EE 40

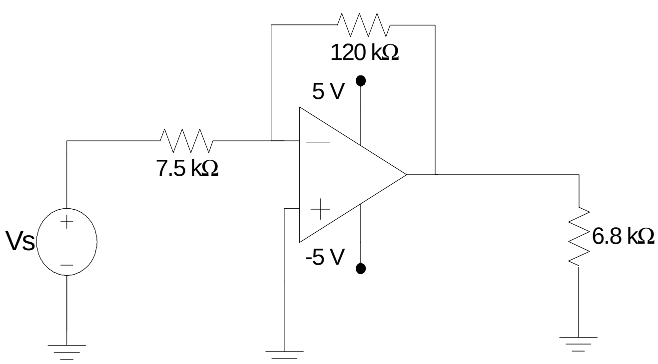
Homework #5

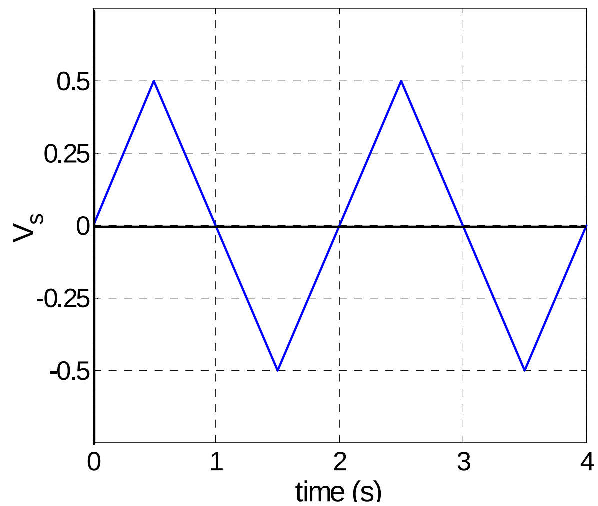
Solutions and grading

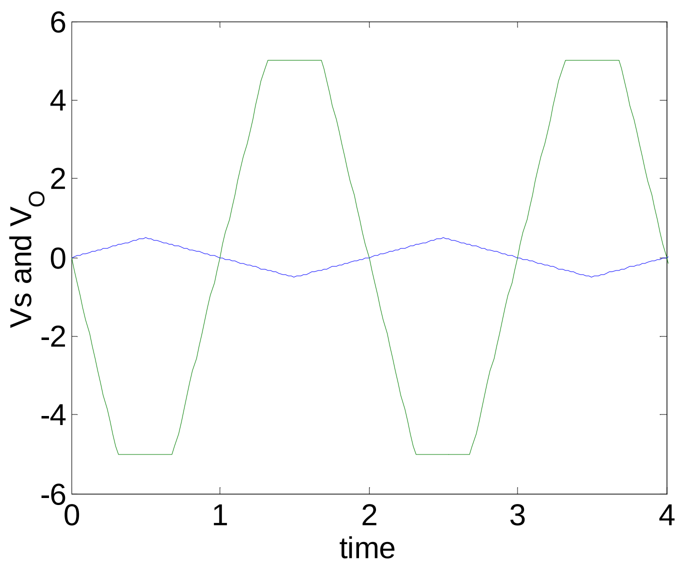
Nearly all problems taken from *Electric Circuits* by Nilsson and Riedel

Notation: The extra connections coming out of the amplifier indicate the “rails”.

Problem 1: **20 Points**







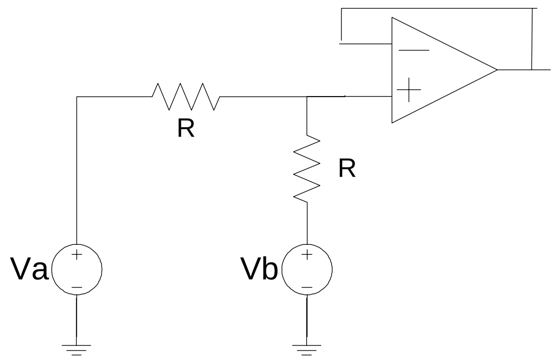
The amplifier above is an inverting amplifier. We showed in class that the output $V_O = -R_F/R_1\ V_i$, so in this case $V_O = -120k/7.5k\ Vs = -16\ Vs$.

We also know that V_O cannot exceed the rail voltages. So V_O is limited to –5 to 5 V. The amplifier will hit the rails when
5 V = VO = -16 Vs, or
Vs = -5/16 = -0.3125 V. Similarly, we hit the bottom rail when Vs = 0.3125 V.

From this, we can draw the graph: the input is inverted, with slope 16 in the linear regions, and we have just defined where the rails occur.

20 points for a correct graph
Subtract 5 points for wrong gain or not inverting
Subtract 10 points for ignoring rails
Minimum credit is 0 points

Problem 2: 20 Points



This is one of many possible answers for Problem 2.

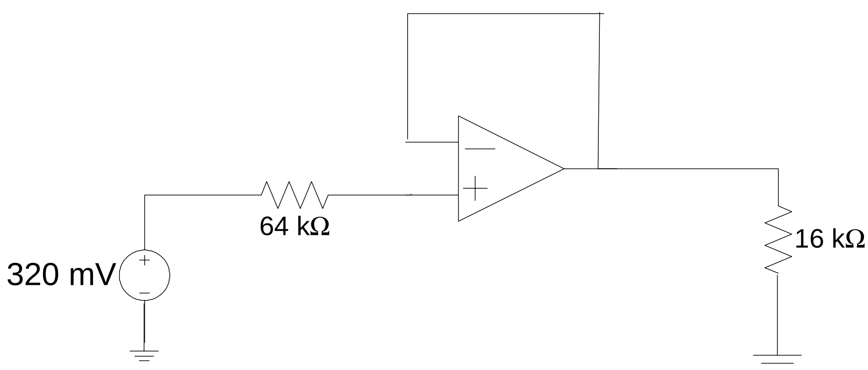
Notice that the resistor in series with Vb carries a voltage of (Va-Vb)/2 .

(Why? Since there is no current going into the op-amp, the resistors are effectively in series and we perform voltage division).

The node voltage at the noninverting terminal, also known as Vp, is thus Vp = (Va-Vb)/2 + Vb. Since the amplifier here is a "voltage-follower", the output voltage is the same as Vp. Thus, V_O=(Va-Vb)/2.

20 Points for ANY circuit that works (even if it does not have an op-amp, although contrary to specs!)
10 Points for "best effort" circuit; one that may not be the right form but most analysis is correct
Subtract 2 points for each math error
Use judgement for other partial credit; minimum score 0 points

Problem 3: 20 Points



a) Since this is again a voltage-follower amplifier, the output voltage is the same as Vp. Since no current can flow into the amplifier input, the 64 kΩ resistor carries no current and therefore no voltage. Vp, and thus V_O, are 320 mV.

$P = I^2R = V^2/R$
$= (320 \times 10^{-3})^2/(16 \times 10^3) = 6.4\ \mu W$

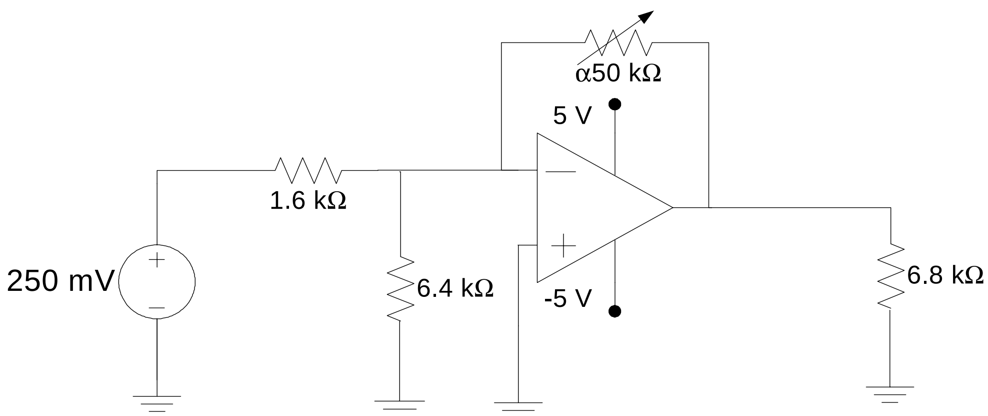
b) Here, by voltage division, the 16 kΩ resistor will take $320\ mV \dfrac{16\ k\Omega}{16\ k\Omega + 64\ k\Omega} = 64\ mV$.

$P = I^2R = V^2/R = (64 \times 10^{-3})^2/(16 \times 10^3) = 256\ nW$

c) $6.4 \times 10^{-6} / 256 \times 10^{-9} = 25$

10 points for part a, 5 points for part b, 5 points for part c
Subtract 2 points for each math error
No other partial credit

Problem 4: 20 Points



Notice that the 6.4 kW resistor carries a voltage of Vn-Vp, which we assume is zero. Thus, no current flows through this resistor, and the resistor has no effect on the rest of the circuit.

This leaves us with a basic inverting amplifier.

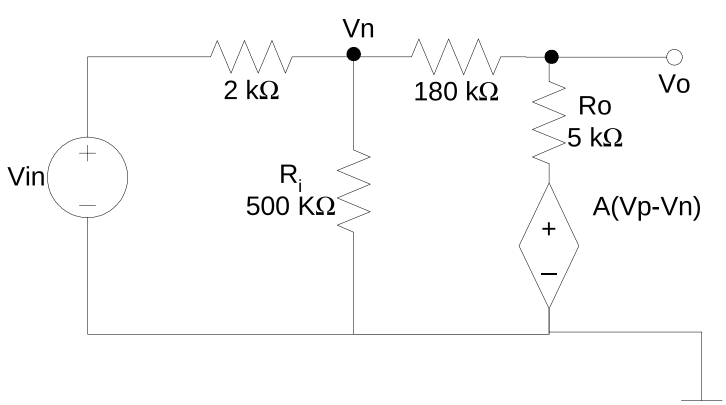
$V_O = -R_F/R_1\ V_i = -(\alpha 50\ k\Omega\ /\ 1.6\ k\Omega)(250\ mV) = -\alpha\ 7.8125\ V$

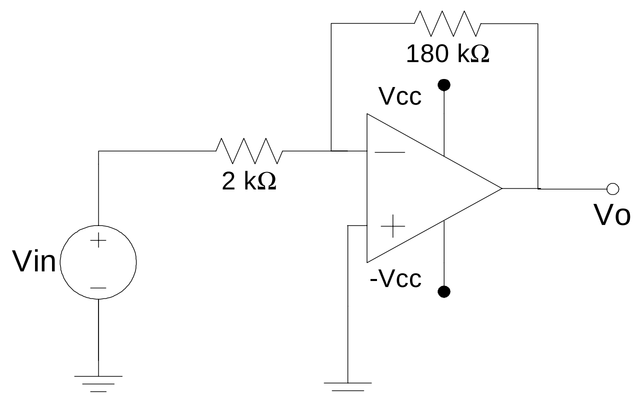
The bottom rail, -5 V, will be hit when $\alpha = -5\ /\ -7.8125 = 0.64$; α can be between 0 and 0.64 .

Since this is an inverting amplifier with positive input voltage, and α must be positive (otherwise the feedback resistance will be negative), the output must always be negative. Therefore, we cannot hit the top rail of 5 V.

20 Points for correct range for α
Subtract 5 points for each significant error in analysis
Subtract 2 points for each math error, or for saying α can be negative (no negative resistance)

Problem 5: 20 Points





a) On the left, we see the non-ideal op-amp circuit, with the op-amp replaced by its circuit equivalent. We analyze it using nodal analysis to find V_O in terms of Vin. Writing equations at Vn and V_O,

$$\frac{Vn - Vin}{2k\Omega} + \frac{Vn}{500k\Omega} + \frac{Vn - Vo}{180k\Omega} = 0 \qquad \frac{Vo - Vn}{180k\Omega} + \frac{Vo - A(Vp - Vn)}{5k\Omega} = 0 \Rightarrow \frac{Vo - Vn}{180k\Omega} + \frac{Vo + 250{,}000\,Vn}{5k\Omega} = 0$$

Manipulating the second equation, we find

$$Vn = \frac{37}{[1-(36)(250{,}000)]} Vo$$

Manipulating the first equation, we find

$$Vin = \left(\frac{1}{250}+\frac{1}{90}+1\right)Vn - \frac{1}{90}Vo = \left[\left(\frac{1}{250}+\frac{1}{90}+1\right)\left(\frac{37}{[1-(36)(250{,}000)]}\right)-\frac{1}{90}\right]Vo$$

Therefore the gain

$$\frac{Vo}{Vin} = \left[\left(\frac{1}{250}+\frac{1}{90}+1\right)\left(\frac{37}{[1-(36)(250{,}000)]}\right)-\frac{1}{90}\right]^{-1} = -89.966$$

b) Using the ideal op-amp model at right, we are dealing with the usual inverting amplifier.

$V_O = -R_F/R_1\ V_{in} = -(180\ k\Omega\ /\ 2\ k\Omega)\ V_{in} = -90\ V_{in}$

Thus, $V_O/ V_{in} = 90$ for the ideal op-amp circuit.

20 Points for correct gains (something close to -89 in part a is ok)
Subtract 5 points for each significant error (putting resistors in the wrong place, Vp-Vn upside down...)
Subtract 2 points for each math error