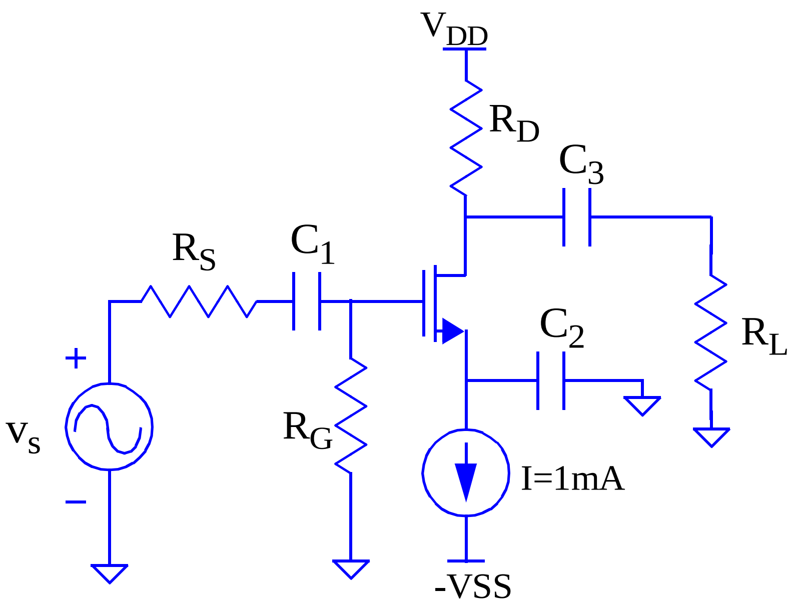
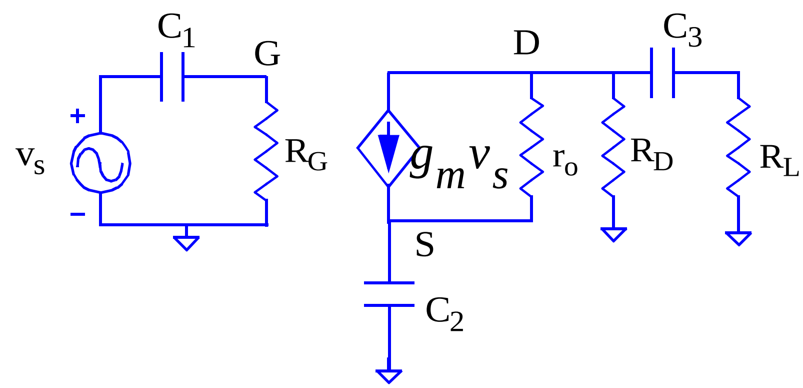
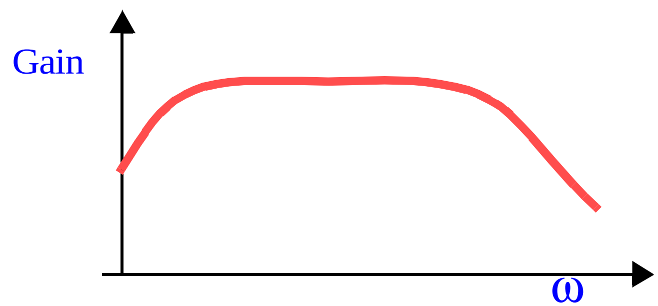
Discrete Amplifier Design: Low Frequency Response

- Are decoupling C's large enough? Is bypass C large enough?
- Why not just use the largest values available?





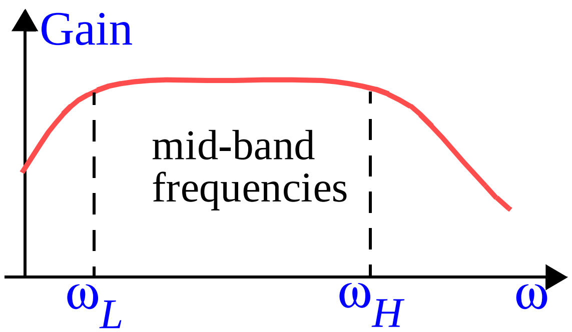


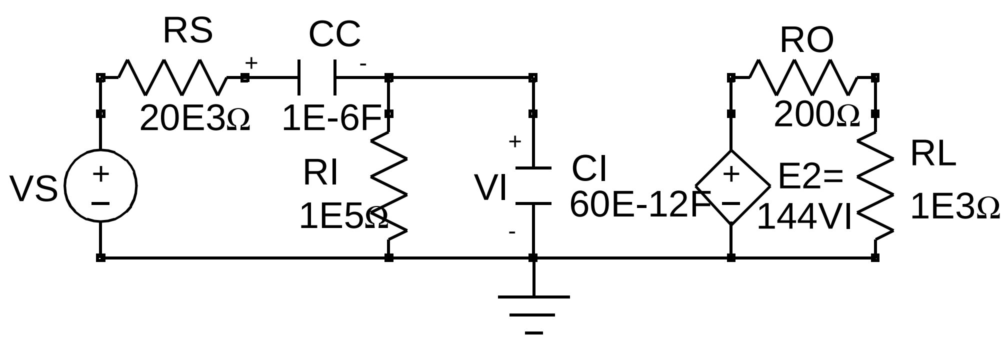
Design Selection of C_C Value

- In general we have to worry about both the added C's and the parasitic C's
- An approximate expression for the low frequency response as a function of C_C can help us to design coupling capacitor
- Similarly, an approximate expression for the high frequency response as a function of the parasitic capacitance would help in achieving the required bandwidth
- We simplify the analysis with some observations:

  1.) At mid-band frequencies we know that the C's do not matter (why?)

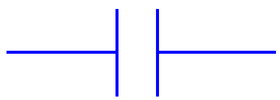
- Hypothetical amplifier example:



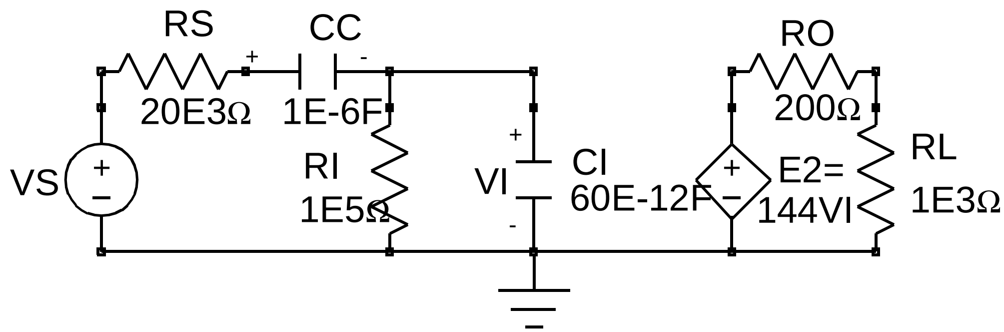


Impact of Decoupling and Parasitic C's

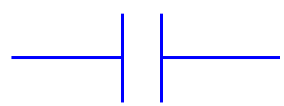
- For frequencies > ω_L the impedance due to C_C is practically zero compared to other impedances (behaves like a short circuit) due to the large value of C
- Only at extremely small frequencies is Z_{CC} a significant impedance



$$Z_{C_C} = \frac{1}{j\omega C_C}$$



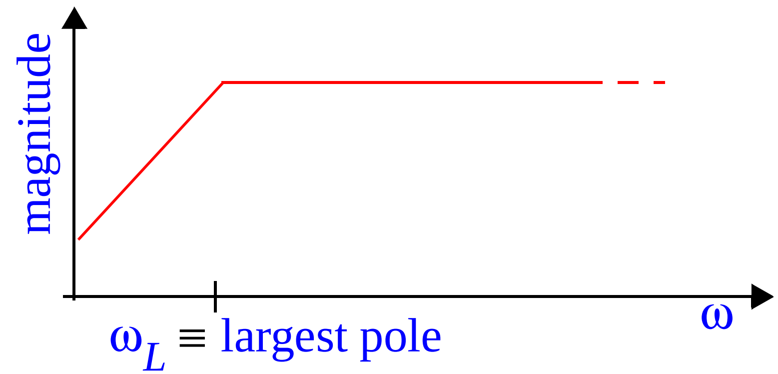
- In contrast, the internal (parasitic) capacitor, C_I behaves like an infinite impedance (open circuit) over the mid-band frequency range, because C_I is small



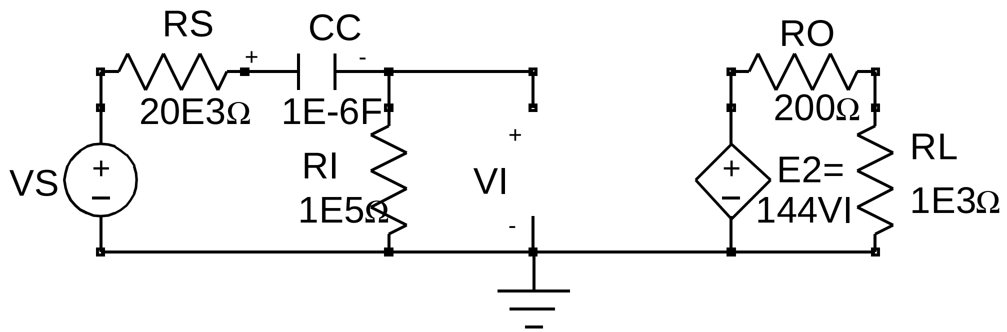
$$Z_{C_I} = \frac{1}{j\omega C_I}$$

Bandwidth Approximations

- At low frequencies, the frequency response is like a high pass filter



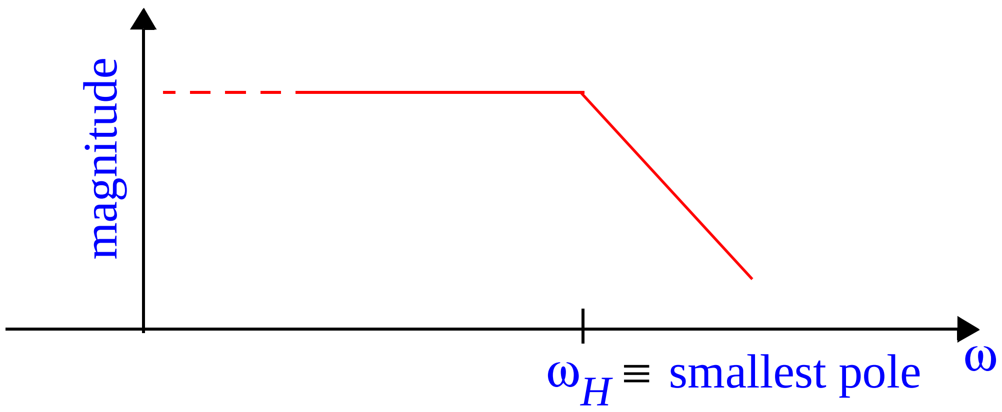
- So the largest pole associated with the low frequency equivalent circuit represents the low frequency 3dB cutoff point (with parasitic C's opened):



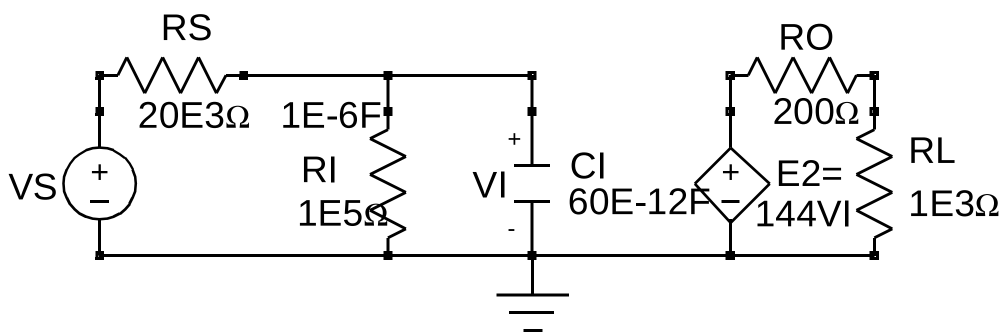
Assuming that there are no other low frequency poles or zeros nearby

Bandwidth Approximations

- At high frequencies, the frequency response is like a low pass filter

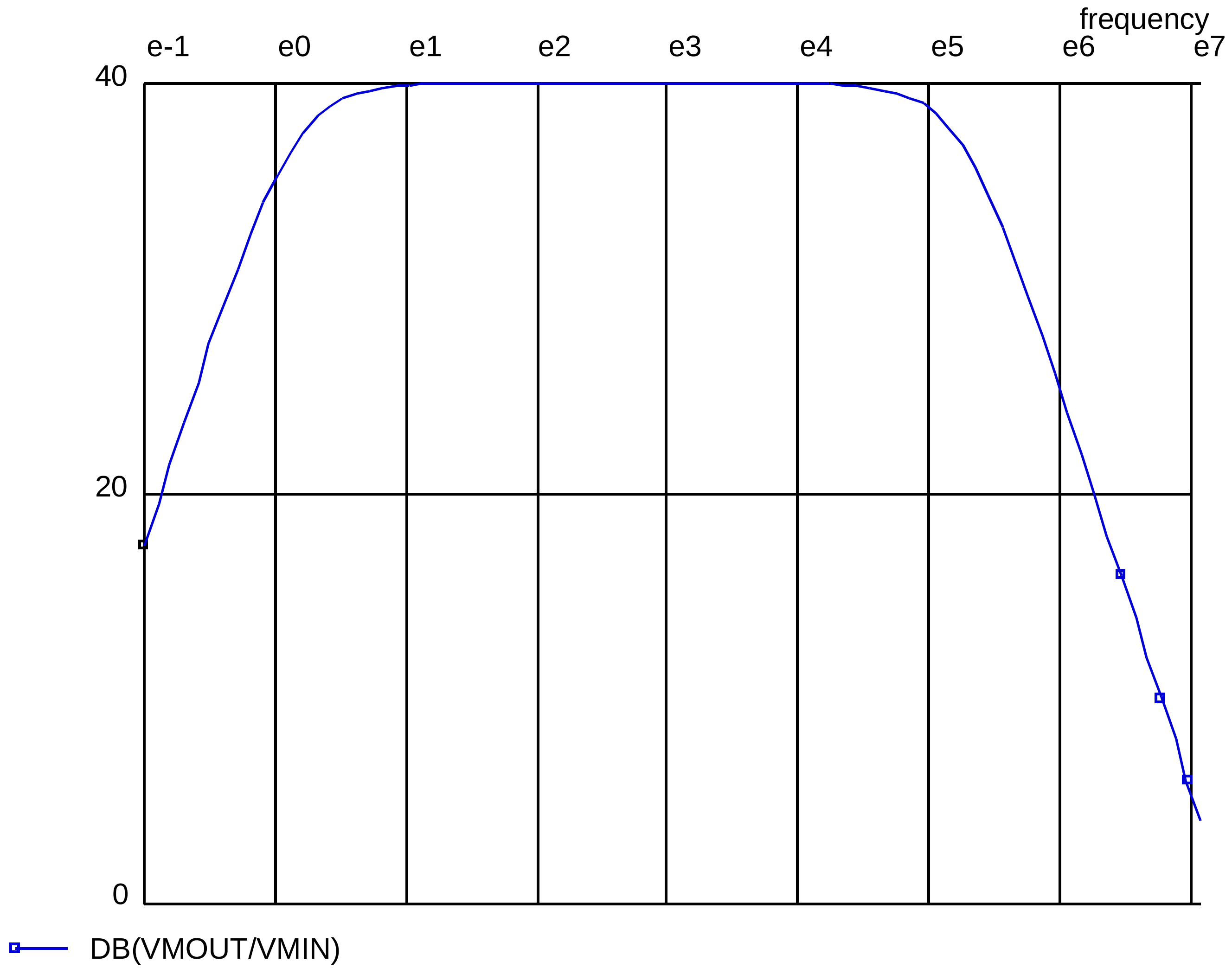


- So the smallest pole associated with the high frequency equivalent circuit represents the high frequency 3dB cutoff point
- The high frequency equivalent circuit is (with decoupling C's shorted):



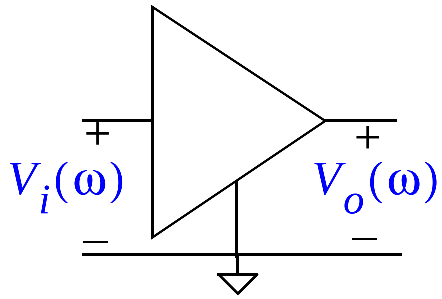
Amplifier Magnitude with C_C

- Excellent agreement, but these low and high frequency equivalent circuits contained only one pole each



Open- and Short-Circuit Time Constants

- Approximating the 3dB frequencies in terms of the smallest and largest poles of the high- and low-frequency equivalent circuits can be done when there are more poles in the circuit too
- In such cases the smallest and largest poles are approximated in terms of the open and short circuit time constants respectively



$$T(\omega) = \frac{V_o(\omega)}{V_i(\omega)} = \frac{1 + a_1 s + a_2 s^2 + \ldots + a_m s^m}{1 + b_1 s + b_2 s^2 + \ldots + b_n s^n}$$

$$= K\frac{1 + a_1 s + a_2 s^2 + \ldots + a_m s^m}{\left(\frac{s}{p_1} + 1\right)\left(\frac{s}{p_2} + 1\right)\ldots\left(\frac{s}{p_n} + 1\right)}$$

- b_1 is the sum of the circuit time constants

Open-Circuit Time Constants

- b_1 can be calculated as the sum of the open circuit time constants[1]

  Calculate the resistance, R, seen by each capacitor, C, when all other C's are open, and sum the corresponding RC products

- If the poles are separated from one another, then one pole will dominate the b_1 term

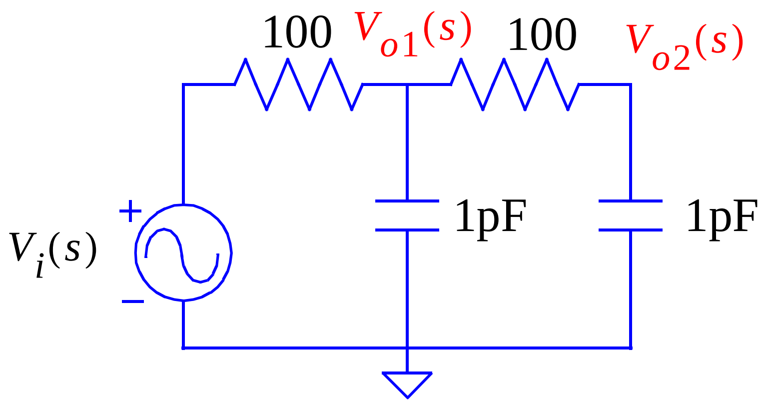
$$b_1 = \sum_{i=1}^{n} \frac{1}{p_i} \cong \frac{1}{p_1} \cong \frac{1}{\omega_H}$$

- Used to approximate the smallest pole (largest time constant) in the ckt

1. The circuit-theoretic foundation for this result can be found in "Analysis and Design of Analog Integrated Circuits," Gray and Meyer, 3rd edition, John Wiley and Sons, pp. 502-505.

Example

- From our simple RC example in lecture 2:



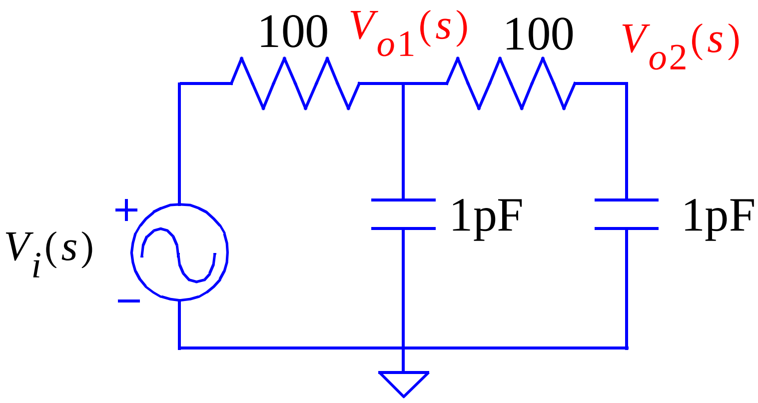
$$H_1(s) = \frac{1}{10^{20}} \cdot \frac{\left(1 + \frac{s}{10^{10}}\right)}{s^2 + s(0.03 \times 10^{12}) + 10^{20}} = \frac{\left(1 + \frac{s}{z}\right)}{\left(\frac{s}{p_1} + 1\right)\left(\frac{s}{p_2} + 1\right)}$$

$$poles \equiv p_{1,\,2} = -(-1.5 \times 10^{10} \pm 1.118 \times 10^{10})$$

$$H_2(s) = \frac{1}{\left(\frac{s}{p_1} + 1\right)\left(\frac{s}{p_2} + 1\right)}$$

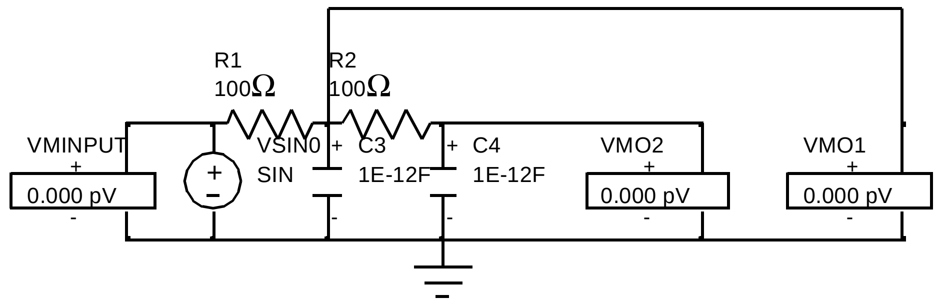
Example

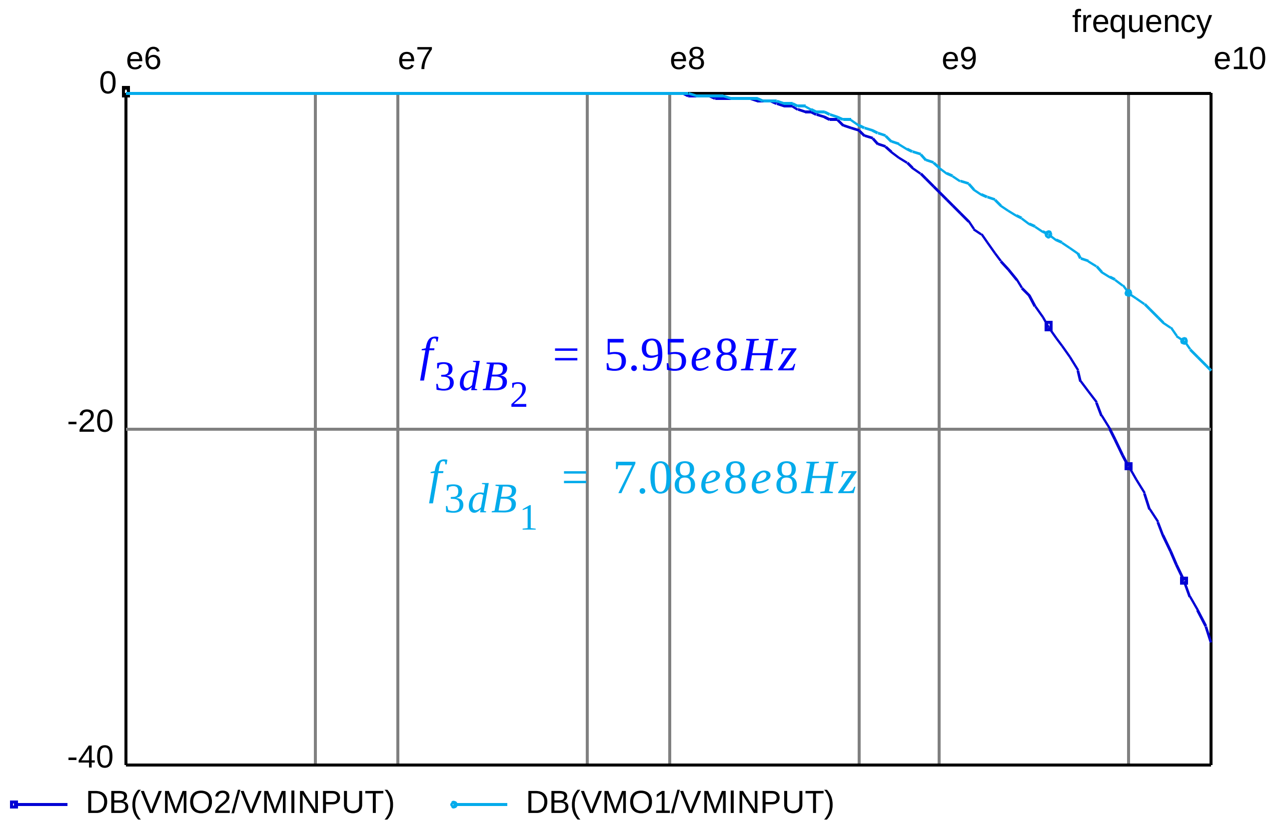
- Calculate the open circuit time constants



SPICE Result

- Why is this approximation more accurate for node 2?





Short-Circuit Time Constants

- The largest pole in a circuit can be approximated in a similar way
- First we express the transfer function in the form:

$$T(\omega) = \frac{1 + a_1 s + a_2 s^2 + \ldots + a_m s^m}{1 + b_1 s + b_2 s^2 + \ldots + b_n s^n} = \frac{s^m + d_1 s^{m-1} + \ldots}{s^n + e_1 s^{n-1} + \ldots}$$

which can be factored into the form:

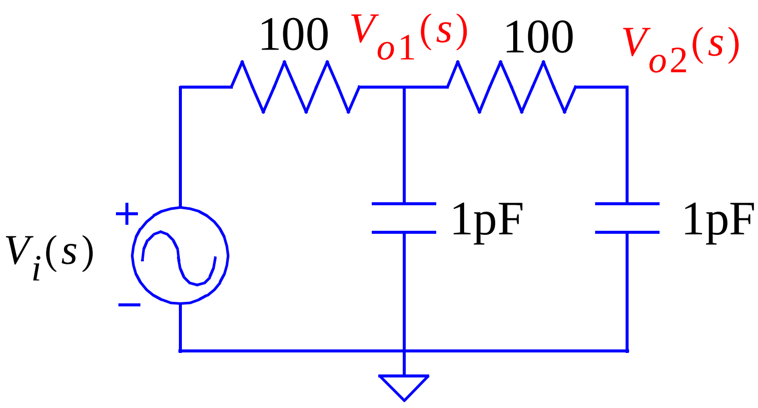
$$= \frac{s^m + d_1 s^{m-1} + \ldots}{(s + p_1)(s + p_2)\ldots(s + p_n)}$$

- e_1 is the sum of the poles
- e_1 can be calculated as the sum of the short circuit reciprocal time constants

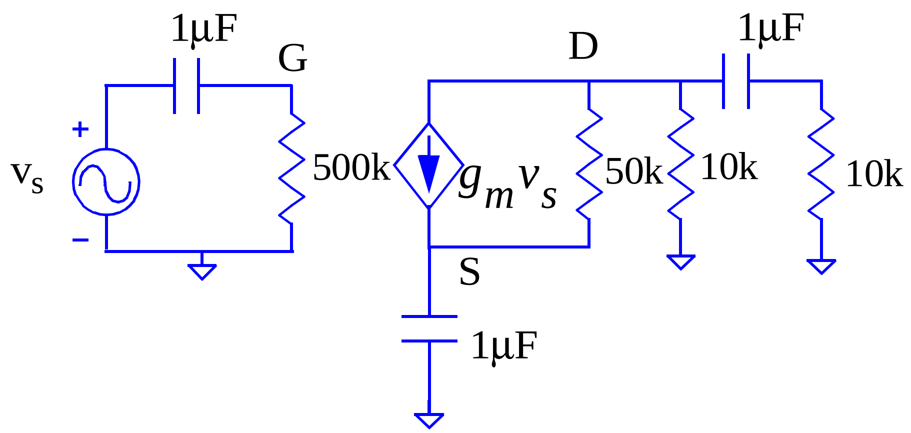
Calculate the resistance, R, seen by each capacitor, C, when all other C's are shorted, and sum the corresponding reciprocal RC products

Example

- Calculate the short circuit reciprocal time constants

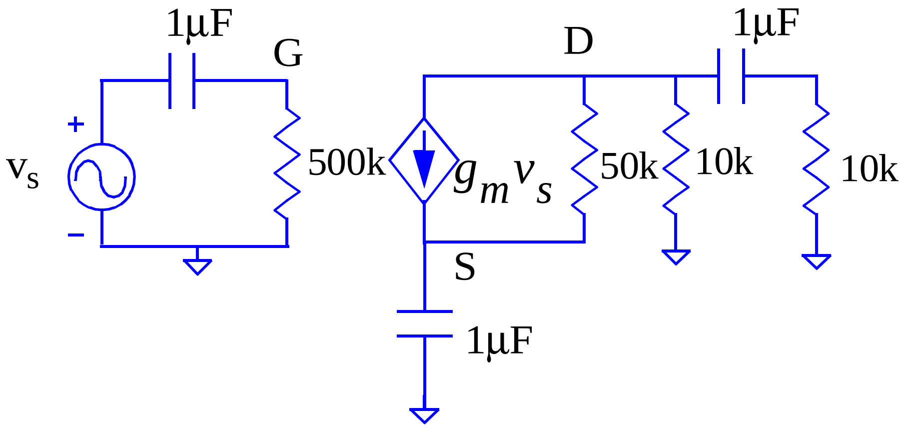


Common Source w/ Decoupling Example



$$g_m = 1m\frac{A}{V}$$

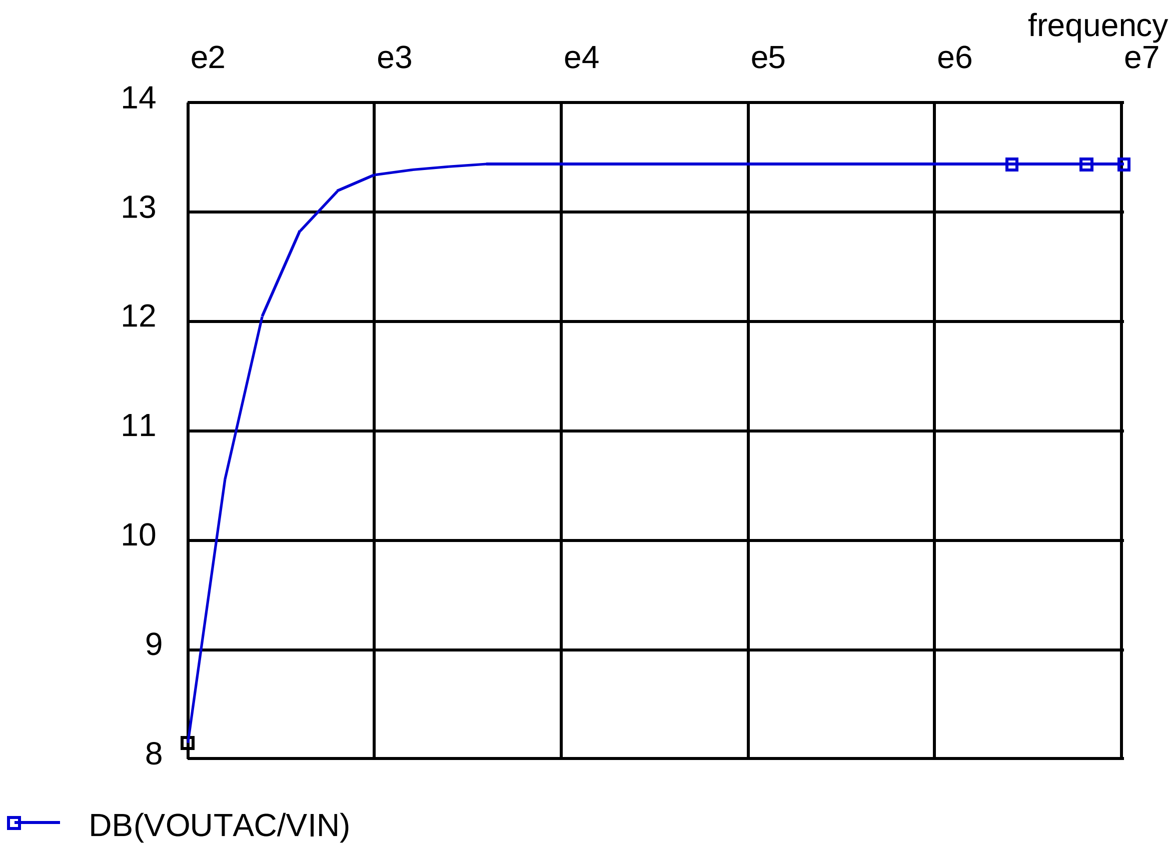
Common Source w/ Decoupling Example



$$g_m = 1m\frac{A}{V}$$

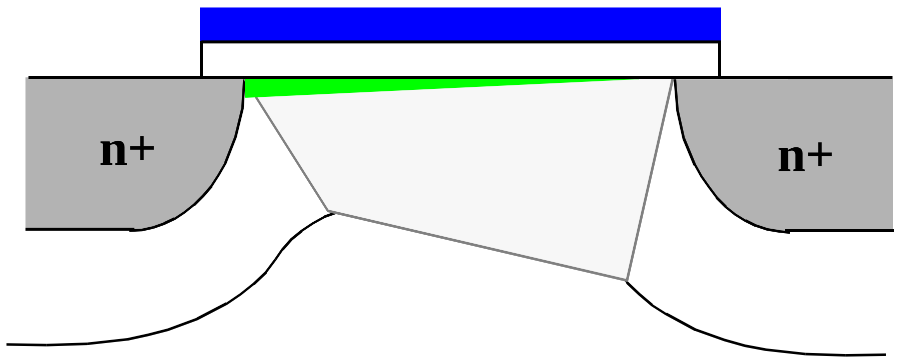
ac Response

- Frequency response for common source amplifier from lecture 22



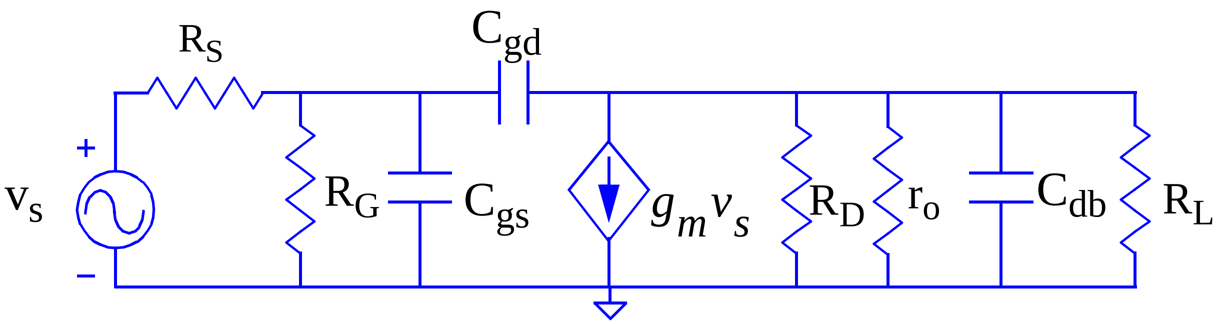
High Frequency Response

- IC amplifiers do not generally use decoupling since fabricating large C's is costly in terms of silicon area --- direct coupled amplifiers
- So we will mainly be interested in the high frequency response for IC amplifiers
- The parasitic capacitances will become evident at high frequencies, especially the gate to drain capacitor
- The impact of the gate-to-drain capacitor is amplified by the Miller Effect

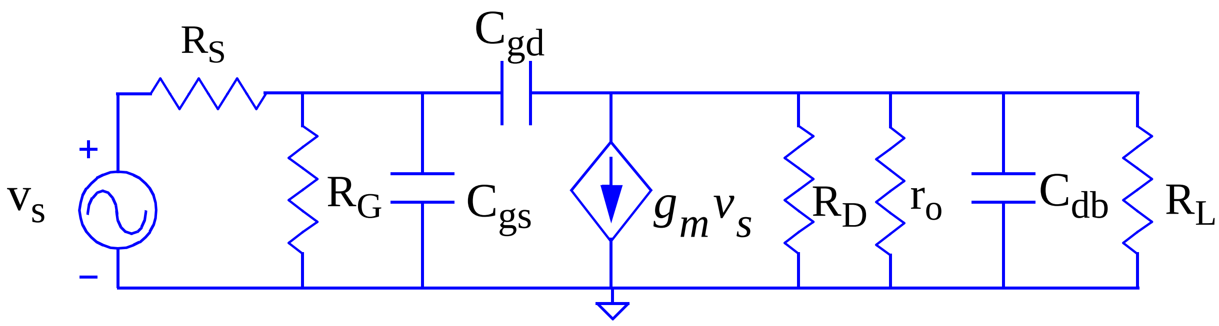


High Frequency Response

- Hypothetical common-source-like amplifier

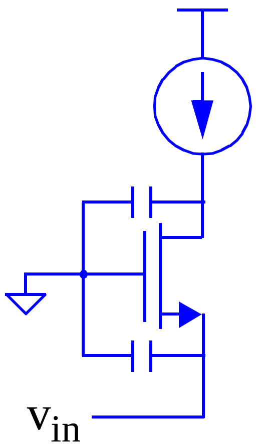


Miller Effect



Common Gate

- High frequency amplifiers must be designed to minimize the Miller effect
- Common gate and common base configurations can provide large gains, low input impedance, and improved high frequency behavior
- Why is Miller effect not a factor?



Cascode Amplifiers

- Cascode configurations combine the best of both common emitter (source) and common base (gate)