EXPERIMENT 3

FREQUENCY RESPONSE OF MOS AMPLIFIERS

## I.   OBJECTIVES

-To study the frequency response of CS MOS and CD MOS Amplifiers

## II.   INTRODUCTION AND THEORY

MOS transistor is a four terminal active device that needs a proper bias or initial DC setting to operate. MOS terminals are known as Drain, Gate, Source and Body (or substrate). The substrate terminal in all the circuits shown below is internally connected with the source terminal.  Similar to the BJT circuit configurations, the MOS transistors can be configured in circuits as Common-Source (CS), Common-Drain (CD) and Common-Gate (CG) amplifiers. Figure 1 shows a single-stage MOS transistor amplifier that can be configured as CS, CD or CG by defining the positions of the input and output signals.
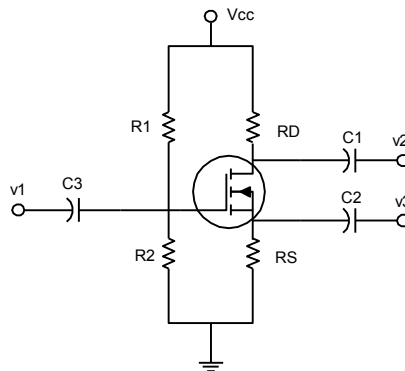


Figure **1** Generalized MOS amplifier stage

Figure 2 shows the three basic configurations of single-stage MOS amplifiers. Notice the difference between the relative positions of the input-output signals.  The bypass capacitors $C_1$, $C_2$ and $C_3$ are large enough so that they effectively produce a short circuit at frequencies equal to or higher than the mid-band frequency of the amplifiers. This type of short circuits is called an AC short circuit. The AC short circuit has no effect on the initial setting of the DC current or voltages of the amplifier. In other words it has no effect on the quiescent point of the amplifier. A signal generator with an output resistance $R$ is attached to the amplifier input.
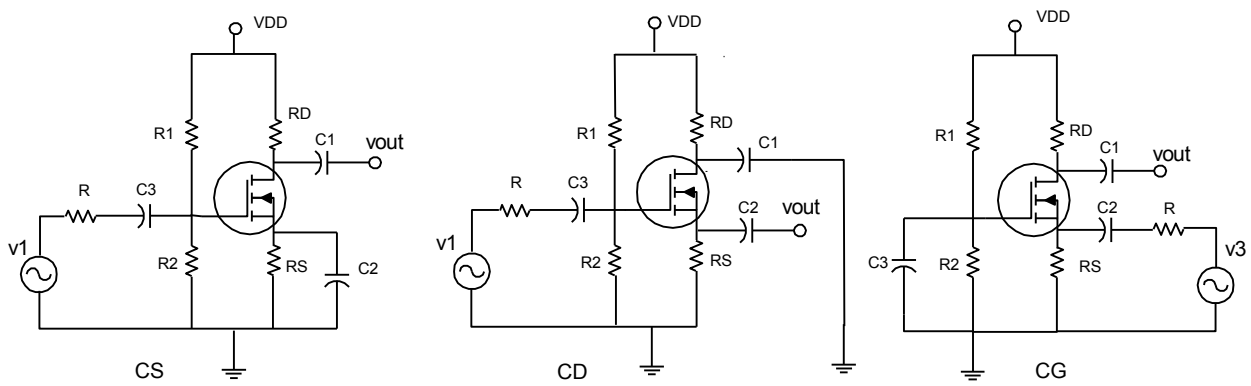
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Figure **2** Circuit configurations of the MOS amplifiers

Figure 3 shows the three terminals of the MOS transistor, the small-signal equivalent circuits (i) for low frequency (i.e., mid-band), and (ii) for high-frequency applications. The small-signal low-frequency equivalent circuit is used to conduct the ac analysis of the amplifier in the mid-band frequency range where the effects of all types of capacitance are neglected. In high-frequency operation, the effect of the internal capacitances of the MOS transistor (or any other active devices for example BJT or Op_Amp) cannot be ignored. The internal capacitances are not lumped elements but their effect will appear at high frequencies. The effect of the internal capacitances can be observed as a gradual drop in the amplifier gain as the frequency gets higher than a certain limit. In figure 3 the internal capacitances are represented by the capacitances $C_{gs}$ and $C_{gd}$ in the high-frequency equivalent circuit. The effect of the capacitance $C_{gd}$ is seen as negative feedback from drain to the gate. The effect of the capacitance $C_{gs}$ can be seen as an ac short circuit that can reduce the input signal level to zero. The first step in conducting an ac analysis of a MOS transistor circuit operating at high frequencies is to replace the device with the high-frequency equivalent circuit, all DC voltages by short circuits, and all current sources by an open circuit. The resulting circuit consists of a number of resistors, input signal and the internal capacitances of the device $C_{gs}$, and $C_{gd}$. This is an active RC circuit. In some transistor circuits such as oscillators or tuned amplifiers, the external circuit (all elements attached to the terminal of the active device) could contain two types of the reactive elements i.e., inductor and capacitor. In such a case the high-frequency equivalent circuit is RLC circuit.

In this experiment the circuit is an active RC circuit. This circuit could be reduced to a single resistance, a single capacitance and input signal by applying Miller's theorem to separate nodes in the circuit and Thevenin's theorem to compute the equivalent resistances seen by each capacitor in the circuit.

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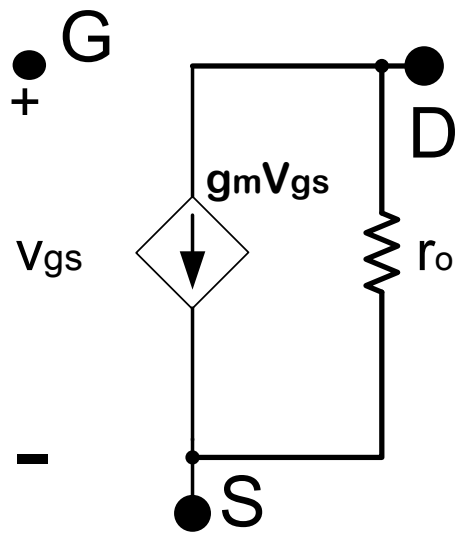
Small-signal equivalent circuit
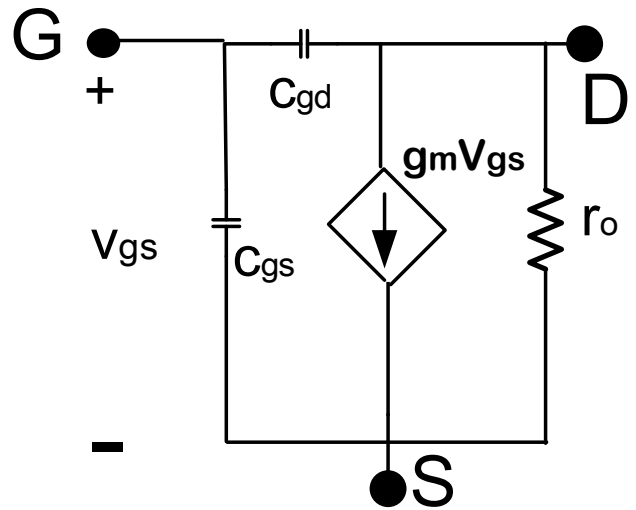
High-frequency equivalent circuit

Figure **3**

## III. Experimental measurement of common-source amplifier

Assemble the circuit shown in Fig. 4.

This circuit is again a common-source amplifier and the bypass capacitor (C-bypass) has been introduced to improve the amplifier gain. The purpose of this measurement activity is to observe the effect of bypass capacitor and the load resistor on the mid-band gain.
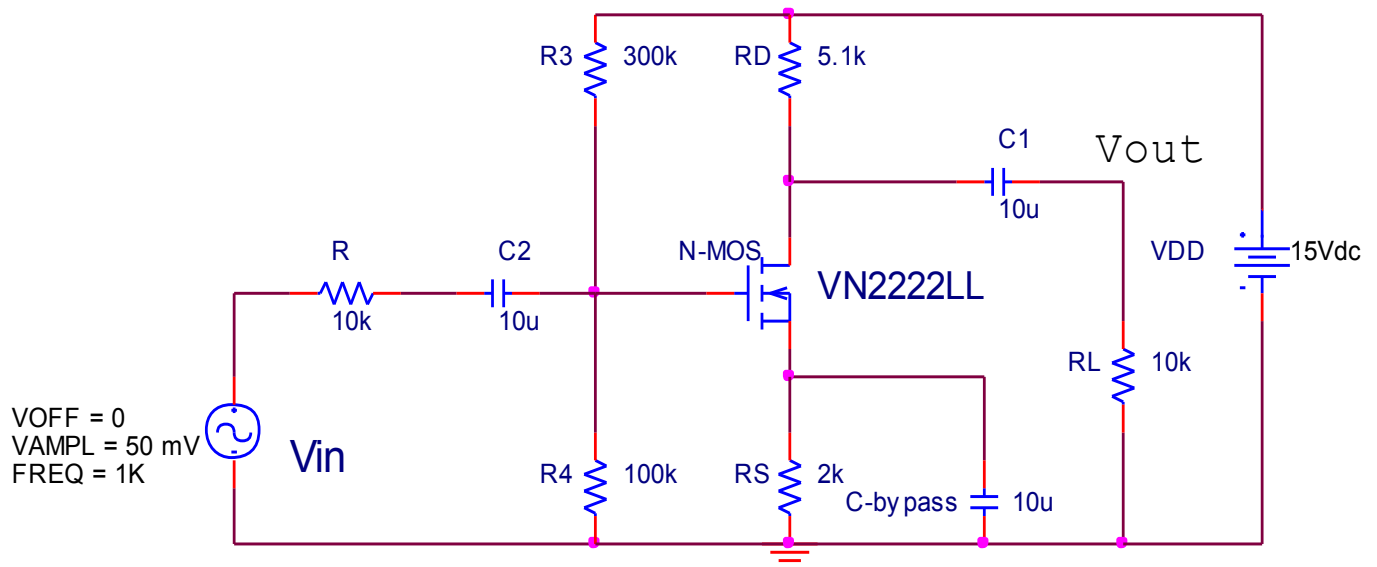


**Figure 4**

The pinout for MOSFET VN2222LL is shown below.

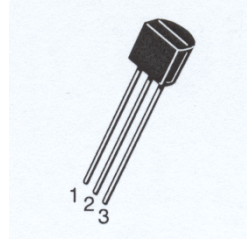| Pin No. | VN2222LL MOSFET |
|---------|-----------------|
| 1 | Source |
| 2 | Gate |
| 3 | Drain |

**Figure 5**

1. For the circuit in figure 4, measure the mid-band gain. By varying the frequency of Vin find the bandwidth (the difference between upper 3dB and lower 3dB). Draw a gain vs. frequency curve. Use a small value for Vin (i.e., 50mV peak).
2. Remove the load resistor RL and find the mid-band gain. You will notice that in the absence of RL, the gain increases. Explain this result utilizing small signal analysis. For this analysis you may ignore the coupling capacitors C1 and C2.
3. Insert the load resistor RL and then remove the bypass capacitor (C-bypass). For this circuit measure the mid-band gain and the bandwidth. Draw gain vs. frequency curve.
4. Absence of bypass capacitor leads to significantly lower gain. You saw that in step 3. Using the small signal analysis explain this behavior. You may ignore the coupling capacitors (C1 and C2) to simplify your analysis.
5. Absence of bypass capacitor leads to a higher bandwidth. What is the reason?

## IV. Experimental measurement of common-drain amplifier

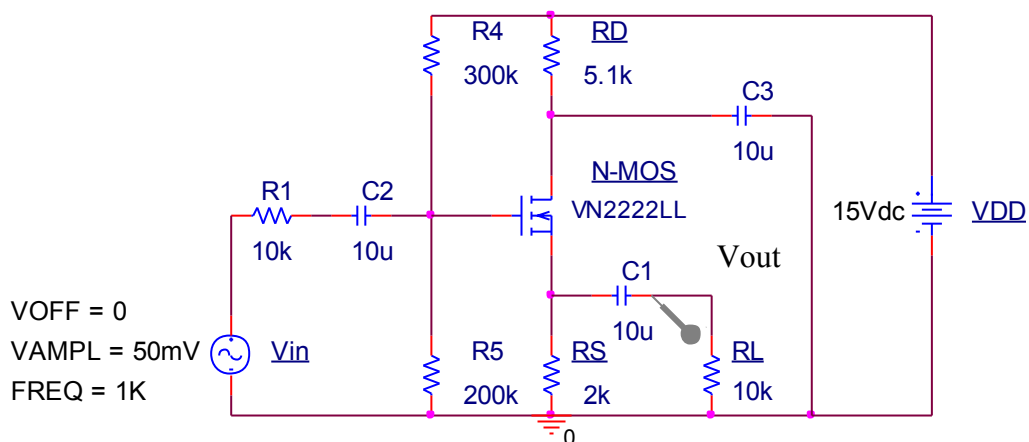Assemble the circuit given below. It is a common-drain amplifier or the source follower.

**FIG. 6**

1 Measure the output (Vout) and compare it to the input.

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2      Change the frequency of the input to obtain the lower- and upper-3dB points.

3      Change the load (RL) to 1K and measure Vout. Explain why Vout decreased.

## V.     QUESTIONS

1    Considering the current IC technology which one is smaller, a MOSFET or a BJT?

2    How do the frequency response (gain vs. frequency) curves of the CS and CD amplifiers compare?

3    Is it possible to design a CD amplifier with a voltage gain > 1?

4    If you are asked to design a voltage buffer amplifier, which of CS and CD stage(s) will you consider?

5    In the circuits that you worked with, what would be the maximum input signal level for small signal ac equivalent circuit to be applicable? Is 50mV amplitude for the input signal satisfactory for this purpose?