EE 204 - Analog Circuits
Lecture 17

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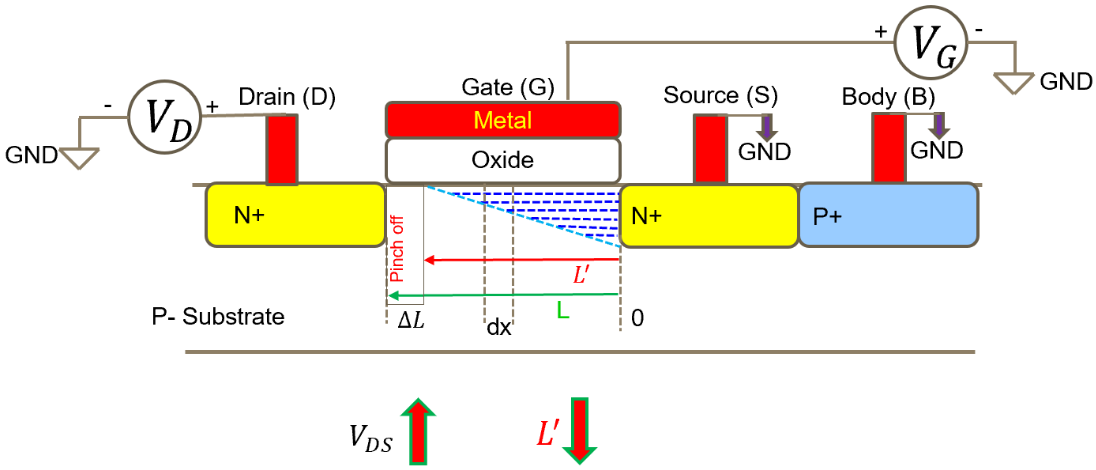
1 Channel Length Modulation Effect

Channel-length modulation, is a phenomenon that occurs in MOSFETs as a result of changes in the length of the conducting channel between the source and the drain terminals.

This effect has important implications for the behavior of MOSFETs, especially when they are used for amplification or switching applications.

When a voltage is applied to the gate to turn the MOSFET on, the channel between the source and the drain opens, and current flows through the channel. However, the channel length is not constant but can vary due to several factors, including manufacturing variations and applied voltages.



1.1 Effects of Varying Channel Length

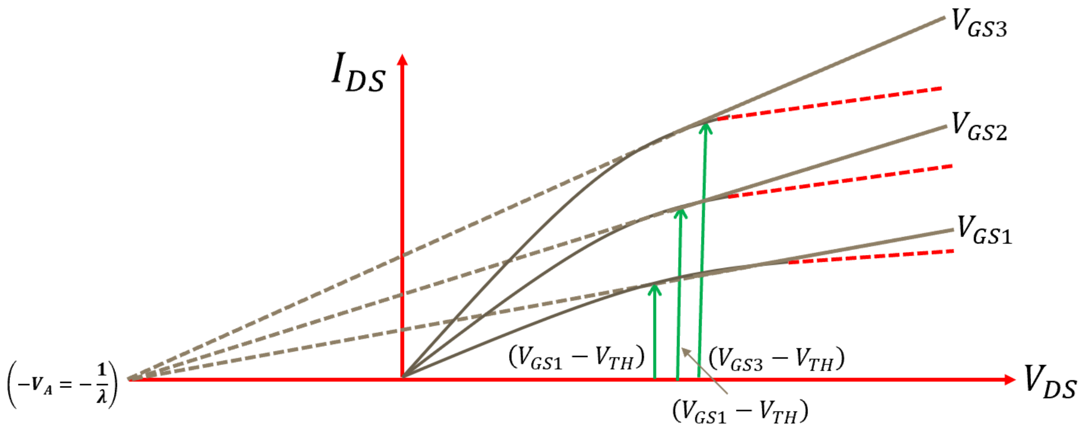
- **Voltage Dependence** : The channel length is influenced by the voltageacross the drain and source terminals (V_{DS}). When V_DS increases, the depletion region around the drain also increases, which effectively shortens the channel length
- **Impact on Output Characteristics** : The variation in channel length due to V_DS affects the output characteristics of the MOSFET. Specifically, it causes a change in the output current (I_{DS}) concerning V_{DS}.

The new I_{DS} that we get by solving with channel length modulation in consideration is the following:

$$I_{DS} = \frac{1}{2}\mu_n \frac{W}{L} C_{ox}(V_{GS} - V_{TH})^2(1 + \lambda\, V_{DS})$$

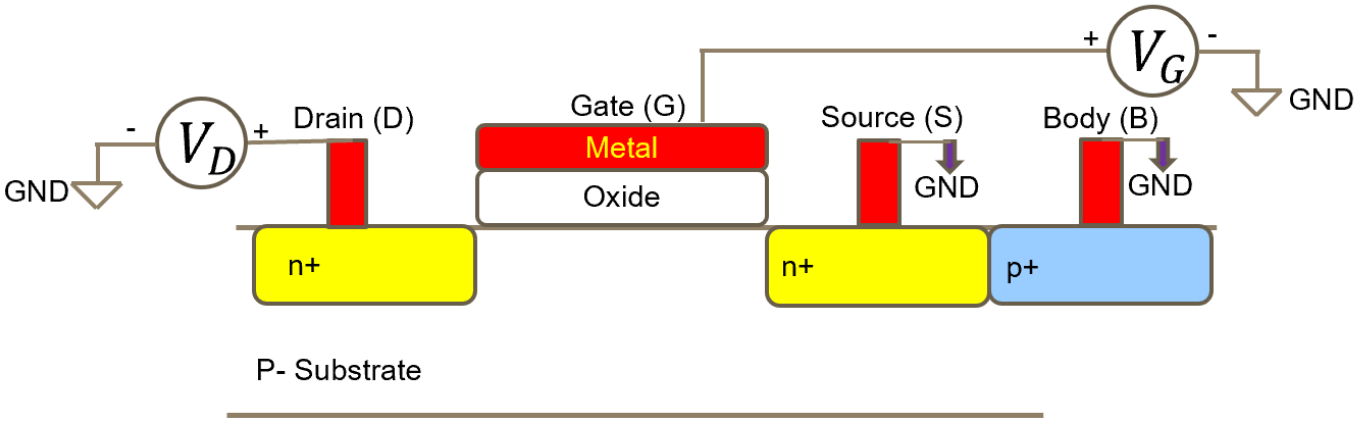
where, λ is the channel length modulation co-efficient.

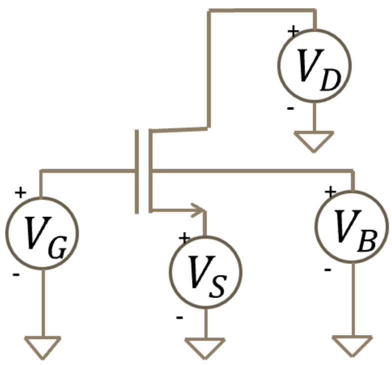
The new I_{DS} vs V_{DS} looks like the following:



2 Body Effect

In body effect, the MOSFET's body (backgate) acts like another gate thus affecting the channel potential.





In the representation diagram above, if V_{SB} increases, then we would require higher V_{GS} to invert the channel, thus leading to an increase in the threshold voltage (V_{TH}).

The expression for V_{TH} when backgate voltage is included is -

$$V_{TH} = V_{THo} + \gamma\left(\sqrt{|2\varphi_F + V_{SB}|} - \sqrt{|2\varphi_F|}\right)$$

where, γ is the body effect coefficient given by -

γ is a technology dependent parameter $\sim 0.3 - 0.4\sqrt{V}$

$$\gamma = \frac{\sqrt{2q\varepsilon_{si}N_{sub}}}{C_{ox}}$$

On decreasing V_{SB} (making it negative), V_{TH} decreases. Thus, V_{TH} can be reduced from V_{THo} by forward biasing $B - S$ junction. We also need to make sure that the current is limited after forward biasing the p-n junction (Bulk-Source).

3 Subthreshold Conduction

Effectively, even for $V_{GS} < V_{TH}$

- A finite current I_{DS} flows through the circuit
- There is an exponential dependence on V_{GS}

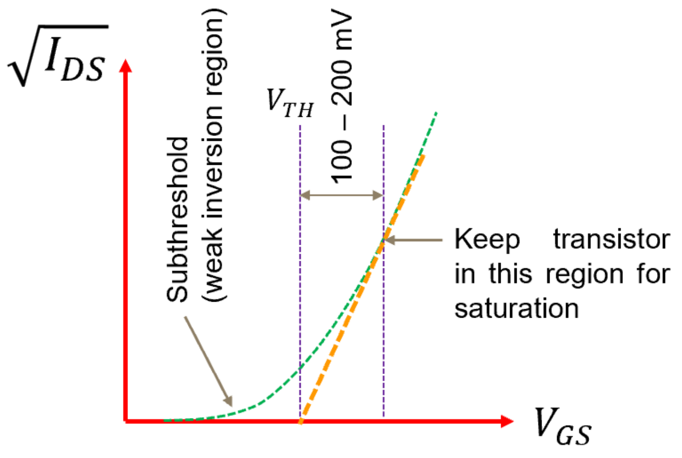
The relation between them comes out to be -

$$I_{DS} = I_o \exp\frac{V_{GS}}{\xi V_T}$$

where,

$$\xi > 1 \quad V_T = \frac{KT}{q}$$

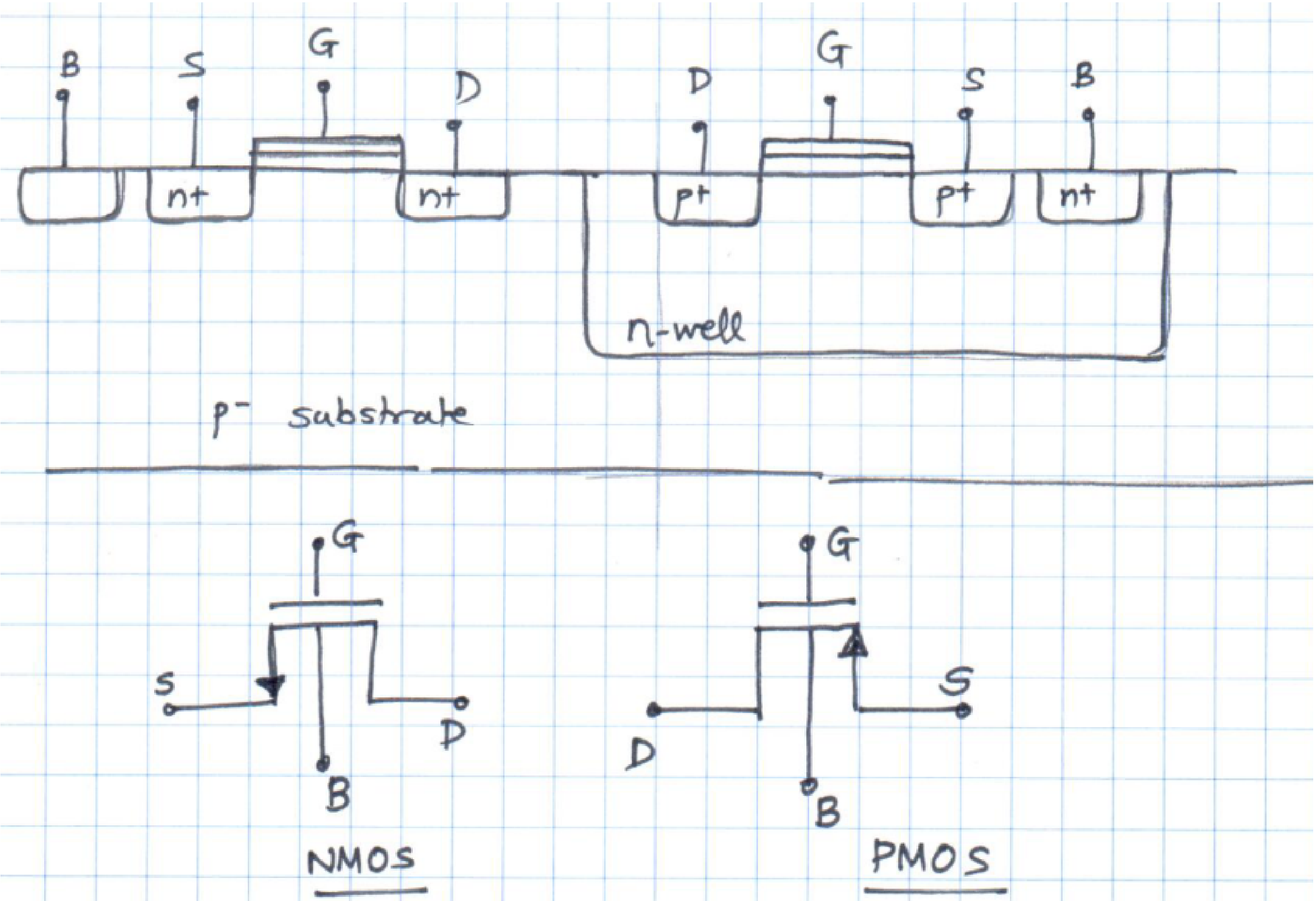
The curve is plotted between $\sqrt{I_{DS}}$ and V_{GS} which looks very similar to the I_C vs V_{BE} graph of BJT (Bipolar Transistor)



4 Large Signal Model

Large Signal behaviour is essentially modeling nonlinear devices in terms of the underlying nonlinear equations. This is a common analysis method used in electronic engineering to describe nonlinear devices.

In this case, we model a CMOS transistor in the Linear/Triode Region as well as the Saturation Region.



The above diagram represents the structure of a CMOS transistor.

The large signal behaviour is modeled using the following equations -

Linear / Triode region, $V_{SD} < (V_{SG} - |V_{THP}|)$

$$I_{SD} = \mu_p \frac{W}{L} C_{ox} (V_{SG} - |V_{THP}|)V_{SD} - \frac{{V_{SD}}^2}{2}$$

Saturation region, $V_{SD} > (V_{SG} - |V_{THP}|)$

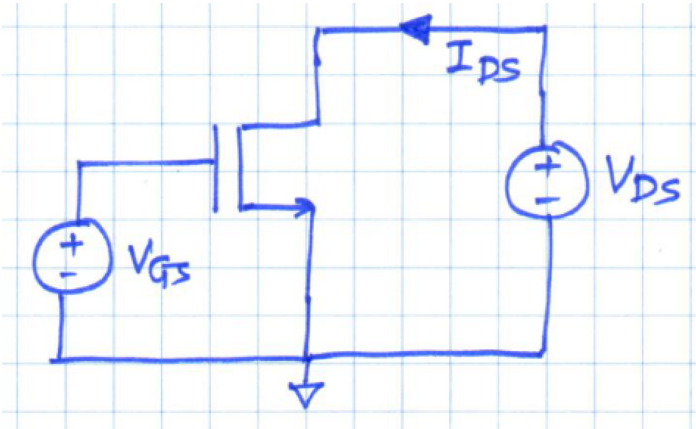
$$I_{SD} = \mu_p \frac{W}{L} C_{ox} (V_{SG} - |V_{THP}|)^2 (1 + \lambda_p V_{SD})$$

5 Small Signal Model

Small-signal modeling is a common analysis technique used to approximate the behavior of nonlinear devices with linear equations. It is applicable to circuits in which the AC signals (i.e., the time-varying currents and voltages in the circuit) are small relative to the DC bias currents and voltages.

A small-signal model is thus an AC equivalent circuit.

The circuit that we begin with in this case is -



In saturation region, changing V_{GS} brings a change in I_{DS}. Thus, it is natural to include transconductance (g_m) in the discussion.

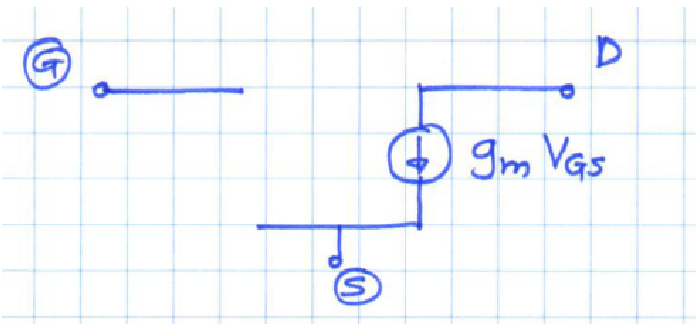
On calculating the expressions for g_m using I_{DS} and V_{GS}, we get the following three equivalent forms -

$$g_m = \frac{\partial I_{DS}}{\partial V_{GS}} = \frac{2I_{DS}}{(V_{GS} - V_{TH})}$$

$$g_m \cong \mu_n \frac{W}{L} C_{ox} (V_{GS} - V_{TH})$$

$$g_m \cong \sqrt{2\mu_n \frac{W}{L} C_{ox} I_{DS}}$$

The first small signal model looks like the following -



On calculating the output resistance which is connected across Drain-Source and parallel to the current source between them, we get

$$r_o = \frac{1}{\lambda I_{DS}}$$

And since we know, for large L the value of λ is smaller and hence resulting in an increase in the value of r_o.

Therefore, we have understood and analysed the large and small signal models in the case of CMOS.