HIGH-FREQUENCY MODELS OF THE FET

- For high-frequency analysis, the relationships must be modified to include the following two effects:
    1. The JFET structure acts as a parallel plate capacitor when viewed from the gate and source terminals, with the gate and channel forming the two plates.
    2. The majority carriers require a finite transition time to cross the source to gate channel.
- The frequency-dependent components are: C_{gs} - gate-to-source capacitance, C_{gd} - gate-to-drain capacitance (sometimes called the overlap capacitance), and C_{ds} - drain-to-source capacitance. Since $C_{gs} >> C_{ds}$, C_{ds} can usually be ignored.
- The drain-source capacitance, C_{ds} , is small and therefore does not appreciably affect the high-frequency response of the FET. The two remaining capacitances can be modeled as voltage dependent capacitors with values determined by the following expressions:

$$C_{gs} = \frac{C_{gso}}{\left(1+\frac{|V_{GS}|}{\psi_o}\right)^m} \quad \text{and} \quad C_{gd} = \frac{C_{gdo}}{\left(1+\frac{|V_{GD}|}{\psi_o}\right)^m} \quad , \text{ where}$$

C_{gso}, C_{gdo} are the zero-bias gate-source and gate-drain junction capacitances, respectively, in Farads;
V_{GS}, V_{DS} are the quiescent gate-source and drain-source voltages, respectively;
m is the gate p-n grading coefficient (SPICE default = 0.5);
ψ_o is the gate junction (barrier) potential, typically 0.6 V (SPICE default = 1V).

- The frequency dependent elements for the MOSFET can be obtained in the same manner as the JFET.
- The capacitance formed by the oxide layer at the gate is defined as $C_{ox} = \frac{\epsilon_{ox} WL}{t_{ox}} = C'_{ox} WL$,

  where
  C_{ox} is the oxide capacitance formed by the gate and channel
  C'_{ox} is the oxide capacitance per unit area
  ϵ_{ox} is the permittivity of the oxide layer (silicon oxide -SiO_2: $3.9\epsilon_o$)
  t_{ox} is the thickness of the oxide layer (separation between the gate and channel)
  W, L are the width and the length of the channel under the gate, respectively.
- The permittivity of vacuum is, $\epsilon_o = 8.851\times 10^{-12}$ F/m. The oxide capacitance per unit area can be calculated from physical parameters:

$$C'_{ox} = \frac{1}{\mu}\left(\frac{2I_{DSS}}{V_{PO}^2}\right) \quad \text{, for depletion MOSFETs} \qquad (10.7\text{-}4a)$$

$$C'_{ox} = \frac{1}{\mu}(2K) \quad \text{, for enhancement MOSFETs,} \qquad (10.7\text{-}4b)$$

  where μ is the charge mobility (typically 600 cm^2/V-s for n-channel, 200 cm^2/V-s for p-channel.
- For a MOSFET operating in saturation, the relevant capacitances for the small-signal high-frequency model are, $C_{gs} = \frac{2}{3}C_{ox} + C_{gso} W$ (10.7-5)

and $C_{gd} = C_{gdo} W$, (10.7-6)

where C_{gso} ,C_{gdo} are the zero bias gate-source and gate drain capacitances, respectively (typically $C_{gso} = C_{gdo} = 3 \times 10^{-12}$ F/m), and are related to C'_{ox} .

- The capacitances in the high-frequency small-signal model of the MOSFET are relatively constant over the frequency range.
- ***Note also that the MOSFET zero bias capacitance has dimensions of F/m and in the JFET, it has units of F.***
- Although the values of the components are different, the JFET and MOSFET share the same small-signal model arrangement shown in Figure 10.7-1.

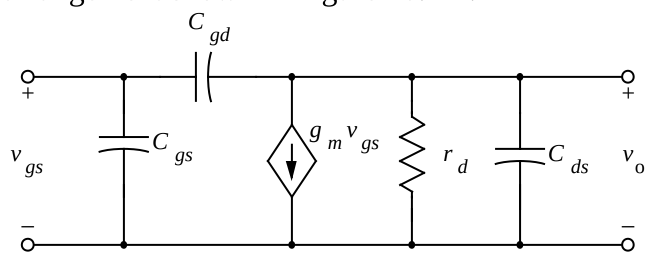

Figure 10.7-1. Accurate FET High-frequency Model

- Since C_{ds} is small compared to C_{gs}, the drain-source capacitance may be ignored in most analysis and design situations, and the simplified model shown in Figure 10.7-2 may be used.

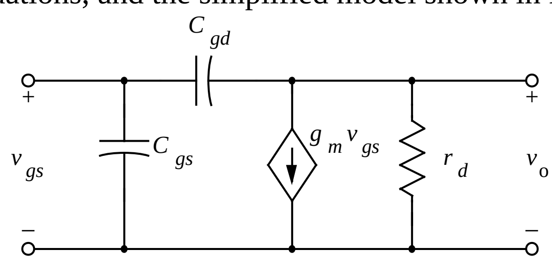

Figure 10.7-2. Simplified FET High-frequency Model

- Circuit parameters, at specific bias conditions, obtained from the manufacturers' data sheets is usually provided in terms of *y*-parameters: the common-source short-circuit input capacitance C_{iss} , reverse transfer capacitance C_{rss}, and output capacitance, C_{oss} are provided:

$$C_{gd} \approx C_{rss} \quad (10.7\text{-}7)$$

$$C_{gs} \approx C_{iss} - C_{rss} \quad (10.7\text{-}8)$$

$$C_{ds} \approx C_{oss} - C_{rss} \quad (10.7\text{-}9)$$

- The maximum operating frequency, ω_T , is the frequency at which the FET no longer amplifies the input signal: that is, the dependent current source $g_m v_{gs}$ is equal to the input current.

$$\omega_T = \frac{g_m}{\left(C_{gs} + C_{ds}\right)} \quad . \quad (10.7\text{-}10)$$

- In general, BJTs have higher maximum operating frequencies than FETs. Two factors are responsible for the lower frequency performance of FETs compared to BJTs:
  - ◊ For a given area and operating current, the g_m of silicon FETs are less than half of silicon BJTs.
  - ◊ In MOSFET structures, considerable capacitance is observed at the input due to the oxide layer. In JFETs, semiconductor properties and physical dimensions of the device result long channel lengths that reduce high-frequency performance.