EE 355 Analog Electronics
Test 1

Name Solutions
September 28, 2017

RULES

This is a closed book, closed notes test. You are, however, allowed one piece of paper (front side only, hand-written) for notes and definitions. You must staple your equations sheet to the back of your test when you hand your test in.

You are permitted to use a calculator.

You have 75 minutes to complete the test. Please read through the entire test before starting, and read through the directions carefully. To receive partial credit, you must show your work.

I you have any questions, please raise your hand, and I will come to you to answer them. Do not hesitate to ask questions.

Circle/box all of your answers.

$n_i=10^{10}cm^{-3}$, $\mu_n=1360cm^2/Vs$, $\mu_p=460cm^2/Vs$, $\tau_n=\tau_p=100\mu s$, $E_g=1.12eV$,
$K_s=11.8$, $\varepsilon_0=8.854x10^{-12}F/m$,
$k=1.38x10^{-23}J/K$, $T=300K$, $q=1.602x10^{-19}C$

Opamp Parameters $V_{sat}=\pm5V$

Diode Parameters $V_{ON}=0.7$, $V_Z=5.6V$, $n=1$, $I_0=0.1pA$

Problem	Value	Score
1	20	
2	10	
3	10	
4	10	
5	20	
6	20	
7	10	
Total	100	

EE 355 Analog Electronics — Name *Solutions*

Test 1 — September 28, 2017

PROBLEM 1 (20 Points)

An amplifier has the following two-port model parameters

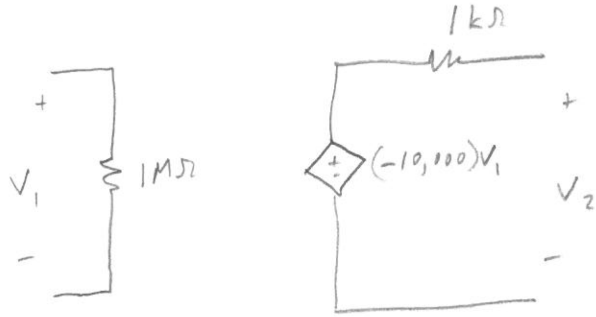
R_{in} = 1MΩ

R_{out} = 1kΩ

A_v = −10,000

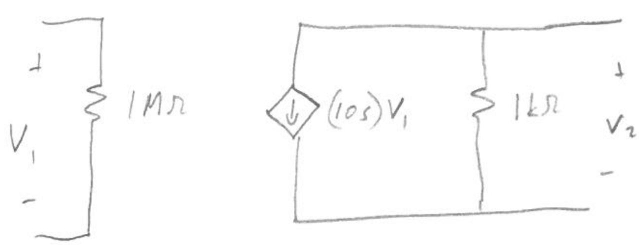
(Note, this amplifier is a *unilateral* amplifier – there is no reverse transconductance)

A. Draw the two-port model using the parameters given. Use numerical values where applicable (for example, write 1MΩ instead of R_{in}). (5 Points)



B. Convert this two-port model to have a Norton-style output. Provide numerical values for each of the parameters. (5 Points)

$A_v = -G_m R_{out} \Rightarrow G_m = \frac{-A_v}{R_{out}} = 10\,S$



C. Determine the unloaded gain of this amplifier. (2 Points)

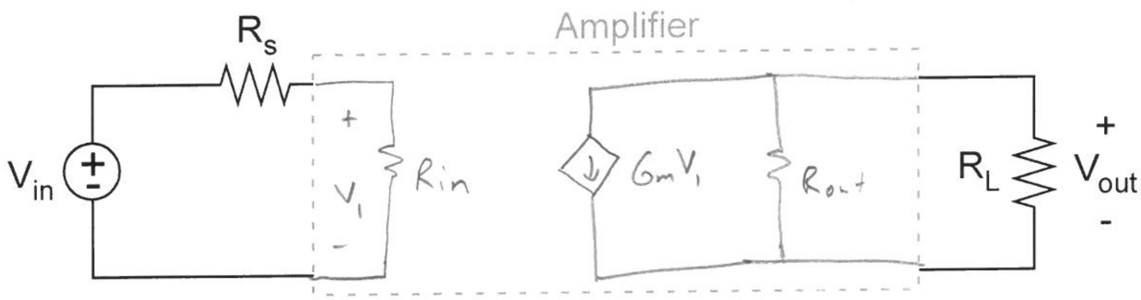
$A_v = -10{,}000$ (Given)

Name Solutions

D. This amplifier is now connected to the a preceding circuit (represented by a Thevenin equivalent), and the amplifier drives the subsequent load resistance, R_L. Determine the gain from V_{in} to V_{out}.

(8 Points)

$R_S = 1M\Omega \quad R_L = 10k\Omega$



$$V_1 = V_{in} \frac{R_{in}}{R_{in} + R_S}$$

$$V_{out} = -G_m V_1 (R_{out} // R_L)$$

$$V_{out} = -(G_m)(V_{in})\left(\frac{R_{in}}{R_{in} + R_S}\right) \frac{R_{out} R_L}{R_{out} + R_L}$$

$$\frac{V_{out}}{V_{in}} = -(10\,S)\left(\frac{1M\Omega}{1M\Omega + 1M\Omega}\right) \frac{(1k\Omega)(10k\Omega)}{1k\Omega + 10k\Omega} = \boxed{-4545}$$

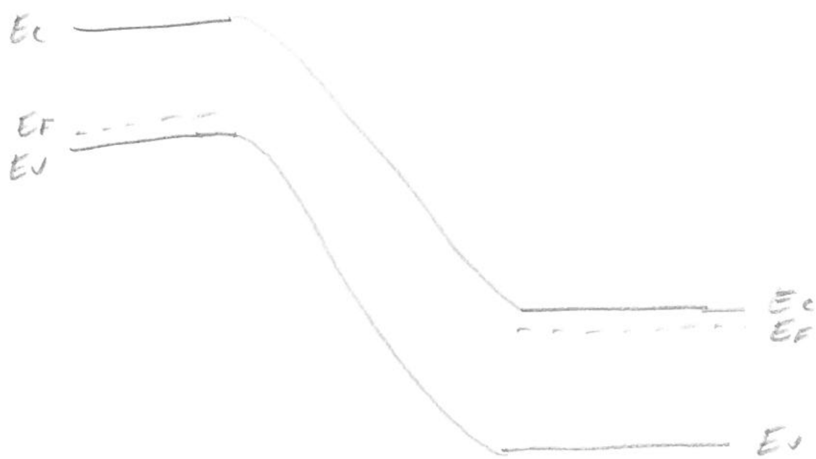
EE 355 Analog Electronics   Name *Solutions*

Test 1   September 28, 2017

PROBLEM 2 (10 Points)

A. Draw the band diagram of a p-n junction with zero applied bias. Label all relevant energy levels and the p-type and n-type sides. (2 Points)

B. Draw the band diagram of a p-n junction with a reverse bias. Label all relevant energy levels and the p-type and n-type sides. (3 Points)



Note. The Fermi levels do not line up.

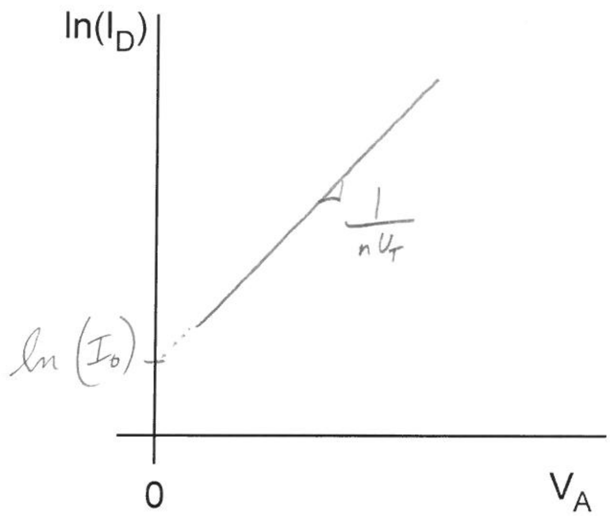
B. What type of thermal motion of charged particles is the primary mechanism of current flow in a reverse-biased diode? (1 Point)

Drift

Name Solutions

B. Draw the forward bias current in a p-n junction on the axes that have been provided. Be sure to label all slopes, intercepts, and/or significant items. (4 Points)

Diode Current (Forward Bias)

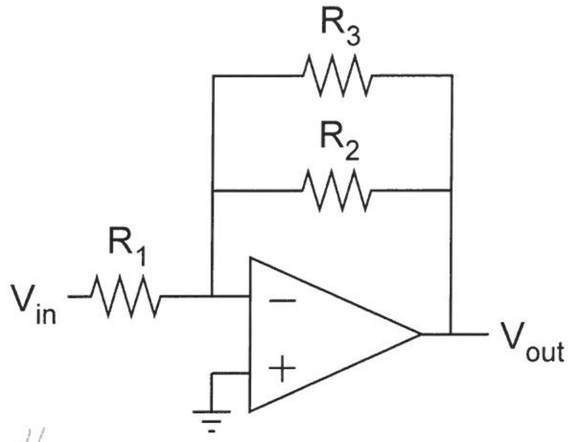


Name Solutions

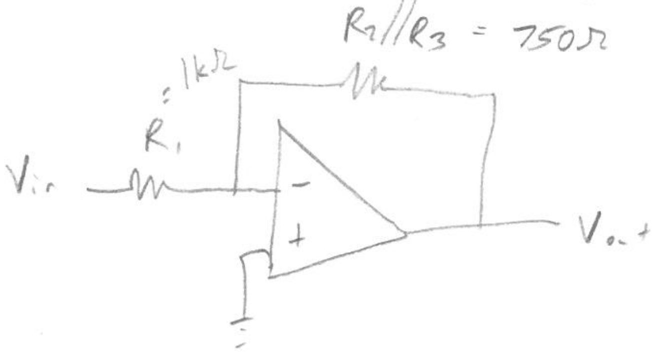
PROBLEM 3 (10 Points)

For the following circuit and the parameters given below, determine voltage gain.

$R_1 = 1k\Omega \quad R_2 = 1k\Omega \quad R_3 = 3k\Omega$



NFB exists!
This is an inverting amp



$$\frac{V_{out}}{V_{in}} = -\frac{R_2 // R_3}{R_1} = \frac{-750\Omega}{1k\Omega} = \boxed{-0.75}$$

EE 355 Analog Electronics
Test 1

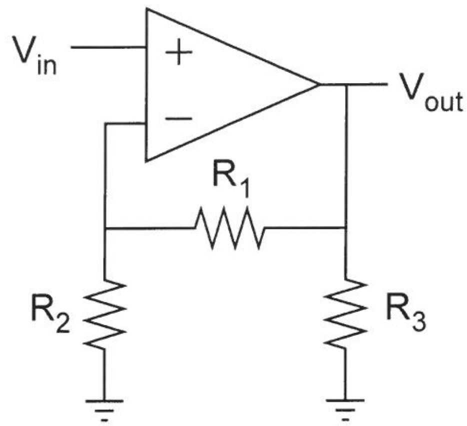
Name Solutions

September 28, 2017

PROBLEM 4 (10 Points)

For the following circuit and the parameters given below, determine the output voltage and the current flowing through each resistor. Write your answers on the lines that have been provided.

V_{in} = 1V R_1 = 1kΩ R_2 = 2kΩ R_3 = 100Ω



V_{out} = 1.5 V

I_{R1} = 0.5 mA

I_{R2} = 0.5 mA

I_{R3} = 15 mA

NFB exists ⇒ $V_+ = V_-$

$\therefore I_{R2} = \frac{V_- - 0V}{R_2} = \frac{1V}{2k\Omega} = 0.5mA$

$I_{R2} = I_{R1}$ (The only place for the current to flow)

Note. This is just a non-inverting amp with a resistor (R_3) connected from the output to GND. Since the ideal opamp has zero output impedance, this effective "load" does not cause any loading effects on the amplifier

$\therefore V_{out} = V_{in}\left(1 + \frac{R_1}{R_2}\right) = (1V)\left(1 + \frac{1}{2}\right) = 1.5V$

$I_{R3} = \frac{V_{out}}{R_3} = \frac{1.5V}{100\Omega} = 15mA$

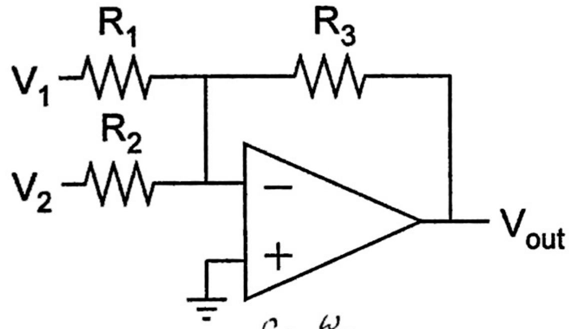
EE 355 Analog Electronics
Test 1

Name Solutions
September 28, 2017

PROBLEM 5 (20 Points)

For the following circuit and the parameters given below, sketch the time-domain waveform for V_{out}.

$V_1 = (0.5)\cos(\omega t)$ $V_2 = 1V$ $R_1 = 1k\Omega$ $R_2 = 2k\Omega$ $R_3 = 1k\Omega$



Inverting Summer Amplifier

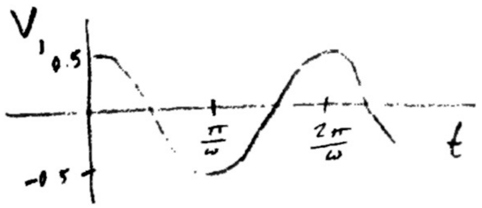
Using superposition

$$V_{out} = -\frac{R_3}{R_1}V_1 - \frac{R_3}{R_2}V_2$$

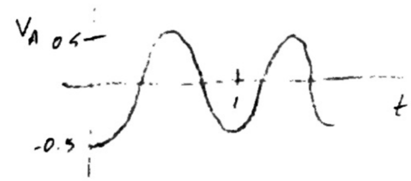
$$V_{out} = \underbrace{-V_1}_{V_A} + \underbrace{-\frac{1}{2}V_2}_{V_B} = -0.5\cos(\omega t) - 0.5$$

$f = \frac{\omega}{2\pi}$

$T = \frac{2\pi}{\omega}$



⇒



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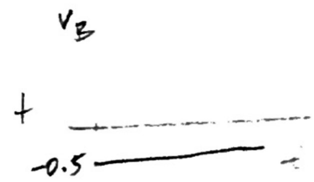
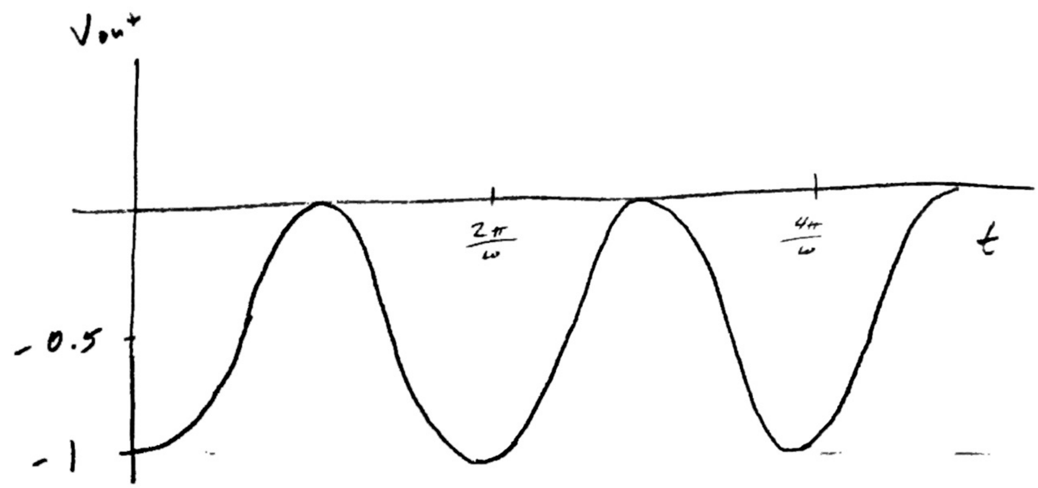




EE 355 Analog Electronics
Test 1

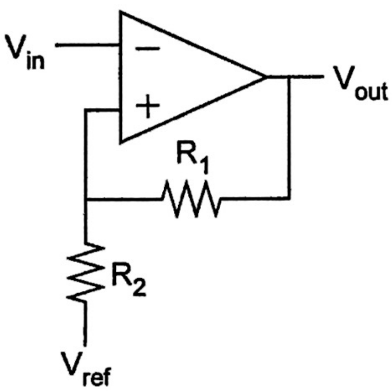
Name *Solutions*
September 28, 2017

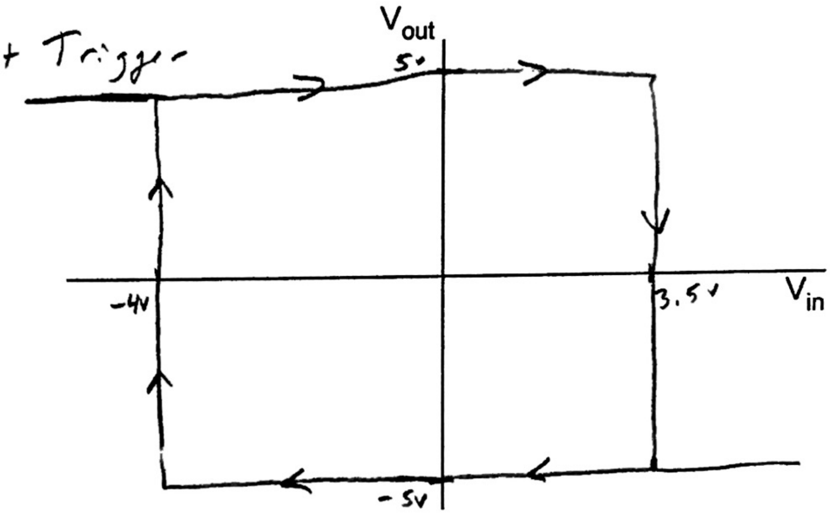
PROBLEM 6 (20 Points)

For the following circuit and the parameters given below, determine the input-to-output voltage relationship (i.e. transfer function). Sketch the transfer function in as much detail as possible on the axes that have been provided. Label all interesting items on the sketch.

$V_{ref} = -1V \quad R_1 = 1k\Omega \quad R_2 = 3k\Omega$

Positive Feedback!
This is a Schmitt Trigger





V_{out} can be either $\pm V_{sat} = \pm 5V$

$$V_+ = (\pm V_{sat})\left(\frac{R_2}{R_1+R_2}\right) + V_{ref}\left(\frac{R_1}{R_1+R_2}\right)$$

$$V_+ = \begin{cases} (5V)\left(\frac{3}{4}\right) + (-1V)\left(\frac{1}{4}\right) = 3.5 & \text{if } V_{out} = +V_{sat} \\ (-5V)\left(\frac{3}{4}\right) + (-1V)\left(\frac{1}{4}\right) = -4 & \text{if } V_{out} = -V_{sat} \end{cases}$$

$\frac{1}{2}$ hysteresis $\pm 3.75V$ offset $= -0.25V$

If V_{out} is high, then the trip point is when $V_{in} = 3.5V$

If $V_{in} > 3.5V \Rightarrow V_{out}$ goes low

If V_{out} is low, then the trip point is when $V_{in} = -4V$

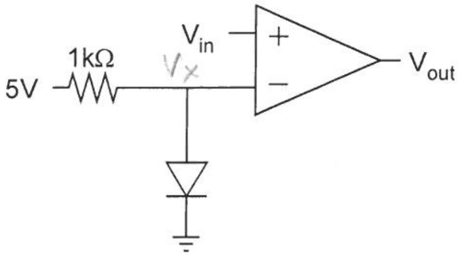
If $V_{in} < -4V \Rightarrow V_{out}$ goes high

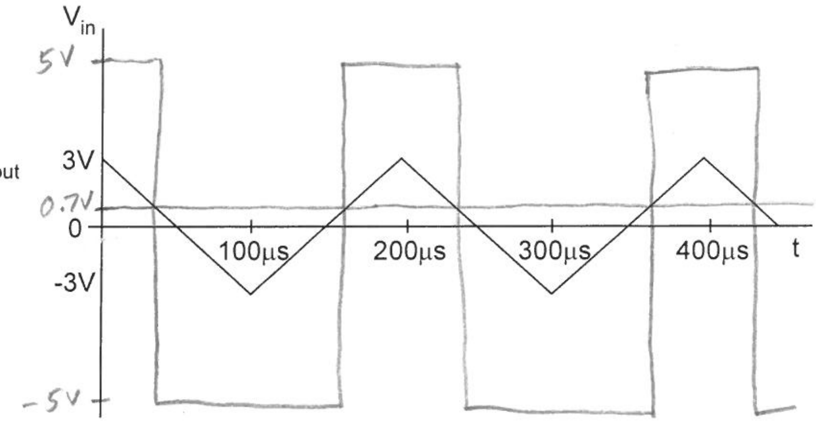
This is an inverting Schmitt Trigger

Name Solutions

PROBLEM 7 (10 Points)

For the following circuit, the input signal is displayed below. Sketch the time-domain value V_{out}.





Note → The diode is forward biased

$\therefore V_x = V_{ON} = 0.7V$

There is no NFB

The acts as a comparator

If $V_{in} > V_x \Rightarrow V_{out}$ goes high