Notes:
- push down for input stage
- NMOS common source amplifier with active load for second stage
- Cc is a compensation capacitor (more on this later)

DC Biasing:
- M8 is biased with \( I_{BS} \) (this is mirrored to \( M5, M7 \) with ratios \( W/L \) of each)
- \( M5 \) and \( M7 \) each have a current of \( I_{BS} \) (assuming \( I_{BS} = \frac{V_{GS}}{2} \))

\( \Rightarrow \) Voltage at \( Q_3 \) is equal to \( V_{GS} \)

\( \Rightarrow \) M4 is biased to have \( I_{BS} \) \( \frac{W/L}{2} \)

\( \Rightarrow \) to avoid an offset voltage, we need \( I_{BS} = I_{BS} \) when the inputs are equal:

\[ I_{BS} \frac{W/L}{2} = I_{BS} \frac{W/L}{4} \]

\( \Rightarrow \) Other wise we will have systematic offset

\( \Rightarrow \) This biasing set-up eliminates the need for blocking capacitors

Voltage Gain:
- Break circuit into 2 stages, calculate gains separately.
  - Gain of diff. input stage: \( A_1 = -g_{m4} \frac{R_{2}}{R_{1}} \)
  - Gain of common source output stage: \( A_2 = -g_{m6} \frac{R_{4}}{R_{1} R_{2}} \)

Total gain: \( A = A_1 A_2 \) (usually around 1000)
Frequency Response: Before we talk about the freq. response of this circuit, let's review general freq. response concepts.

1. Circuit it has 2 main behavior characteristics
   - Gain fell off at low freq due to blocking capacitors
   - Gain fell off at high freq due to inherent MOSTET caps (on board)
2. Most IC circuit implementations don't use blocking caps, and so the gain does not fall off at ac.

General expression for gain: \( A(s) = \frac{A_{dc}}{1 + F(s)} \)

\( F(s) = \frac{(1 + \frac{s}{\omega_1})(1 + \frac{s}{\omega_2})}{(1 + \frac{s}{\omega_p})(1 + \frac{s}{\omega_z})} \)

- \( \omega_n \) represents the \( n \)th zero frequency
- \( \omega_p \) represents the \( n \)th pole frequency
- As \( s \to 0 \), \( F(s) \to 1 \), \( A(s) \to A_{dc} \)

Remember that \( s = j\omega \)

Zeros: What does a zero do?

\( H(s) = (1 + \frac{s}{\omega_1}) = (1 + j \frac{\omega}{\omega_1}) \)

- for \( \omega < \omega_1 \), \( (1 + j \frac{\omega}{\omega_1}) \approx 1 \), zero has no effect.
  \( \rightarrow \) magnitude \( = 1 \), phase \( = 0^\circ \)
- for \( \omega = \omega_1 \), \( (1 + j \frac{\omega}{\omega_1}) = (1 + j) \)
  \( \rightarrow \) magnitude \( = \sqrt{1^2 + 1^2} = 1 \), phase \( = 45^\circ \)
  \( \rightarrow \) magnitude \( = \frac{\omega}{\omega_1} \to 20 \cdot \log(\frac{\omega}{\omega_1}) \to \) increases by 20 db/decade
- for \( \omega > \omega_1 \), \( (1 + j \frac{\omega}{\omega_1}) \approx j \frac{\omega}{\omega_1} \)
  \( \rightarrow \) magnitude \( = \frac{\omega}{\omega_1} \)
  \( \rightarrow \) phase \( = 90^\circ \)
Draw bode plot:
20 log |H(s)|

-20 dB/decade.

\[ |H(s)| \approx \frac{1}{(1 + j\frac{w}{w_p})} \]

1. For \( w \ll w_p \), \( \frac{1}{1 + j\frac{w}{w_p}} \approx 1 \), pole has no effect.
   - Magnitude = 1 (0 dB), phase = 0°

2. For \( w = w_p \), \( \frac{1}{1 + j\frac{w}{w_p}} = \frac{1}{1 + j} \)
   - Magnitude = \( \frac{1}{\sqrt{2}} \) = -3 dB
   - Phase = -45°

3. For \( w >> w_p \), \( \frac{1}{1 + j\frac{w}{w_p}} \approx \frac{1}{w/w_p} \)
   - Magnitude = \( \frac{1}{w/w_p} \) → \(-20 \log (\frac{w}{w_p})\) → decreases by 20 dB/decade.
   - Phase = -90°

As long as poles are adequately spaced, this makes it easy to sketch Bode plots.