Lab 3: Frequency Response of CS Amplifier.

1. OBJECTIVES

Understand the role of load in determining a bandwidth of CS amplifier:

Measure the frequency response of CS amplifier with resistive load;

Measure the frequency response of CS amplifier with capacitive load.

2. INTRODUCTION

2.1. Frequency response of CS amplifier.

Ultimate bandwidth of single stage MOSFET amplifier is determined by speed limitations of the transistor itself. In simple terms, this means that it takes certain time for charge carriers to move from source to drain and device cannot work faster than that. Of course it is only qualitative statement and a lot of details are needed to be able to predict the frequency response of the particular transistor. Often the unity-gain frequency (f_T) is introduced. This is the frequency at which short-circuit current gain of the common-source configuration becomes unity. The value of unity-gain frequency can be estimated in the framework of the simplistic lumped capacitor model:

$$f_T \approx \frac{g_m}{2 \cdot \pi \cdot (C_{GS} + C_{GD})}, \qquad (1)$$

where g_m is gate transconductance and C_{GS} and C_{GD} are net equivalent MOSFET capacitances. The MOSFET capacitances have both internal and external contributions. Of course, much more detailed modeling is required to predict the unity-gain bandwidth accurately but the equation (1) is OK as an estimate in many cases.

The bandwidth (BW) of MOSFET amplifiers rarely can approach f_T due to additional limitations caused by particular circuit layout. Usually, BW << f_T. Figure below (taken from recommended book) shows the generic form of the CS amplifier with resistive load.

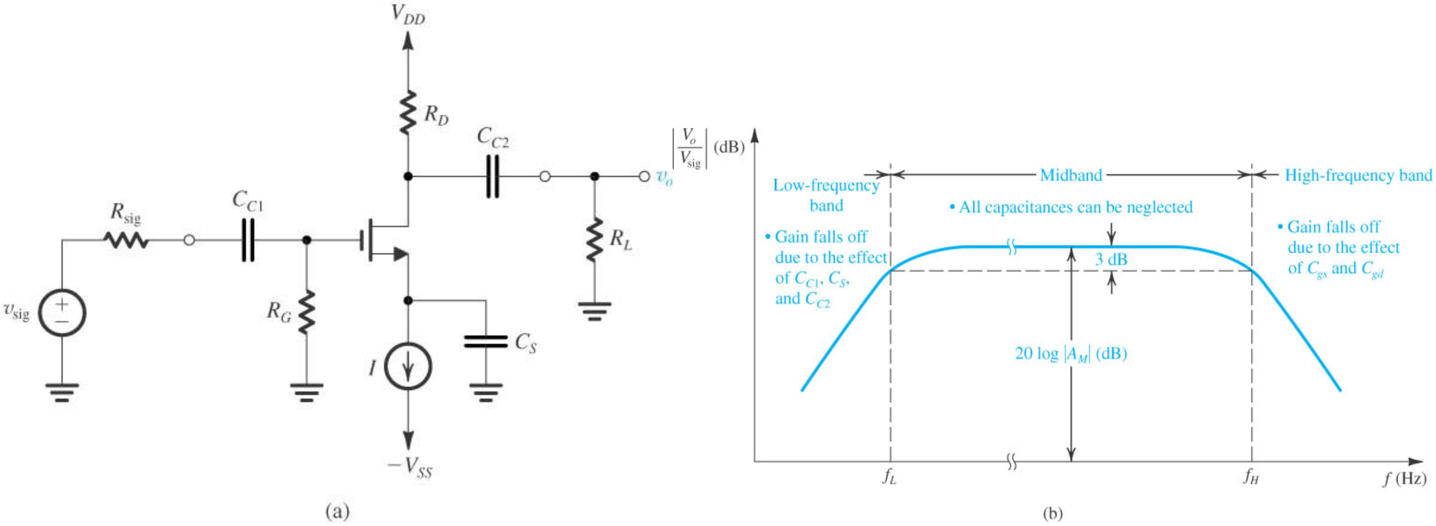


Figure 1.

Midband gain is determined by open circuit voltage gain we have measured in lab 2. For the specific circuit above its net midband voltage gain is equal to:

$$G_V = \frac{V_O}{V_{sig}} = \frac{R_{in}}{R_{in}+R_{sig}} \cdot A_{VO} \cdot \frac{R_L}{R_L+R_O} = \frac{R_G}{R_G+R_{sig}} \cdot \left(-g_m \cdot \left(r_O \parallel R_D \parallel R_L\right)\right) \approx -g_m \cdot \left(r_O \parallel R_D \parallel R_L\right). \qquad (2)$$

Voltage gain in low- and high-frequency bands is smaller than midband gain due to effects of coupling/bypass and transistor capacitors, respectively. Often C_S (bypass capacitor) determines the low 3dB frequency f_L, then:

$$f_L \approx \frac{g_m}{2 \cdot \pi \cdot C_S}. \qquad (3)$$

Of course, C_{C1} and C_{C2} also matter but usually they “see” higher impedances, hence lead to large time constants, i.e. lower 3dB frequencies of the corresponding equivalent first order high pass filters at the input.

The high 3dB frequency in CS amplifier with gain is determined by Miller effect caused by C_{GD} coupling between output and input. We will study this important phenomenon in details when we discuss active filters. In this lab experiment we will learn that the high 3dB frequency can be determined by different and equally important effect. Namely, load capacitor, i.e. capacitor C_L in parallel with R_L, will introduce the low pass filter at the output. Sometimes, the BW limitations cased by load capacitance occur at frequencies that are much smaller than f_H determined by Miller effect. Then equivalent circuit from Figure 2a below can be used to predict new f_H and f_T.

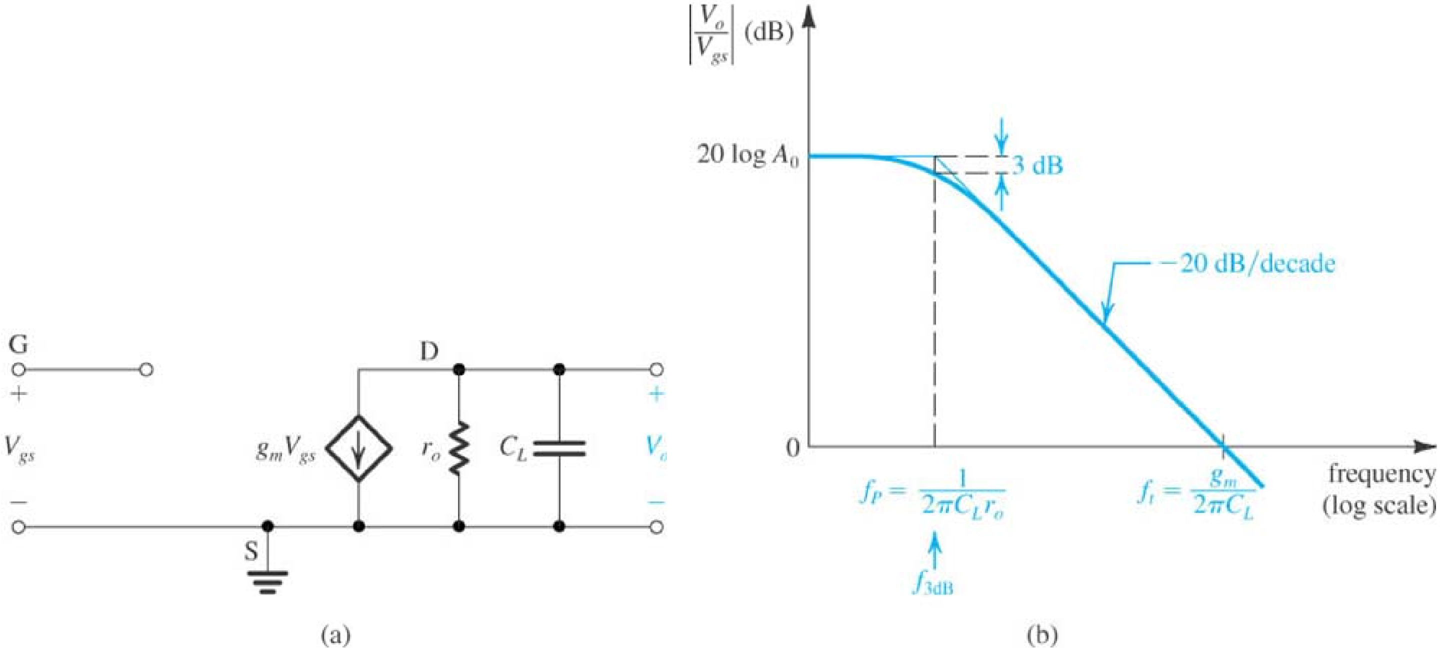


Figure 2.

Clearly, if R_D and/or R_L are comparable or smaller than r_0, then ($R_L \| R_D \| r_0$) should be used in place of r_0 for calculation of the corresponding high 3dB frequency f_H. (pole frequency f_P in Figure 2b above.) then:

$$f_H \approx \frac{1}{2\cdot\pi\cdot C_L\cdot(R_L \parallel R_D \parallel r_0)}. \tag{4}$$

Hence, BW can become dependent on both R_L and C_L. The gain-BW product though is determined only by transistor bias through g_m and value of the load capacitor C_L:

$$G_V \cdot BW = \frac{g_m\cdot(R_L \parallel R_D \parallel r_0)}{2\cdot\pi\cdot C_L\cdot(R_L \parallel R_D \parallel r_0)} = \frac{g_m}{2\cdot\pi\cdot C_L}. \tag{5}$$

Lab experiment will be based on current source biased CS amplifier from lab 02 (Figure 3). The parameters are taken from your lab 2 experiment, i.e. bias current is about 250 μA and R_D is 15 - 20 kΩ. Values of C_S, C_L and R_L will be varied. Frequency response measurements will be performed using oscilloscope and DMM. Note that cables and characterization equipment inputs all have parasitic capacitances that can affect your experimental values.

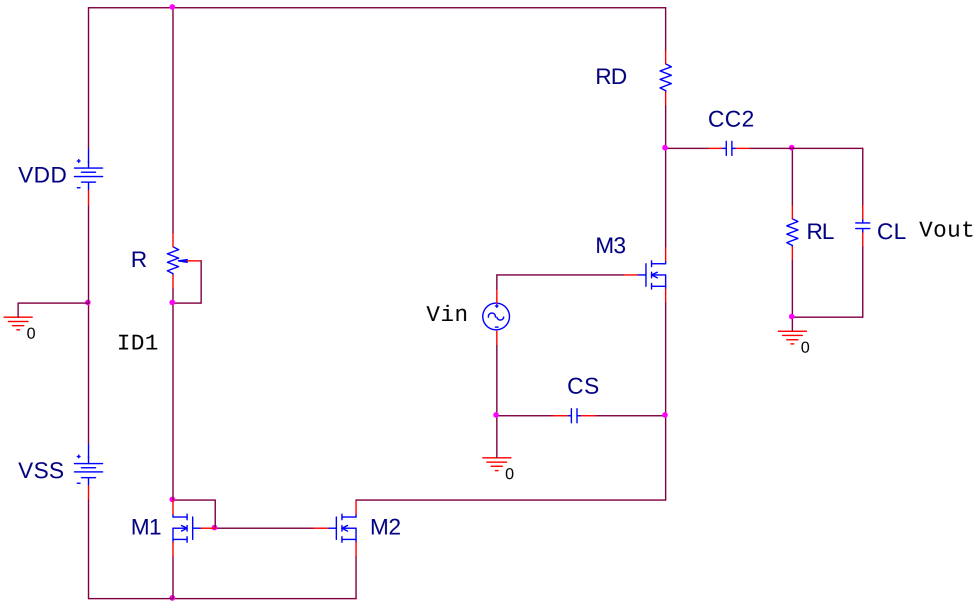
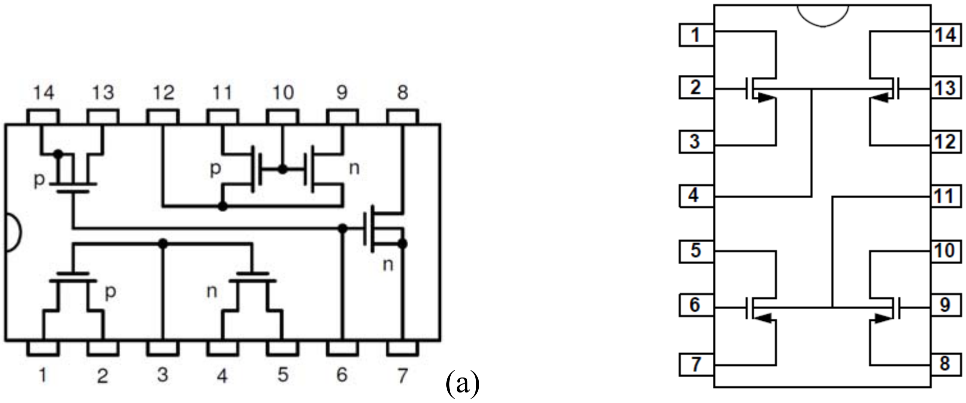


Figure 3.

Current mirror (M1 and M2) is constructed out of NFETs from CD4007. Gain transistor M3 is taken from ALD1105.



(a) (b)

Figure 1. Pin-out of (a) CD4007 and (b) ALD1105 MOSFET array chips.

3. PRELIMINARY LAB

3.1. Using the value of the gate transconductance from lab 02 find the low 3dB frequency corresponding to $C_S = 1\ \mu F$.

3.2. Find the value of C_{C2} that would produce the same low 3dB frequency for $R_L = R_D$. Assume R_D from lab 02 experiment.

3.3. Find the high 3dB frequency and open-circuit ($R_L = \infty$) gain-BW product for $C_L = 20$ pF. Use g_m and R_D from your lab 02 results.

3.4. Sketch the Bode plot of the magnitude frequency response of the CS amplifier from Figure 3. You should obtain something similar to Figure 1b graph. Mark the plot with measured (in lab 02) and calculated (parts 3.1 and 3.3 above) values of midband gain and f_L, f_H, respectively.

4. EXPERIMENT

4.1. Build the circuit shown in Figure 3 using VDD = VSS = 5 V. Select 50 kΩ potentiometer and adjust it to obtain 250 μA bias current for M3. Use C_S and R_D from lab 02 or prelab. Use no R_L and C_L, i.e. deal with open circuit voltage gain. Use oscilloscope to visualize both input (from function generator) and output sinusoidal waveforms. Obviously, select amplitude of the input waveform low enough not to produce any distortion in output waveform. By measuring amplitudes and relative phases of input and output signal obtain the magnitude and phase frequency responses.

Hint: Prior to taking experimental data. Make a couple of measurements in midband and try to find low and high 3dB frequencies by changing frequency and watching output voltage amplitude. Once you found 3dB point try to put your experimental points wisely to resolve important features.

Present the measurement results in the form of table. Plot the experimental results. Comment on values of the 3 dB low and high frequencies.

4.2. Replace C_S with ten times smaller value. Repeat measurement of the magnitude response only.

Present the measurement results in the form of table. Plot the experimental results. Comment on values of the 3 dB low and high frequencies.

4.3. Put back original value of C_S. Augment circuit with C_{C2} and $R_L = R_D/3$. Repeat measurement of the magnitude response only.

Present the measurement results in the form of table. Plot the experimental results. Comment on values of midband gain as well as 3 dB low and high frequencies.

4.4. Remove C_{C2} and R_L. Augment circuit with C_L = 300 pF. Repeat measurement of the magnitude response only.

Present the measurement results in the form of table. Plot the experimental results. Comment on values of the 3 dB low and high frequencies?

4.5. Repeat measurements of magnitude response only for the circuit from 4.1 but use DMM instead of oscilloscope.

Do DMM measurements produce different value of f_H? Would you expect any difference with 4.1 data?

5. REPORT

The report should include the lab goals, short description of the work, the experimental and simulated data presented in plots, the data analysis and comparison followed by conclusions. Please follow the steps in the experimental part and clearly present all the results of measurements. Be creative; try to find something interesting to comment on.