EE 2010 Circuit Analysis
Lab 08: Dependent Source Model for 2N7000 MOSFET

Lab Section: **Printed Name (Last, First):**

Learning Objectives:

- Use Multisim to simulate and validate a single-transistor amplifier
- Understand the notions of DC bias and small-signal analysis
- Understand the production of gain
- Measure the gain and phase of an amplifier via Multisim
- Explore the differences between the operations of a device and its idealized model

A. Before coming to lab:

1. Background

1.1 Read this Introduction to amplifiers.

1.2 Read the introduction section on MOSFETs at WikiPedia.

1.3 Read this description of a MOSFET amplifier paying particular attention to the production of **gain**.

1.4 View this video developing the small signal model of a 2N7000 MOSFET transistor.

2. A Single Transistor Amplifier Circuit Simulation

For this lab, we employ both "Transient" and "AC-Sweep" functions in a Multisim simulation to observe both gain and the frequency-dependent behavior of our simulated circuit.

2.1 Construct a simulation of the circuit shown below:

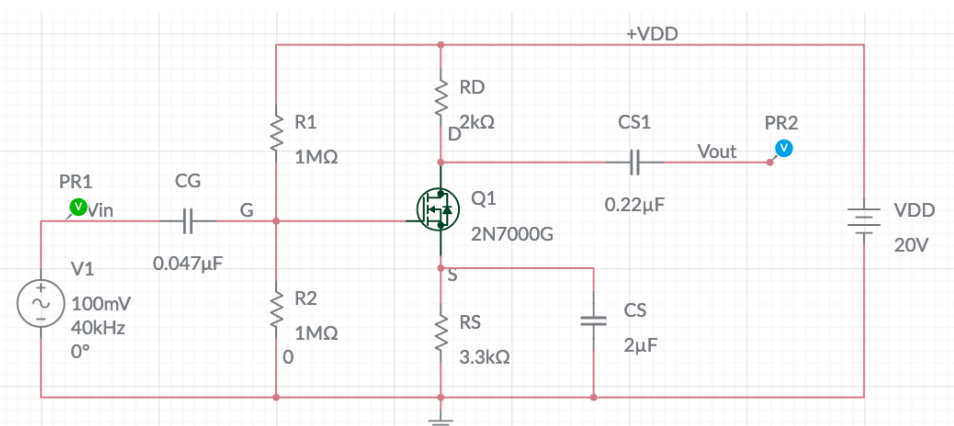


Figure 1: Single transistor circuit schematic diagram

2.2 Initially, we set the input waveform as a constant-amplitude sinusoid. We will observe the "output voltage" to gain insight to the operation of the circuit.

2.3 In the simulation control bar, select the "Transient" simulation mode.

2.4 Adjust the settings to determine the limits and appearance of the resulting simulation as shown below:

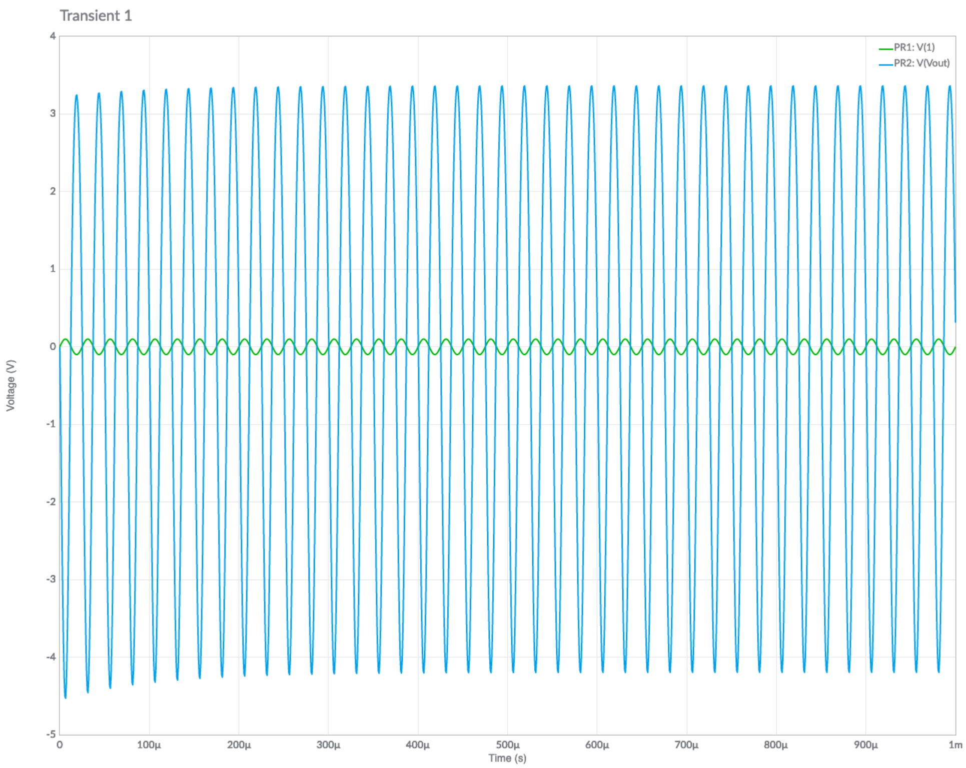


Figure 2: AC-signal amplification of a single-transistor amplifier

2.5 This figure illustrates the input-output signal amplification of this simple amplifier.

2.6 Notice that there is significant voltage gain, although the sinusoid is effectively inverted (180° phase shift).

2.7 Run the simulation and capture the results. Include the schematic and the grapher figures in your lab report.

2.8 For the same circuit schematic, now select the "AC-Sweep" simulation mode.

2.9 Set the sweep parameters as opened by selecting the settings icon.

2.10 Notice especially the "Log" sweep mode and the minimum and maximum frequencies of 1Hz and 1M Hz.

2.11 These settings determine the limits and appearance of the resulting simulation as shown below:

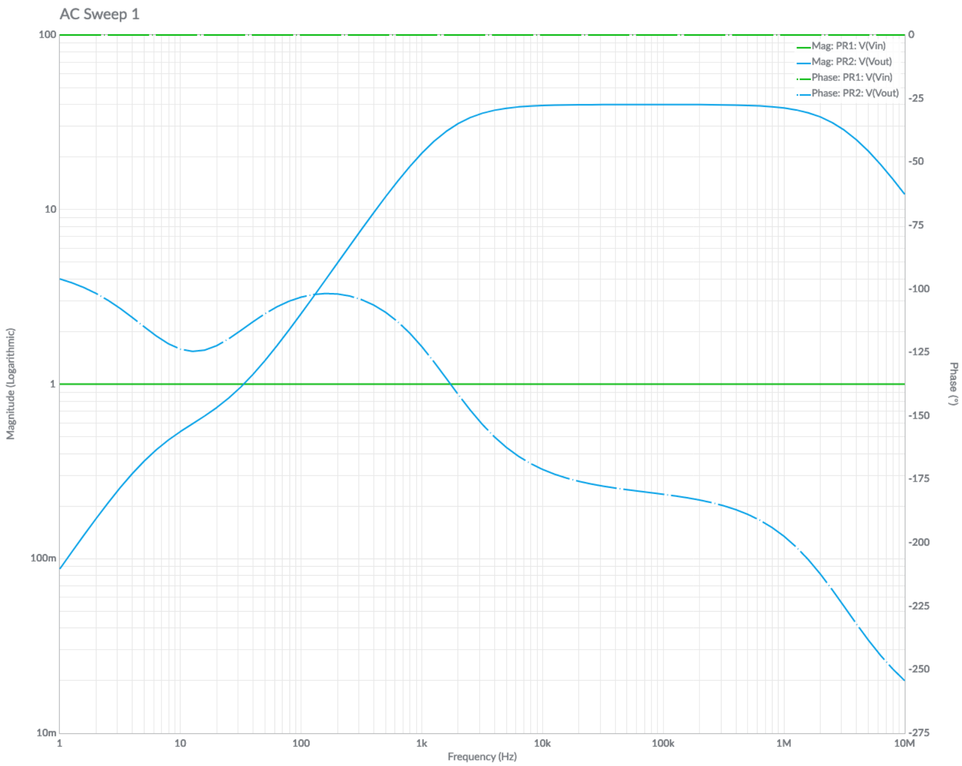


Figure 3: AC-Sweep simulation of a single-transistor amplifier

2.12 This figure illustrates the magnitude and phase of the transfer function $H(s)$ for frequencies ranging from 1Hz to 1MHz.

2.13 Run the simulation and capture the results. Include the schematic and the AC-sweep figures in your lab report.

3. Observations

3.1 Notice there are interesting changes in both gain and phase curves for the amplifier transfer function.

3.2 While we will not now dwell on the implications of the phase shift, we note that the phase is also influenced by the operation of the transistor amplifier.

4. Simulation of a Dependent-Source Model for a Single Transistor Amplifier Circuit

We have analyzed a number of circuits that included dependent sources. Dependent sources are used to model "active elements" such as the 2N7000 transistor presently under consideration.

4.1 Construct a simulation of the dependent-source model circuit shown below:

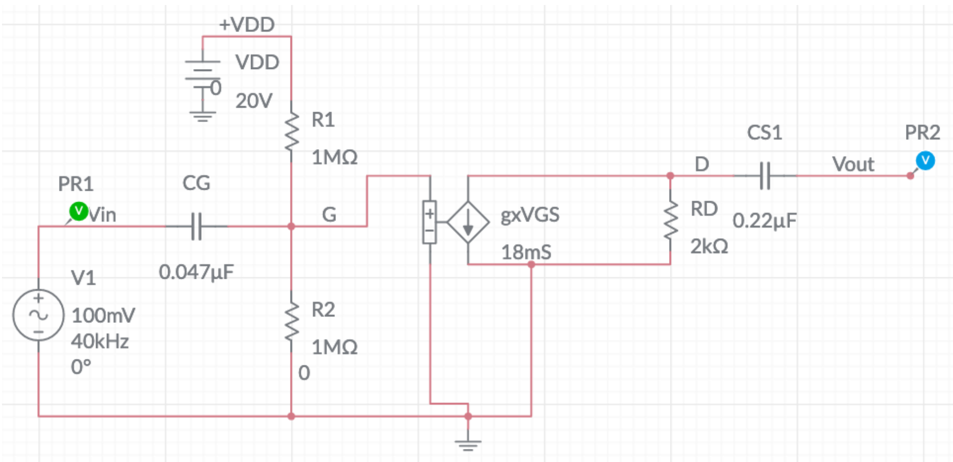


Figure 4: Dependent source model of a single transistor circuit

4.2 Initially, we set the input waveform as a constant-amplitude sinusoid. We will observe the "output voltage" to gain insight to the operation of the circuit.

4.3 In the simulation control bar, select the "Transient" simulation mode.

4.4 Adjust the settings to determine the limits and appearance of the resulting simulation as shown below:

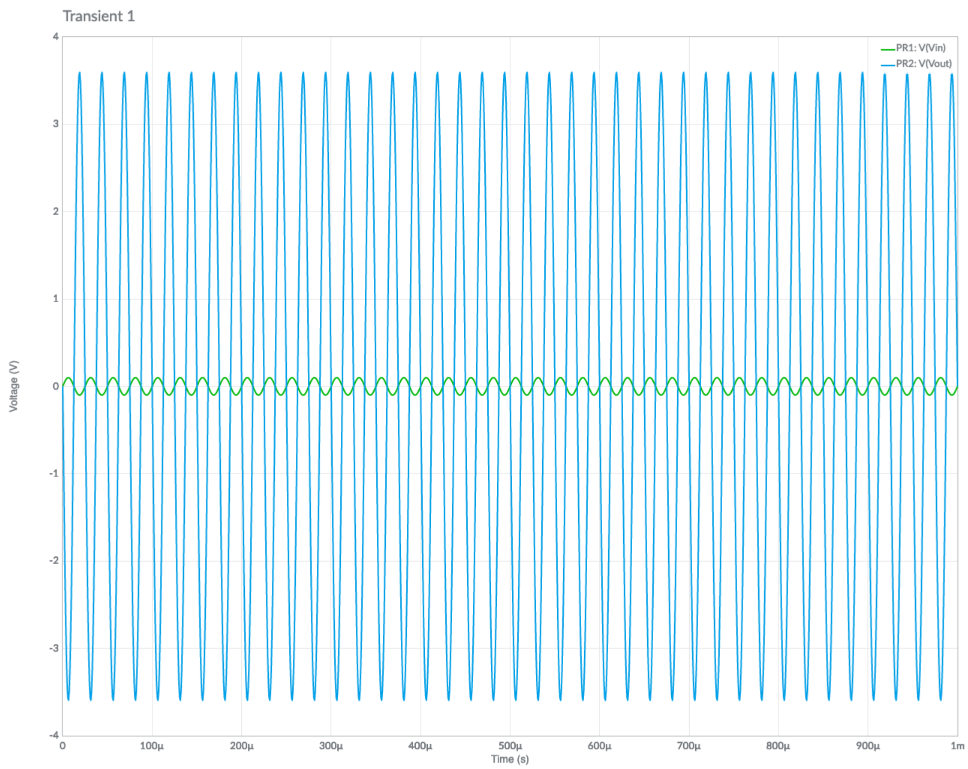


Figure 5: AC-signal amplification of a dependent-source model amplifier

4.5 This figure illustrates the input-output signal amplification of this ideal amplifier model.

4.6 Notice that there is, once again, significant voltage gain, although the sinusoid is effectively inverted (180° phase shift) as it was for the 2N7000 element.

4.7 Run the simulation and capture the results. Include the schematic and the grapher figures in your lab report.

4.8 For the same circuit schematic, now select the "AC-Sweep" simulation mode.

4.9 Set the sweep parameters as opened by selecting the settings icon.

4.10 Notice especially the "Log" sweep mode and the minimum and maximum frequencies of 1Hz and 1M Hz.

4.11 These settings determine the limits and appearance of the resulting simulation as shown below:

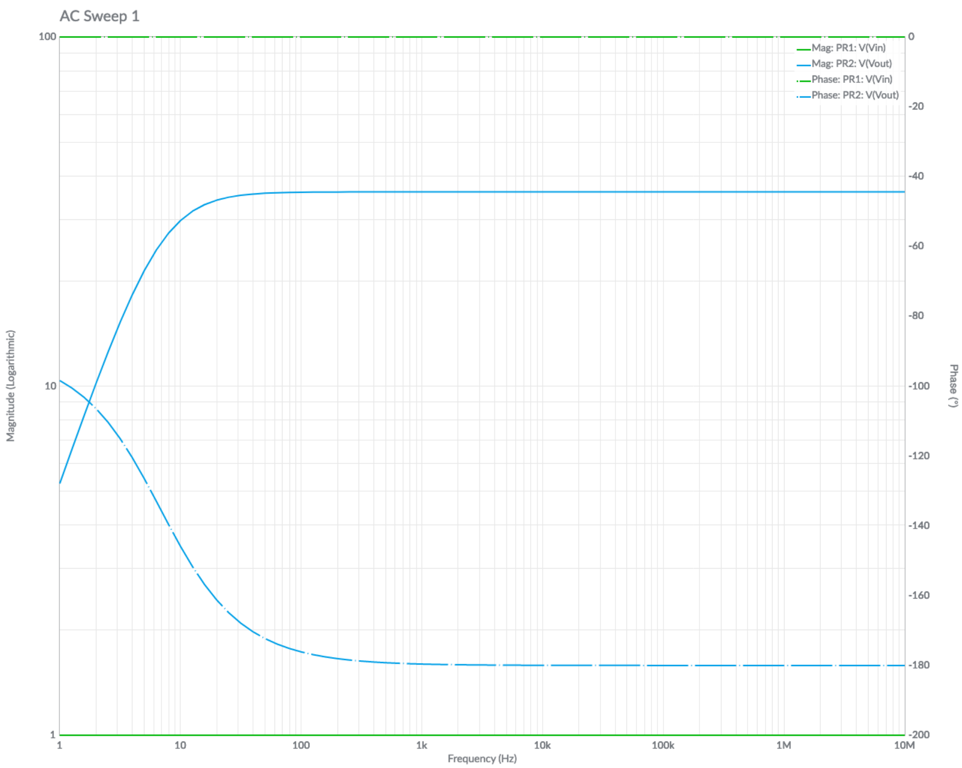


Figure 6: AC-Sweep simulation of a single-transistor amplifier

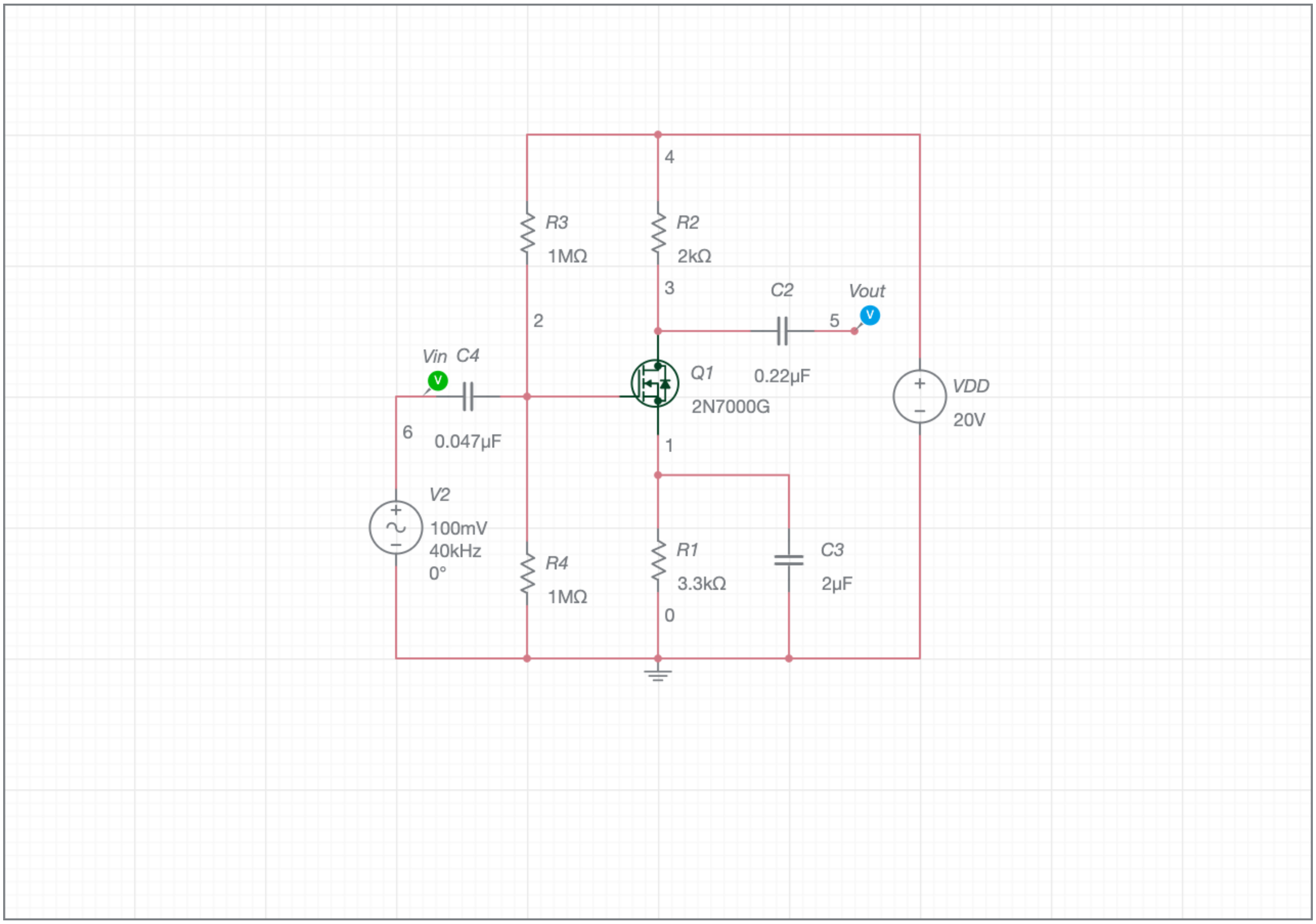
4.12 This figure illustrates the magnitude and phase of the transfer function $H(s)$ for frequencies ranging from 1Hz to 1MHz.

4.13 Run the simulation and capture the results. Include the schematic and the AC-sweep figures in your lab report.

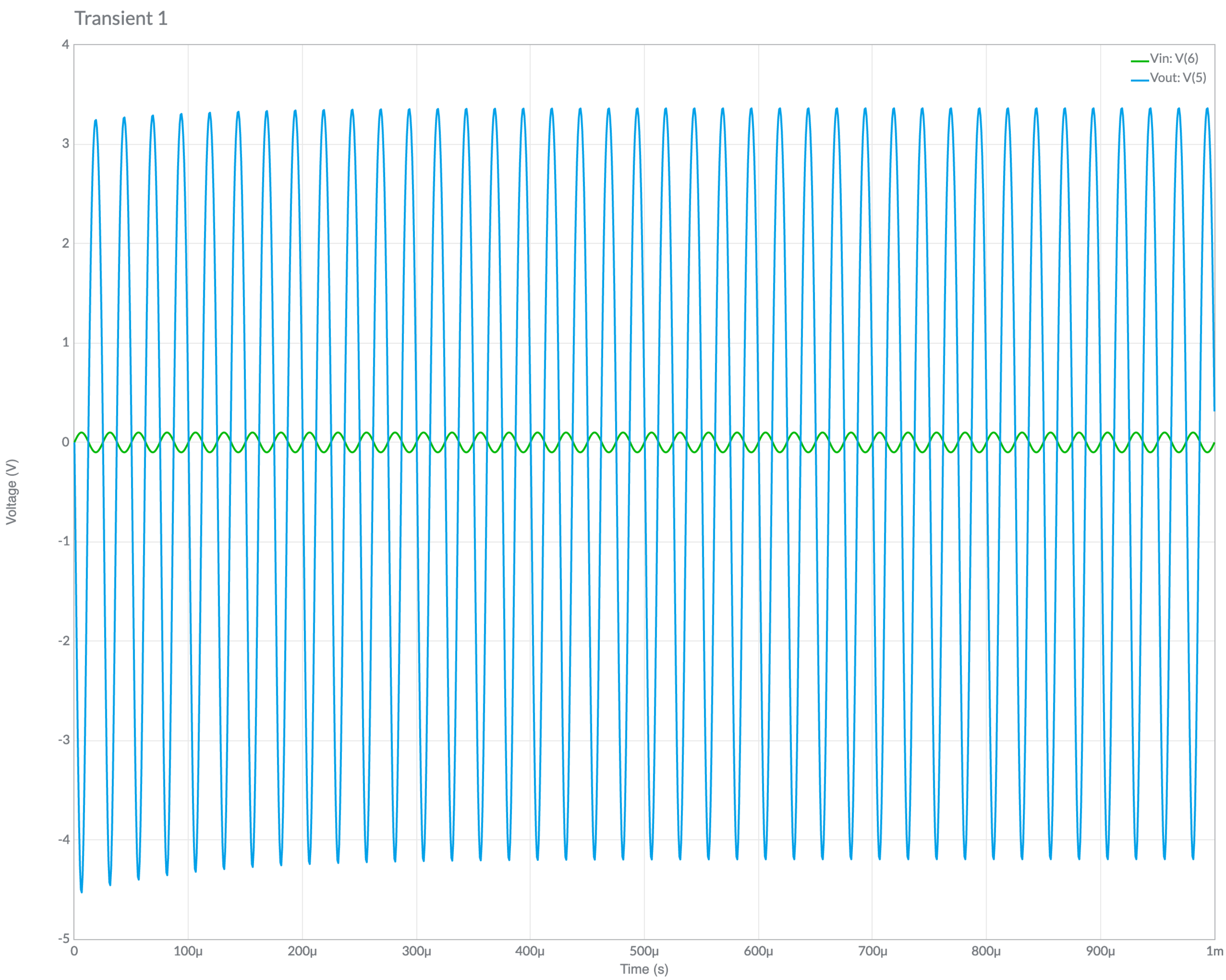
5. Observations

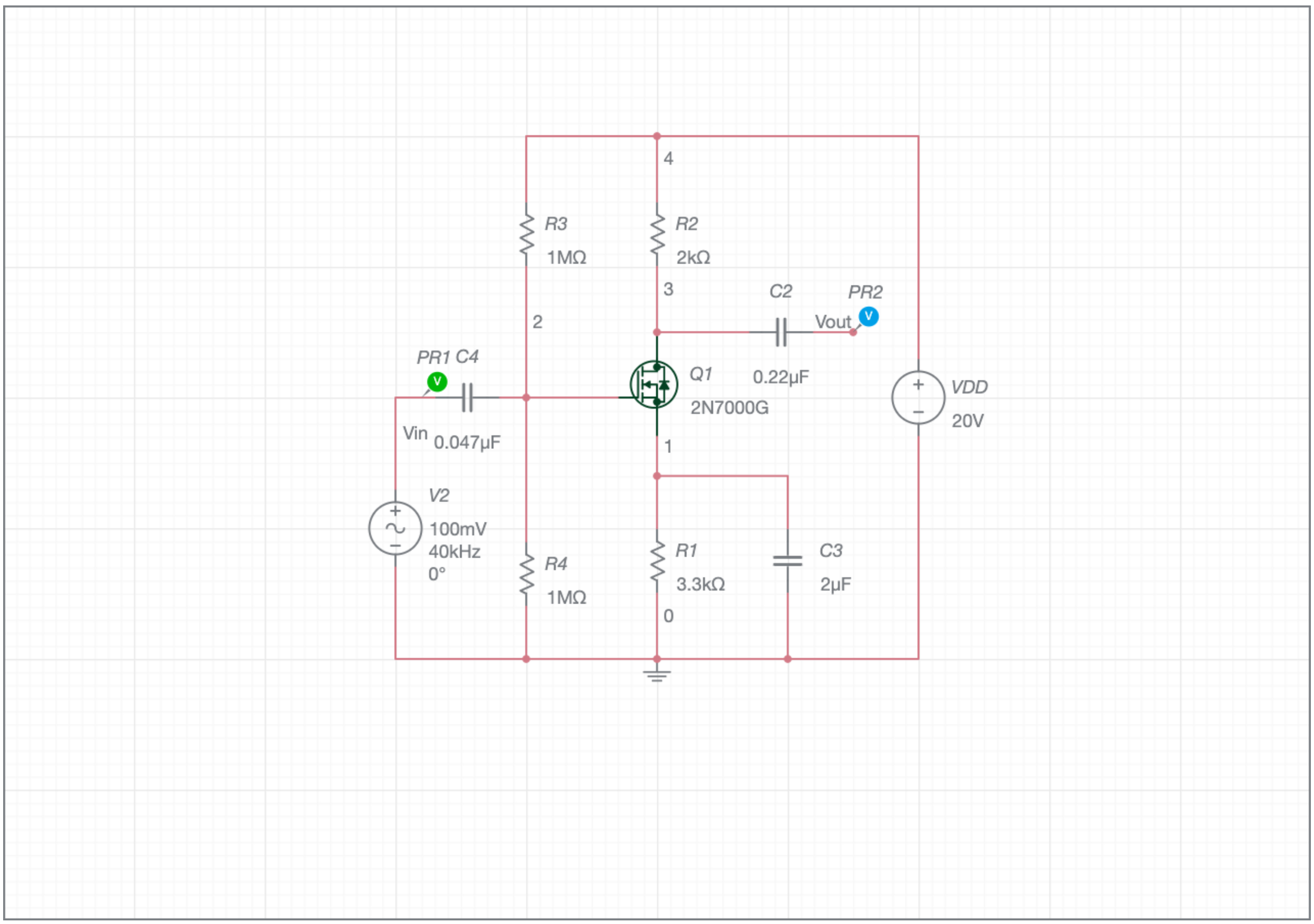
5.1 Notice the much more "ideal" characteristics of gain and phase for the modeled amplifier transfer function.

5.2 While we will not now dwell on the implications of the phase shift, we note that the phase is also influenced by the operation of the transistor amplifier.

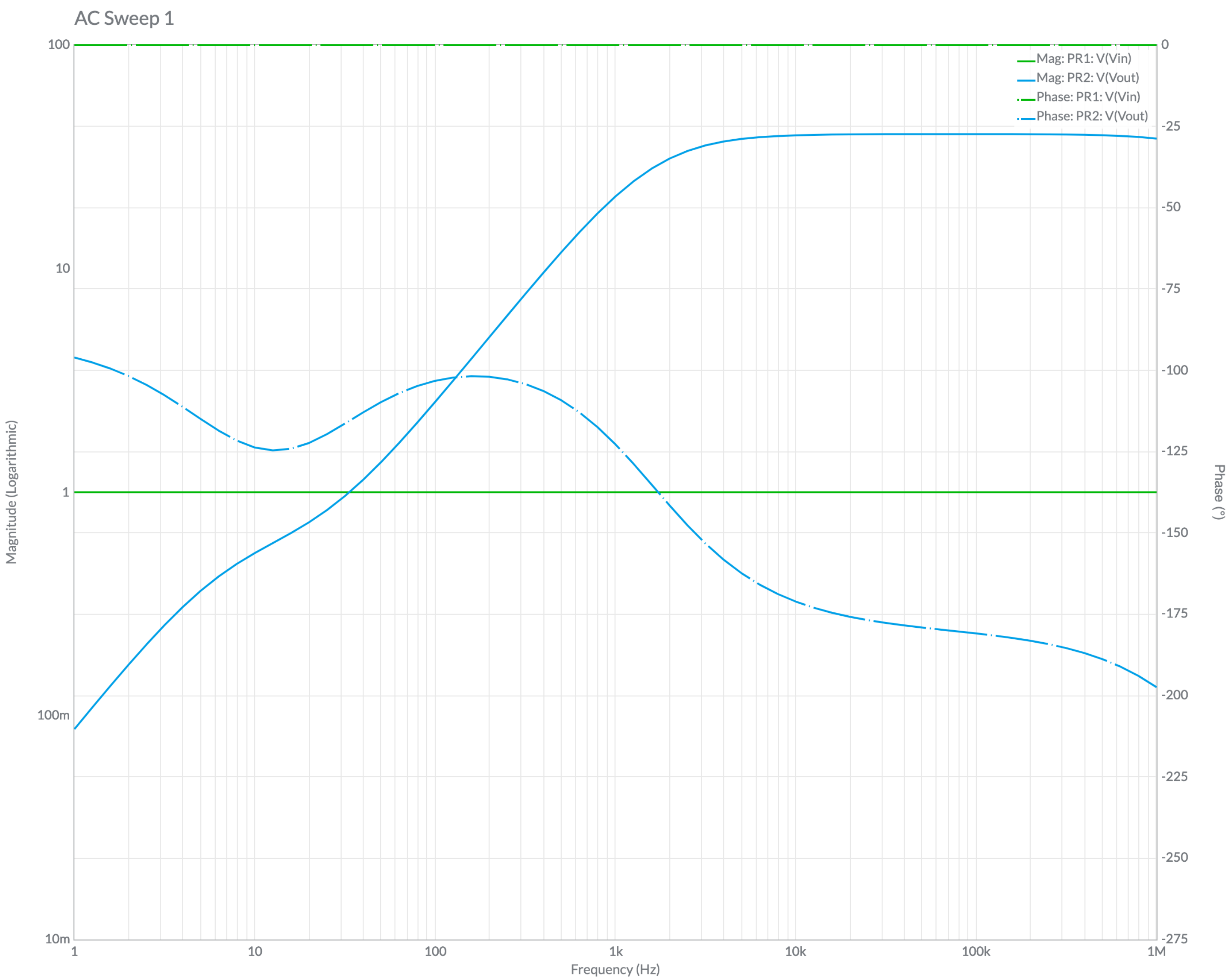


4
R3
1MΩ
R2
2kΩ
3
C2
Vout
5
2
Vin
C4
Q1
0.22µF
VDD
2N7000G
20V
6
0.047µF
1
V2
100mV
40kHz
0°
R4
1MΩ
R1
3.3kΩ
C3
2µF
0

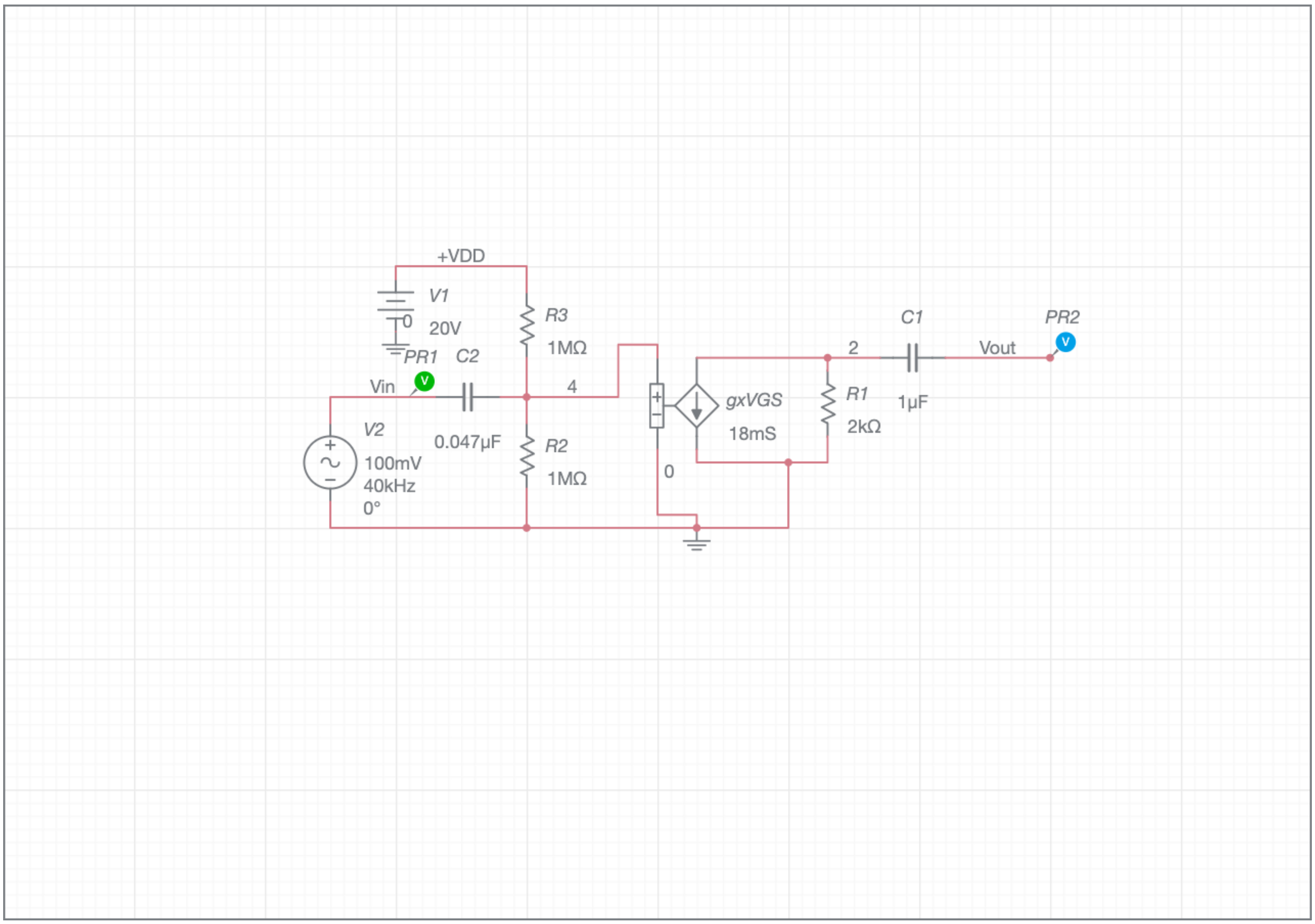

Transient 1
Vin: V(6)
Vout: V(5)
Voltage (V)
Time (s)
4
3
2
1
0
-1
-2
-3
-4
-5
0
100µ
200µ
300µ
400µ
500µ
600µ
700µ
800µ
900µ
1m

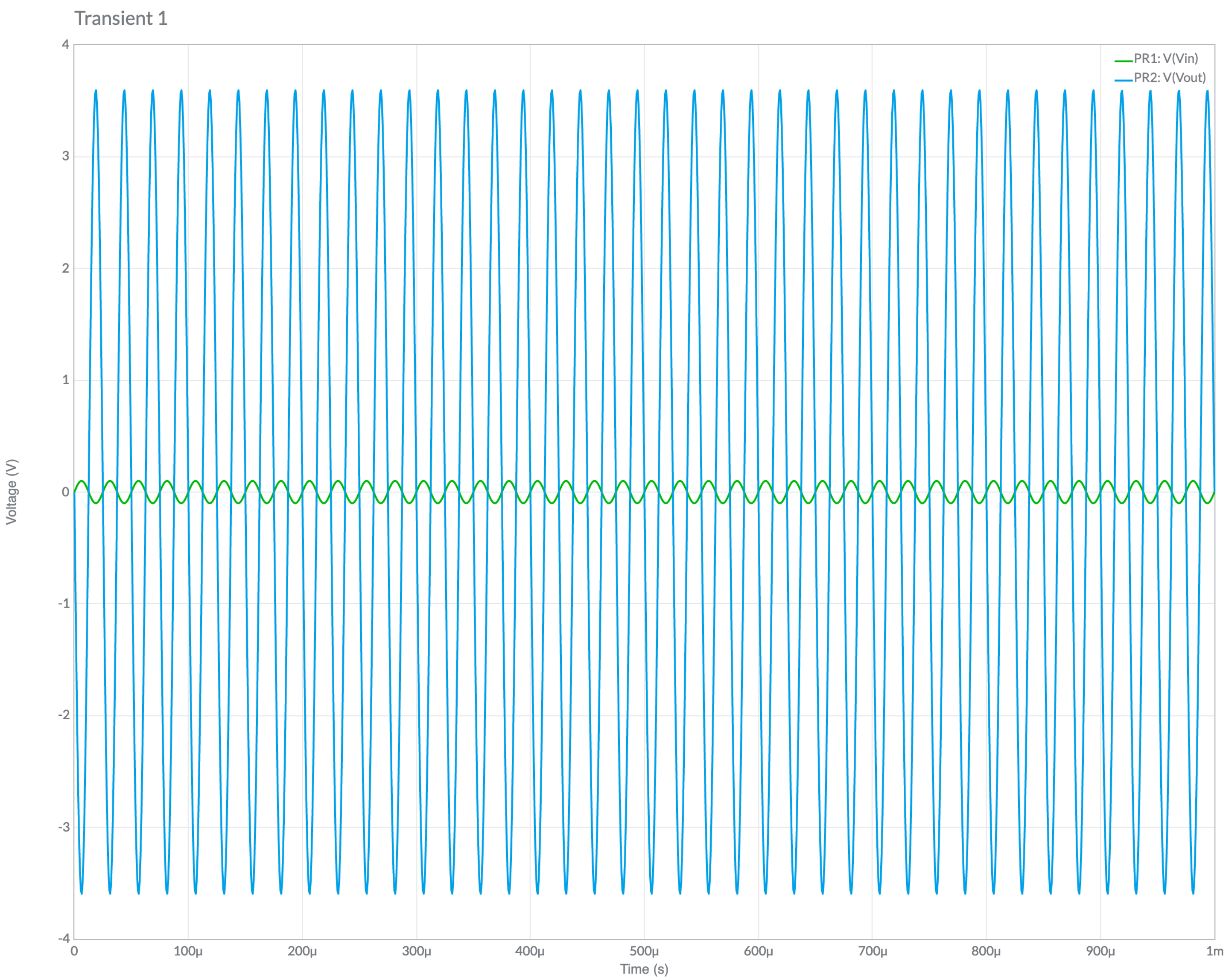


4
R3
1MΩ
R2
2kΩ
3
C2
PR2
Vout
2
PR1 C4
Q1
0.22μF
2N7000G
VDD
20V
Vin
0.047μF
1
V2
100mV
40kHz
0°
R4
1MΩ
R1
3.3kΩ
C3
2μF
0

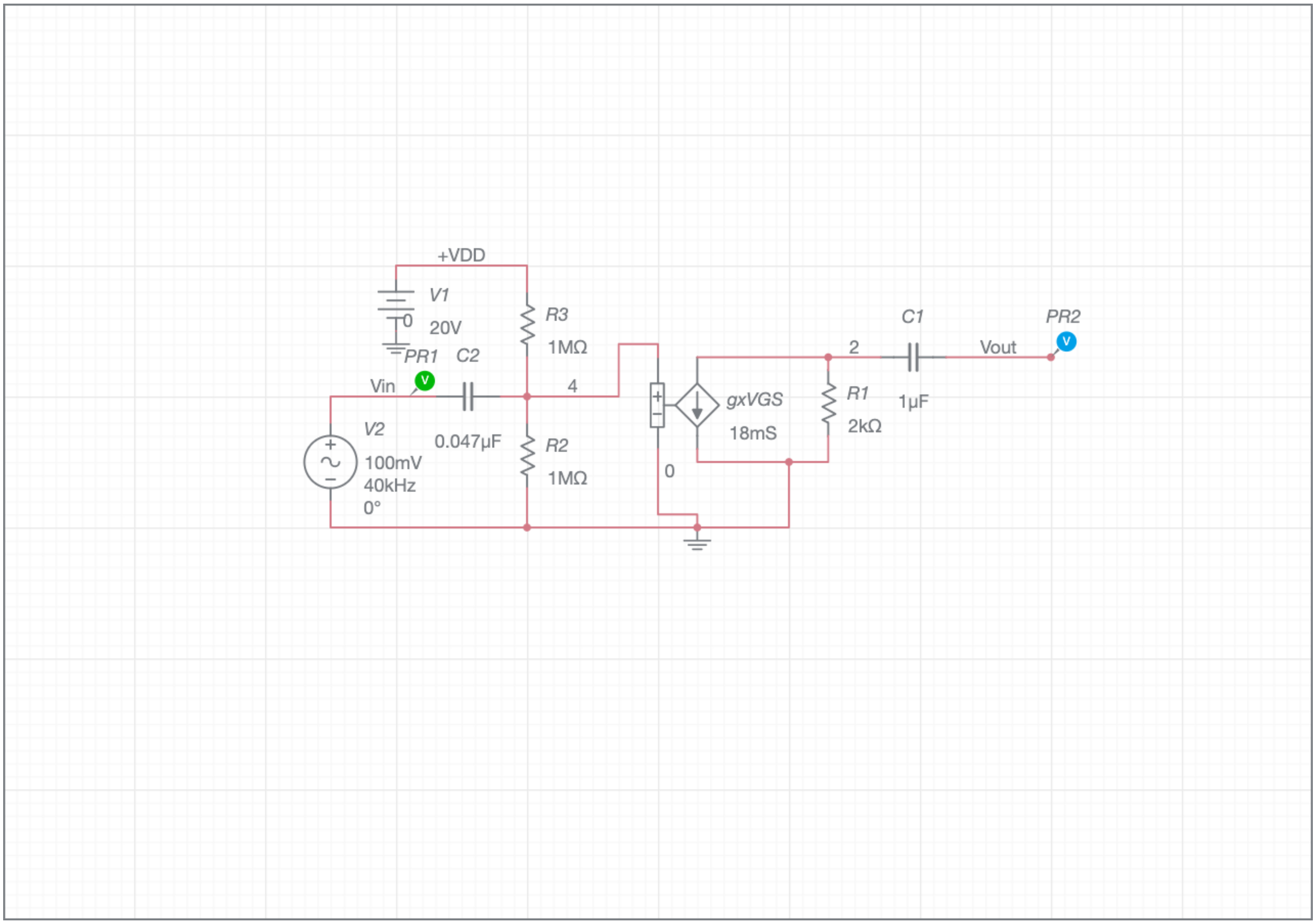


AC Sweep 1
Mag: PR1: V(Vin)
Mag: PR2: V(Vout)
Phase: PR1: V(Vin)
Phase: PR2: V(Vout)
Magnitude (Logarithmic)
100
10
1
100m
10m
Phase (°)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
-250
-275
1
10
100
1k
10k
100k
1M
Frequency (Hz)

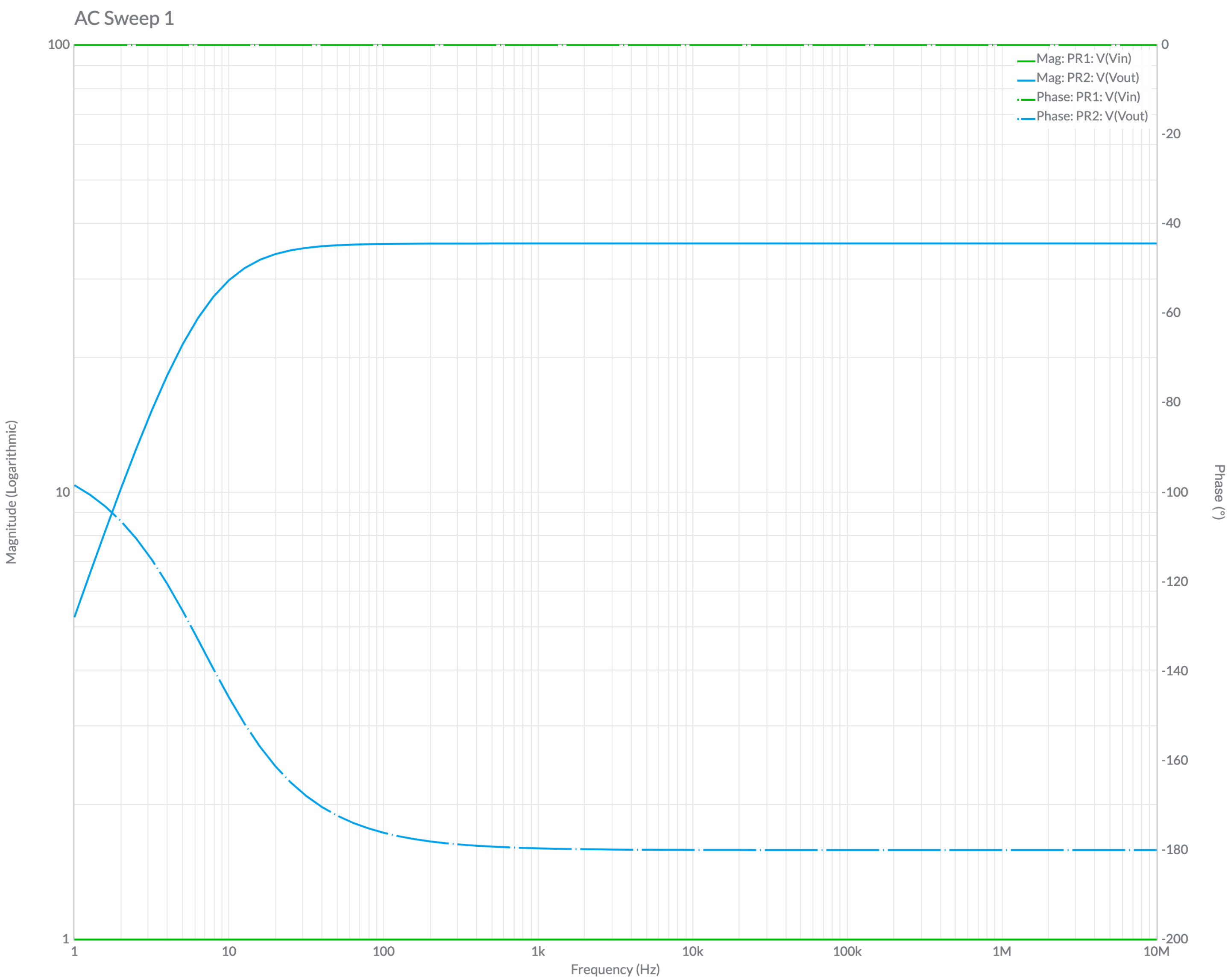

+VDD
V1
20V
0
R3
1MΩ
PR1
C2
Vin
0.047µF
4
V2
100mV
40kHz
0°
R2
1MΩ
gxVGS
18mS
0
2
R1
2kΩ
C1
1µF
Vout
PR2



Transient 1
PR1: V(Vin)
PR2: V(Vout)
Voltage (V)
4
3
2
1
0
-1
-2
-3
-4
0
100µ
200µ
300µ
400µ
500µ
600µ
700µ
800µ
900µ
1m
Time (s)



+VDD
V1
0
20V
R3
1MΩ
PR1
C2
Vin
4
V2
100mV
40kHz
0°
0.047µF
R2
1MΩ
gxVGS
18mS
0
2
C1
PR2
Vout
R1
2kΩ
1µF


AC Sweep 1
Mag: PR1: V(Vin)
Mag: PR2: V(Vout)
Phase: PR1: V(Vin)
Phase: PR2: V(Vout)
Magnitude (Logarithmic)
Phase (°)
Frequency (Hz)
100
10
1
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
-200
1
10
100
1k
10k
100k
1M
10M

B. In Lab Procedures

In this lab session you will realize and validate the single-transistor amplifier from the Pre-Lab simulations.

1. Construct the Single Transistor Amplifier Circuit

1.1 Assemble the circuit to resemble the simulated circuit below.

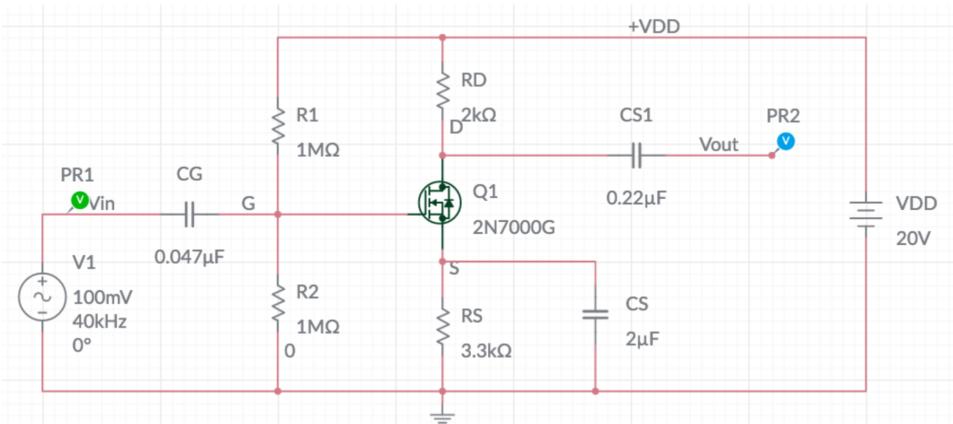


Figure 7: Single-transistor amplifier

1.2 Use the bench power supply to provide the 20VDC required for the *biasing voltage*.

1.3 DO NOT yet apply the input signal.

1.4 Measure the DC voltages at the *Gate* of the transistor: 6.61V

1.5 Measure the DC voltages at the *Drain* (top) of the transistor: 15.22V

1.6 Measure the DC voltages at the *Source* (bottom) of the transistor: 8.02V

Note: These should approximate 10V, 13V, and 7V, respectively.

1.7 Now apply the input signal as, generated by the function generator,0

1.8 Connect one channel of the oscilloscope to the function generator (this is the reference signal) and the other channel across the resistor.

1.9 Turn on the oscilloscope. Press the **Auto-scale** button to get the waveform in to view on the oscilloscope.

1.10 The three *Measure* buttons can be used to obtain amplitude, frequency, and time measurements.

1.11 Press the **Voltage** button to open up the Voltage Measurement Softkey Options at the bottom of the display. Make sure that the **Source** is set to whichever source the oscilloscope are probes connected to. Select the V_{p-p} option to measure the peak-to-peak voltage.

1.12 Measure the phase of the output by measuring the difference in time between zero-crossings of the two waveforms. Select the V_{p-p} option to measure the peak-to-peak voltage.

1.13 With the initial frequency at 40 kHz, fill out the following table adjusting the frequency of the input accordingly. As you change the frequency you will likely have to rescale the oscilloscope display.

Frequency (Hz)	Vin_{p-p} (V)	$Vout_{p-p}$ (V)	Gain	Phase (degrees)
100Hz	268mV	728mV	2.7	110.8
40kHz	252mV	4.4V	17.4	174.19
100kHz	256mV	4.4V	17.2	176.33

1.14 Were these the results that you expected from the amplifier we constructed? Compare to the results of the Pre-Lab.

yes, as expected from prelab

C. Takeaways:

- Dependent sources are useful for approximate (idealized) modeling of the behavior of active elements.
- As is the case for models for any physical component - "All models are wrong, some are useful."
- Engineers must understand the risks and limitations of employing simple, idealized models.