Lab 5: Hands-On AC Analysis of NMOS Transistors

EECS 170LB

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Roman Parise (59611417)
Johnathan Fritsche (11106947)
Jason Wang (42873192)

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Lab TA: Dmitry Oshmarin

1 Introduction

In this lab, an AC analysis of a common source amplifier with an NMOS transistor and a passive load is performed. The circuit used for both sections of this lab is shown in figure 1.

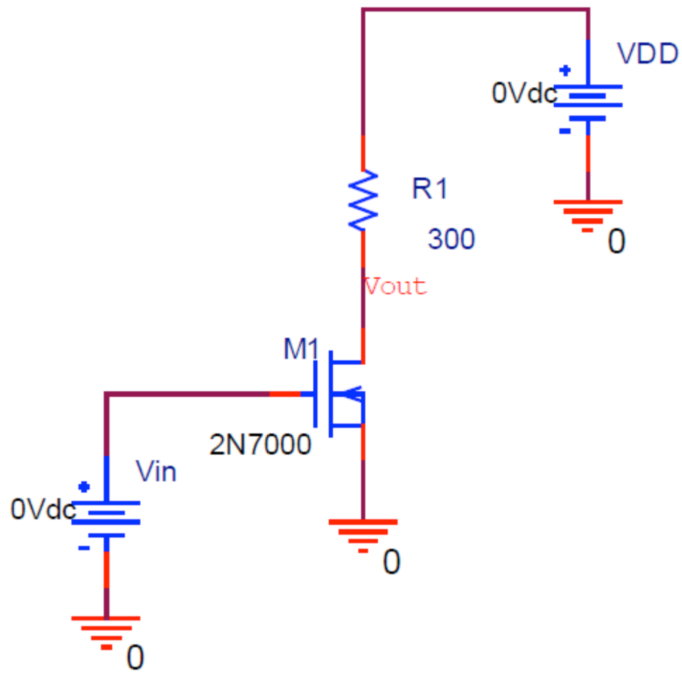

Figure 1: The Common Source NMOS Amplifier with a Passive Load

The voltage transfer characteristic is acquired. From the curve, the optimal bias point and threshold voltage are determined. The MOSFET's transconductance, amplifier bias current, and the gain of the amplifier are then acquired. They are compared to the theoretical values.

2 Voltage Transfer Curve

2.1 Procedure

For the circuit shown in figure 1, the X-Y mode of the oscilloscope is used to find and display the voltage transfer curve. The value of the resistor is $R = 295.3\Omega$. The power supply uses an over-current protection of $200mA$ and a supply voltage $V_{dd} = 10V$. The function generator uses a sine wave with $V_{offset} = 5V$ and a peak-to-peak voltage $V_{pp} = 10V$. The output frequency is set to $f = 100Hz$. This acts as V_{in} on the reference circuit from figure 1.

2.2 Results

With the X-Axis corresponding to V_{in} and the Y-Axis corresponding to V_{out}, the resulting VTC graph is presented in figure 2. From this graph, the threshold voltage is $V_{tn} \approx 2.0V$. This is consistent with the provided values in the manufacturer's data sheet that lists the threshold voltage in the range from $0.8V \leq V_{tn} \leq 3.0V$.

The optimal biasing point is when $V_{in} = 2.556V$. This produces an output voltage of $V_{out} = 4.875V$.

When the frequency of the AC input signal is lowered from $f = 100Hz$ to $f = 1Hz$, the voltage transfer line is no longer continuous when viewed on the oscilloscope. There is only one "dot" which moves back and forth along the same path as the original curve, but very slowly. The only reason the curve at $100Hz$ appears to be continuous is because the "dot" moves back and forth at a very high speed. The "dot" really represents a point (V_{in}, V_{out}), which oscillates like a sine wave at the prescribed frequency. At $1Hz$, the dot moves slowly enough to observe its motion, but appears to just be a continuous curve at $100Hz$.

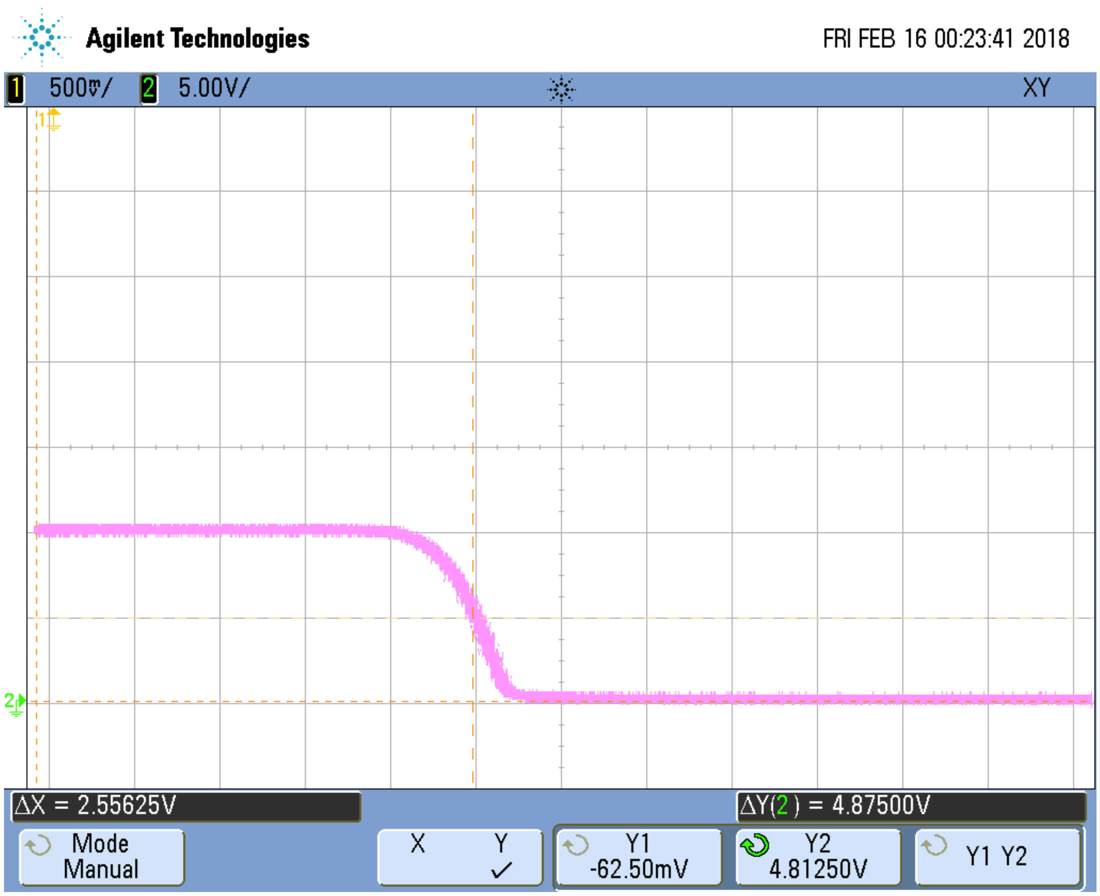

Figure 2: Oscilloscope Output for Voltage Transfer Curve Figure 1 Circuit

3 Common Source Amplifier

3.1 Procedure

The input source of the circuit in figure 1 is set to a $50mVpp$ sinusoid with a $1kHz$ frequency. The sinusoidal input signal is offset by $2.5V$ DC, after making necessary adjustments to the bias point found in the previous portion of the experiment. The oscilloscope is set to measure time-domain signals to find the amplitude of the output signal. The gain of the amplifier is then calculated from the measurements and is compared to the theoretical result.

3.2 Results

The DC bias current I_D of the amplifier is found using the values found for V_{DD}, V_{out}, and R in the previous section.

$$I_D = \frac{V_{DD} - V_{out}}{R} = \frac{10V - 4.875V}{295.3\Omega} = 17.4mA \tag{1}$$

The theoretical transconductance g_m of the amplifier can be calculated using the given transconductance parameter k_n of $80mA/V$ and the I_D found in equation 1.

$$g_m = \sqrt{2k_n I_D} = \sqrt{2(80mA/V^2)(17.4mA)} = 52.8mA/V \tag{2}$$

The theoretical open loop gain A_{vo} of the amplifier can then be found using the transconductance g_m.

$$A_{vo} = -g_m R = -(52.8mA/V)(295.3\Omega) = -15.6V/V \tag{3}$$

$$gain\ in\ dB = 20log(|-15.6|) = 23.9dB \tag{4}$$

The following input and output voltages are measured using the oscilloscope.

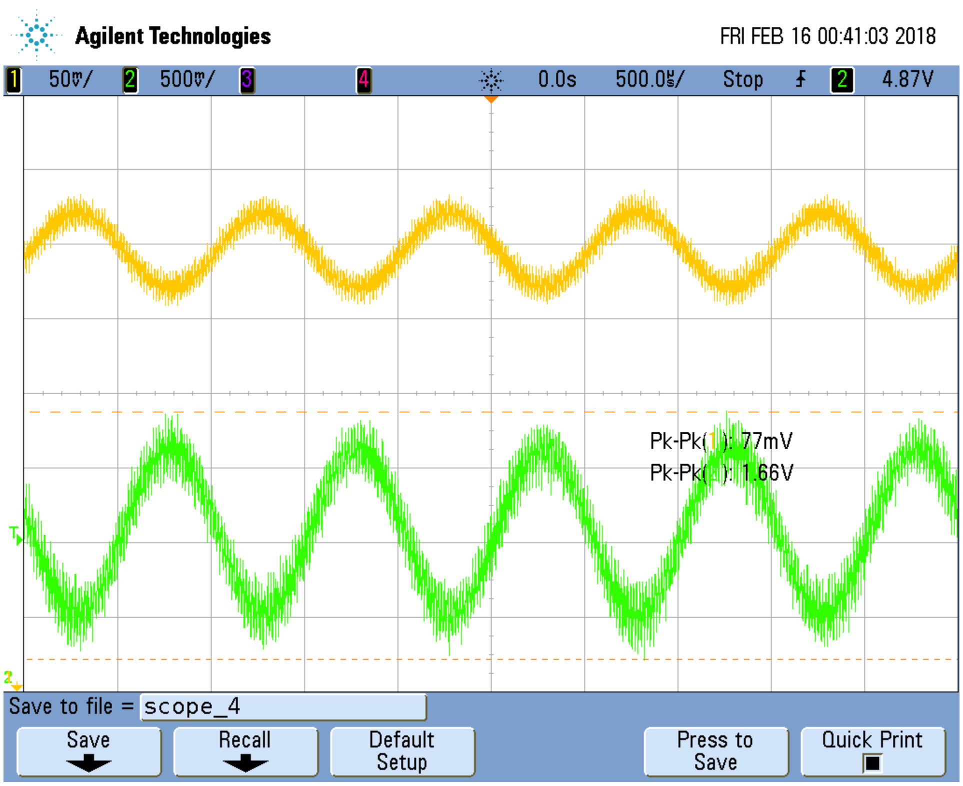

Figure 3: Input and Output Voltages Measured

From figure 3, the measured peak-to-peak amplitudes of V_{in} and V_{out} are $77mVpp$ and $-1.66Vpp$, respectively. The peak-to-peak amplitude of the input signal measured from the oscilloscope will be used instead of the ideal $50mVpp$ value set on the function generator because the signals measured on the oscilloscope account for noise, loading effects, and other nonidealities in the waveforms. The values found in figure 3 are used to calculate the measured gain of the amplifier.

$$A_{vo} = -\frac{V_{out}}{V_{in}} = \frac{-1.66V}{0.077V} = -21.6V/V \tag{5}$$

$$gain\ in\ dB = 20log(|-21.6|) = 26.7dB \tag{6}$$

The percent error of the measured and theoretical gains are found using the following equation:

$$error\ in\ amplitude\ gain = -|\frac{(-21.6) - (-15.6)}{-15.6}| * 100\% = 38\% \tag{7}$$

$$error\ in\ dB\ gain = -|\frac{26.7dB - 23.9dB}{23.9dB}| * 100\% = 12\% \tag{8}$$

The measured gain and theoretical gain are in the same order of magnitude and the measured gain in dB is close to the theoretical value. Therefore, the measured results show that the theoretical model of the MOSFET is adequate in predicting experimental behavior.

4 Conclusion

4.1 Voltage Transfer Curve

The voltage transfer curve of the common-source amplifier closely aligns with the results predicted by theory, namely the inverting properties of the amplifier and the clamping of the output near V_{DD} and ground. The optimal bias point is chosen to be in the middle of the curve since this is where the output swing is maximized and high linearity is achieved. The threshold voltage is also acquired by observing where the transistor exits cutoff, evident from the point at which the voltage transfer curve begins to decrease.

4.2 Common-Source Amplifier with Passive Load

Various small-signal properties of the common-source amplifier circuit are ascertained in the experiment. The measured gain differs from theoretical results, but lies within the same order of magnitude as the theoretical gain. Thus, the MOSFET and amplifier models used are somewhat reliable. Theoretical results have difficulty accounting for manufacturing and environmental variations in the components. Therefore, a truly reliable analysis is difficult to achieve.