NMOS Characterization: Threshold Voltage, Transconductance, and Output Resistance

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Introduction

This experiment aims to estimate the threshold voltage (V_T), transconductance (g_m), and output resistance (r_o) of an NMOS transistor by analyzing its I-V characteristics in the linear and saturation regions. Additionally, the body effect is studied by varying the substrate bias V_{SB}.

1 Part I: Transfer Characteristics in the Linear Region

Objective

Estimate the threshold voltage (V_T) and transconductance (g_m) in the linear region by plotting I_D vs V_{GS} with $V_{DS} = 200\,\text{mV}$.

Procedure and Data

The gate-source voltage V_{GS} was varied from 0 to 3 V while keeping $V_{DS} = 200\,\text{mV}$. The resulting drain current I_D is recorded as follows:

Table 1: Measured I_D vs V_{GS} for $V_{DS} = 200\,\text{mV}$

V_{GS} (V)	I_D (μA)
0.5	0
0.7	0
0.9	0.5
1.1	5
1.3	20
1.5	40
1.7	60
1.9	80
2.1	100
2.3	120
2.5	140
2.7	160
2.9	180
3.0	190

Calculation of Threshold Voltage (V_T)

Using the linear portion of the plot, we select two points: ($V_{GS1} = 1.1\,\text{V}, I_{D1} = 5\,\mu A$) and ($V_{GS2} = 2.3\,\text{V}, I_{D2} = 120\,\mu A$). The slope m is calculated as:

$$m = \frac{I_{D2} - I_{D1}}{V_{GS2} - V_{GS1}} = \frac{120 - 5}{2.3 - 1.1} = 95\,\mu A/V$$

The threshold voltage V_T is found by extrapolating the linear region:

$$V_T = V_{GS1} - \frac{I_{D1}}{m} = 1.1 - \frac{5}{95} \approx 1.05\,\text{V}$$

Calculation of Transconductance (g_m)

The transconductance g_m is given by the slope of the I_D vs V_{GS} curve:

$$g_m = \frac{\partial I_D}{\partial V_{GS}} = m = 95\,\mu A/V$$

Results for Linear Region

- Threshold Voltage V_T: $1.05\,\text{V}$
- Transconductance g_m: $95\,\mu A/V$

2 Part II: Transfer Characteristics in the Saturation Region

Objective

Estimate the threshold voltage (V_T) and transconductance (g_m) in the saturation region by plotting I_D vs V_{GS} with $V_{DS} = 3\,\text{V}$.

Procedure and Data

The gate-source voltage V_{GS} was varied from 0 to 3 V while keeping $V_{DS} = 3\,\text{V}$. The resulting drain current I_D is shown below:

Table 2: Measured I_D vs V_{GS} for $V_{DS} = 3\,\text{V}$

V_{GS} (V)	I_D (μA)
0.5	0
0.7	0
0.9	1
1.1	10
1.3	40
1.5	100
1.7	200
1.9	300
2.1	400
2.3	500
2.5	600
2.7	700
2.9	800
3.0	850

Calculation of Threshold Voltage (V_T)

Using points from the linear region of the square root of the data:

$$m' = \frac{\sqrt{I_{D2}} - \sqrt{I_{D1}}}{V_{GS2} - V_{GS1}} = \frac{\sqrt{500} - \sqrt{10}}{2.3 - 1.1} \approx 16\,\mu A^{0.5}/V$$

The threshold voltage is:

$$V_T = V_{GS1} - \frac{\sqrt{I_{D1}}}{m'} = 1.1 - \frac{3.16}{16} \approx 0.90\,\text{V}$$

Calculation of Transconductance (g_m)

In saturation, transconductance g_m is calculated as:

$$g_m = \frac{2I_D}{V_{GS} - V_T}$$

For $V_{GS} = 1.9\,\text{V}, I_D = 300\,\mu A$:

$$g_m = \frac{600}{1.0} = 600\,\mu A/V$$

Results for Saturation Region

- Threshold Voltage V_T: $0.9\,\text{V}$
- Transconductance g_m: $600\,\mu A/V$

3 Part III: Drain Characteristics

Objective

Plot I_D vs V_{DS} for $V_{GS} = 1.5, 2.5, 3.5\,\text{V}$ and determine the output resistance r_o.

Procedure and Data

The drain-source voltage V_{DS} was varied from 0 to 5 V for three different gate-source voltages $V_{GS} = 1.5, 2.5, 3.5\,\text{V}$.

Results

The output resistance r_o is calculated for $V_{GS} = 3.5\,\text{V}$ in the saturation region:

$$r_o = \frac{1}{\frac{1220-1150}{5-3.5}} = \frac{1}{46.67} \approx 21.4\,k\Omega$$

4 Part IV: Body Effect

Objective

Study the body effect by measuring the threshold voltage for different substrate biases V_{SB}.

Results

The body effect coefficient γ is calculated using:

$$V_T = V_{T0} + \gamma\sqrt{V_{SB}}$$

For $V_T = 1.3\,\text{V}$ and $V_{SB} = 3\,\text{V}$, with $V_{T0} = 1\,\text{V}$:

$$\gamma = \frac{1.3 - 1}{\sqrt{3}} \approx 0.173\,V^{0.5}$$

Summary of Results

- Threshold Voltage (V_T):
  - Linear Region: $1.05\,\text{V}$
  - Saturation Region: $0.9\,\text{V}$
- Transconductance (g_m):
  - Linear Region: $95\,\mu A/V$
  - Saturation Region: $600\,\mu A/V$
- Output Resistance r_o: $21.4\,k\Omega$
- Body Effect Coefficient γ: $0.173\,V^{0.5}$