From *Semiconductor Physics and Devices: Basic Principles* (4th Edition), Donald A. Neamen, McGraw Hill, 2012, ISBN 978-0-07-352958-5.

n-channel MOSFET

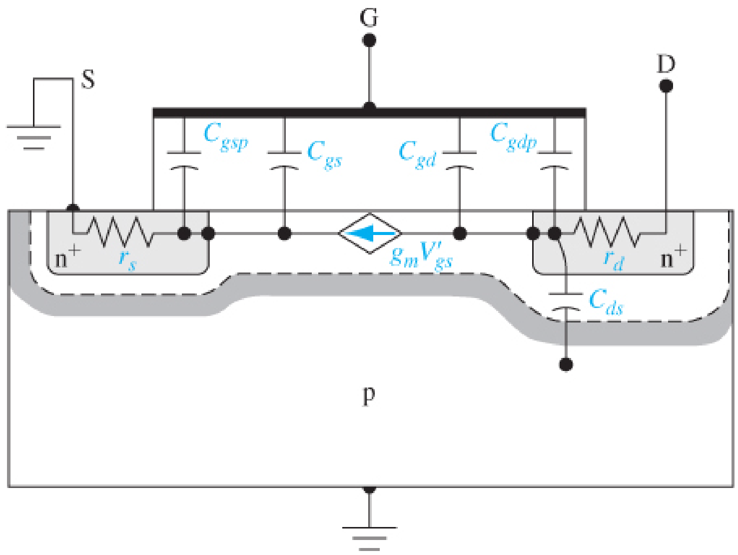

Figure 10.52 | Inherent resistances and capacitances in the n-channel MOSFET structure.

- Note that the body (B) and source (S) are both grounded (common-source).
- There are gate-source C_{gs} and gate-drain C_{gd} capacitances to represent the interaction between the gate and the channel charges on each end (D & S).
- In addition, there are <u>parasitic</u> gate-source C_{gsp} and gate-drain C_{gdp} capacitances due to manufacturing issues which cause gate oxide and the drain & source regions to overlap. $C_{gsp} = C_{ox}$ (gate-source overlap area) and $C_{gdp} = C_{ox}$ (gate-drain overlap area).
- There is a drain-to-substrate C_{ds} capacitance to represent the pn junction capacitance. [Not needed for source-to-substrate as they are both grounded.]
- The drain and source will have some series resistances, r_d and r_s.
- Lastly, we have the voltage-controlled current-source (VCCS) element, $g_m V_{gs}$', to represent the I-V relation of the MOSFET.
- The transconductance g_m was defined earlier.
- The internal gate-to-source voltage is V_{gs}' is what controls the current through the channel. It is the gate-to-source voltage less the voltage drop across the source resistance r_s.

Small-signal circuit model for common-source n-channel MOSFET

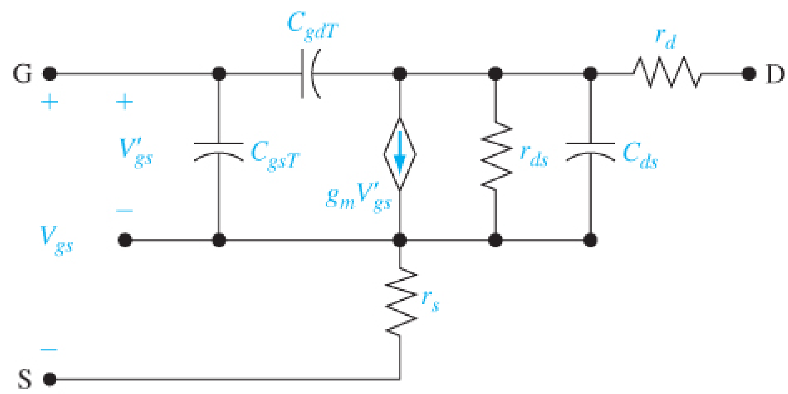

Figure 10.53 | Small-signal equivalent circuit of a common-source n-channel MOSFET.

- This small-signal model uses total gate-source $C_{gsT} = C_{gs} + C_{gsp}$ and total gate-drain $C_{gdT} = C_{gd} + C_{gdp}$ capacitances, i.e., combine regular and parasitic capacitances.
- Model adds a resistance r_{ds} to account for slope of MOSFET I-V curve. In saturation, $r_{ds} \to \infty$.
- For p-channel model, reverse voltage polarities and current directions.

Low frequency small-signal circuit models

- At low frequencies, the capacitors act like open circuits.
- Note that the impedance looking into the gate is infinite in both models.

Model 1

- Neglect r_s and r_d, but keep r_{ds}.

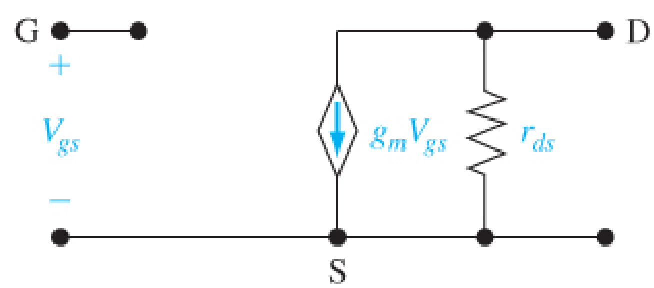

Figure 10.54 | Simplified, low-frequency small-signal equivalent circuit of a common-source n-channel MOSFET.

Model 2

- Neglect r_{ds} and r_d, but keep r_s.

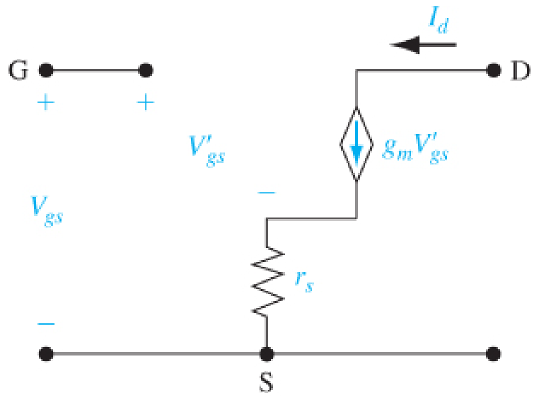

Figure 10.55 | Simplified, low-frequency small-signal equivalent circuit of common-source n-channel MOSFET including source resistance r_s.

- Here, $I_d = g_m V'_{gs}$.
- By KVL, $V_{gs} = V'_{gs} + I_d\, r_s = V'_{gs} + g_m V'_{gs}\, r_s = (1 + g_m\, r_s)\, V'_{gs}$.
- Combining these two equations, we get $I_d = \left(\dfrac{g_m}{1+g_m r_s}\right) V_{gs} = g_m' V_{gs}$ where

  $g_m' = \dfrac{g_m}{1+g_m r_s}$ is the effective transconductance which is less than g_m.