Extracting Threshold Voltage and Transconductance from NMOS VI Characteristics

1 Introduction

This document outlines the step-by-step procedure to extract the threshold voltage (V_{th}) and transconductance (g_m) of an NMOS transistor from its VI characteristics.

2 Step-by-Step Procedure

2.1 Step 1: Plot I_D vs V_{GS} for Linear Region

We have measured the drain current (I_D) for different gate-to-source voltages (V_{GS}) at a fixed drain-to-source voltage ($V_{DS} = 0.1\,\mathrm{V}$). The data is as follows:

Table 1: Linear Region Data ($V_{DS} = 0.1\,\mathrm{V}$)

V_{GS} (V)	I_D (μA)
0.5	0
0.7	0
0.9	0
1.1	5
1.3	20
1.5	35
1.7	50
1.9	65
2.1	80
2.3	95

2.2 Step 2: Determine V_{th} in the Linear Region

The threshold voltage V_{th} is found by extrapolating the linear part of the I_D vs V_{GS} curve.

- Select two points from the linear region:

$$\text{Point 1: } V_{GS1} = 1.1\,\text{V},\ I_{D1} = 5\,\mu\text{A},$$
$$\text{Point 2: } V_{GS2} = 2.3\,\text{V},\ I_{D2} = 95\,\mu\text{A}.$$

- Calculate the slope m:

$$m = \frac{I_{D2} - I_{D1}}{V_{GS2} - V_{GS1}} = \frac{95\,\mu A - 5\,\mu A}{2.3\,\text{V} - 1.1\,\text{V}}$$
$$= 75\,\mu A/\text{V}.$$

- The threshold voltage V_{th} is:

$$V_{th} = V_{GS1} - \frac{I_{D1}}{m} = 1.1\,\text{V} - \frac{5\,\mu A}{75\,\mu A/\text{V}}$$
$$= 1.033\,\text{V}.$$

Thus, $V_{th} \approx 1.03\,\text{V}$ in the linear region.

2.3 Step 3: Calculate g_m in the Linear Region

Transconductance g_m is the slope of the linear portion:

$$g_m = m = 75\,\mu A/\text{V}.$$

Alternatively, using $g_m = kV_{DS}$:

$$k = \frac{g_m}{V_{DS}} = \frac{75\,\mu A/\text{V}}{0.1\,\text{V}} = 750\,\mu A/\text{V}^2.$$

2.4 Step 4: Plot I_D vs V_{GS} for Saturation Region

Next, we measure I_D at $V_{DS} = 2\,\text{V}$. The data is as follows:

Table 2: Saturation Region Data ($V_{DS} = 2\,\text{V}$)

V_{GS} (V)	I_D (μA)
0.5	0
0.7	0
0.9	0
1.1	2
1.3	8
1.5	18
1.7	32
1.9	50
2.1	72
2.3	98

2.5 Step 5: Determine V_{th} in the Saturation Region

We use the $\sqrt{I_D}$ vs V_{GS} plot to find V_{th}. Calculate $\sqrt{I_D}$:

Table 3: $\sqrt{I_D}$ for Saturation Region

V_{GS} (V)	I_D (μA)	$\sqrt{I_D}$ ($\mu A^{0.5}$)
1.1	2	1.414
1.3	8	2.828
1.5	18	4.243
1.7	32	5.657
1.9	50	7.071
2.1	72	8.485
2.3	98	9.899

By selecting two points, we calculate the slope m':

$$m' = \frac{\sqrt{I_{D_B}} - \sqrt{I_{D_A}}}{V_{GS_B} - V_{GS_A}} = \frac{9.899 - 2.828}{2.3 - 1.3} = 7.071\,\mu A^{0.5}/\mathrm{V}.$$

Using this, we find:

$$V_{th} = V_{GS_A} - \frac{\sqrt{I_{D_A}}}{m'} = 1.3\,\mathrm{V} - \frac{2.828}{7.071} = 0.9\,\mathrm{V}.$$

Thus, $V_{th} \approx 0.9\,\mathrm{V}$ in the saturation region.

2.6 Step 6: Calculate g_m in the Saturation Region

The transconductance in the saturation region is calculated using:

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

For $V_{GS} = 1.9\,\mathrm{V}$ and $I_D = 50\,\mu A$:

$$g_m = \frac{2 \times 50\,\mu A}{1.0\,\mathrm{V}} = 100\,\mu A/\mathrm{V}.$$

3 Summary

The threshold voltage and transconductance are as follows:

- V_{th} (Linear Region): $1.03\,\mathrm{V}$
- V_{th} (Saturation Region): $0.9\,\mathrm{V}$
- g_m (Linear Region): $75\,\mu A/\mathrm{V}$
- g_m (Saturation Region): $100\,\mu A/\mathrm{V}$