!

\[
I_c \approx \frac{V_{cc} - V_C}{R_{bias}} = \frac{V_{cc} - V_{BE(on)}}{R_{bias}}
\]

equal if \( B = \infty \)
Current Mirrors

\[ I_{cc} = \frac{V_{cc} - V_{BE(on)}}{R_{bias}} \]

\[ I_{bias} = I_{cc} \frac{\beta}{\beta + 2} \]

\[ I_{bias} = 3I_{cc} \]

Say we want...