Electronics 2
Semester 6

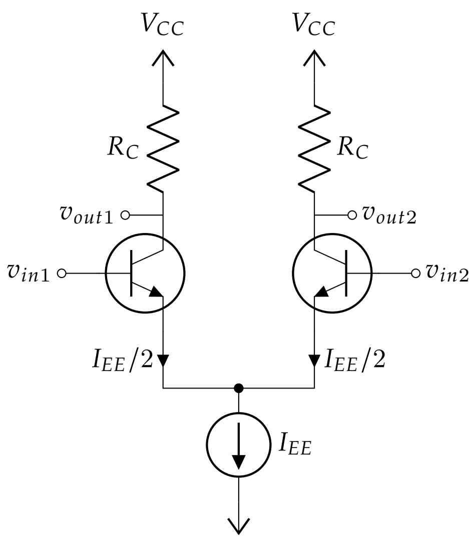
Ahmad Abu Zainab

Contents

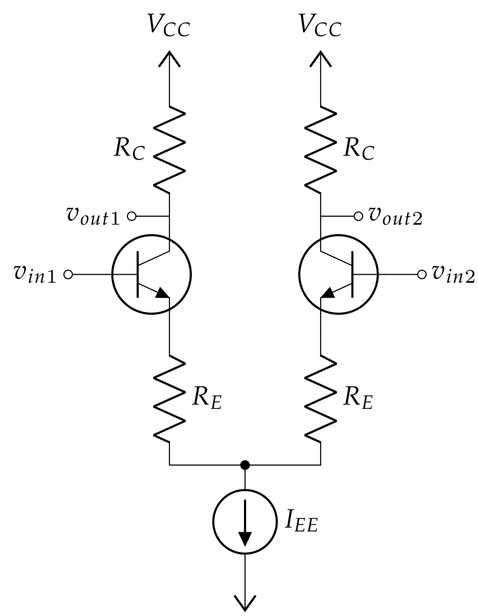
Chapter 1

Differential Amplifiers

1.1 BJT Differential Amplifier



(a) BJT Differential Amplifier



(b) BJT Differential Amplifier with Emitter Resistance

The gain of the differential amplifier is given by

$$|A_d| = \begin{cases} \dfrac{\text{Total resistance in the collectors}}{\text{Total resistance in the emitters}} & \text{with emitter resistance} \\ g_m \cdot R_C & \text{without emitter resistance} \end{cases}.$$

The common mode gain is given by

$$|A_{\mathrm{cm}}| = \frac{\Delta R_C}{2R_E E} = \frac{\Delta R_C}{2R_E + 2r_e}.$$

The common mode rejection ratio is given by

$$\mathrm{CMRR} = 20 \log \frac{|A_d|}{|A_{\mathrm{cm}}|}.$$

The minimum and maximum common mode input voltage (to operate the amplifier) is given by

$$V_{CM\,\mathrm{max}} = V_{CC} - \alpha \frac{1}{2} R_C + 0.4\,\mathrm{V} \quad ; \quad V_{CM\,\mathrm{min}} = -V_{EE} + V_{CS} + V_{EE}.$$

1.2 MOSFET Differential Amplifier

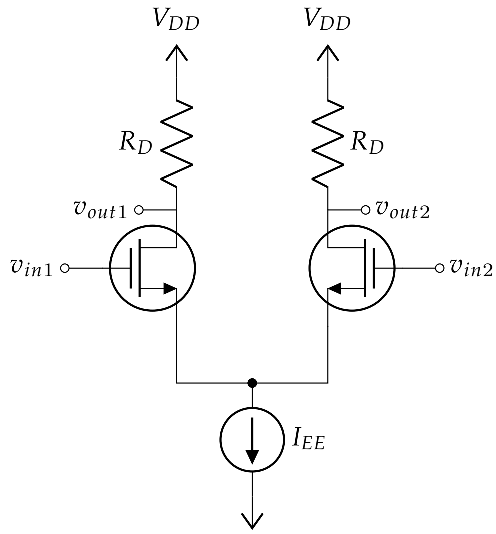


Figure 1.2: MOSFET Differential Amplifier

Similarly, the gain of the differential amplifier is given by

$$|A_d| = g_m \cdot R_D.$$

The minimum and maximum common mode input voltage (to operate the amplifier) is given by

$$V_{CM\,\max} = V_t + V_{DD} - \frac{I}{2}R_D \quad ; \quad V_{CM\,\min} = -V_{SS} + V_{CS} + V_t + V_{OV}.$$

Chapter 2

Current Mirrors

2.1 Current Mirror

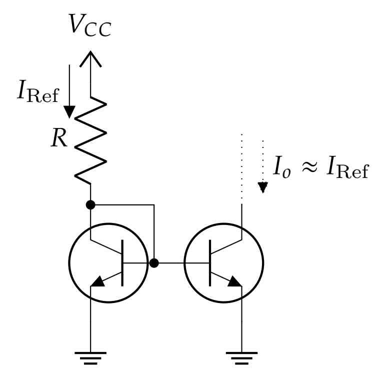


Figure 2.1: BJT Current Mirror

2.2 Wilson Current Mirror

A Wilson current mirror is a current mirror that uses two transistors to provide a more accurate current mirror.

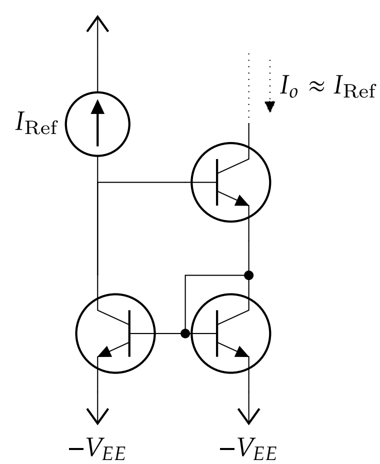


Figure 2.2: Wilson Current Mirror

2.3 Widlar Current Source

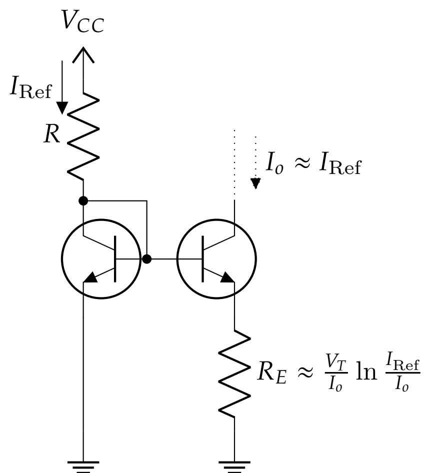


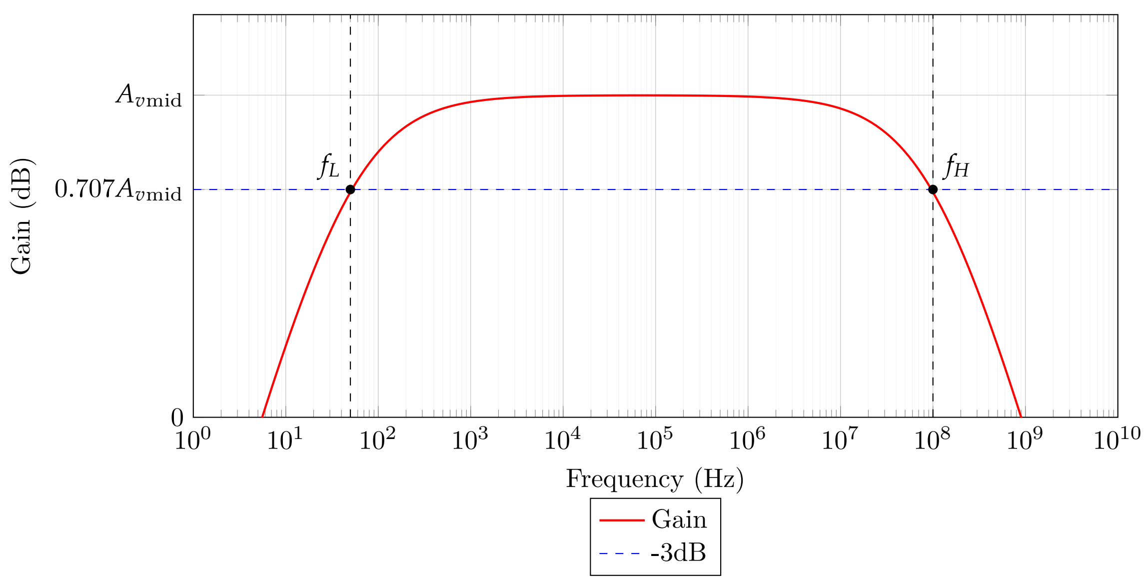
Figure 2.3: Widlar Current Source

Chapter 3

Frequency Response

The amplifier's gain varies with frequency. The response is studied at 3 points:

1. Low frequency: Coupling and bypass capacitors are not shorted.
2. Mid frequency: Typical gain, all capacitors are shorted.
3. High frequency: Coupling and bypass capacitors are shorted, but internal capacitances of the transistors are considered.



The cutoff frequencies are the frequencies at which the gain is reduced by 3 dB, and the bandwidth is the difference between the two cutoff frequencies.

$$\text{BW} = f_H - f_L = f_2 - f_1 \quad ; \quad \begin{cases} f_L \text{ determined using the critical frequency of } C_i, C_o, C_E \\ f_H \text{ determined using the critical frequency of } C_\pi, C_\mu, C_{\text{cs}} \end{cases} .$$

3.1 Low Frequency Response of Amplifiers

3.1.1 Low Frequency Response of CE Amplifiers

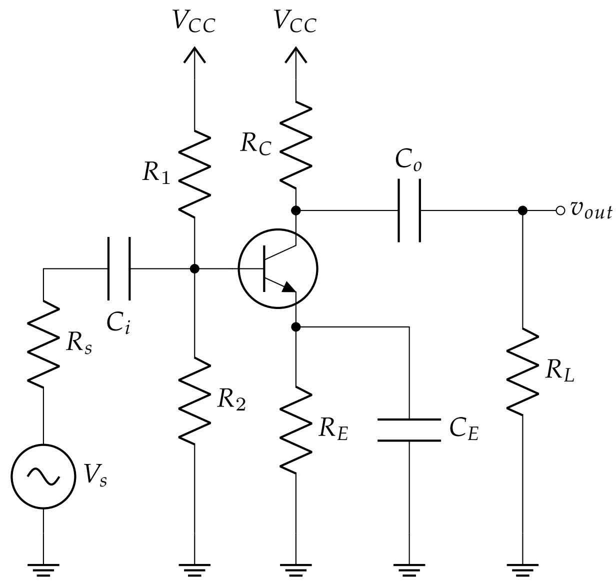


Figure 3.1: CE Amplifier

To determine the cutoff frequencies for each capacitor, we short the other capacitors and determine the critical frequency for each capacitor.

$$f_{Ci} = \frac{1}{2\pi(R_s + R_i)C_i} \quad ; \quad R_i = R_1 \parallel R_2 \parallel (\beta+1)r_e$$

$$f_{Co} = \frac{1}{2\pi(R_o + R_L)C_o} \quad ; \quad R_o = R_C \parallel r_o$$

$$f_{CE} = \frac{1}{2\pi R_{\text{eq}} C_E} \quad ; \quad R_{\text{eq}} = R_E \parallel \left[\frac{R_s \parallel R_1 \parallel R_2}{\beta+1} + r_e\right]$$

3.1.2 Low Frequency Response of CS Amplifiers

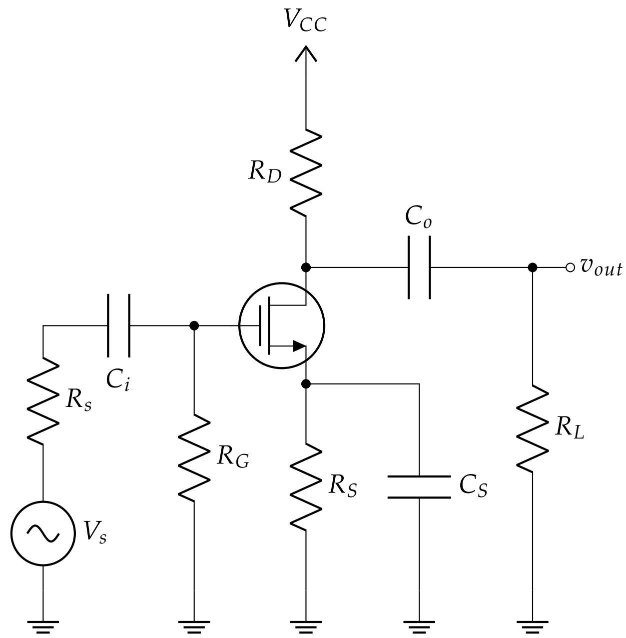


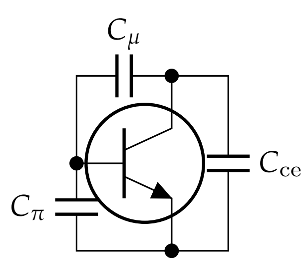
Figure 3.2: CS Amplifier

$$
\begin{aligned}
f_{Ci} &= \frac{1}{2\pi(R_s + R_G)C_i} \\
f_{Co} &= \frac{1}{2\pi(R_L + R_o)C_L} \quad ; \quad R_o = R_D \parallel r_o \\
f_{CS} &= \frac{1}{2\pi R_{\text{eq}} C_S} \quad ; \quad R_{\text{eq}} = R_S \parallel \frac{1}{g_m}
\end{aligned}
$$

3.2 High Frequency Response of Amplifiers

3.2.1 High Frequency Response of CE Amplifiers

We consider the internal capacitances of the transistor, $C_\pi(C_{\text{be}})$, $C_\mu(C_{\text{bc}})$, and C_{ce} as well as the wiring capacitances C_{wi} and C_{wo}. We say that C_i, C_o, and C_E are shorted.



Theorem 3.2.1 Miller Effect

The capacitor connected between the input and output is called the feedback capacitor. Miller's theorem states that the feedback capacitor is equivalent to two capacitors at the inout and output.

$$C_{Mi} = C_f(1 - A_v)$$
$$C_{Mo} = C_f\left(1 - \frac{1}{A_v}\right)$$

Using Miller's theorem, we say that

$$C_{Mi} = (1 - A_v)C_{\text{bc}} \qquad C_i = C_{wi} + C_{\text{be}} + C_{Mi}$$
$$C_{Mo} = \left(1 - \frac{1}{A_v}\right)C_{\text{bc}} \qquad C_o = C_{wo} + C_{\text{ce}} + C_{Mo}$$

The cutoff frequency is given by

$$f_{Hi} = \frac{1}{2\pi R_{Thi}C_i} \qquad R_{Thi} = R_s \parallel R_1 \parallel R_2 \parallel r_\pi$$
$$f_{Ho} = \frac{1}{2\pi R_{Tho}C_o} \qquad R_{Tho} = R_L \parallel R_C \parallel r_o$$

3.2.2 High Frequency Response of CS Amplifiers

$$R_{Thi} = R_s \parallel R_G \qquad R_{Tho} = R_D \parallel R_L \parallel r_d$$
$$C_{Mi} = (1 - A_v)C_{\text{gd}} \qquad C_{Mo} = \left(1 - \frac{1}{A_v}\right)C_{\text{gd}}$$
$$C_i = C_{wi} + C_{\text{gs}} + C_{Mi} \qquad C_o = C_{wo} + C_{\text{ds}} + C_{Mo}$$
$$f_{Hi} = \frac{1}{2\pi R_{Thi}C_i} \qquad f_{Ho} = \frac{1}{2\pi R_{Tho}C_o}$$

3.3 Open-Circuit Time Constants

Open-circuit time constants is a method used to approximate the cutoff frequencies of the amplifier.

$$b_1 = \sum_{i=1}^{n} C_i R_i^0$$
$$b_2 = \sum_{i=1}^{n} \sum_{j} C_i R_i^0 R_j^i C_j$$

Where R_i^0 is the resistance seen by the capacitor when all other capacitors are shorted.

$$\omega_H \approx p_1 \approx \frac{1}{b_1} = \frac{1}{\sum_{i=1}^{n} C_i R_i^0}.$$

Chapter 4

Negative Feedback

There are 4 types of negative feedback topologies:

1. Feedback Voltage Amplifier (Series—Shunt)
2. Feedback Transconductance Amplifier (Series—Series)
3. Feedback Transresistance Amplifier (Shunt—Shunt)
4. Feedback Current Amplifier (Shunt—Series)

We define

$$\begin{cases} \beta = \dfrac{x_f}{x_o} & \text{Feedback factor} \\ A & \text{Open-loop gain} \\ A\beta & \text{Loop gain} \\ A_f = \dfrac{A}{1 + A\beta} & \text{Closed-loop gain} \end{cases}.$$

	Series-Shunt V-V	Shunt-Shunt I-V	Series-Series V-I	Shunt-Series I-I
R_{if}	$R_i(1 + A\beta)$	$\dfrac{R_i}{1 + A\beta}$	$R_i(1 + A\beta)$	$\dfrac{R_i}{1 + A\beta}$
R_{of}	$\dfrac{R_o}{1 + A\beta}$	$\dfrac{R_o}{1 + A\beta}$	$R_o(1 + A\beta)$	$R_o(1 + A\beta)$
β	$\dfrac{V_f}{V_o}$	$\dfrac{I_f}{V_o}$	$\dfrac{V_f}{I_o}$	$\dfrac{I_f}{I_o}$