University of Technology, Sydney

Faculty of Engineering and Information Technology

Subject: **48521 Fundamentals of Electrical Engineering**

Assessment Number: **4**

Assessment Title: **Lab 4 – MOSFET Amplifier**

Tutorial Group:

Students Name(s) and Number(s)

Student Number	Family Name	First Name

Declaration of Originality:

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Statement of Collaboration:

Signature(s)

Marks

Lab work	/1
Analysis	/2
Questions	/2
TOTAL	/5

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key

Assessment Submission Receipt

Assessment Title:	**Lab 4 – MOSFET Amplifier**
Student's Name:	
Date Submitted:	
Tutor Signature:	

Lab 4 – MOSFET Amplifier

MOSFET characteristic. Common-source amplifier.

Introduction

The MOSFET can be operated in a number of regions. In the saturation region, the device is used to amplify signals. In the cutoff and saturation regions it behaves like a switch. There is also the triode region where the transistor behaves like a variable resistor. We will examine the saturation region.

The MOSFET's output characteristic will be measured using a curve tracer. The AC parameters of the MOSFET can then be accurately evaluated. A comparison of the measured results and a theoretical analysis can then be made.

The MOSFET will be biased using the voltage-divider technique. The DC conditions of the circuit will be measured so we know the transistor's operating point (whether it is in the cutoff, triode or saturation region).

We will then construct a common-source amplifier, measure the voltage gain, and then examine the effect of varying the circuit's configuration.

Objectives

1. To measure a MOSFET's output characteristic, and to obtain the small-signal AC parameters for use in modelling the MOSFET.

2. To build and test a MOSFET common-source amplifier, and to compare experimental results with that predicted by theory.

L4.2

Equipment

- 1 Digital Storage Oscilloscope (DSO) – Hewlett Packard HP54621A
- 1 function generator (FG) – GFG-8016G or GFG-8020G or GFG-8016D
- 1 curve tracer (CT) – Goodwill GCT-1212A
- 1 digital multimeter – GW GDM-8045G or GW GDM-8135
- 1 x 2N7000 n-channel enhancement MOSFET
- 1 x 750 kΩ resistor
- 1 x 240 kΩ resistor
- 1 x 10 kΩ resistor
- 1 x 7.5 kΩ resistor
- 1 x 2.4 kΩ resistor
- 1 x 1 kΩ resistor
- 1 x 820 Ω resistor
- 1 x 100 Ω resistor
- 1 x 62 Ω resistor
- 2 x 4.7 μF capacitors
- 1 x 47 μF capacitor
- 1 Breadboard
- Hook-up wire
- 2 x 4mm to BNC leads

Safety

Cat. A lab

This is a Category A laboratory experiment. Please adhere to the Category A safety guidelines (issued separately).

Theory

Common-Source MOSFET Amplifier Circuit

A common-source MOSFET amplifier is illustrated in Figure L4.1 (a) below, together with its AC equivalent circuit.

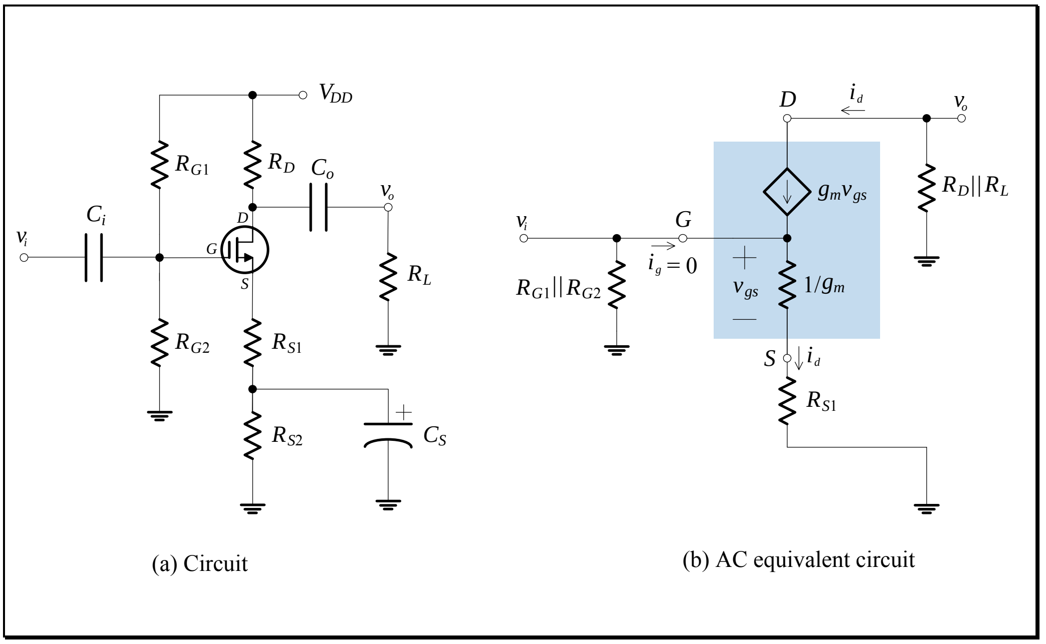


Figure L4.1

The bias establishes the proper DC operating conditions for the transistor. The DC parameters are analyzed first, then the AC parameters for the amplifier can be evaluated. The equivalent AC circuit is shown in Figure L4.1 (b). The capacitors appear to be an AC short. Thus, the AC equivalent circuit does not contain R_{S2}. Using superposition, V_{DD} is replaced with a short, placing it at AC common. Therefore R_D and R_L appear in parallel.

L4.4

Analysis Steps

1. The DC bias conditions need to be determined to find I_D, V_{GS} and V_{DS}.

2. Replace all capacitors with a short and place V_{DD} at AC common. Compute the AC transconductance of the MOSFET, g_m, from the equation:

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

3. Compute the amplifier's voltage gain. Voltage gain is the ratio of the output voltage divided by the input voltage. The input voltage is across the AC source resistance of the MOSFET, which is $1/g_m$, in series with R_{S1}. The output voltage is taken across the AC resistance from drain to common. For the circuit in Figure L4.1 (b), the output voltage divided by the input voltage can be written:

$$A_v = \frac{v_o}{v_i} = \frac{-i_d\left(R_D \parallel R_L\right)}{i_d\left(1/g_m + R_{S1}\right)} = \frac{-\left(R_D \parallel R_L\right)}{1/g_m + R_{S1}}$$

Notice that voltage gain from gate to drain is simply *the ratio of the total resistance in the drain*, $\left(R_D \parallel R_L\right)$, *to the total resistance in the source*, $\left(1/g_m + R_{S1}\right)$.

The open-circuit voltage gain is obtained by setting $R_L = \infty$:

$$A_{vo} = -\frac{R_D}{1/g_m + R_{S1}}$$

4. Compute the total input resistance seen by the AC signal:

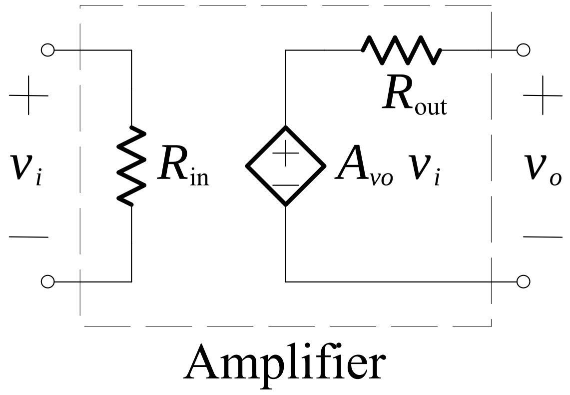
$$R_{\text{in}} = R_{G1} \parallel R_{G2}$$

Notice that the AC resistance of the source circuit is not seen when "looking into" the gate, since $i_g = 0$.

5. Compute the total AC output resistance:

$$R_{\text{out}} = R_D$$

6. The AC small-signal equivalent circuit of the amplifier can now be derived:



Lab Work [1 mark]

MOSFET Characteristic

To examine the MOSFET's characteristic, we will use a curve tracer adapter. This will give us the output, or $i_D \sim v_{DS}$, characteristic from which we can derive linear models.

In the Lab – Setting up the Curve Tracer Adapter

Setting up the CTA

1. Set the following on the curve tracer adapter:

POWER	OFF
POLARITY	N-CHANNEL
CURRENT LIMIT	SIGNAL
H-LENGTH	fully clockwise
GATE VOLTAGE	EXT. BIAS
COLLECTOR SWEEP VOLTAGE	10 V
TRANS / FET	TRANS
SELECTOR	A

Note:

a) We will initially bias the MOSFET with an externally derived voltage, hence the "EXT. BIAS" setting.

b) Enhancement-type MOSFETs need the TRANS setting, the FET setting is for depletion-type MOSFETs.

In the Lab – Setting up the DSO

Setting up the DSO

1. Turn the DSO on.

2. In the File section, press the `Save-Recall` button, then choose the softkey `Default Setup`. This will ensure the DSO is in a known state, e.g. all probe ratios are restored to 1:1, trigger set to Ch 1, etc.

3. Connect Channel 1 of the DSO to the HORIZONTAL output of the CTA. Connect Channel 2 of the DSO to the VERTICAL output of the CTA.

4. Set the DSO to X-Y mode (Push the `Main-Delayed` button, then choose the softkey `XY`). This now means that the two signals applied to Channel 1 and 2 will provide the X deflection and Y deflection. (Normally the X deflection is an internally generated signal that sweeps across in a certain amount of time).

5. Push the `Acquire` key (in the Waveform section) and choose `Averaging` to reduce the noise on the display.

In the Lab – MOSFET Threshold Voltage

1. The pin-out for the 2N7000 is shown below:

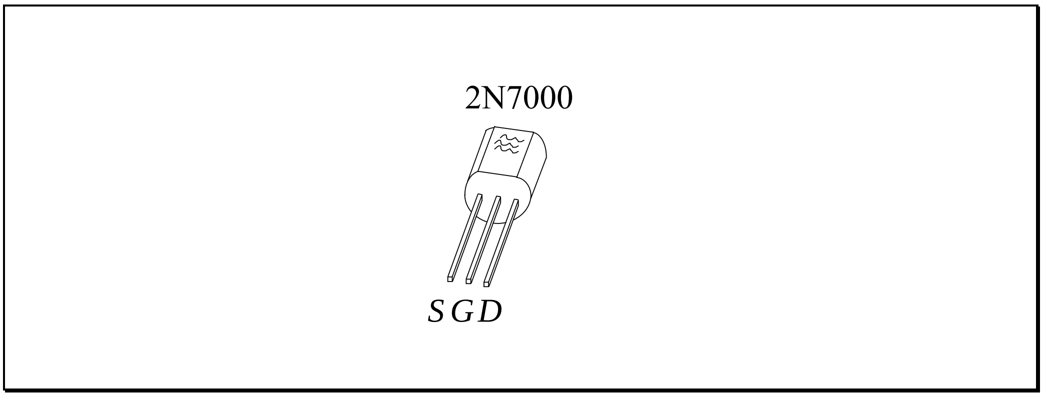


Figure L4.2

2. Set up the following circuit, which is used to add a DC voltage to the curve tracer's gate output voltage:

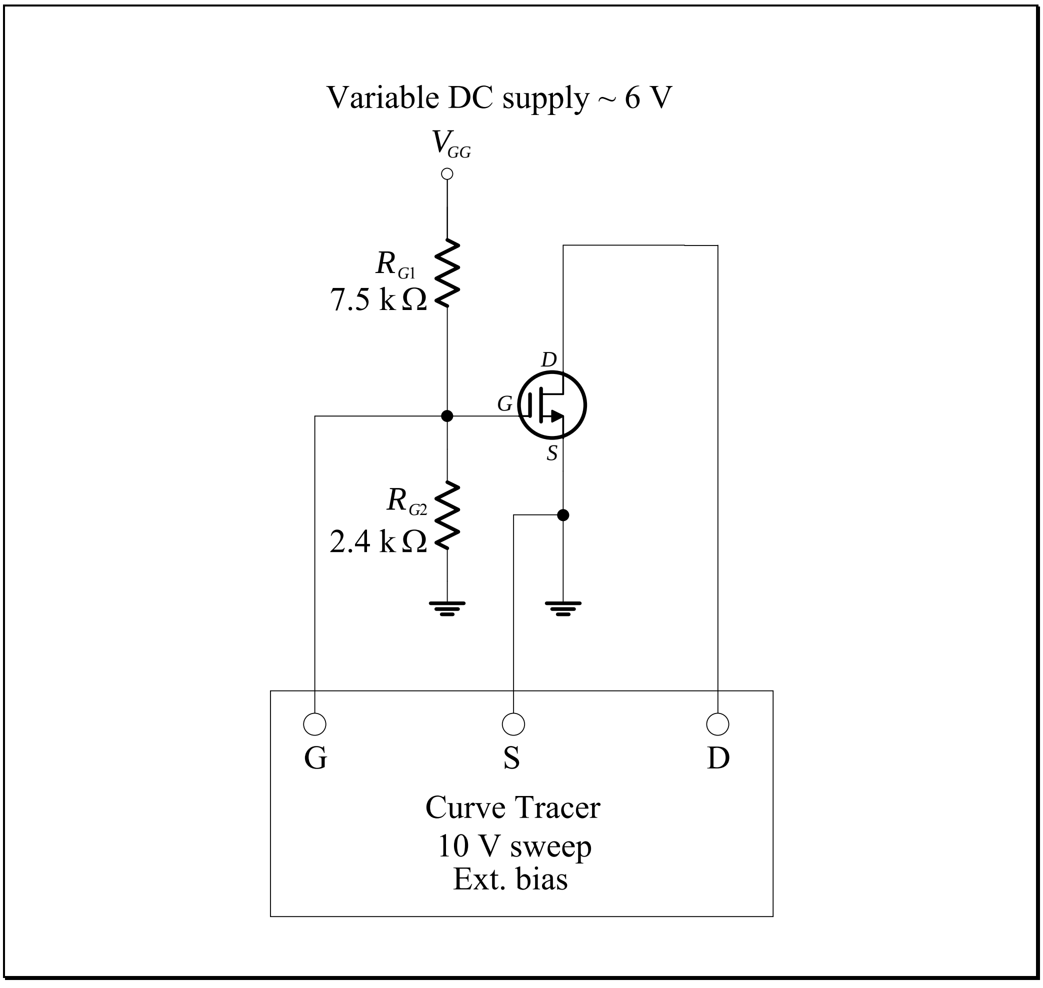


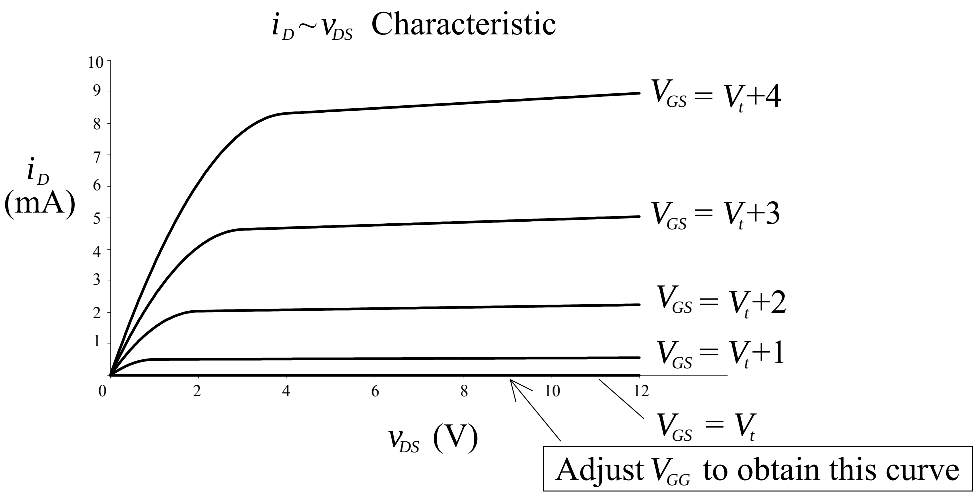
Figure L4.3

3. Turn the CTA and variable DC supply on.

4. For Channel 1: Set the Volts / div to 1 V / div, and use the Vertical Position knob to set a 5 V offset.

5. For Channel 2: Set the Volts / div to 100 mV / div, and use the Vertical Position knob to set a 300 mV offset.

6. With the CT set to Ext. Bias, we can now set a single gate voltage. Adjust the variable DC supply to give a MOSFET output characteristic that is just on the verge of conduction:

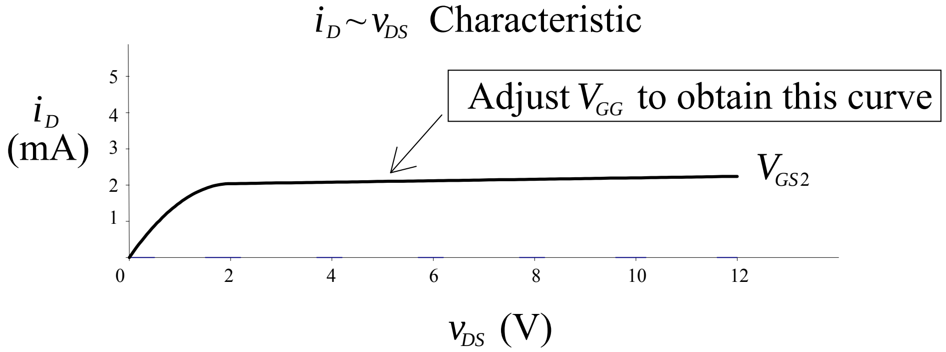


7. Measure the MOSFET's threshold voltage with a digital multimeter (by measuring the value of V_{GS} which is causing the verge of conduction):

$$V_t =$$

In the Lab – MOSFET Transconductance

1. Adjust the DC supply to give a characteristic which saturates at 2 mA (2 divisions).



2. Measure the value of V_{GS} which causes this characteristic:

$$V_{GS2} =$$

3. Now set $V_{GS} = V_{GS2} + 0.1$ (i.e. apply a small change $\Delta v_{GS} = 0.1\,\mathrm{V}$). Measure the change in the current in the saturation region and therefore calculate the transconductance:

$$g_m = \frac{\partial i_D}{\partial v_{GS}} \approx \frac{\Delta i_D}{\Delta v_{GS}} = \frac{\Delta i_D}{0.1} = \qquad \mathrm{mS}$$

In the Lab – MOSFET Output Characteristic

1. Adjust the DC supply to give a characteristic which saturates at 2 mA (2 divisions), i.e. $V_{GS} = V_{GS2}$.

2. Set the Base Current / Gate Voltage to the $10\,\mu\text{A}$ setting. On a Base Current setting, the CT places a large output resistor in series with its internal gate output voltage to create an approximate current source. The equivalent of the lab setup is:

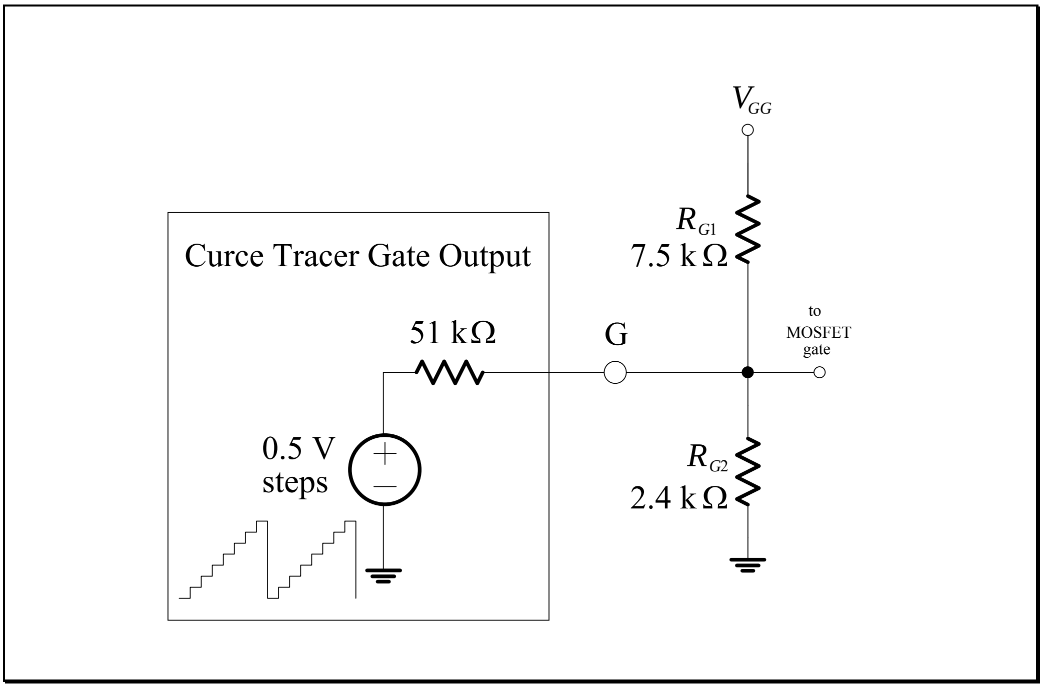


Figure L4.4

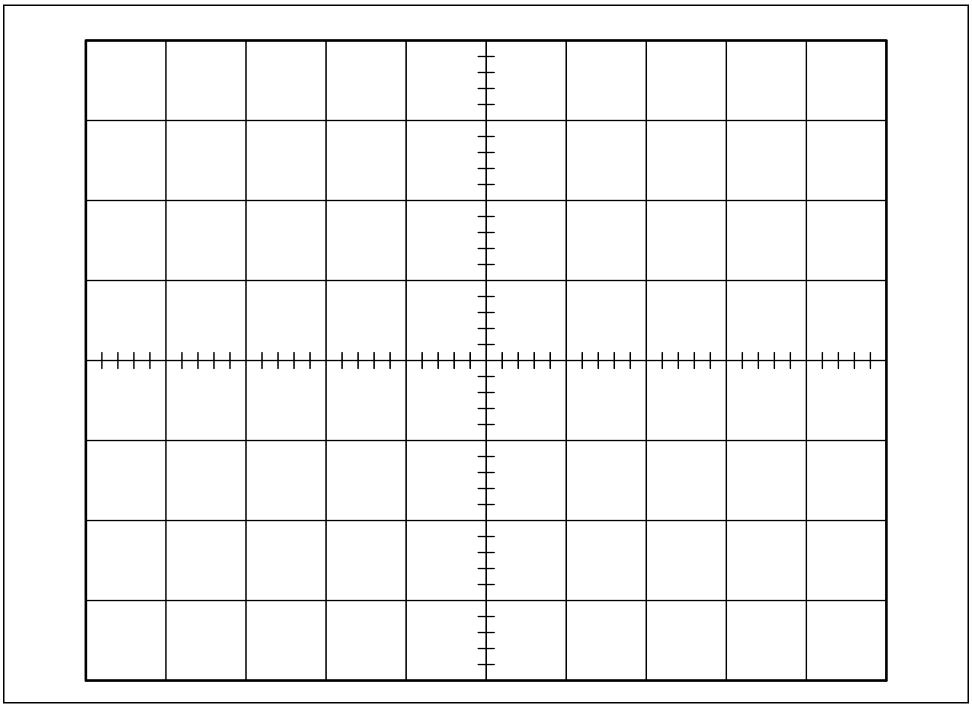
3. Since the gate of a MOSFET is effectively an open-circuit, you can now analyse Figure L4.4 to determine the value of each gate voltage step (there are 8 steps, starting from 0 V).

$\Delta V_{GS} =$ mV

4. You should see the output characteristic of the MOSFET on the DSO. If your characteristic appears to be going “down” instead of “up”, you will have to invert Channel 2 to obtain a correct polarity for the vertical scale (some CTAs have output inverters, some don’t). To invert Channel 2, push the channel `2` button, then select the softkey `Invert`.

5. Accurately sketch the MOSFET’s output $i_D \sim v_{DS}$ characteristic, noting both horizontal and vertical scales.

MOSFET output characteristic



Remember: the vertical scale on the DSO is the voltage across the internal 100 Ω resistor of the CT, so you will have to scale the vertical voltage to get the current.

Questions – MOSFET AC Equivalent Circuit

1. Derive the MOSFET small-signal AC equivalent circuit from your measurements (include the output resistance, r_o, in your model). State the value of all circuit elements.

Answer:

MOSFET small-signal AC equivalent circuit

Resistor Measurement

To get accurate results, we'll record the values of all the resistors we're going to be using.

In the Lab – Resistor Measurement

1. Measure and record the resistance of the resistors listed.

Resistor	Listed Value	Measured Value
R_{G1}	750 kΩ	
R_{G2}	240 kΩ	
R_D	820 Ω	
R_{S1}	100 Ω	
R_{S2}	62 Ω	
R_L	10 kΩ	

Table L4.1

Bias Conditions

We will compare the measured DC operating point with that predicted by theory.

Theory – Bias Conditions

1. Compute the DC parameters listed in Table L4.2 for the common-source amplifier shown in Figure L4.5. Note that V_G, V_S and V_D are with respect to the circuit's common. Use $\left(R_{S1}+R_{S2}\right)$ times I_D to compute the DC source voltage, V_S. Compute V_D by subtracting V_{R_D} from V_{DD}.

DC Parameter	Computed Value	Measured Value
V_G		
V_S		
I_D		
V_D		
V_{DS}		
V_{DD}		

Table L4.2

MOSFET Common-Source Amplifier

We are going to examine only one type of MOSFET amplifier – the common-source amplifier. The input signal is applied between the gate and source and the output signal is developed between the drain and source. The transistor's source is *common* to both the input and output circuits, hence the term common-source.

In the Lab – MOSFET Common-Source Amplifier

1. Construct the amplifier shown below.

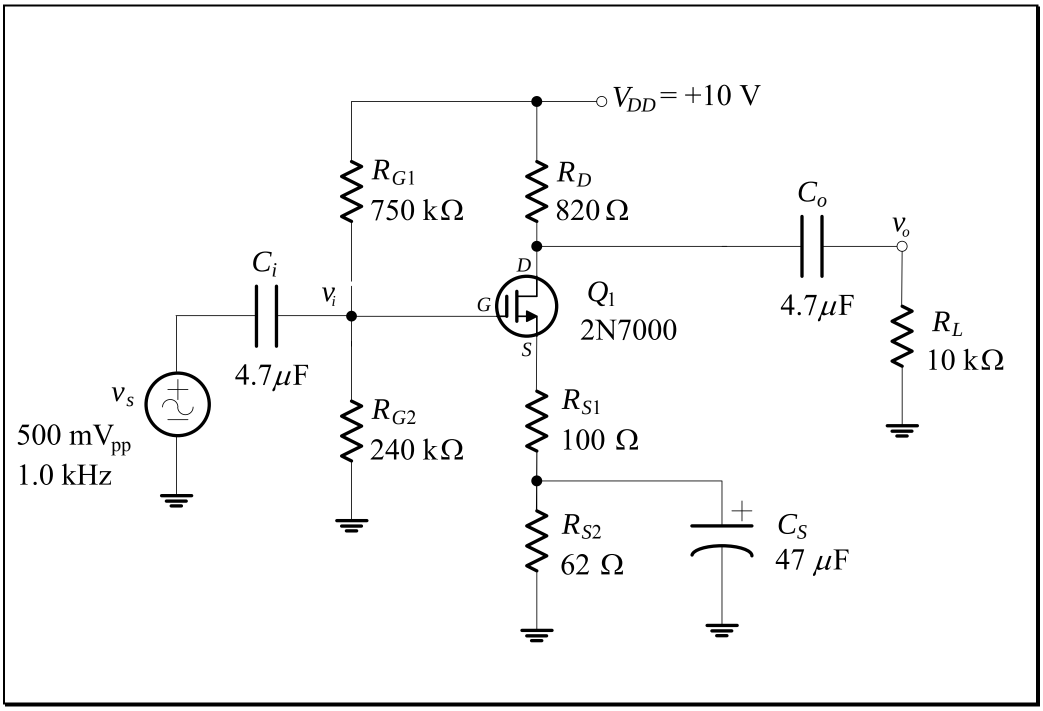


Figure L4.5

2. Measure and record the DC voltages listed in Table L4.2. Calculate the drain current by using relevant measured voltage and resistor values.

3. Compute the AC parameters listed in the table below. The input signal, v_i, is set for 500 mV$_{pp}$. This is both v_i and the AC gate voltage, v_g. Multiply v_i by the computed voltage gain to calculate the AC voltage at the drain; this is both v_d and v_o.

AC Parameter	Computed Value	Measured Value
$v_i = v_g$	500 mV$_{pp}$	
$\lvert A_v \rvert$		
$v_o = v_d$		
R_{in}		
R_{out}		

Table L4.3

4. Turn on the function generator and set v_i for 500 mV$_{pp}$ at 1.0 kHz with the function generator connected to the circuit. Use the oscilloscope to set the proper voltage and check the frequency.

5. Measure the AC signal voltage at the transistor's drain.

6. Use v_i and the AC drain voltage v_o to determine the measured voltage gain, A_v. Record the AC measurements in Table L4.3.

7. Compare the input and output waveforms. What is the phase relationship between v_i and v_o?

Answer:

8. Remove the bypass capacitor, C_S, from the circuit. Measure the AC signal voltage at the transistor's gate, source and drain. Measure the voltage gain of the amplifier. What conclusion can you make about the amplifier's performance with C_S open?

Answer:

9. Replace C_S and reduce R_L to $1.0\,\mathrm{k}\Omega$. Observe the AC signal voltage at the transistor's gate and drain and measure the voltage gain of the amplifier. Use this result to determine the measured output resistance, R_{out}. Record the result in Table L4.3. What conclusion can you make about the amplifier's performance with R_L reduced to $1.0\,\mathrm{k}\Omega$?

Answer:

L4.18

Questions [2 marks]

Encircle the correct answer, cross out the wrong answers. [one or none correct]

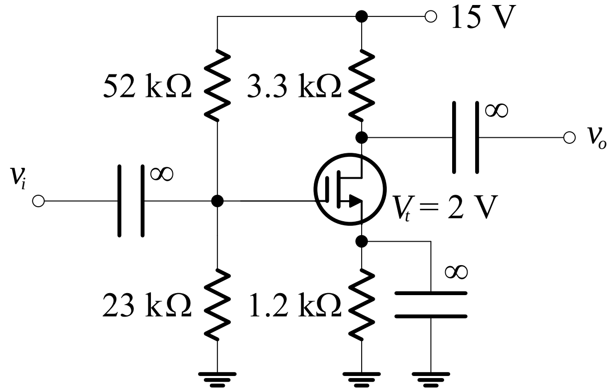
All questions are worth 0.2 marks each.

(i)

For an *n*-channel MOSFET, when v_{DS} is held constant and v_{GS} is increased beyond the threshold voltage, i_D:

(a) increases (b) does not change (c) decreases

(ii)



The MOSFET has small-signal parameters:

$g_m = 20$ mS

$r_o = 10$ kΩ

The open circuit voltage gain, A_{vo}, is

(a) -66.0 V/V (b) -200 V/V (c) -49.6 V/V

(iii)

The AC input resistance, R_i, of the amplifier in question (ii) is:

(a) infinite (b) 15.95 kΩ (c) 1.140 kΩ

(iv)

The AC output resistance, R_o, of the amplifier in question (ii) is:

(a) 3.3 kΩ (b) infinite (c) 2.48 kΩ

(v)

For a MOSFET at low frequencies:

(a) $\frac{1}{r_o} = \frac{\partial i_D}{\partial v_{GS}}, \quad g_m = \frac{\partial i_D}{\partial v_{DS}}$

(b) $\frac{1}{g_m} = \frac{\partial v_{DS}}{\partial i_S}, \quad r_o = \frac{\partial v_{DS}}{\partial i_D}$

(c) $g_m = \frac{\partial v_{GS}}{\partial i_D}, \quad r_o = \frac{\partial v_{GS}}{\partial i_S}$

(vi)

The DC bias current, I_D, in question (ii) is:

(a) 2 mA (b) 20 mA (c) 50 mA

(vii)

The input impedance of a "voltage amplifier", compared with the impedance of the signal source, should be:

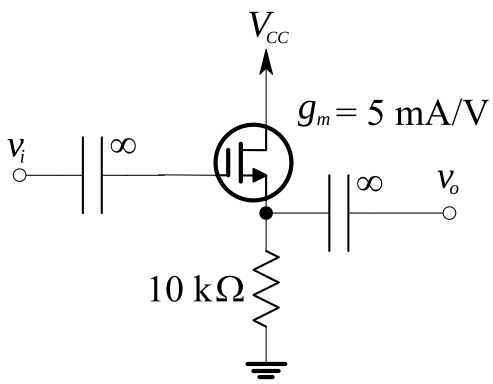
(a) very large (b) equal (c) small

(viii)

The "decibel" is a measure of:

(a) voltage gain (b) power gain (c) noise

(ix)



The source follower circuit shown has open-circuit small-signal voltage gain A_{vo}, input resistance R_{in} and output resistance R_{out}.

(a) $A_{vo} \approx 1$, $R_{in} \approx 10\,k\Omega$, $R_{out} < 5\,\Omega$

(b) $A_{vo} < 1$, $R_{in} \approx \infty\,\Omega$, $R_{out} < 200\,\Omega$

(c) $A_{vo} > 1$, R_{in} is large, R_{out} is small

(x)

Including an un-bypassed resistor R_S in the source lead of the common-source MOSFET amplifier:

(a) reduces the gain, but makes it nearly independent of the MOSFET.

(b) keeps the gain the same, but increases the input resistance.

(c) increases the gain, but reduces the input resistance.

L4.20

Report

Only submit ***ONE*** report per lab group.

Complete the assignment cover sheet.

Ensure you have completed:

1. ***Lab Work*** – waveforms, readings, calculations.

2. ***Analysis*** – explanations where required.

3. ***Questions*** – multiple choice questions.

The lab report is due at the time stated in the Learning Guide.

You should hand the report directly to your tutor.