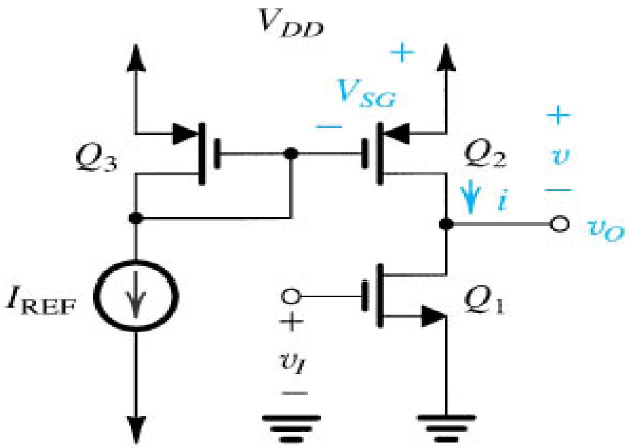
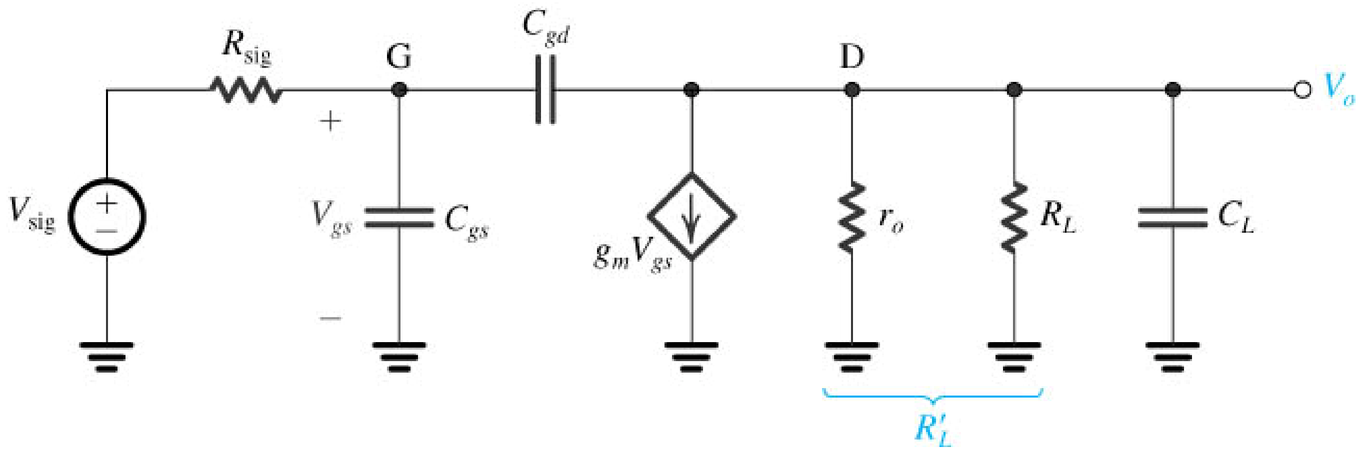
Lect. 24: High-Frequency Response of MOSFET CS

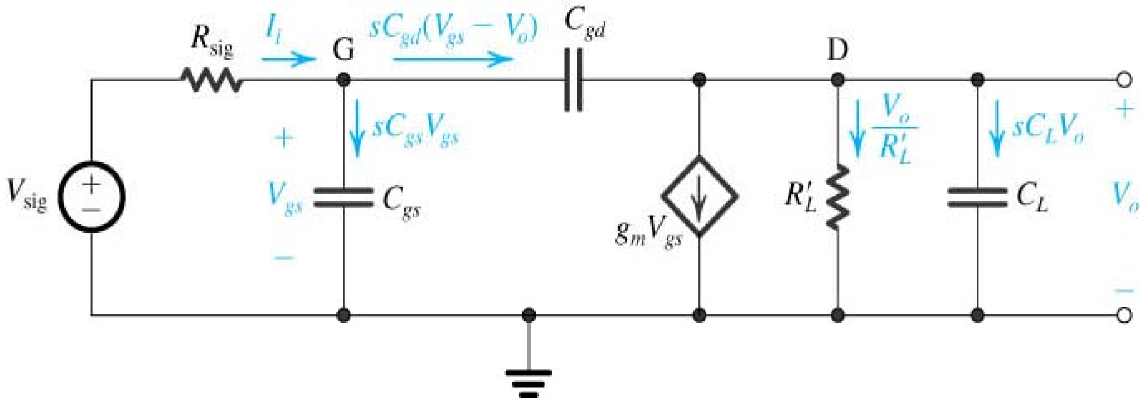


How fast can this operate?



R_L, C_L due to Q_2 and external load

Lect. 24: High-Frequency Response of MOSFET CS



It can be shown from an exact (but complicated) analysis that

$$\frac{V_o}{V_{sig}} = \frac{-\left(g_m R_L'\right)\left[1 - s\left(C_{gd}/g_m\right)\right]}{1 + s\left\{\left[C_{gs} + C_{gd}\left(1 + g_m R_L'\right)\right] R_{sig} + \left(C_L + C_{gd}\right) R_L'\right\} + s^2\left[\left(C_L + C_{gd}\right) C_{gs} + C_L C_{gd}\right] R_{sig} R_L'}$$

Too complex. A simpler way of estimating f_H, high-frequency 3-dB frequency?

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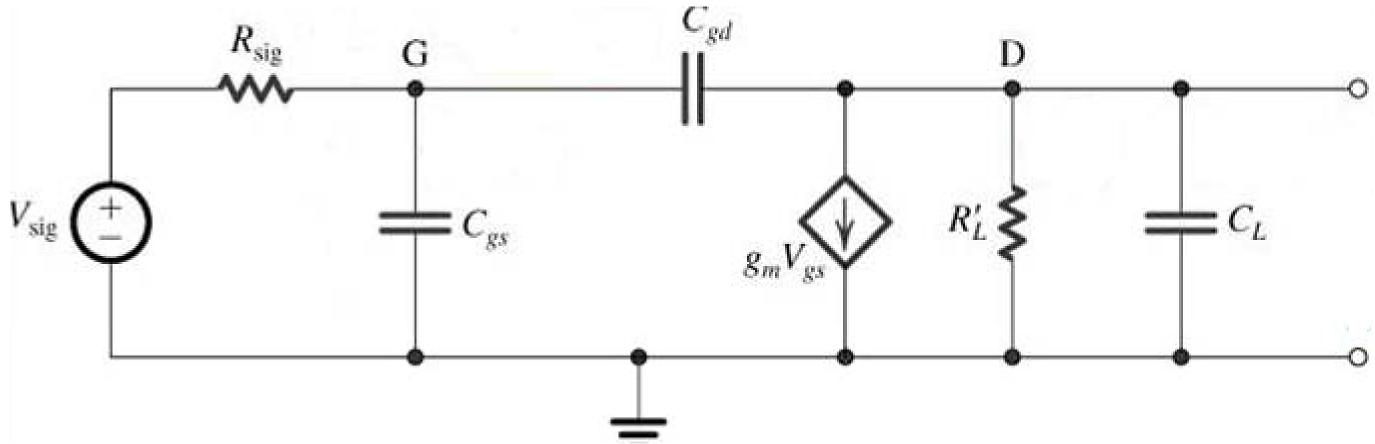

Open-Circuit Time Constant Method for approximating f_H

1. Select one capacitor, C_i, and set others to open.
2. Determine R_i, the resistance seen by C_i.
3. Repeat above for all capacitors.

Then, $\omega_H \sim \dfrac{1}{\sum_i C_i R_i}$

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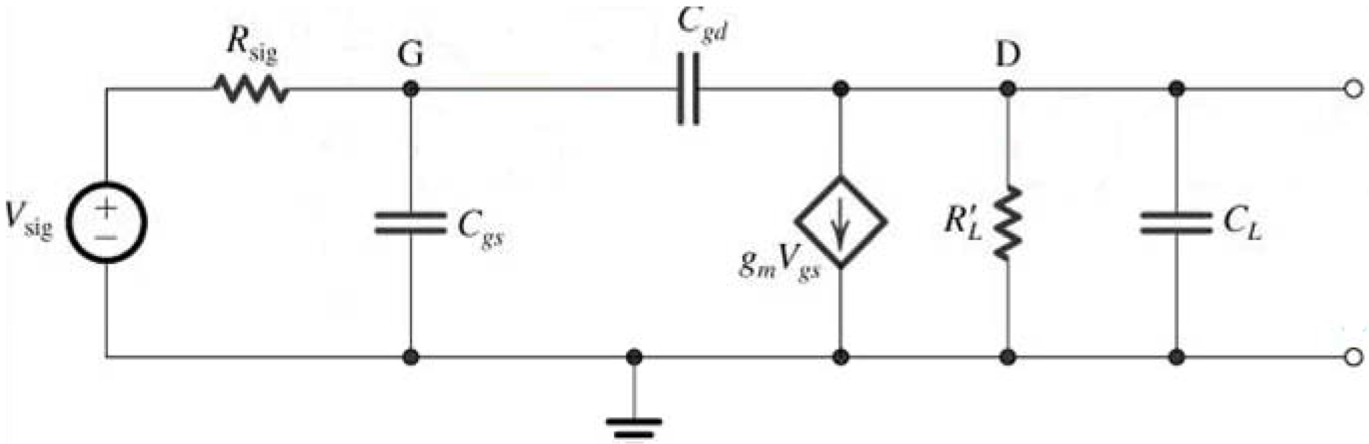
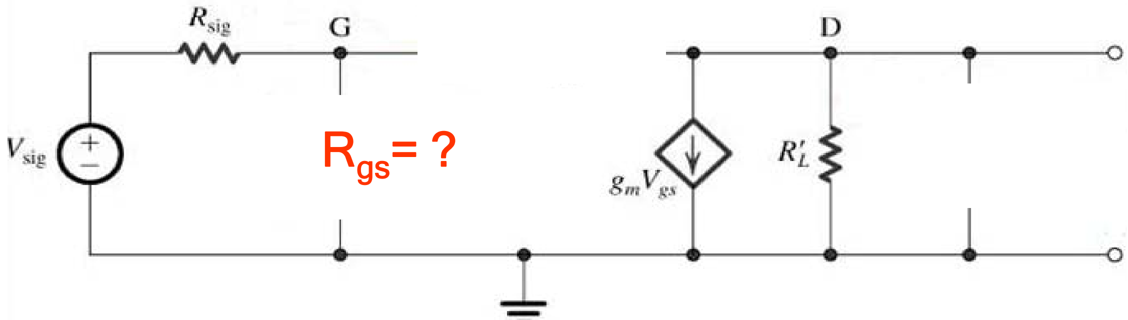
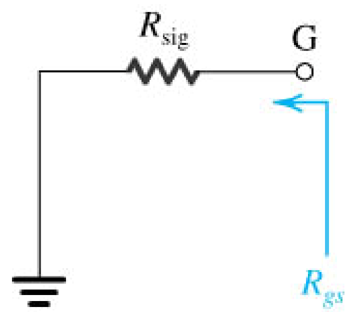


For C_{gs},



R_{gs}= ?



$R_{gs}=R_{sig}$

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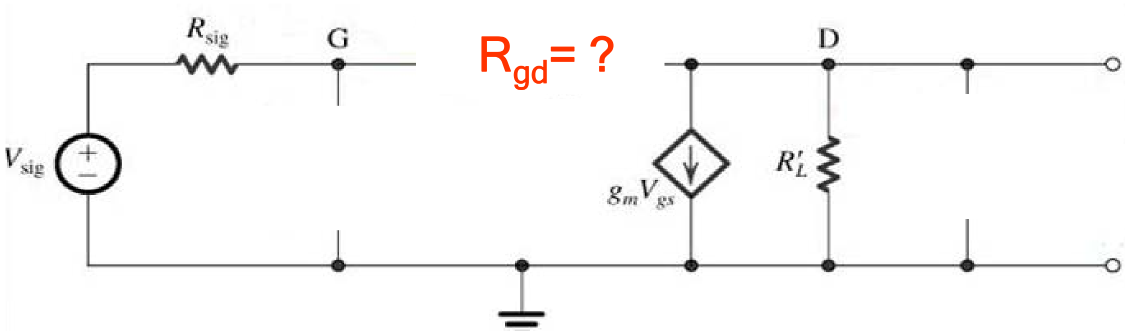
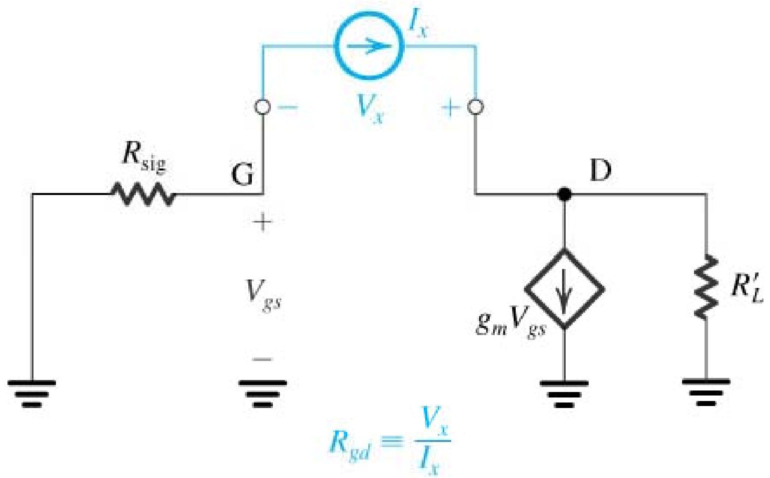
For C_{gd},





(b)

$$I_x = g_m V_{gs} + \frac{V_{gs} + V_x}{R_L'}$$

$$V_{gs} = -I_x R_{sig}$$

$$I_x = -g_m I_x R_{sig} + \frac{-I_x R_{sig} + V_x}{R_L'}$$

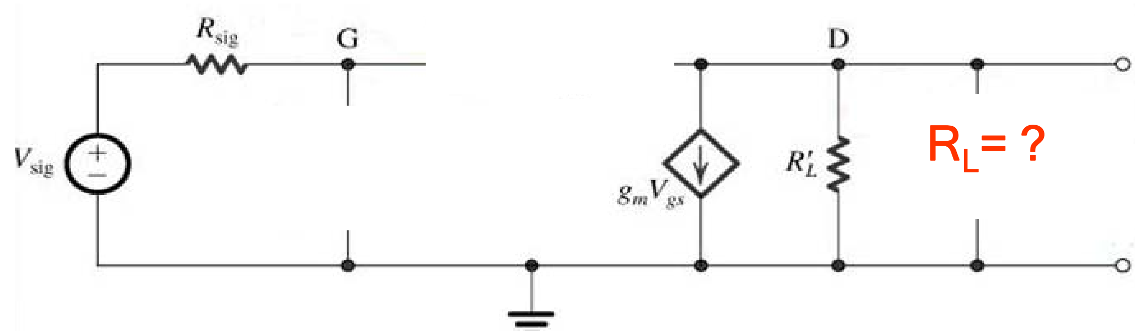
$$I_x (1 + g_m R_{sig} + \frac{R_{sig}}{R_L'}) = \frac{V_x}{R_L'}$$

$$\frac{V_x}{I_x} = (1 + g_m R_{sig} + \frac{R_{sig}}{R_L'}) R_L' = R_L' + g_m R_{sig} R_L' + R_{sig}$$

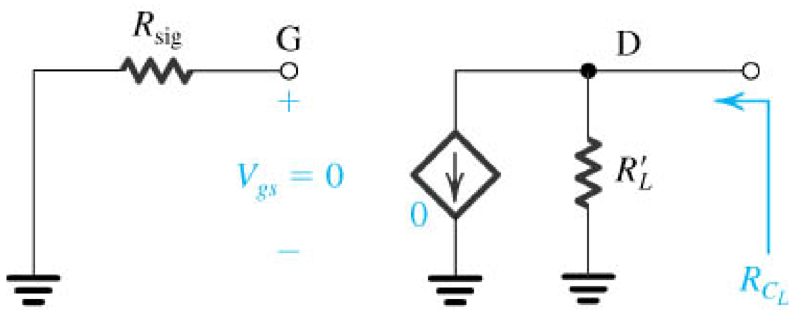
$$\therefore R_{gd} = R_{sig}(1 + g_m R_L') + R_L'$$

Lect. 24: High-Frequency Response of MOSFET CS

For C_L,



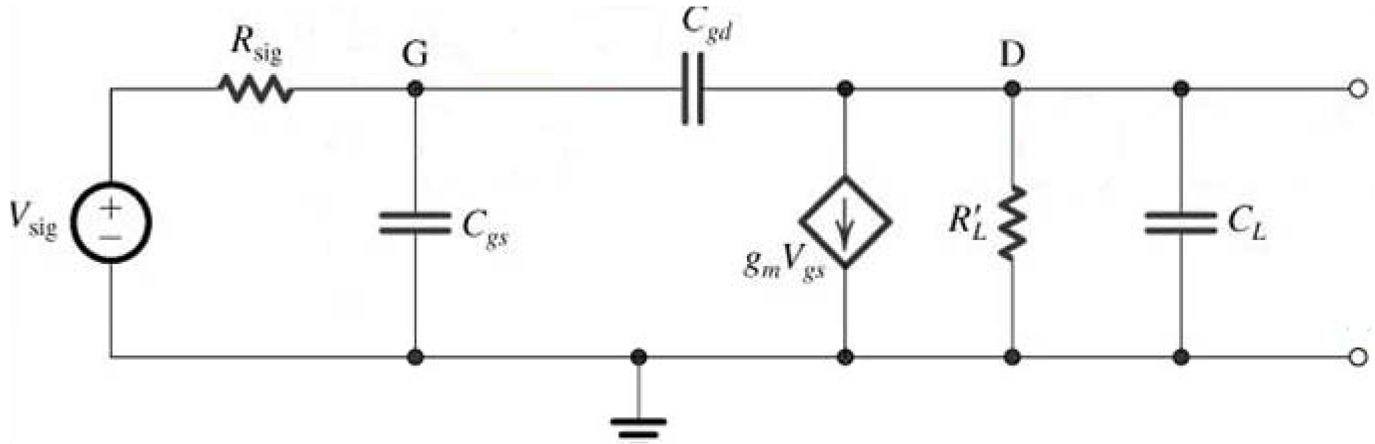
R_L= ?



(c)

R_L=R_L’

Lect. 24: High-Frequency Response of MOSFET CS



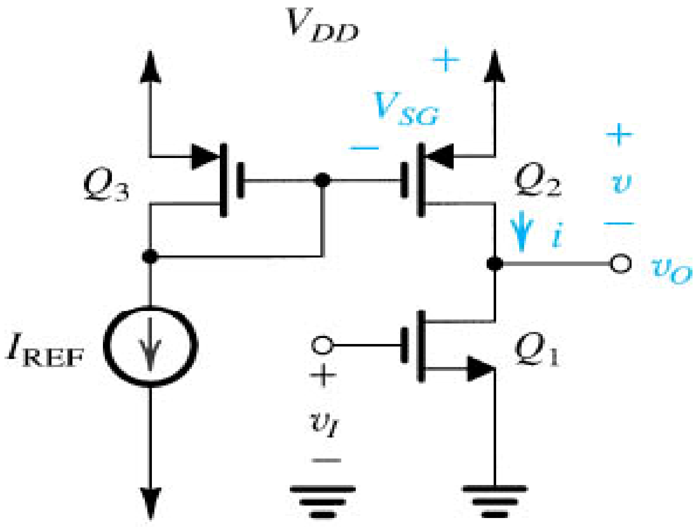
Open-Circuit Time Constant Method for approximating f_H

1. Select one capacitor, C_i, and set others to open.
2. Determine R_i, the resistance seen by C_i.
3. Repeat above for all capacitors.

$$\omega_H \sim \frac{1}{\sum_i C_i R_i} = \frac{1}{\tau_H}, \text{ where } \tau_H = C_{gs}R_{sig} + C_{gd}[R_{sig}(1+g_m R_L') + R_L'] + C_L R_L'$$

Miller Effect!

Lect. 24: High-Frequency Response of MOSFET CS



Determine f_H for the CS shown left.

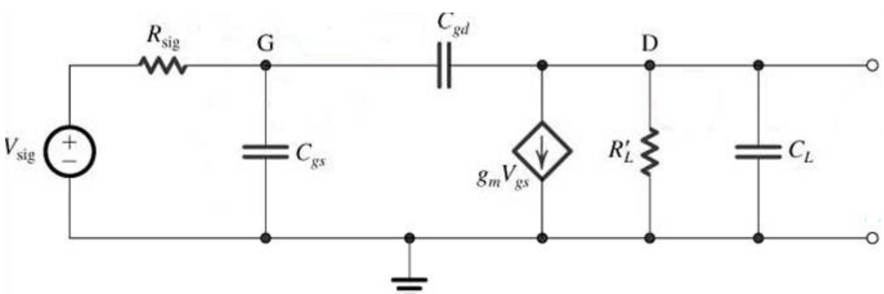
I_{REF}=100μA, W/L=7.2μm/0.36μm
k_n'=387μA/V², k_p'=86μA/V²,
r_{o1}=18kΩ, r_{o2}=22kΩ
C_{gs}=20fF, C_{gd}=5fF, C_L=25fF, R_{sig}=10kΩ.

It can be shown

$$R_{gs} = R_{sig} = 10\,\text{k}\Omega$$

$$R_{gd} = R_{sig}\left(1 + g_m R_L^{'}\right) + R_L^{'} = 142.8\,\text{k}\Omega$$

$$R_{C_L} = R_L^{'} = 9.82\,\text{k}\Omega$$



$$\tau_{gs} = C_{gs} R_{gs} = 200\,\text{ps}$$

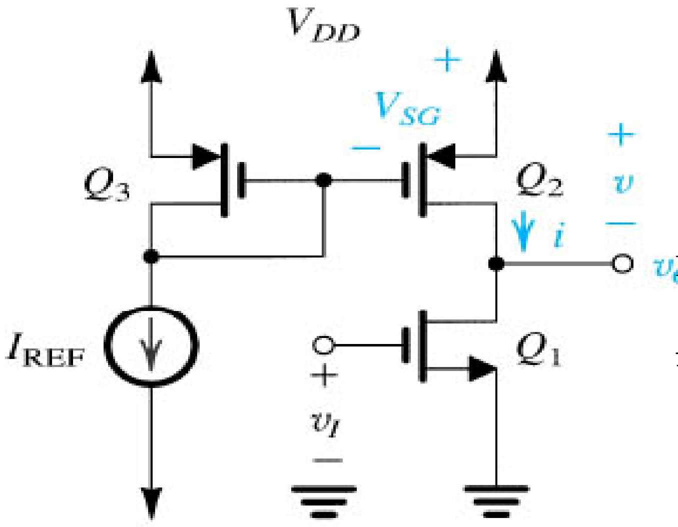
$$\tau_{gd} = C_{gd} R_{gd} = 714\,\text{ps}$$

$$\tau_{C_L} = C_L R_{C_L} = 246\,\text{ps}$$

$$\tau_H = \tau_{gs} + \tau_{gd} + \tau_{C_L} = 1160\,\text{ps}$$

$$f_H = \frac{1}{2\pi\tau_H} = \frac{1}{2\pi \times 1160 \times 10^{-12}} = 137\,\text{MHz}$$

Lect. 24: High-Frequency Response of MOSFET CS

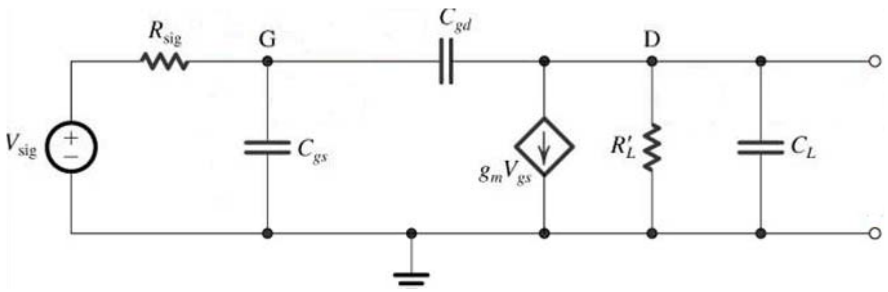


How accurate is f_H= 137MHz estimated by the open-circuit time constant method?

From the exact analysis,

$$\frac{V_o}{V_{sig}} = \frac{-(g_m R_L^{'})\left[1 - s(C_{gd}/g_m)\right]}{1 + s\left\{\left[C_{gs} + C_{gd}(1 + g_m R_L^{'})\right]R_{sig} + (C_L + C_{gd})R_L^{'}\right\} + s^2\left[(C_L + C_{gd})C_{gs} + C_L C_{gd}\right]R_{sig}R_L^{'}}$$

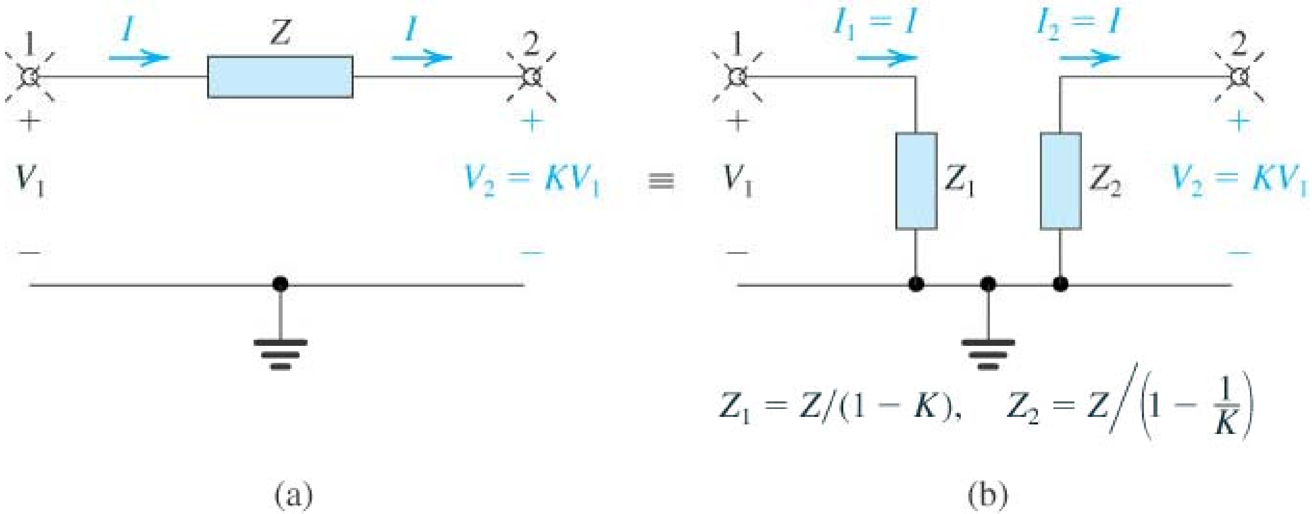
f_H = 145.3MHz



What is the most influential capacitor for f_H?

Lect. 24: High-Frequency Response of MOSFET CS

Miller's Theorem:
Two circuits below are identical assuming the rest of circuit does not change



$$I_1 = \frac{V_1}{Z_1} = I = \left(\frac{V_1 - KV_1}{Z}\right)$$

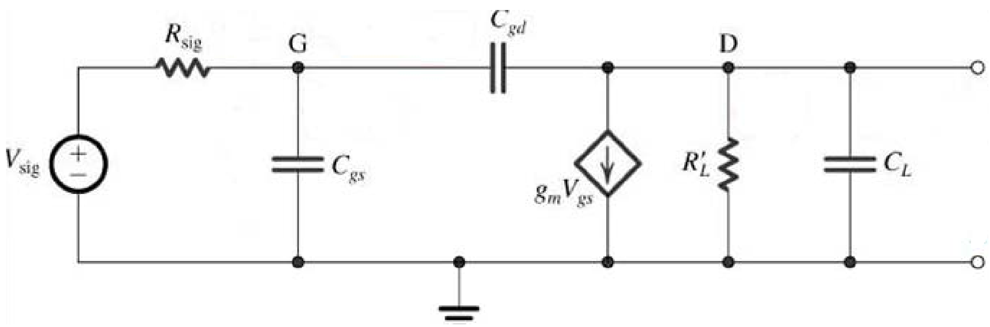
$$I_2 = \frac{0 - V_2}{Z_2} = \frac{0 - KV_1}{Z_2} = I = \frac{V_1 - KV_1}{Z}$$

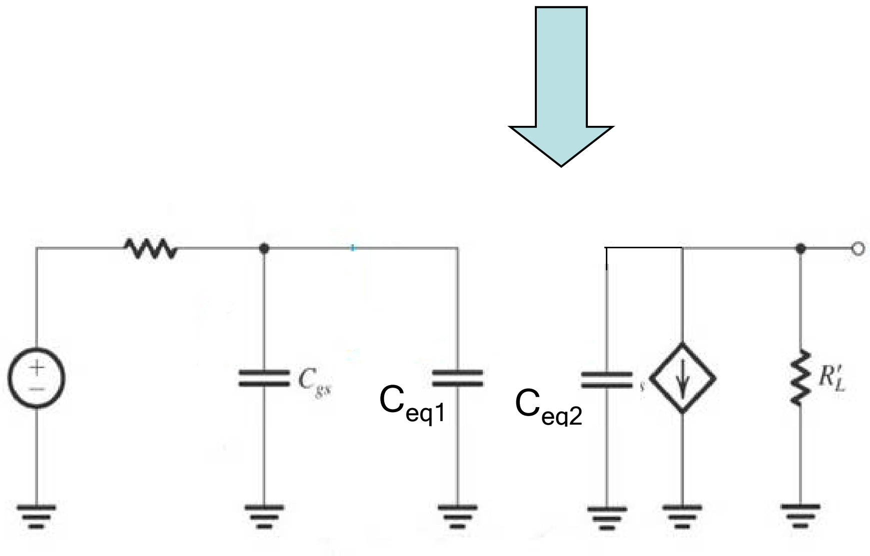
$$\therefore Z_1 = \frac{V_1 Z}{V_1 - KV_1} = \frac{Z}{1-K}$$

$$\therefore Z_2 = \frac{-KV_1 Z}{V_1 - KV_1} = \frac{Z}{(1-\frac{1}{K})}$$

Lect. 24: High-Frequency Response of MOSFET CS

CS amplifier





With Miller Theorem,

$$Z_1 = \frac{Z}{1-K}, \quad Z_2 = \frac{Z}{(1-\frac{1}{K})}$$

$$\frac{1}{sC_{eq1}} = \frac{1}{sC_{gd}} \frac{1}{1-K}$$

$$\therefore C_{eq1} = C_{gd}(1-K) = C_{gd}(1+g_m R_L')$$

$$\frac{1}{sC_{eq2}} = \frac{1}{sC_{gd}} \frac{1}{1-1/K}$$

$$\therefore C_{eq2} = C_{gd}(1-1/K) = C_{gd}(1+\frac{1}{g_m R_L'})$$

For f_H, the influence of C_{gd} becomes larger by factor of $(1+g_m R_L')$: Miller Effect

➔CS amplifier is slow!