High Freq Cutoff

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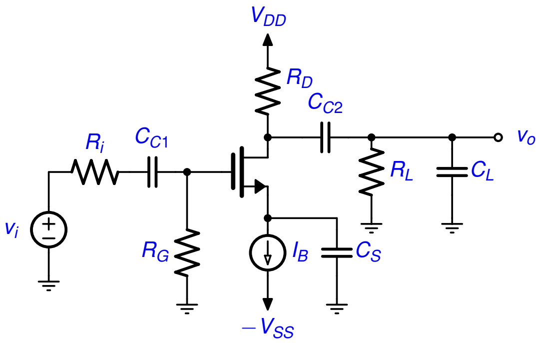
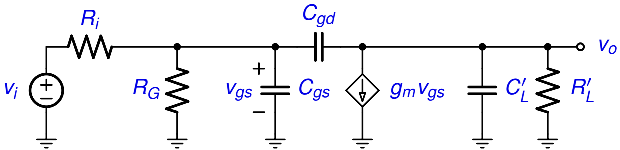
High Frequency Cutoff - Common Source Amp



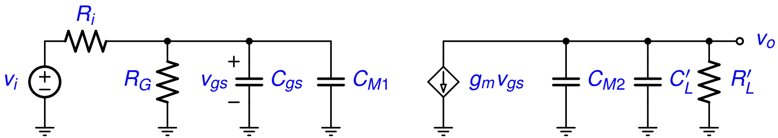
- Capacitors C_{C1}, C_{C2}, C_S are low freq caps and are all shorted for high frequency analysis

High Frequency Cutoff - Common Source Amp

- Small signal model for high freq analysis



- $C_L' = C_L || C_{db}$ $\qquad R_L' = R_L || r_o || R_D$
- $\frac{v_o}{v_{gs}} = -g_m R_L'$
- Break C_{gd} into C_{M1} and C_{M2}



- $C_{M1} = C_{gd}(1 + g_m R_L')$ $\qquad C_{M2} = C_{gd}(1 + \frac{1}{g_m R_L'})$

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- We see that for a large gain for $\frac{v_o}{v_{gs}}$, C_{M1} can be large and limit the high freq response.
- $\omega_{p1} = \frac{1}{(C_{gs}+C_{M1})(R_i||R_G)}$
- $\omega_{p2} = \frac{1}{(C'_L+C_{M2})R'_L}$

$$\frac{v_o}{v_i} = \frac{-g_m R'_L \times \left(\frac{R_G}{R_G+R_i}\right)}{(1+\frac{s}{\omega_{p1}})(1+\frac{s}{\omega_{p2}})} \tag{1}$$

- We can estimate the high freq cutoff, ω_H, as $\omega_H \approx \omega_{p1}||\omega_{p2}$

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- It is interesting to look at case where $R_i = 0$
- Here, $\omega_{p1} \to \infty$
- $\omega_H = \omega_{p2} = \frac{1}{(C_L' + C_{M2})R_L'}$
- Low freq gain, $A_M = -g_m R_L'$
- This is a single-time constant circuit
- Assuming $|A_M| \gg 1$ then $C_{M2} \approx C_{gd}$
- The unity gain freq, ω_t can be found as
  $\omega_t \approx |A_M|\omega_H = \frac{g_m}{C_L' + C_{gd}}$
- The unity gain freq, ω_t, is **INDEPENDENT** of R_L'

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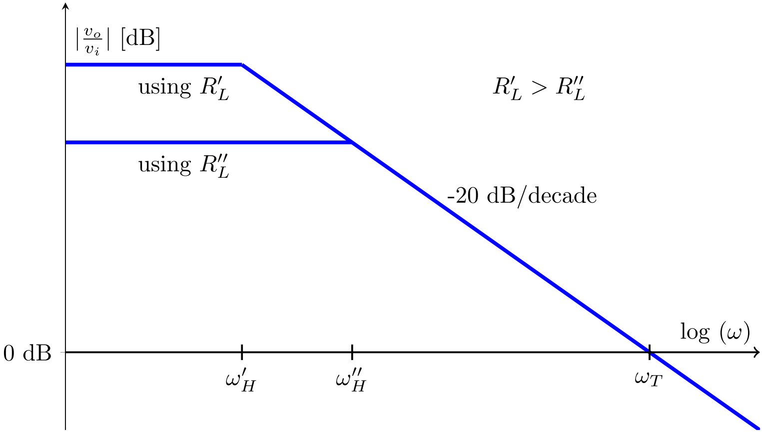

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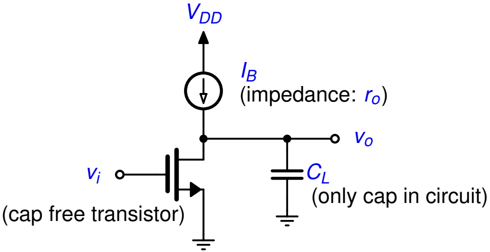
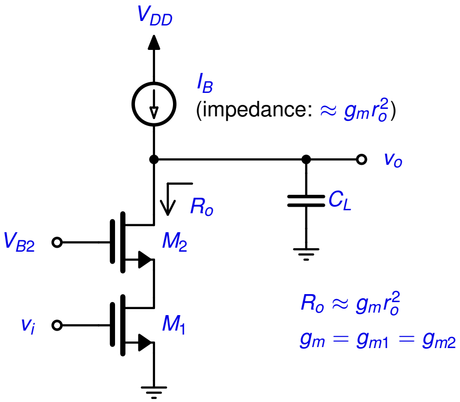


- DC Gain: $-g_m(r_o/2)$
- $\omega_H = \frac{1}{C_L(r_o/2)}$
- $\omega_t = \frac{g_m}{C_L}$

High Frequency Cutoff - Cascode Amp

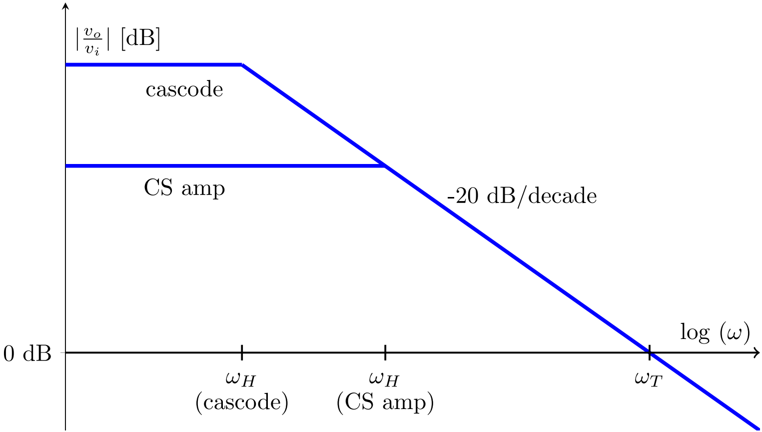


DC Gain: $\frac{-g_m^2 r_o^2}{2}$ — increased by $g_m r_o$

$\omega_H = \frac{1}{C_L (r_o/2)(g_m r_o)}$ — decreased by $g_m r_o$

$\omega_t = \frac{g_m}{C_L}$ — unchanged

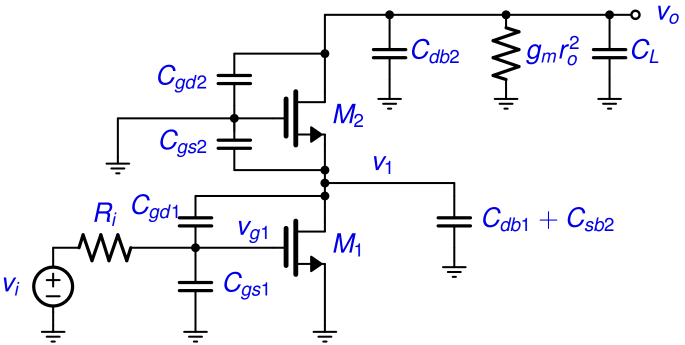
High Frequency Cutoff - Cascode Amp



- If output load determines ω_H
  - cascode and common-source amp have the same ω_t
  - cascode amp has higher dc gain and lower ω_H

High Frequency Cutoff - Cascode Amp

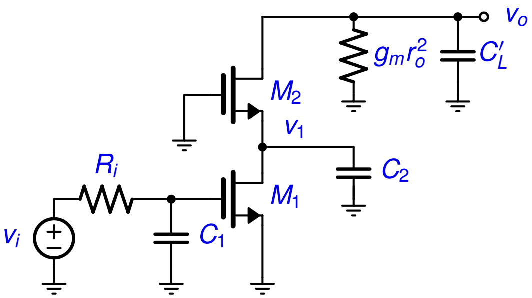
- Other caps in cascode amp



- $g_m r_o^2$ is the impedance of the top current mirror
- C_L includes the cap of top current mirror plus load cap

High Frequency Cutoff - Cascode Amp

- Since the gate of M_2 is grounded, we do not have worry about the Miller Effect for C_{gd2}
- We can break up C_{gd1} by defining $K \equiv \frac{v_1}{v_{g1}}$ leading to ...



- $C_L' = C_L + C_{db2} + C_{gd2}$

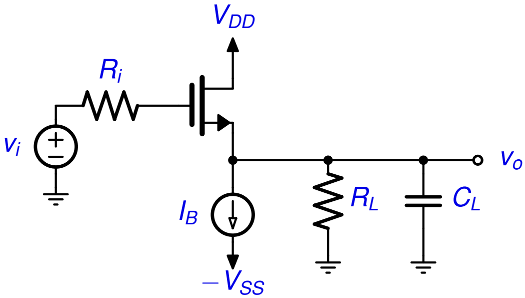
High Frequency Cutoff - Cascode Amp

- $C_2 = C_{db1} + C_{sb2} + (1 - \frac{1}{K})C_{gd1} + C_{gs2}$
- $C_1 = C_{gs1} + (1 - K)C_{gd1}$
- So we have 3 poles ...

$$\omega_{p1} \approx \frac{1}{C'_L\left(\frac{g_m r_o^2}{2}\right)} \qquad \omega_{p2} = \frac{1}{C_1 R_i} \qquad \omega_{p3} \approx \frac{1}{C_2\left(\frac{1}{g_{m2}}\right)}$$

- Generally we find $K \approx -\left(\frac{g_{m1}}{g_{m2}}\right)$ at frequencies that determine ω_{p2} and ω_{p3}
  - Due to C'_L impedance being much less than $g_m r_o^2$ at those frequencies
- So we do NOT see a large Miller multiplication effect for C_{gs1}
- Generally we find ω_{p1} dominates and determines ω_H

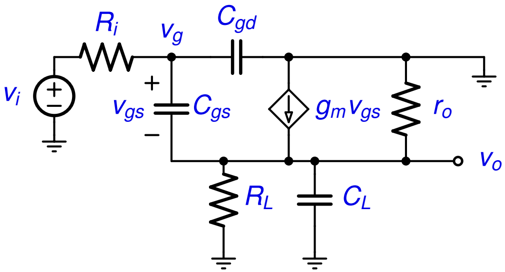
High Frequency Cutoff - Source Follower



- For simplicity, assume an ideal current source
- While this circuit has a voltage gain less than 1
  - it generally has a lower output impedance than a common-source amplifier
  - It can generally drive a lower resistive load

High Frequency Cutoff - Source Follower

- The small signal circuit with caps is ...



- Let $R_L' = R_L || r_o$ and $r_s = \frac{1}{g_m}$
- The midband gain is $A_M = \frac{R_L'}{R_L + r_s}$
- The output impedance is $R_{out} = r_s || r_o$

High Frequency Cutoff - Source Follower

- It turns out that using Miller's Theorem to break up C_{gd} is not very accurate here due to the small gain from v_g to v_o as well as the freq dependency at v_o
- We can still look at the open circuit time-constant to find the poles, however ...
  - While we will find 3 poles, in fact there are only 2 poles since the 3 capacitor voltages all add up to zero and are therefore not all independent
- The 3 poles for C_{gd}, C_L, and C_{gs} are ...
- $\omega_{p1} = \frac{1}{C_{gd} R_i}$
- $\omega_{p2} = \frac{1}{C_L (R_L || r_o || r_s)} \approx \frac{1}{C_L r_s}$ (assuming $r_s \ll R_L || r_o$)

High Frequency Cutoff - Source Follower

- For C_{gs}, we need to find impedance that C_{gs} "sees" when C_{gd}, C_L are both open.
  - This analysis is left to the student but is found to be ...

    $R_{gs} = \frac{R_i + R_L'}{1 + g_m R_L'}$
- $\omega_{p3} = \frac{1}{C_{gs} R_{gs}}$
- All 3 of these poles are generally higher than the common-source case, so in general, the source follower is faster
- However, it turns out there is some feedback in this circuit
  - For certain values, the circuit may have ringing in the step response
  - Need to be careful when driving large capacitive loads

Topics Covered

- High freq cutoff
  - Common-source amp
  - Cascode amp
    - same unity gain freq as common-source amp
    - small Miller effect on input capacitance
    - more dc gain
  - Source-follower amp