4.8 The MOSFET Internal Capacitances and High-Frequency Model

Reading Assignment: *pp. 320-325*

Like the BJT, MOSFETs have internal **parasitic** capacitances that will ultimately limit amplifier bandwidth.

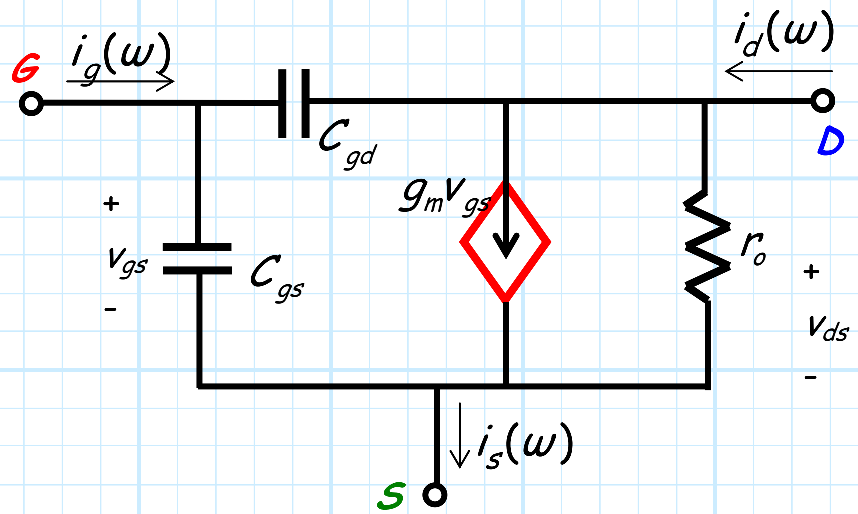
HO: The MOSFET High-Frequency Model

A measure of a MOSFETs "bandwith" is its **unity gain frequency**.

HO: MOSFET Unity Gain Frequency

The MOSFET High-Frequency Small-Signal Model

Combine the internal capacitances in a **modified** MOSFET small-signal model.



* Therefore use this model to construct small-signal circuit when v_i is operating at **high** frequency.

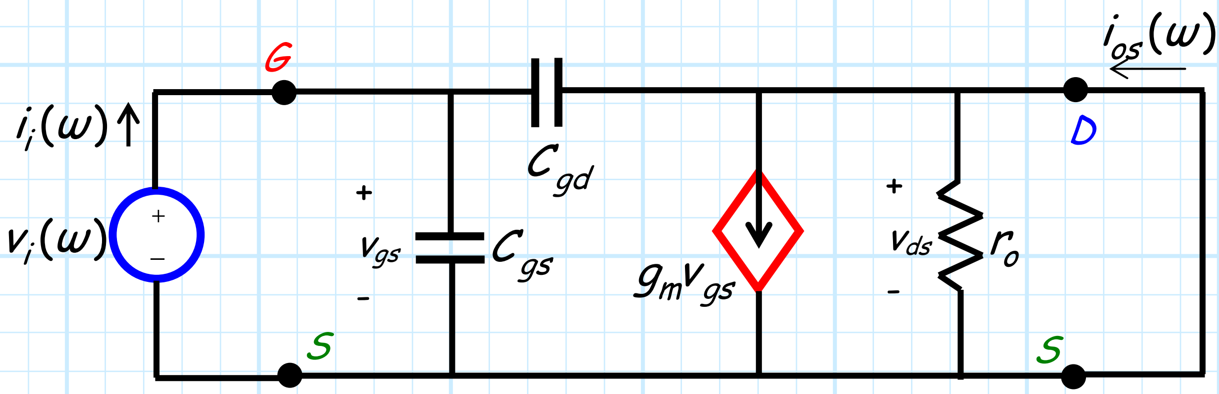
* Note since , all currents and voltages will be **dependent on operating frequency** ω.

* Note that at high frequencies, the gate current is **non-zero** (i.e., $i_g(\omega) \neq 0$)!!! Therefore, $i_d(\omega) \neq i_s(\omega)$.

* Note at low-frequencies, the model reverts to the **original** MOSFET small-signal model.

The MOSFET Unity Gain Frequency

Consider the **short-circuit current gain** of the high-frequency MOSFET small-signal model:



Note that because of the output short, $v_d = v_s$, so that $v_i = v_{gs} = v_{gd}$.

Therefore:

$$
\begin{aligned}
i_{os}(\omega) &= g_m v_{gs}(\omega) - j\omega C_{gd} v_{gd}(\omega) \\
&= g_m v_{gs}(\omega) - j\omega C_{gd} v_{gs}(\omega) \\
&= \left(g_m - j\omega C_{gd}\right) v_i(\omega)
\end{aligned}
$$

and

$$
\begin{aligned}
i_i(\omega) &= j\omega C_{gs} v_{gs}(\omega) + j\omega C_{gd} v_{gd}(\omega) \\
&= j\omega C_{gs} v_{gs}(\omega) + j\omega C_{gd} v_{gs}(\omega) \\
&= j\omega \left(C_{gs} + C_{gd}\right) v_i(\omega)
\end{aligned}
$$

The **short-circuit current gain** of the MOSFET is thus:

$$\begin{aligned}\frac{i_{os}}{i_i} &= \frac{\left(g_m - jwC_{gd}\right)v_i(\omega)}{jw\left(C_{gs}+C_{gd}\right)v_i(\omega)}\\ &= \frac{\left(g_m - jwC_{gd}\right)}{jw\left(C_{gs}+C_{gd}\right)}\\ &\approx \frac{g_m}{jw\left(C_{gs}+C_{gd}\right)}\end{aligned}$$

Note that this is **not** a **low-pass function**! Therefore, there is no "break" frequency associated with this frequency response.

However, there is a "**unity gain**" frequency ω_T—it's the frequency where the short-circuit current gain is equal to **one**:

$$\left|\frac{i_{os}(\omega=\omega_T)}{i_i(\omega=\omega_T)}\right| = 1 = \frac{g_m}{\omega_T\left(C_{gs}+C_{gd}\right)}$$

Therefore we find that the **unity-gain frequency** of a MOSFET is:

$$\omega_T = \frac{g_m}{C_{gs}+C_{gd}}$$

Note as the capacitances get **smaller**, the unity gain frequency gets **larger**. The unity gain frequency is a MOSFET **device parameter**—the larger the value, the better the MOSFET high frequency performance.