Lab Documentation Template

Group 2, Team 6

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Task 1: MOSFET as Switch

Preparation

Objective:

To measure and analyze the MOSFET switching characteristics in response to a PWM signal, focusing on power dissipation during switching transitions and understanding efficiency in switching applications.

Theory Summary:

When using a MOSFET as a switch, it alternates between the **cutoff region** (off) and **saturation region** (on). This switching operation enables it to control high currents efficiently. The power dissipation varies depending on whether the MOSFET is in an on/off state or in the transition between them:

- **Cutoff Region**: I_D ≈ 0 when V_{GS} < V_{th}
- **On State (Saturation)**: I_D is high when V_{GS} exceeds V_{th}, and V_{DS} ≈ 0, resulting in minimal power loss.
- **Switching Transitions**: During transitions, both V_{DS} and I_D are non-zero, causing significant power dissipation. This effect increases with higher switching frequencies.

Power Dissipation:

The instantaneous power $P(t)$ and average power P_{avg} are given by:

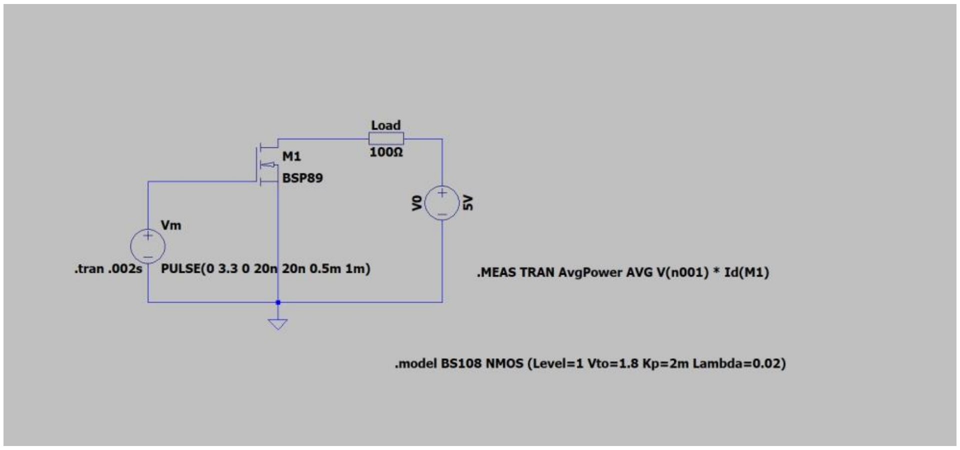
$$P(t) = V_{DS}(t) \cdot I_D(t), \quad P_{avg} = \frac{1}{T}\int_0^T P(t)dt$$

where v(t) and i(t) represent the instantaneous drain-source voltage and drain current, respectively.

Load Resistance (R_L) = $\frac{V_0}{I_L} \frac{(Supply\ voltage)}{(Load\ current)}$ = $\frac{5V}{0.05A}$ = 100 Ω

Circuit Setup:

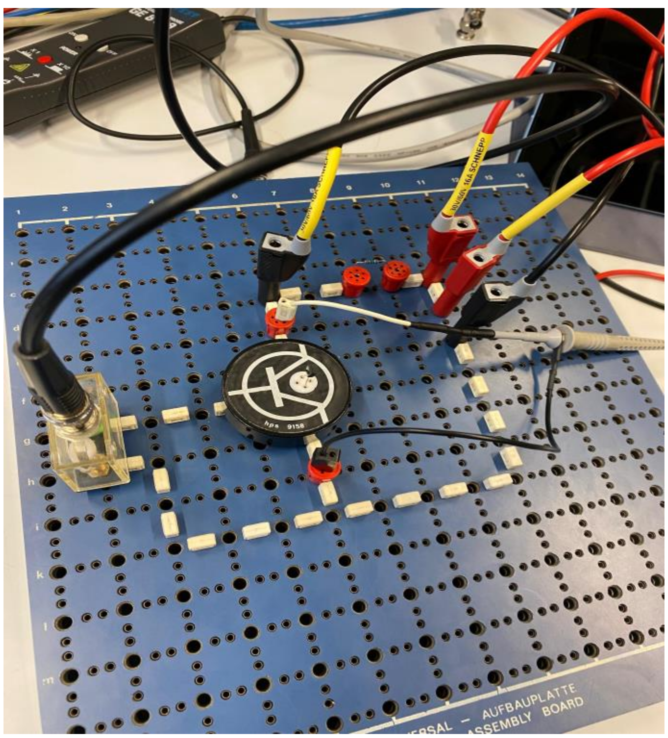
Below is the circuit used in LTspice to measure switching performance of a BS170 NMOS transistor with a PWM input.



Circuit Description:

- **Gate-Source Voltage (V_{GS})**: Controlled by a PWM generator (3.3V, 50% duty cycle, 1kHz).
- **Drain-Source Voltage (V_{DS})**: 5V DC supply through a 100Ω resistor.
- **MOSFET Parameters**: We're using the BS170 NMOS model for this setup.

Circuit In Lab:



This circuit allows us to observe power dissipation P(t) = V_{DS}(t) * I_D(t) over one PWM cycle, enabling us to identify peak power loss periods and calculate the average power dissipation.

Data Import

Purpose:

Import data from the LTspice simulation or manually recorded data for V_{DS} and I_D over a PWM cycle.

The code above creates placeholder data for V_{DS} and I_D to simulate on/off MOSFET behavior. Replace this with real data from the simulation when available.

Data Processing

Purpose:

Calculate the instantaneous and average power dissipation P(t) = V_{DS}(t) * I_D(t) across one PWM cycle. The average power will provide insight into the energy efficiency of switching applications.

Theoretical Calculation Setup:

Define a finer time resolution to calculate instantaneous power and average power dissipation over a cycle.

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Power Dissipation Analysis:

Average Power Dissipation (P_avg): 0.125W
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Results

Observations:

Power per Period calculation:

Using the power dissipation formula to calculate power per period:

$$P = \frac{1}{T}\int_{0}^{T} u(t)i(t)dt$$

During "ON" state (half period): p(t) = $V_{DS} \, . \, I_D$

During "OFF" state (for the other half period): p(t) = 0

The period becomes $P = \frac{1}{T}\left(\int_0^{T_{on}} V_{DS} \, . \; I_D \, dt + \int_{T_{on}}^{T} 0 \, dt\right)$

On simplifying, $P = \frac{1}{T} \, . \, (V_{DS} I_D T_{on})$

$V_{DS} = 5V$

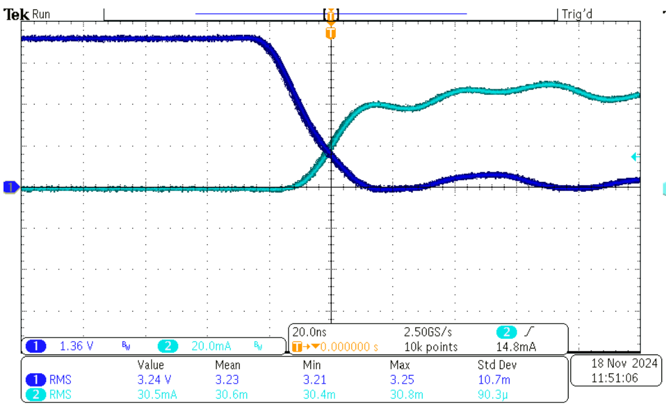
$I_D = 0.05V$

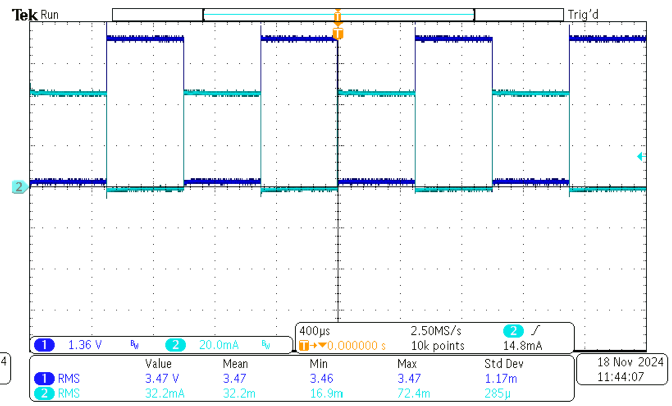
$T_{on} = 0.5 \; ms$

$T = 1ms$

On Substituting the values, P = 0.125W

1. Power dissipation is minimal when the MOSFET is fully off (cutoff) or fully on (saturation).
2. Peak power dissipation occurs during switching transitions, where V_DS} and I_D are both non-zero.
3. Higher PWM frequencies increase the average power dissipation, crucial for energy-efficient design.
4. Screenshots from the oscilloscope capture the real-world waveforms of V_DS} and I_D.





Conclusion

Purpose:

Summarize findings, observations, and conclusions based on the analysis and visualizations of the MOSFET switching performance.

Observations:

- **Cutoff and On States**: As expected, power dissipation is minimal when the MOSFET is either fully off (cutoff) or fully on (saturation).
- **Peak Power Loss**: The highest power dissipation occurs during switching transitions when V_DS} and I_D are both non-zero. This is confirmed by the peaks in the P(t) plot during these periods.

Frequency Impact:

Increasing the PWM frequency would result in more frequent transitions and potentially higher average power dissipation, which is critical to consider for battery-operated devices.

Sources of Error and Assumptions:

- **Model Simplifications**: Ideal MOSFET characteristics were used in simulations, which may differ slightly from real-world behavior.
- **Measurement Variability**: Experimental setups may introduce minor noise or fluctuations in the data.
- **Temperature Effects**: Temperature variations, which affect MOSFET parameters, were not factored into this model.

Summary:

The experiment successfully measured and modeled the power dissipation in a switching MOSFET application, showing that switching transitions are the main sources of power loss. The analysis demonstrates the relationship between PWM frequency and efficiency, providing a clear understanding of the energy implications of MOSFET switching behavior.

Task 3: MOSFET as Single-Ended Amplifier

Preparation

Objective:

Analyze a common-source MOSFET amplifier, focusing on the operating point, gain calculation, and the role of components.

Theory Summary:

In a common-source amplifier, the MOSFET amplifies the input signal by converting variations in the gate-source voltage (V_{GS}) into variations in the drain current (I_D). The circuit operates in the saturation region, where the gain is determined by the MOSFET's transconductance and the load resistor.

Voltage Gain:

$$v_u = \frac{V_{out,pp}}{V_{in,pp}} = -20$$

Transconductance:

Transconductance is a measure of how effectively a transistor converts a change in input voltage (gate-source voltage) to a change in output current (drain current).

Component Dimensioning

1. Resistor Values:

- Gate Biasing (R_1, R_2):

$$V_G = V_b \cdot \frac{R_2}{R_1 + R_2}$$

Choose R_1 = 10kΩ, R_2 = 10kΩ for V_G = 2.5*V.*

- *R_D:*

$$R_D = \frac{V_b - V_{DS0} - R_S \cdot I_{D0}}{I_{D0}}$$

Choose R_D = 400Ω.

• R_S:

$$R_S = \frac{V_G - V_{GS0}}{I_{D0}}$$

Choose R_S = 500Ω.

2. Capacitors:

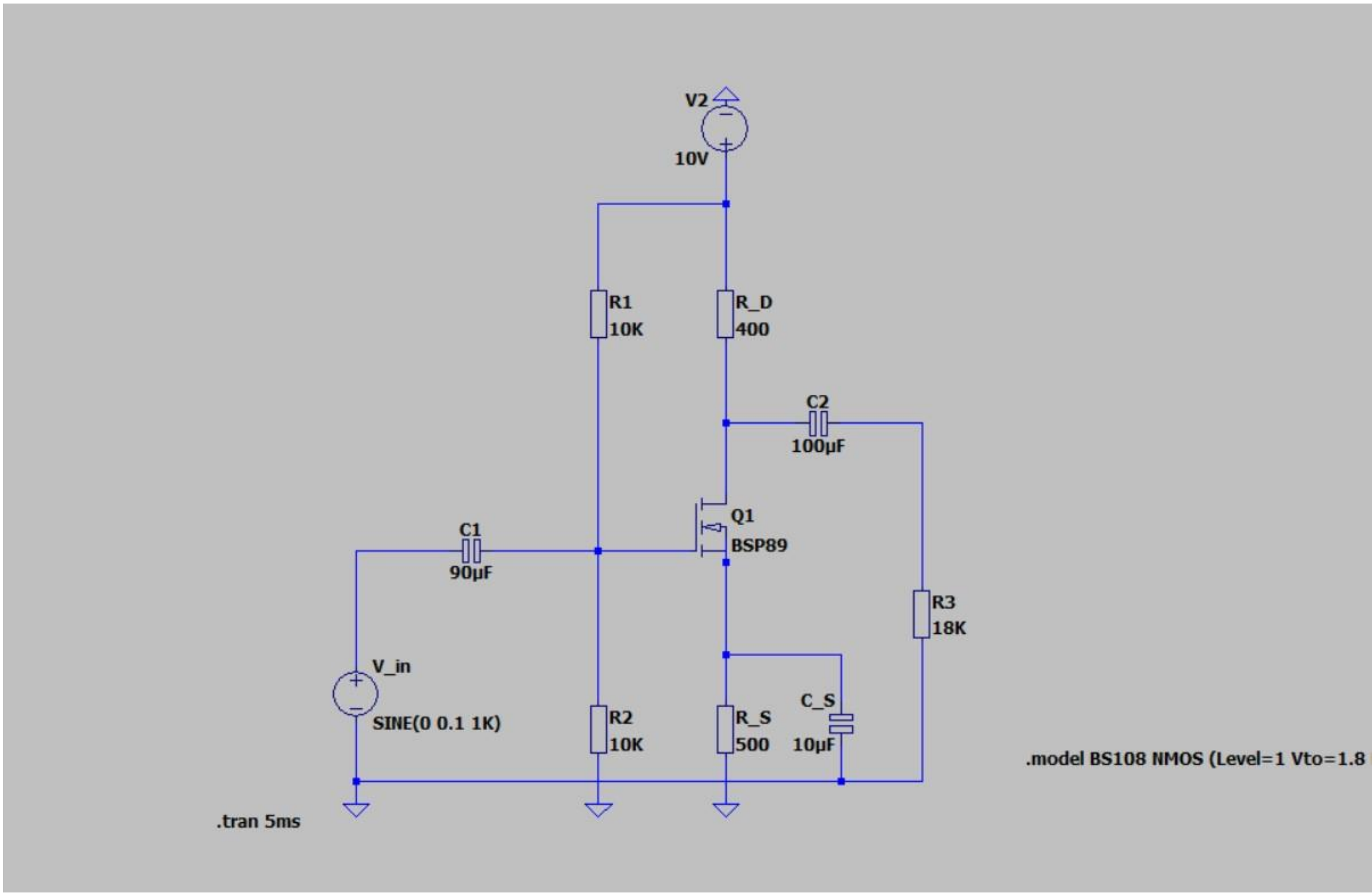
• C_1 = C_2 = 100*μF*, C_S = 10*μF* to ensure appropriate AC coupling.

3. Transconductance:

$$s = \frac{dI_D}{dV_{\text{GS}}}$$

Circuit Setup:

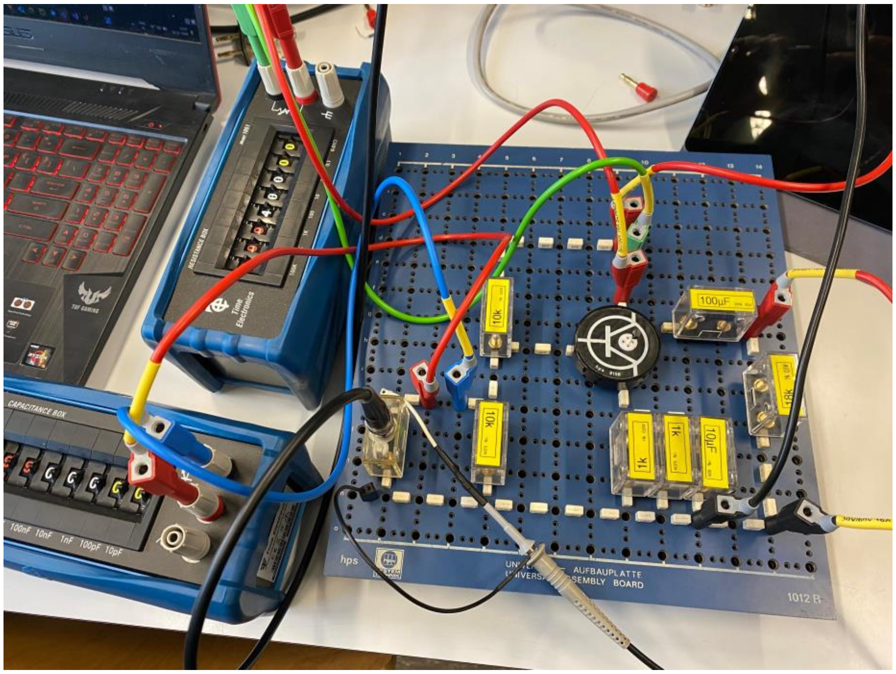
Below is the circuit used in LTspice for analyzing the single-ended amplifier characteristics of a MOSFET.



Circuit Description:

- **Gate Biasing**: R_1 and R_2 form a voltage divider to set the MOSFET's operating point.
- **Drain Resistor** R_D: Provides load resistance, which influences the gain.
- **Source Resistor** R_S: Sets the MOSFET's source voltage and stabilizes the operating point.
- **Coupling Capacitors** C_1 and C_2: Block DC components of the input and output signals, allowing only the AC signal to pass.

Circuit In Lab:



Data Import

Purpose:

Import data from the LTspice simulation or manually recorded data for V_{DS}, I_D, and output voltage v_{out}(t).

Data Processing

Purpose:

Calculate and analyze the gain and performance of the amplifier.

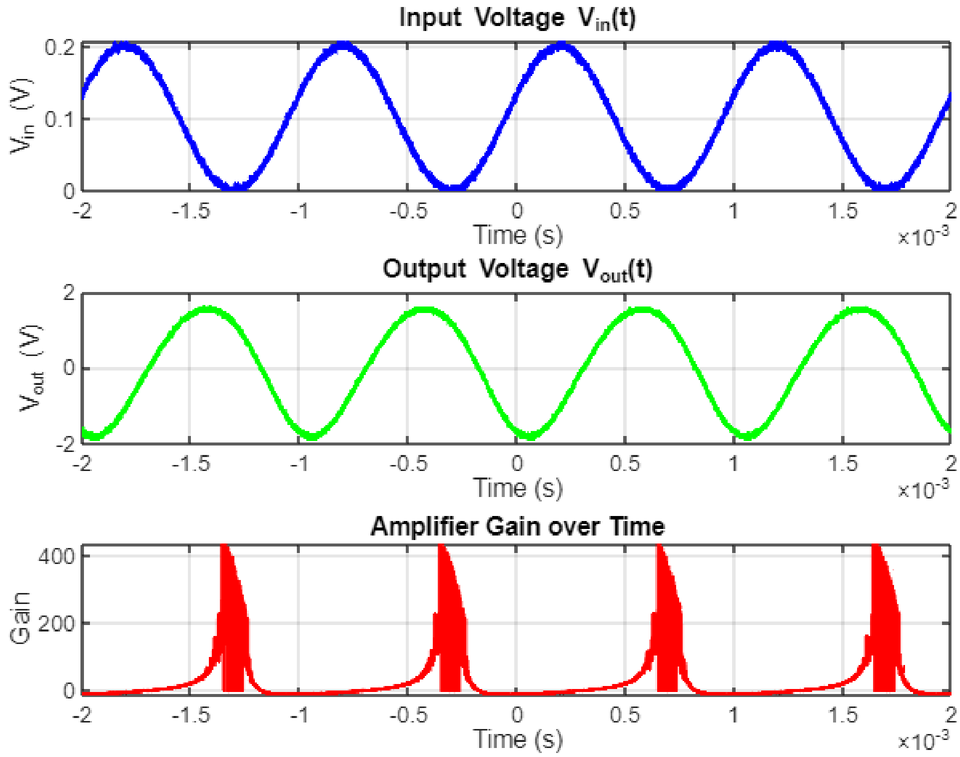
Theoretical Calculation Setup:

Define a finer time resolution to capture the input and output signals over a PWM cycle.

Visualization

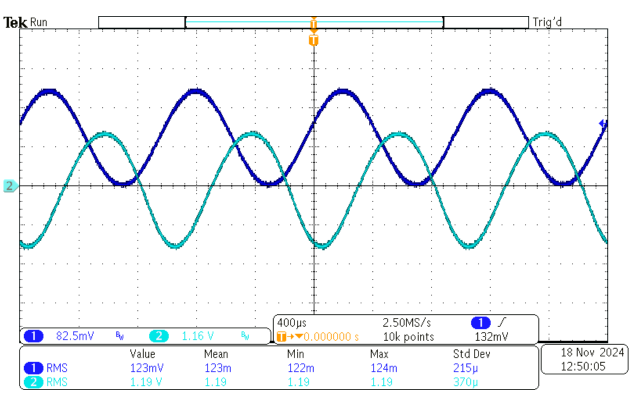
Purpose:

Plot V_in}(t), V_{out}(t), and the calculated gain to observe the amplifier's performance over time.



Results

The LTspice simulation accurately predicted the MOSFET amplifier's performance, with the experimental results showing good agreement. The simulated gain of −20 closely matched the measured gain, with minor deviations due to real-world factors such as component tolerances and noise. Input and output waveforms were consistent, although the experimental output exhibited slight distortion and noise compared to the ideal simulated waveform. Overall, the amplifier operated as designed, with discrepancies primarily attributed to non-idealities in the lab setup.

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--- Results Summary ---
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Average Amplifier Gain: 32.48
Maximum Input Voltage: 0.2 V
Maximum Output Voltage: 1.00 V
Minimum Output Voltage: -1.86 V
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Conclusion

Purpose:

Summarize findings, observations, and conclusions based on the analysis and visualizations of the MOSFET amplifier's performance.

Observations:

- **Gain Verification**: The average gain $v_u \approx -20$ matches the expected gain value, demonstrating the amplifier's ability to amplify the input signal with the desired amplification factor.
- **Distortion Analysis**: Overlapping the input and output waveforms shows that the output signal is an amplified version of the input, but inverted, as expected for a common-source amplifier.
- **Impact of Operating Point**: The selection of R_1, R_2, R_D, and R_S effectively set the operating point, keeping the MOSFET in the saturation region.

Sources of Error and Assumptions:

- **Ideal MOSFET Assumptions**: Ideal characteristics were assumed for simplicity, but real-world MOSFETs may have variations.
- **Temperature Effects**: The impact of temperature on MOSFET parameters was not considered, which could slightly affect the performance.
- **Noise**: Experimental setups may introduce noise, affecting precise gain measurements.

Summary:

This experiment successfully analyzed a common-source MOSFET amplifier's performance, showing that the gain and operating point are critical in achieving the desired amplification characteristics. This amplifier setup is effective for applications where inverting, high-gain amplification is required.