EE105
Microelectronic Devices and Circuits
Frequency Response

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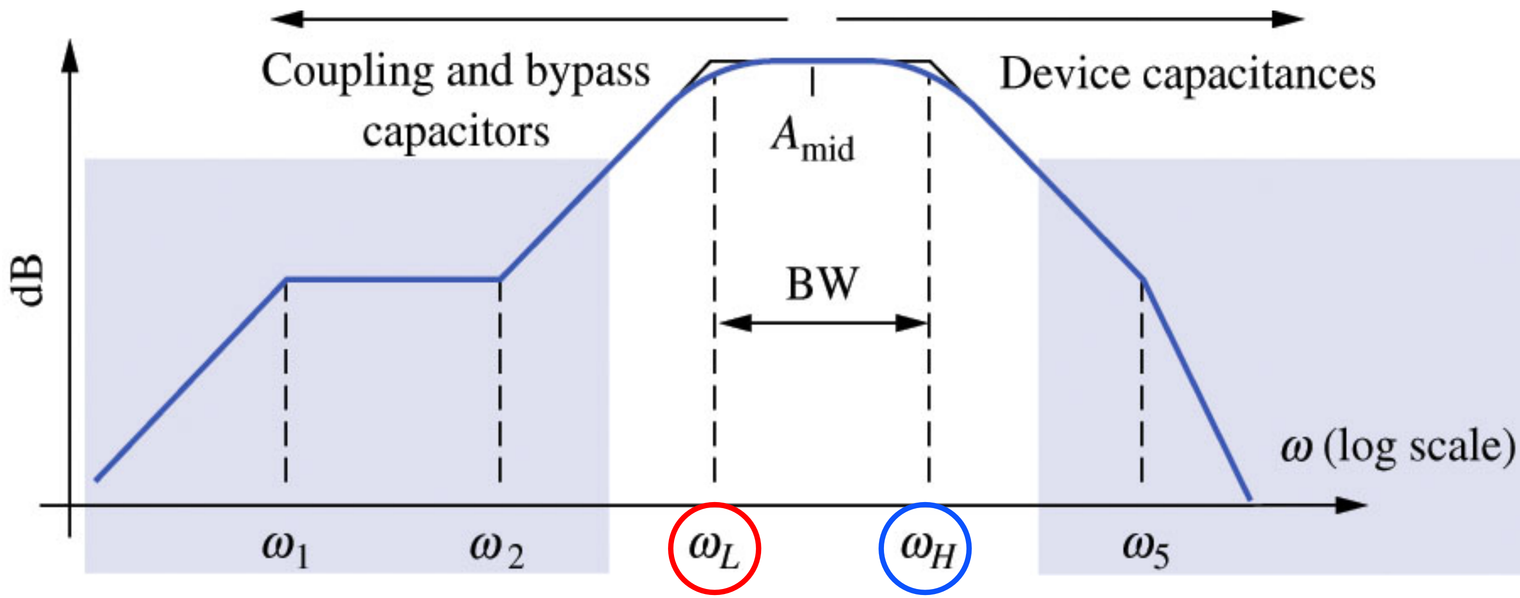
Amplifier Frequency Response: Lower and Upper Cutoff Frequency



- **Midband gain A_{mid} and upper and lower cutoff frequencies ω_H and ω_L that define bandwidth of an amplifier are often of more interest than the complete transfer function**
- **Coupling and bypass capacitors (~ μF) determine ω_L**
- **Transistor (and stray) capacitances (~ pF) determine ω_H**

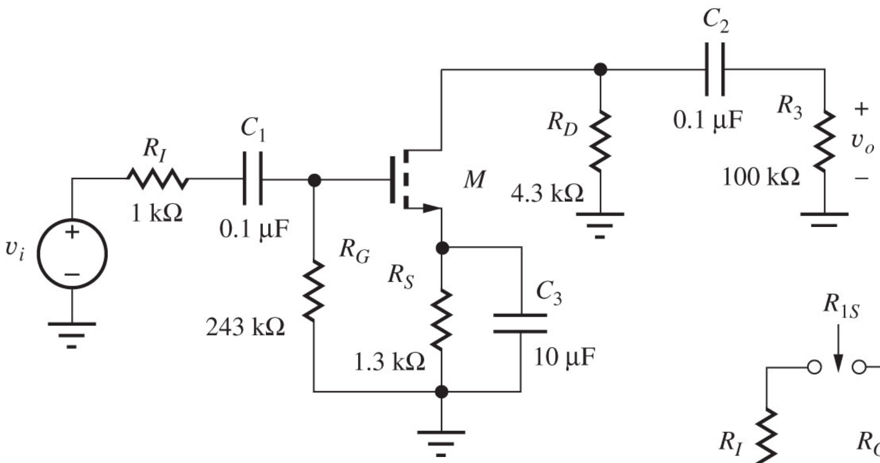
Lower Cutoff Frequency (ω_L) Approximation: Short-Circuit Time Constant (SCTC) Method

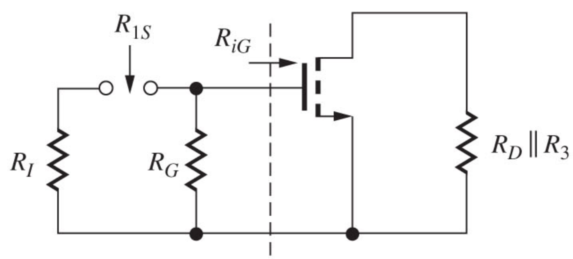
1. **Identify all coupling and bypass capacitors**
2. **Pick one capacitor (C_i) at a time, replace all others with short circuits**
3. **Replace independent voltage source with *short*, and independent current source with *open***
4. **Calculate the resistance (R_{iS}) in parallel with C_i**
5. **Calculate the time constant, $\frac{1}{R_{iS}C_i}$**
6. **Repeat this for each of the n capacitor**
7. **The low cut-off frequency can be approximated by**

$$\omega_L \cong \sum_{i=1}^{n} \frac{1}{R_{iS}C_i}$$

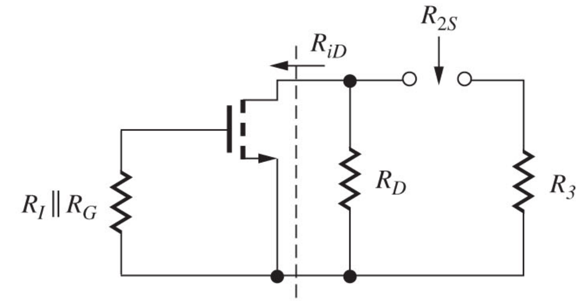
Note: this is an approximation. The real low cut-off is slightly lower

Lower Cutoff Frequency (ω_L) Using SCTC Method for CS Amplifier





(a)



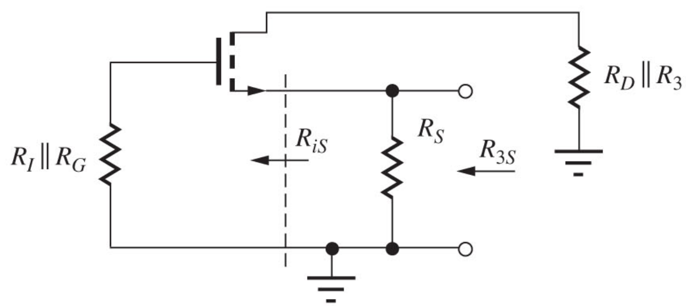
(b)

SCTC Method:

$$f_L \cong \frac{1}{2\pi} \sum_{i=1}^{n} \frac{1}{R_{iS} C_i}$$

For the Common-Source Amplifier:

$$f_L \cong \frac{1}{2\pi} \left(\frac{1}{R_{1S} C_1} + \frac{1}{R_{2S} C_2} + \frac{1}{R_{3S} C_3} \right)$$



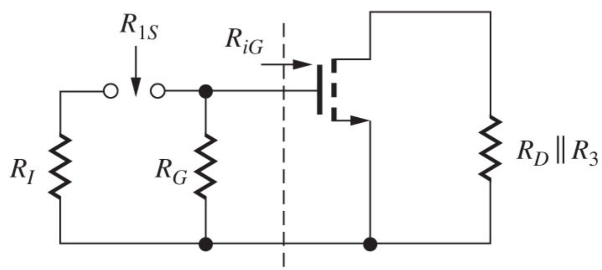
Lower Cutoff Frequency (ω_L) Using SCTC Method for CS Amplifier

Using the SCTC method:

$$f_L \cong \frac{1}{2\pi}\left(\frac{1}{R_{1S}C_1}+\frac{1}{R_{2S}C_2}+\frac{1}{R_{3S}C_3}\right)$$

For C_1:

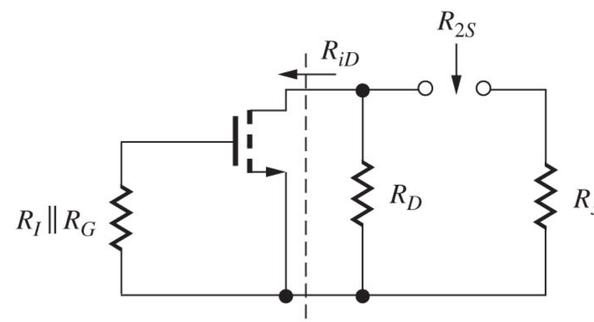
$$R_{1S} = R_I + \left(R_G \| R_{iG}\right) = R_I + R_G$$



(a)

For C_2 :

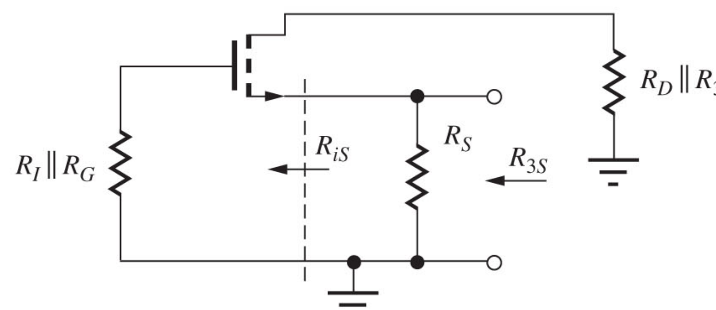
$$R_{3S} = R_3 + \left(R_D \| R_{iD}\right) = R_3 + \left(R_D \| r_o\right)$$



(b)

For C_3 :

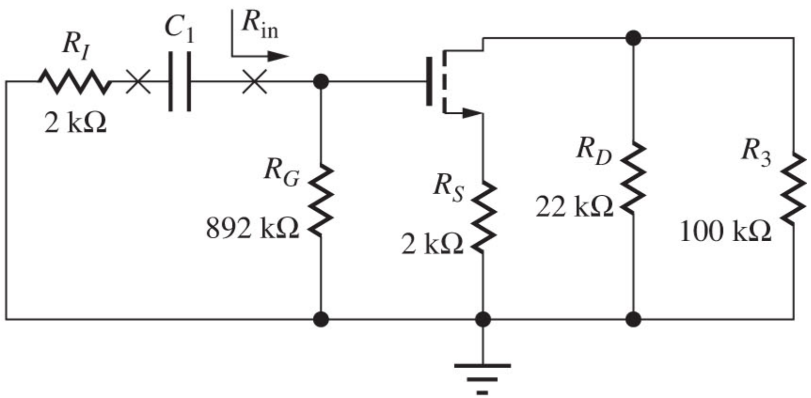
$$R_{2S} = R_S \| R_{iS} = R_S \| \frac{1}{g_m}$$



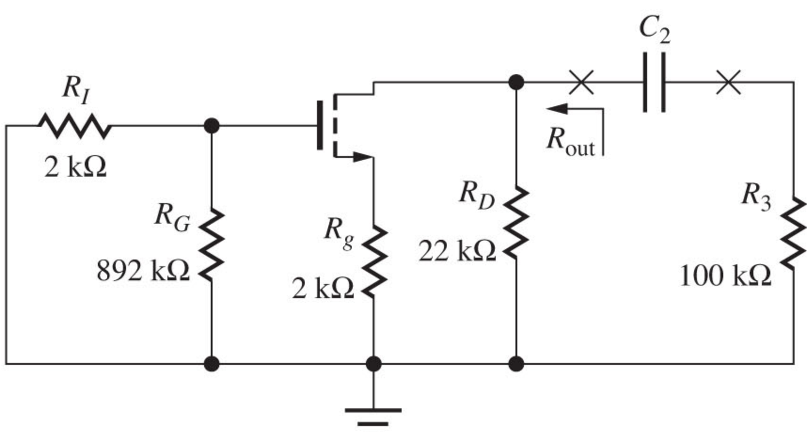
Design: How Do We Choose the Coupling and Bypass Capacitor Values?

- **Since the impedance of a capacitor increases with decreasing frequency, coupling/bypass capacitors reduce amplifier gain at low frequencies.**
- **To choose capacitor values, the short-circuit time constant (SCTC) method is used: each capacitor is considered separately with all other capacitors replaced by short circuits.**
- **To be able to neglect a capacitor at a given frequency, the magnitude of the capacitor's impedance must be much smaller than the equivalent resistance appearing at its terminals at that frequency**

Coupling and Bypass Capacitor Design Common-Source Amplifiers



(b)



For the C-S Amplifier:

$$R_{in} = R_G \| R_{in}^{CS} \qquad R_{out} = R_D \| R_{out}^{CS}$$

For coupling capacitor C_1 :

$$C_1 >> \frac{1}{\omega\left(R_I + R_{in}\right)}$$

For coupling capacitor C_3 :

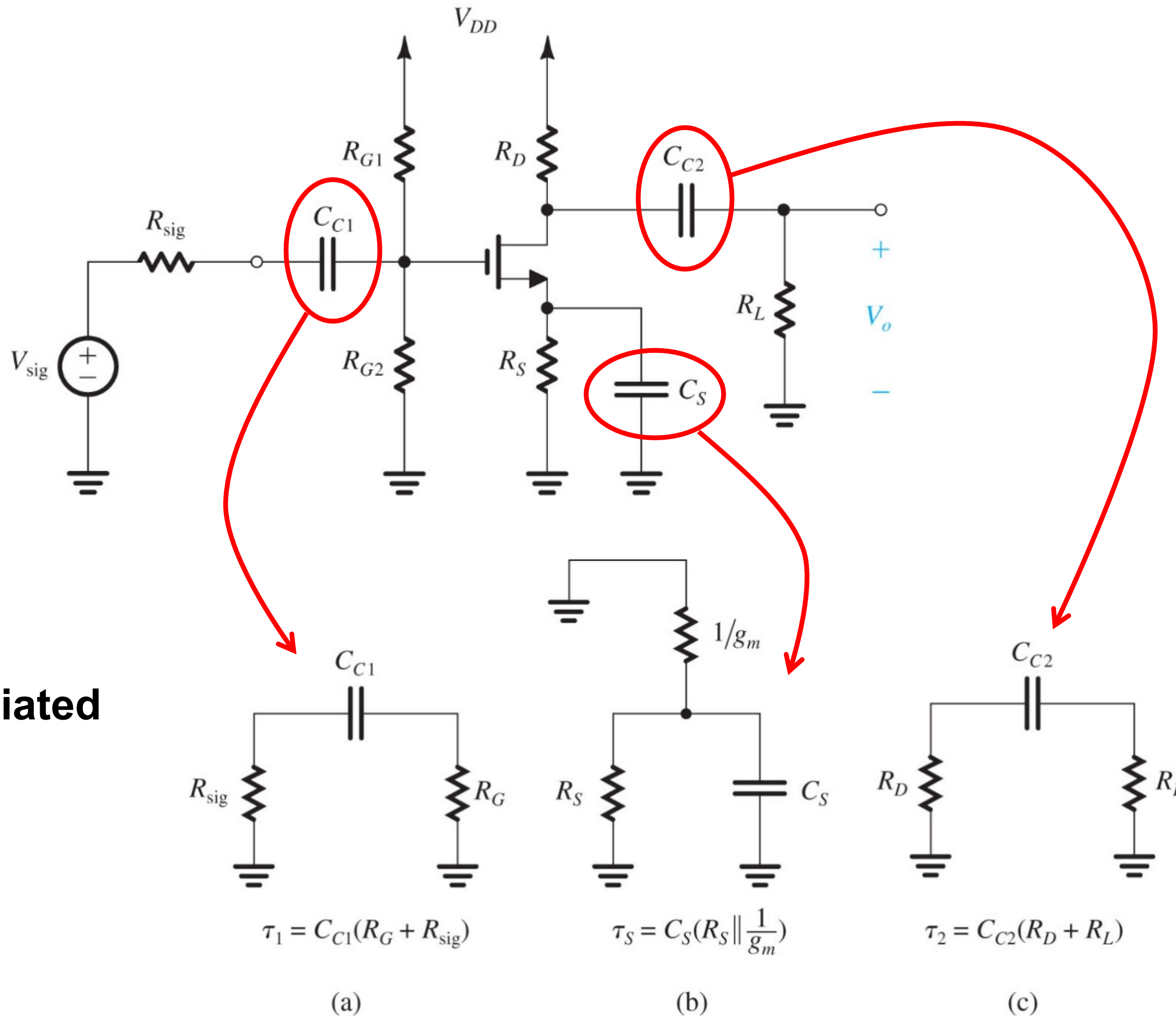
$$C_2 >> \frac{1}{\omega\left(R_3 + R_{out}\right)}$$

Lower Cutoff Frequency f_L
Dominant Pole Design

- Instead of having the lower cutoff frequency set by the interaction of several poles, it can be set by the pole associated with just one of the capacitors. The other capacitors are then chosen to have their pole frequencies much below f_L.
- The capacitor associated with the emitter or source part of the circuit tends to be the largest due to low resistance presented by emitter or source terminal of transistor and is commonly used to set f_L.
- Values of other capacitors are increased by a factor of 10 to push their corresponding poles to much lower frequencies.

Capacitively Coupled CS Amplifier

Find the pole frequency associated with each coupling/bypass capacitor:



Low Frequency Response

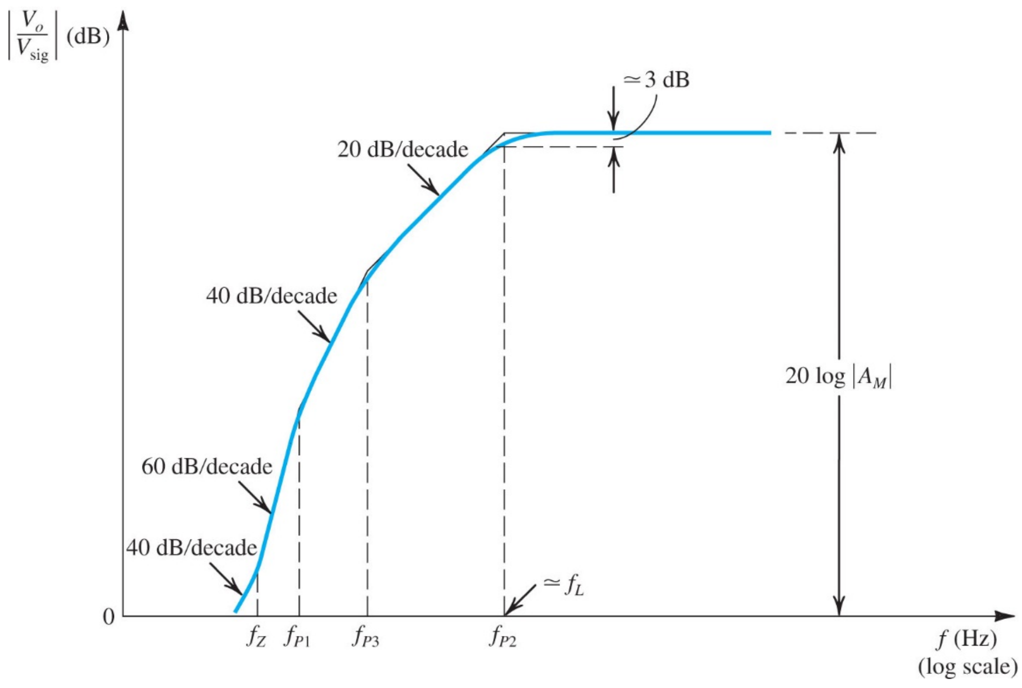
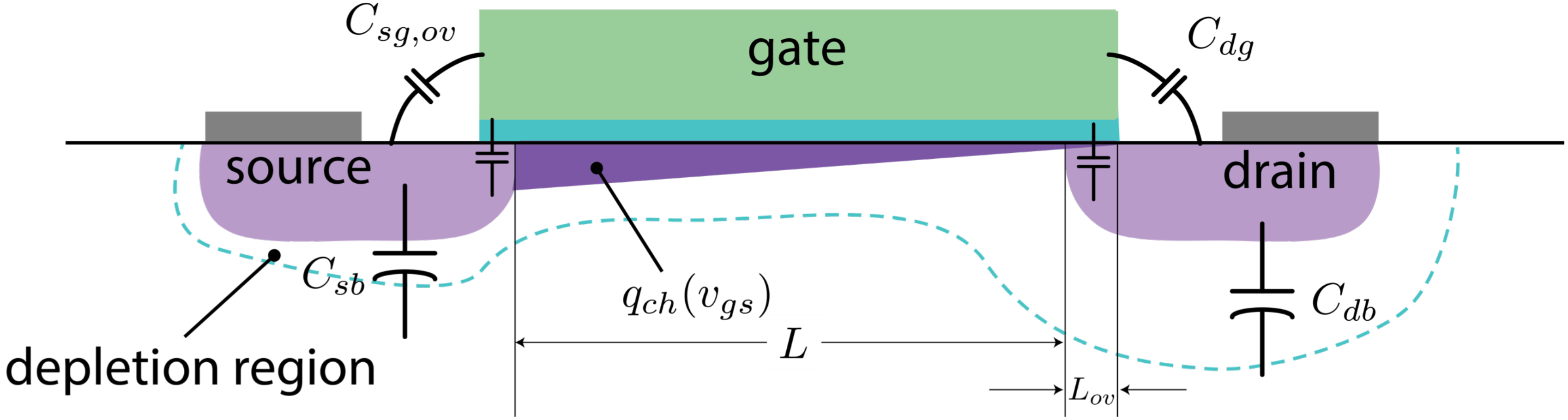


Figure 10.7 Sketch of the low-frequency magnitude response of a CS amplifier for which the three pole frequencies are sufficiently separated for their effects to appear distinct.

High Frequency Response

Capacitors in MOS Device



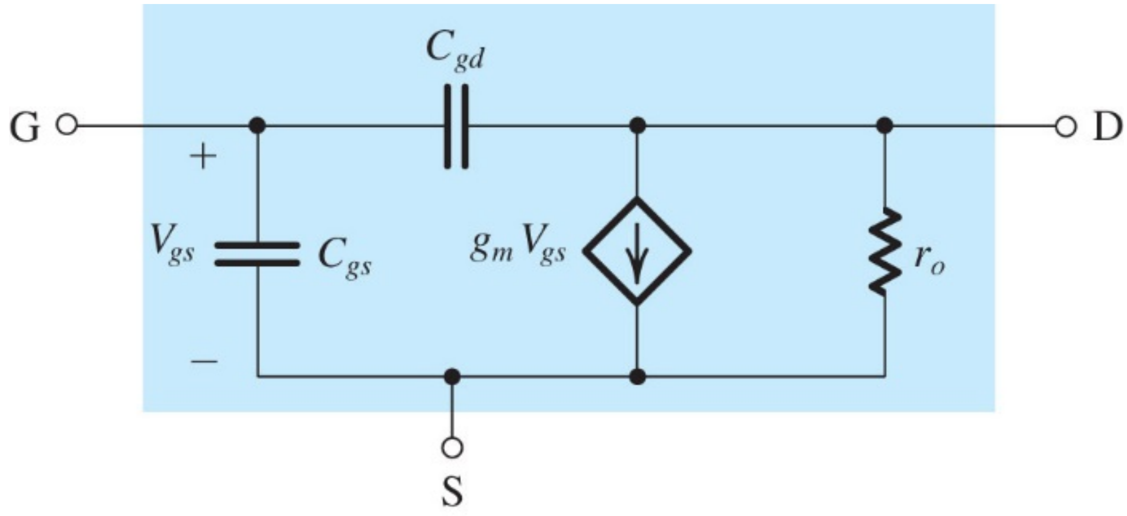
$$C_{gs} = (2/3)WLC_{ox} + C_{ov}$$

$$C_{gd} = C_{ov}$$

$$C_{sb} = C_{jsb}(area + perimeter)\, junction$$

$$C_{db} = C_{jdb}(area + perimeter)\, junction$$

(Simplified) High-Frequency Equivalent-Circuit Model for MOSFET



Capacitances between source/body, C_{sb}, and between drain/body, C_{db}, are neglected