Lab 8: Nodal Analysis of Common-Source Small-Signal Model

EE 3310L

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1. Introduction

The purpose of this lab is to plot the frequency response of a common-source MOSFET voltage amplifier using s- domain nodal analysis of the small-signal model [1]. MATLAB can be used to solve systems of equations. With MATLAB all nodal equations generated from any circuit in s-domain can be solved.

2. Experimental Methodology [1]

The first step of the experiment is to draw the small signal model of a common-source n-channel MOSFET voltage amplifier with all capacitances included, mainly cgs, cgd, and cds where the letters g, d, and s correspond to gate, drain, and source respectively as seen in figure 1 below.

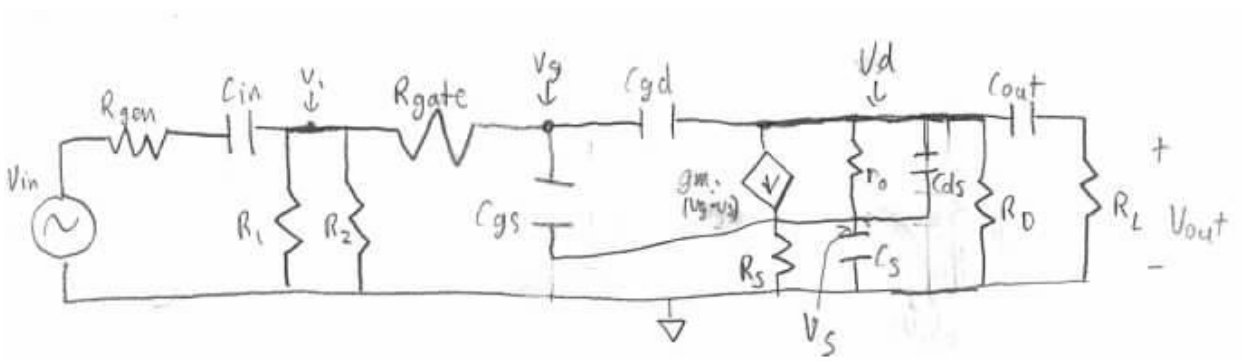

Figure 1: Small signal model of a common-source n-channel MOSFET voltage amplifier with all capacitors.

From the circuit in figure 1 above, nodal analysis is performed in s-domain with the equations displayed in figure A1 in the appendix. The node equations from figure A1 are then put into MATLAB to be solved and have the gain and phase graph displayed as seen in figure A2 in the appendix.

3. Results and Description

The gain and phase graphs generated from the MATLAB code as seen in figure A2 in the appendix can be seen below in figure 2.

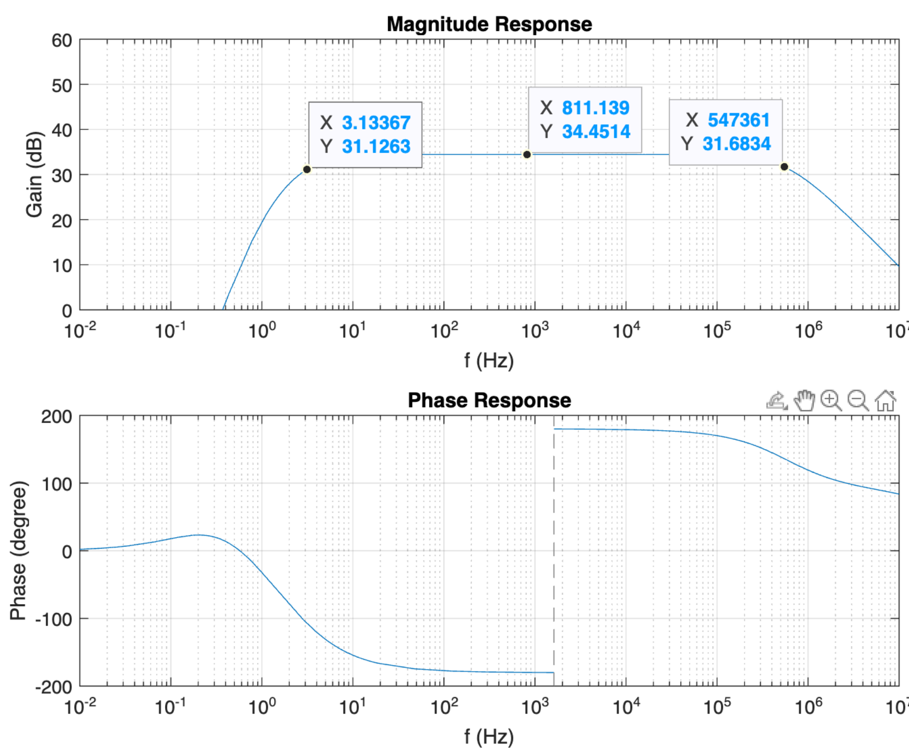

Figure 2: MATLAB generated gain and phase graphs of a common-source n-channel MOSFET voltage amplifier with all capacitors.

Due to MATLAB calculating phase from -π to π instead of 0 to 2π, we are unable to obtain a connected phase response graph and instead have a disconnect where the value abruptly increases.

4. Discussion

The gain from Multisim and calculation as seen in EE Lab 7 are similar to the MATLAB value while the experimental gain was slightly lower [2]. The MATLAB and Multisim upper cutoff frequencies were similar, while the experimental and calculated upper cutoff frequencies were similar [2]. The MATLAB, Multisim, and calculated lower cutoff frequencies were similar while the experimental lower cutoff frequency was slightly higher [2].

5. Summary and Conclusions

The most of lab itself is simple and straightforward to complete due to the given instructions and MATLAB code.

Reference

[1] Tritschler, Joe. "Nodal Analysis of Common-Source Small-Signal Model." N.p., n.d. Web. 10 Mar 2023.

[2] Yeoh, Alex. "Lab 7: Common-Source N-Channel MOSFET Voltage Amplifier." N.p., n.d. Web. 11 Mar 2023.

Appendix A

Analytical Calculations for Lab 7

$$V_1: \frac{V_1 - V_{in}}{R_{gen} + \frac{1}{C_{in} \cdot s}} + \frac{V_1}{R_1} + \frac{V_1}{R_2} + \frac{V_1 - V_g}{R_{gate}} = 0$$

$$V_g: \frac{V_g - V_1}{R_{gate}} + (V_g - V_s) C_{gs} \cdot s + (V_g - V_d) C_{gd} \cdot s = 0$$

$$V_d: (V_d - V_g) C_{gd} \cdot s + g_m \cdot (V_g - V_s) + \frac{V_d - V_s}{r_o} + (V_d - V_s) C_{ds} \cdot s + \frac{V_d}{R_D} + (V_d - V_{out}) C_{out} \cdot s = 0$$

$$V_s: -g_m (V_g - V_s) + \frac{V_s}{R_s} + \frac{V_s - V_d}{r_o} + V_s C_s \cdot s + (V_s - V_d) C_{ds} \cdot s + (V_s - V_g) C_{gs} \cdot s = 0$$

$$V_{out}: (V_{out} - V_d) C_{out} \cdot s + \frac{V_{out}}{R_L} = 0$$

Figure A1: Nodal analysis for a common-source n-channel MOSFET voltage amplifier.

```
clear all
% Declare all symbolic variables, including the Laplace variable s and frequency f
syms VOUT VIN vg vs vd RGEN R1 R2 CS RS gm ro RD RL s f Cin Cout Cgs Cgd Cds v1 Rgate
% Enter node voltage equations, solve for outputs VOUT, vg, vs, and vd (note we don't actually use vd yet)
[v1 vg vd vs VOUT] = solve ( ...
    (v1-VIN)/(RGEN+1/(Cin*s))  +  v1/R1  +  v1/R2  +  (v1-vg)/Rgate == 0, ...
    (vg-v1)/Rgate  +  (vg-vs)*Cgs*s  +  (vg-vd)*Cgd*s == 0, ...
    (vd-vg)*Cgd*s  +  gm*(vg-vs)  +  (vd-vs)/ro  +  (vd-vs)*Cds*s  +  vd/RD  +  (vd-VOUT)*Cout*s == 0, ...
    -gm*(vg-vs)  +  vs/RS  +  (vs-vd)/ro  +  vs*CS*s  +  (vs-vd)*Cds*s  +  (vs-vg)*Cgs*s == 0, ...
    (VOUT-vd)*Cout*s  +  VOUT/RL == 0, v1, vg, vd, vs, VOUT);
% Compute the s-domain transfer function H(s)
H(s) = simplify (VOUT/VIN)
% Plug in external component values and dynamic parameters gm and ro
RGEN = 50;
R1 = 1000000;
R2 = 240000;
CS = 0.001;
RS = 1000;
gm = 0.017;
ro = 110000;
RD = 4700;
RL = 10000;
Cin = 1e-6;
Cout = 10e-6;
Cgs = 16e-12;
Cgd = 4e-12;
Cds = 7e-12;
Rgate = 1000;
% Determine transfer function with component values
H(s)=subs(H(s))
% Symbolically define the gain at 1 kHz as 'm,' meaning 'midfrequency'
m=[abs(H(j*2*pi*1000)),angle(H(j*2*pi*1000))]
% determine the 1 kHz magnitude and phase
double (abs(m))
% plot the frequency response from 0.01 Hz to 1 MHz on a semilogarithmic frequency scale
fmin = 0.01;
fmax = 10e6;
figure(8)
subplot(2,1,1)
fplot((20*log10(abs(H(j*2*pi*f)))),[fmin,fmax]), grid
set(gca, 'XScale','log')
axis([fmin,fmax, 0, 60])
title('Magnitude Response'); xlabel('f (Hz)'); ylabel('Gain (dB)')
subplot(2,1,2)
fplot(angle(H(j*2*pi*f))*180/pi,[fmin,fmax]), grid;
set(gca, 'XScale','log')
axis([fmin,fmax, -200,200])
title('Phase Response'); xlabel('f (Hz)'); ylabel('Phase (degree)')
snapnow;
```

Figure A2: MATLAB code of the nodal analysis.