Name:____

Massachusetts Institute of Technology

Department of Nuclear Science and Engineering
Department of Electrical Engineering and Computer Science

22.071/6.071 – Introduction to Electronics, Signals and Measurement
Spring 2006

Final Exam

- Please write your name on each page of the exam in the space provided
- Please verify that there are 26 pages in your exam.
- To the extent possible, do your work for each question within the boundaries of the question or on the back side of the page preceding the question. Extra pages are also provided for computation.
- Note that the total number of points is 100.
- Closed book. No Calculators
- Partial credit adds up so make sure that you show your work.

Problem	Points
1	
2	
3	
4	
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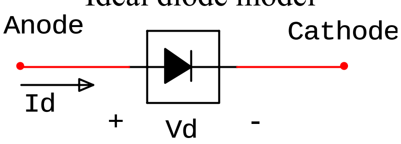
7	
8	
9	
10	
Total	

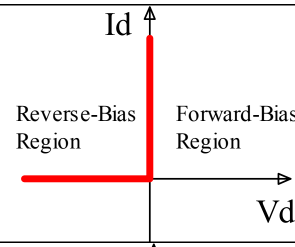
Name:____

General Useful Information

Diodes:

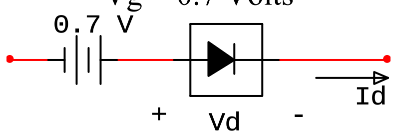
Ideal diode model

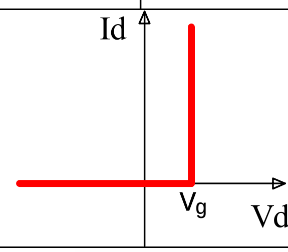




0.7 Volt offset model

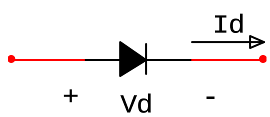
Vg = 0.7 Volts

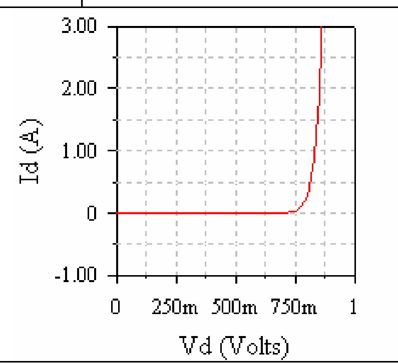




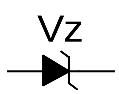
Full diode model $Id = Is\left[\exp\left(\frac{Vd}{V_T}\right) - 1\right]$

$V_T \simeq 25\,mV$

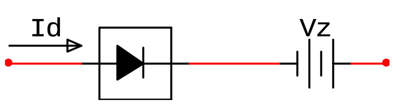


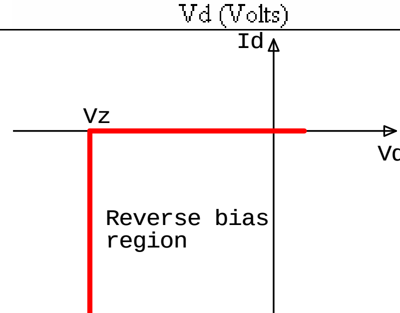


Zener Diode



Ideal model



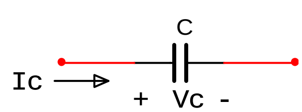


Reactive Elements:

Capacitor

$$I_c = C\frac{dV_c}{dt}$$

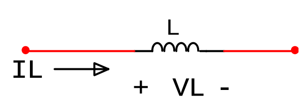
$$Z_C = -\frac{j}{\omega C}$$



Inductor

$$V_L = L\frac{dI_L}{dt}$$

$$Z_L = j\omega L$$



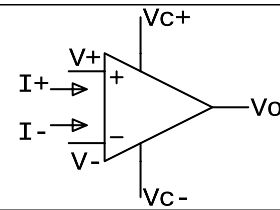
Name:____

General Useful Information

Op-Amps

Ideal Op-amp model (negative feedback)

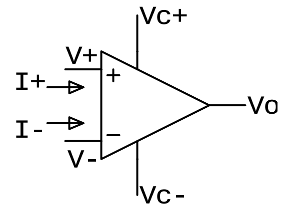
I+ = I- = 0
V+ = V-



Ideal 3 state op-amp model (open loop and positive feedback)

I+ = I- = 0

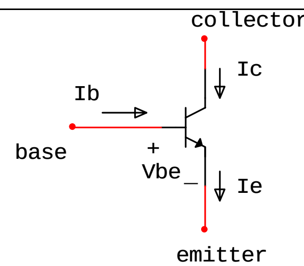
$$V_o = \begin{cases} V_{c+}, & \text{for } A(V+ - V-) > V_{c+} \text{ ; non-linear} \\ A(V+ - V-), & \text{for } V_{c-} < A(V+ - V-) < V_{c+} \text{ ; linear} \\ V_{c-}, & \text{for } A(V+ - V-) < V_c, \text{ ; non-linear} \end{cases}$$

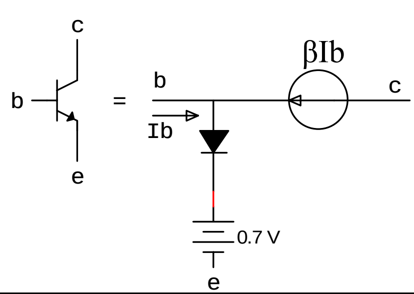


BJTs

Ie = Ic + Ib

For operation in the active region
Ic = βIb
Vbe=0.7 V



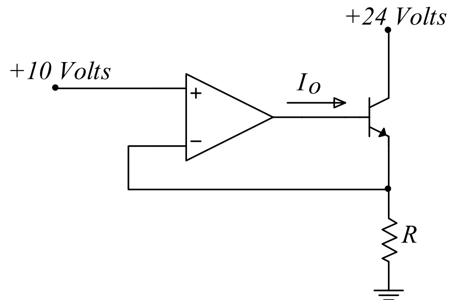


Boolean Identities	
A + 0 = A	A • 1=A
A + B = B + A	AB=BA
A + (B + C) = (A + B) + C	A(BC) = (AB)C
A + BC = (A +B)(A + C)	A(B+C) = AB + AC
A + A = A	$A \bullet \overline{A} = 0$
A + 1 = 1	A • A = A
$A + \overline{A} = 1$	A • 0=0
A + AB = A	A(A +B)=A
$A + \overline{A}B = A+B$	(A + B) (A + C) = A + B C
$\overline{AB} = \overline{A} + \overline{B}$	$\overline{A+B} = \overline{A} \bullet \overline{B}$

Name:____

Problem 1 - (10 points)

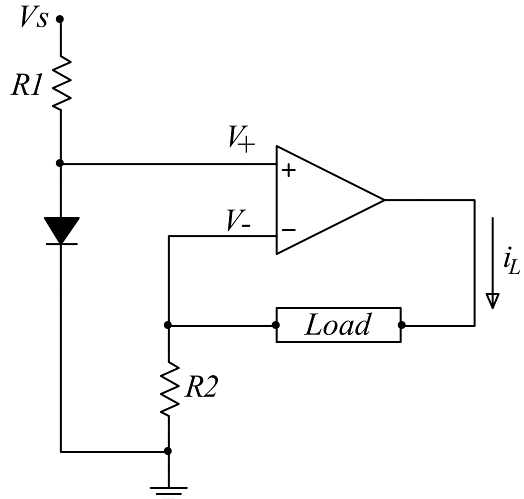
The op-amp in the following circuit outputs a current of 5 mA. (Io =5 mA). The transistor has β=100. Calculate the value of the resistor R.



Name:____

Problem 2 - (10 points)

In this circuit the op-amp may be considered to be ideal and it is not saturated. It drives a load of unspecified resistance.



A. Approximately what is the voltage V_+?

B. What is the voltage V_-?

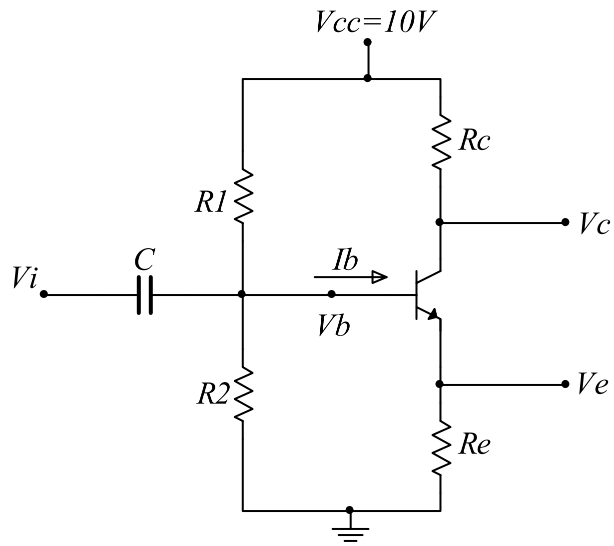
C. Therefore, what is the current i_L and what is the purpose of this circuit?

D. If R1 is increased by a factor $\exp(1)$, what is the expected change in i_L ? (Hint: use the I-V characteristic relationship for a diode)

Name:____

Problem 3 - (10 points)

In this circuit *R1*=100kΩ, *R2*=25kΩ, *Rc*=25kΩ, *Re*=5kΩ, *C*=1μF and the β of the transistor at its DC operating point is 100.



A. If *Ib* is negligible, what is the steady state (DC) value of *Vb*?

B. In that case, using a standard simplified model of the transistor, determine the DC values of *Vc* and *Ve*.

C. Estimate the DC value of *Ib* in that case

D. If this value of *Ib* is accounted for in calculating *Vb*, then how much does it change from your answer in A?

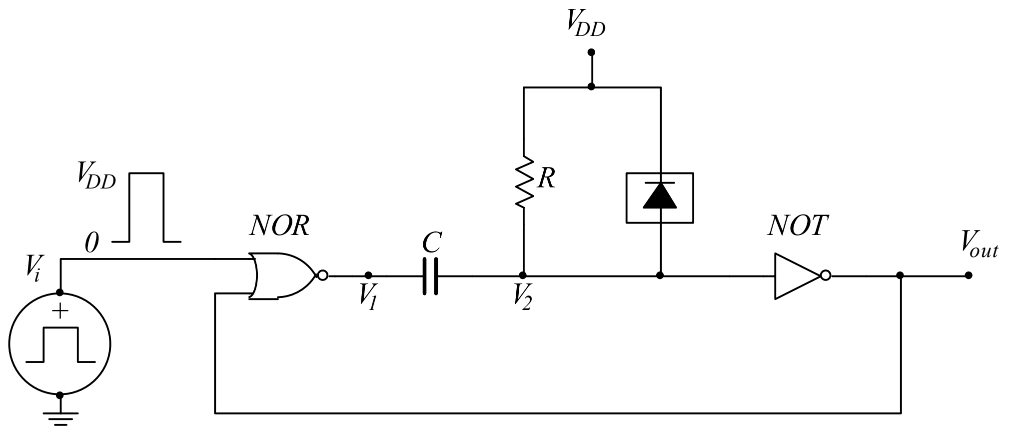
E. Approximately what is the time constant of the high-pass filter made up by *C* and the rest of the circuit?

F. For AC signal frequencies well above the high-pass cut-off, what are the small signal voltage gains of the circuit at the outputs i.e. vc/vi and ve/vi?

Name:____

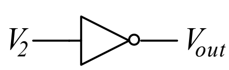
Problem 4 - (10 points)

Here you will analyze the following circuit.

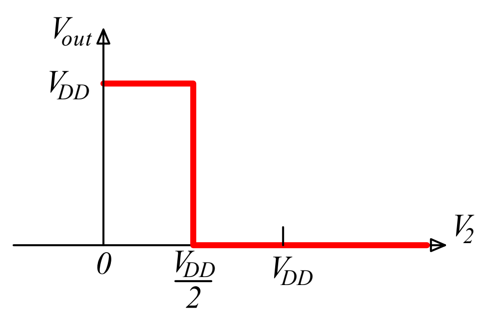


This circuit combines two logic gates (NOR and NOT) and an RC network.

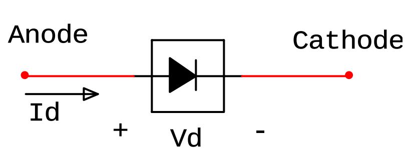
Assume that the logic gates are ideal: no delay time between the output and the input and the output swings between *0* and V_{DD}. Furthermore the voltage transfer characteristic of the inverter gate (*NOT*) is:

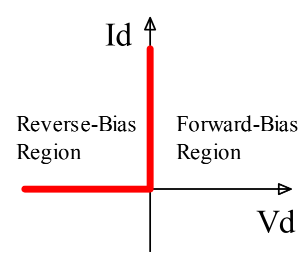


V_2	V_{out}
$> \frac{V_{DD}}{2}$	0
$< \frac{V_{DD}}{2}$	V_{DD}



Also assume that the diode is ideal with the following Id-Vd characteristic curve.



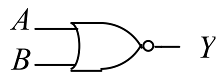


We will apply a trigger pulse V_i and arrange our circuit parameters so that the output V_{out} is a pulse of specified duration.

Name:____

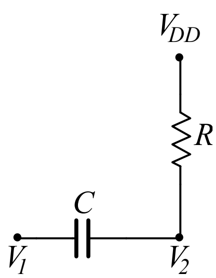
We will solve this problem by breaking it down into small parts, analyze each part and then put it all together for the final answer.

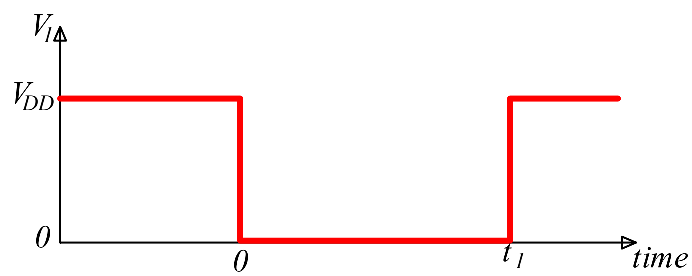
A. Fill in the truth table for the NOR gate



A	B	Y
0	0	
0	V_{DD}	
V_{DD}	0	
V_{DD}	V_{DD}	

B. Now let's independently consider the *RC* network in order to explore its general characteristics. The voltage V_1 has the form shown on the graph below. It has been at V_{DD} Volts for a very long time and then at *time=0* goes to zero Volts, returning to V_{DD} at time t_1.





What is the voltage V_2 at $time=0^-$?

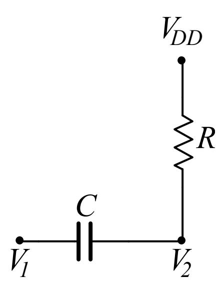
What is the voltage V_2 at $time=0^+$?

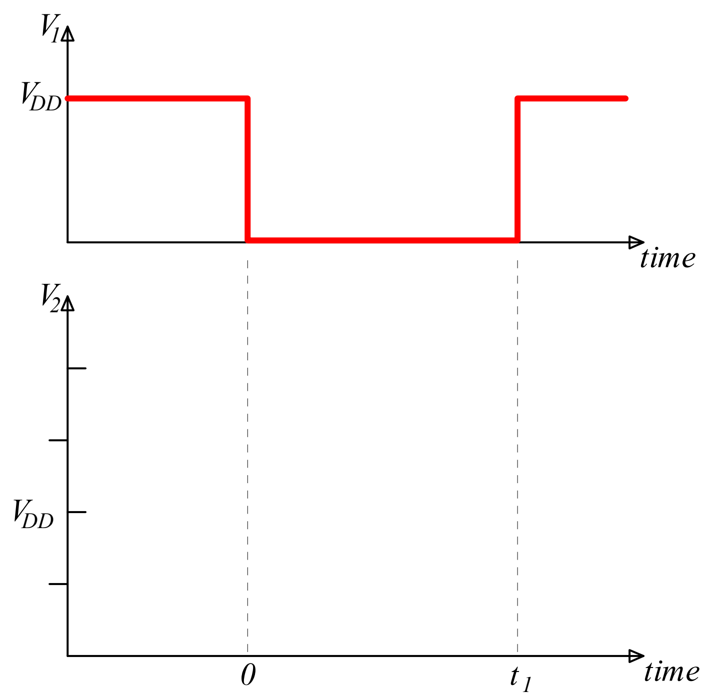
Give an expression for the voltage V_2 for $time \geq 0$

Name:____

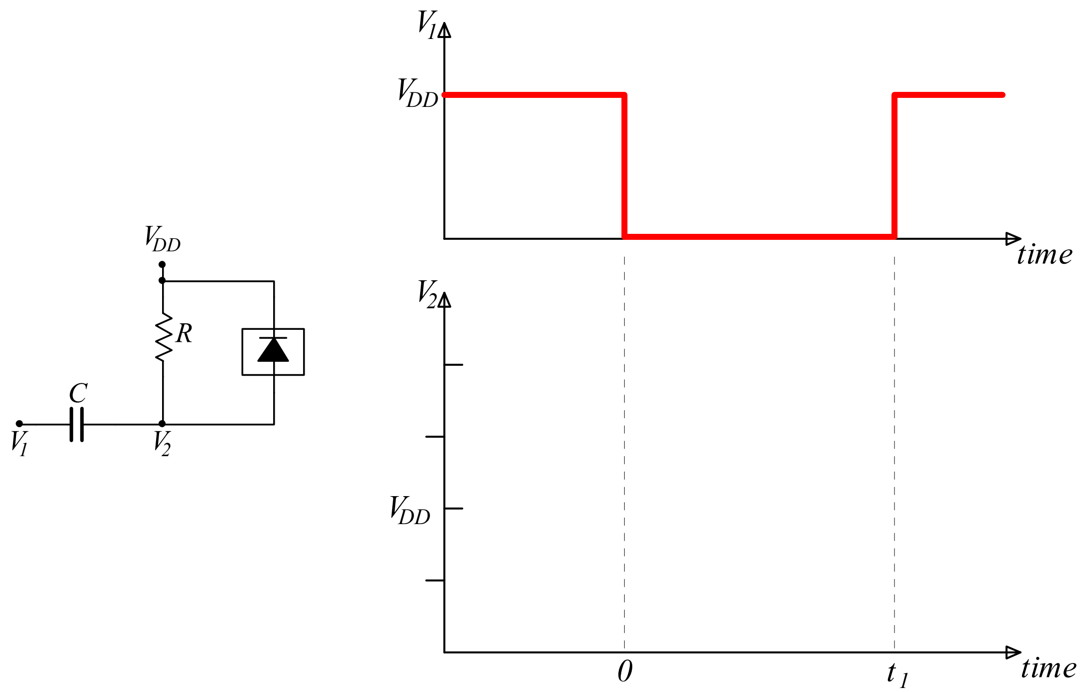
Assuming that $t_1 = RC\ln(2)$, what is the voltage V_2 at $time = t_1^+$? (Hint: the voltage across the capacitor is $V_2 - V_1$)

C. Draw the complete evolution for V_2.

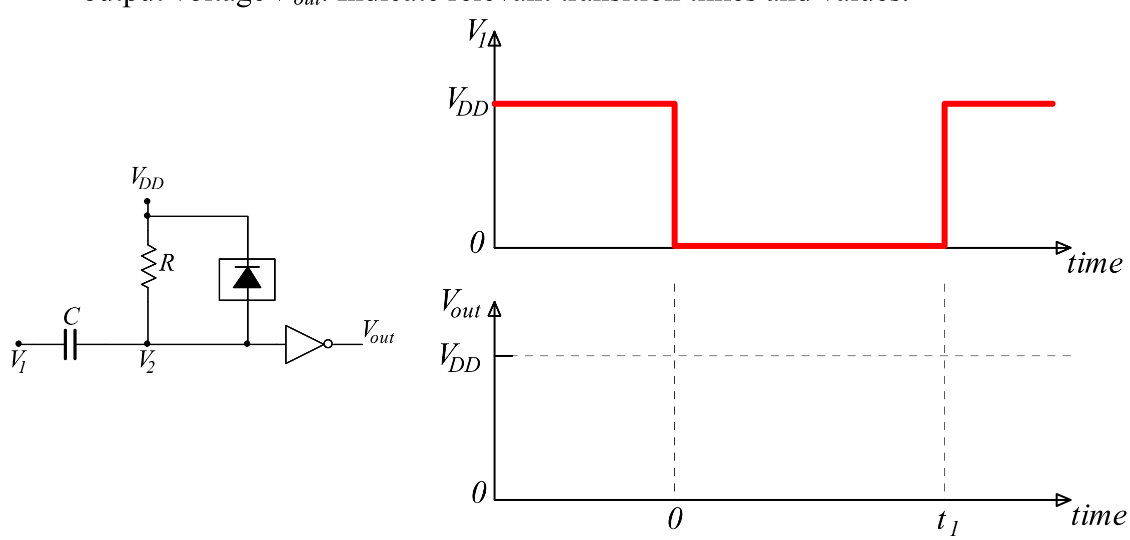




D. Now let's connect a diode to the *RC* circuit as shown below. Draw the evolution of V_2 in this case.

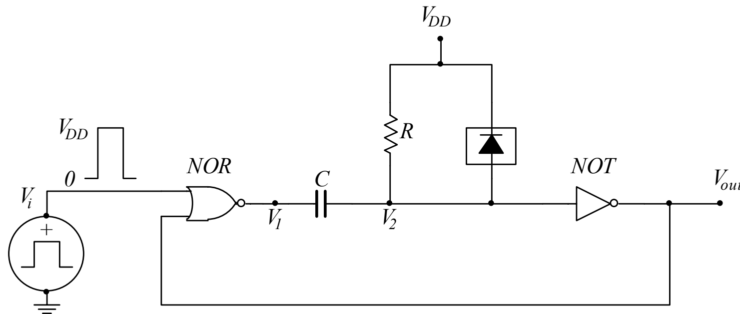


E. Now connect the NOT gate as shown below. With the given voltage transfer characteristic for the inverter gate and for $t_1 = RC\ln(2)$ draw the evolution of the output voltage V_{out}. Indicate relevant transition times and values.

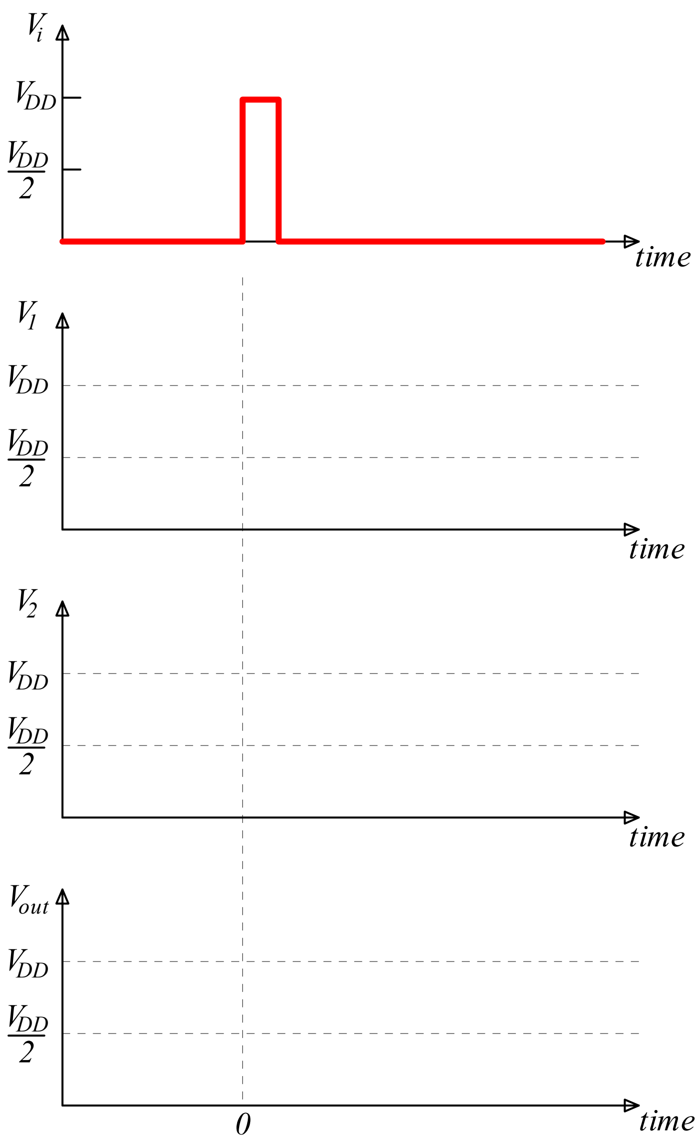


Name:____

F. Now let's put it all together. The complete circuit is reproduced here for your convenience.



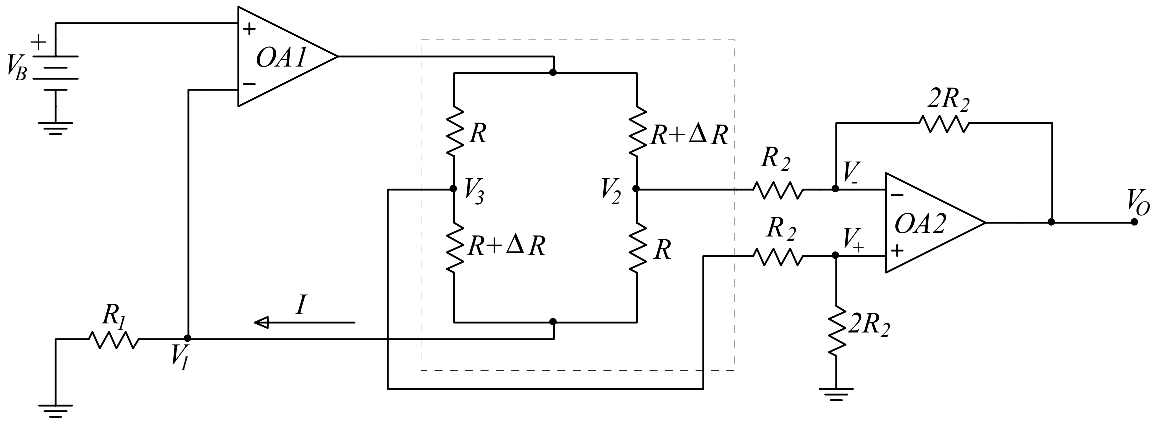
The signal V_i is a pulse as shown below. Draw the form of the voltage V_1, V_2, and V_{out}. Indicate all relevant transition times and values.



Name:____

Problem 5 - (10 points)

This circuit explores the principles of signal measurement using bridge circuits and op-amps.



You should recognize that the resistor network enclosed by the dotted rectangle is a Wheatstone bridge. In practice such a bridge may be used in performing strain-gauge or temperature measurements.

Here we have two such strain-gauges whose resistance is given by $R+\Delta R$. R is the unstrained resistance and ΔR represents the change in resistance due the loading of the structure that the gauge is attached to. We will analyze this circuit in steps in order to eventually calculate the voltage V_O at the output of op-amp *OA2*.

A. What is the voltage V_1?

B. What is the current *I*?

Name:____

C. Write an expression for the voltages V_2 and V_3. (Assume that the resistance $R_2 >> 2R + R_1$)

D. What is the voltage V_+?

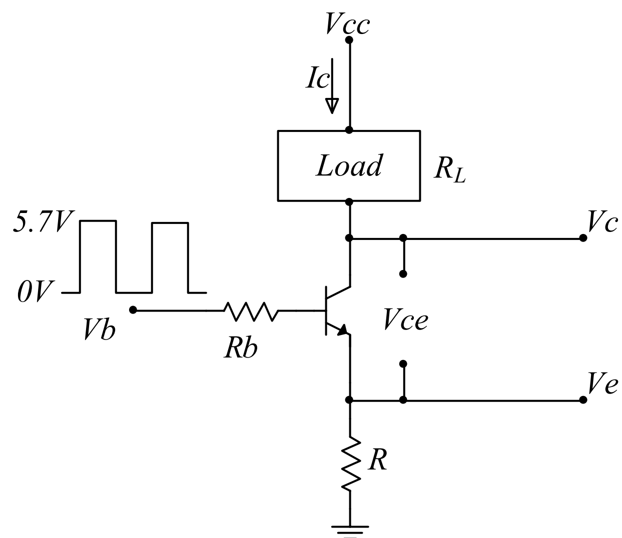
E. What is the voltage V_-?

F. Calculate the voltage V_O

Name:____

Problem 6 - (10 points)

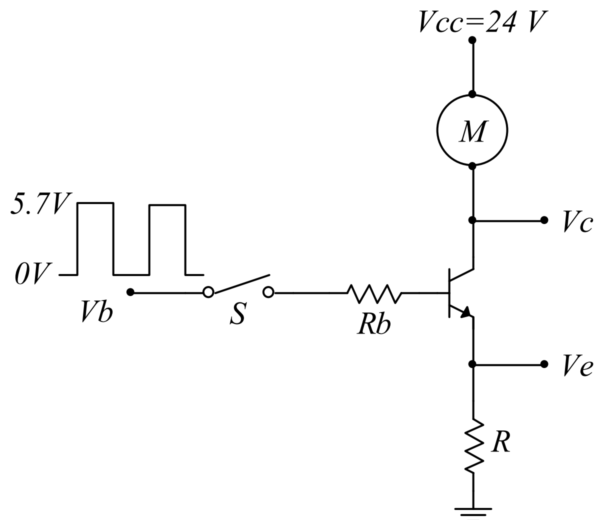
The *Load* in this circuit is powered by *Vcc* and the maximum current through it is determined by the maximum current that can be provided the BJT. The BJT has β=100 and a maximum continuous collector current of 50 mA. The voltage, *Vb*, at the base of the BJT varies between *0* and *5.7* Volts as indicated.



A. For *Vcc*=10.2 Volts, determine the value of the load resistance R_L and the emitter resistor *R* so that the BJT operates in the active region and the current constraint is not violated (i.e. $Vce \geq 0.2\ Volts$ and $Ic \leq 50\, mA$).

Name:____

B. Egatlov's cousin, N.Rub, who went to some school on the west coast, wanted to drive a motor and he used the arrangement shown below. The control voltage *Vb* is a square wave of 50% duty cycle ranging from 0 to 5.7 Volts.



N.Rub, was careful to limit the current though the BJT by appropriately selecting resistor *R* and now he was ready to turn it on by closing switch *S*.

As soon as N.Rub closed the switch, the motor started to turn and immediately it stopped! He checked *Vb* and *Vcc*, double checked the resistor value for *R* and everything seemed to be OK.

He closed the switch again but now nothing happened. He replaces the BJT and the motor, closes the switch and again and the motor makes a few turns and it stops.

N.Rub had no idea what to do next. He asks his coworker Edoid for help. Edoid, who actually took 6.071, looks at the circuit, skims the data sheet of the BJT and the motor and says:

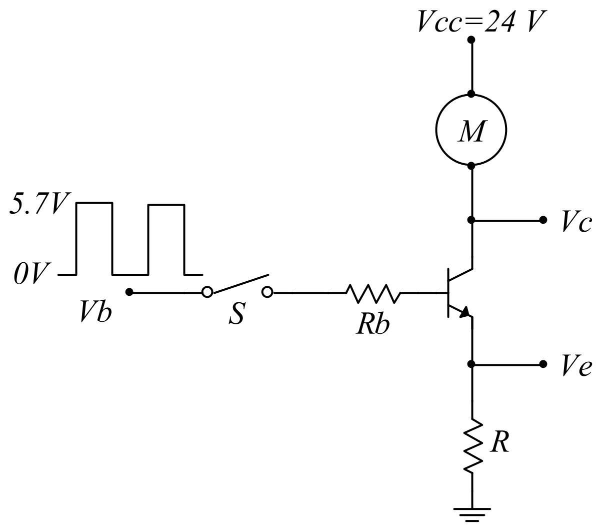
Well, you are trying to drive an inductive load and thus every time you activate the circuit, the maximum voltage rating of the BJT is exceeded destroying the transistor.

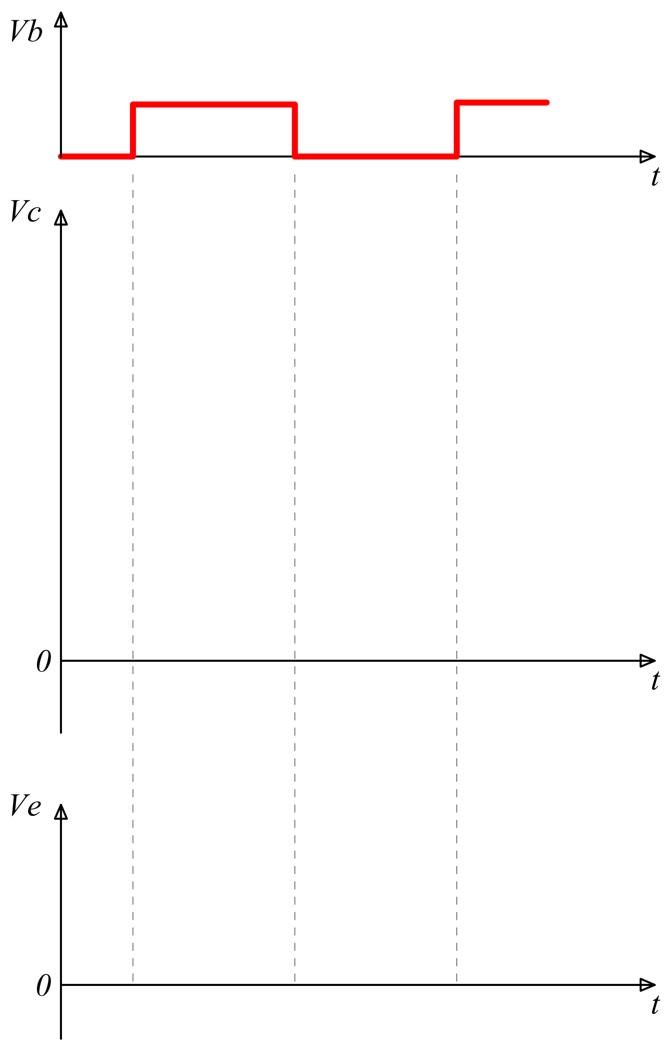
A solution is to place a ______________ in _____________ with the motor.

fill in the name

Show us how Edoid proposes to modify the circuit and give a general plot the voltages *Vc* and *Ve* for both with and without the circuit modification. (next page)

Name:____

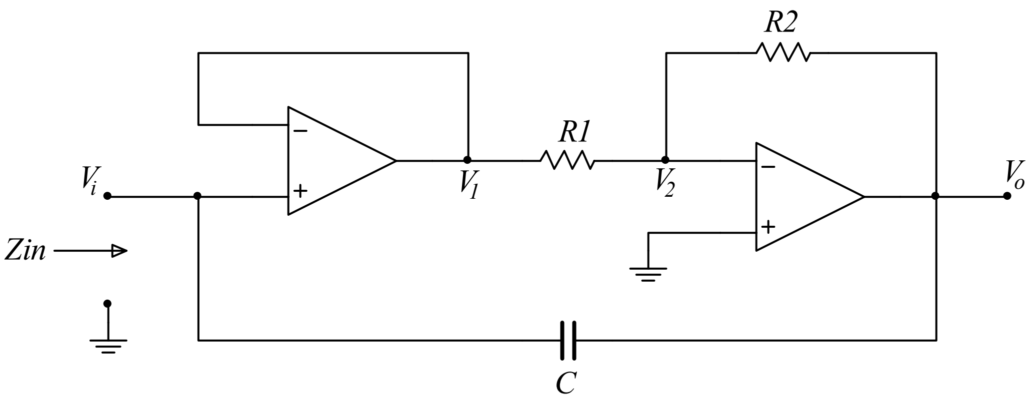




Name:____

Problem 7 - (10 points)

For the following circuit:



A. What is the voltage V_1?

B. What is the voltage V_2?

C. Calculate the voltage gain $\frac{V_o}{V_i}$

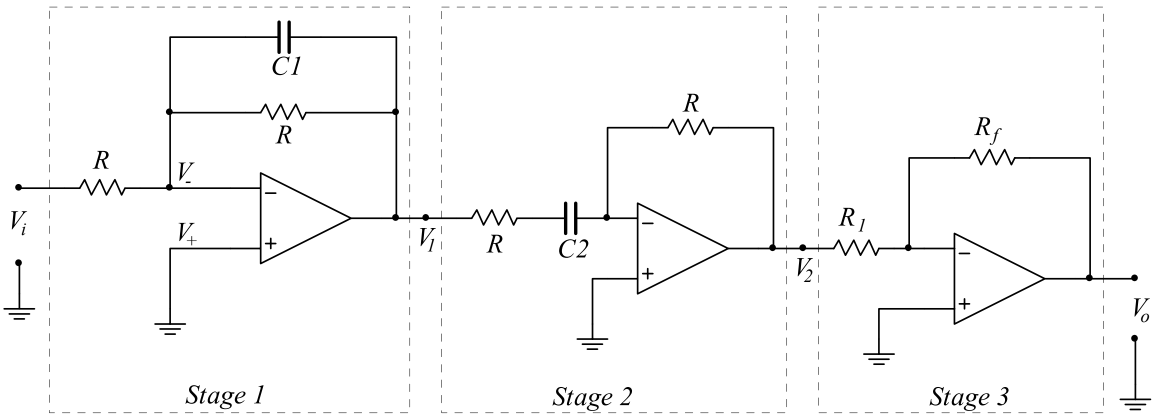
D. Determine the input impedance *Zin* seen by the voltage V_i.

In this impedance inductive, capacitive or resistive?

Name:____

Problem 8 - (10 points)

For the following circuit



A. Derive an expression for $\frac{V_1}{V_i}$

B. Derive an expression for $\frac{V_2}{V_1}$

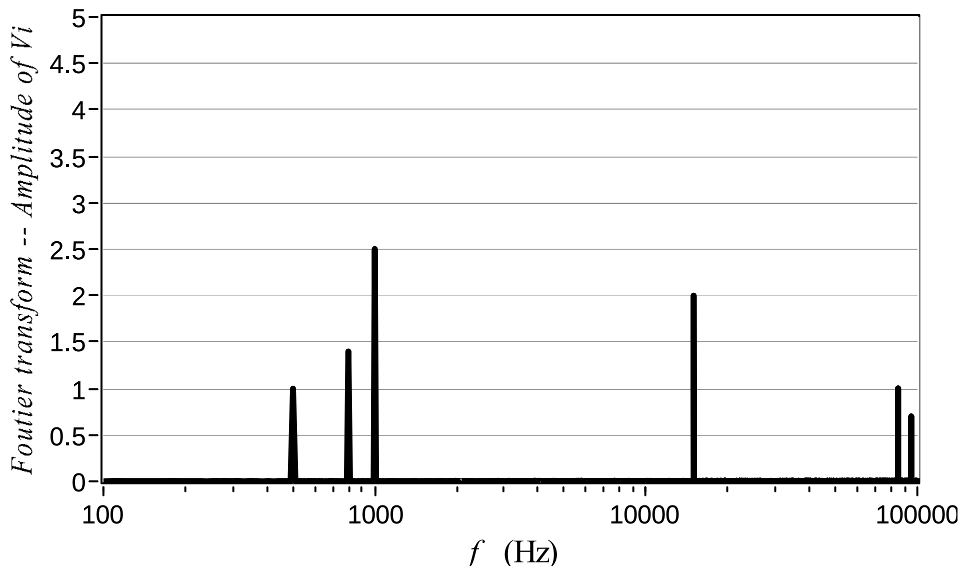
C. Derive an expression for $\frac{V_o}{V_i}$

Name:____

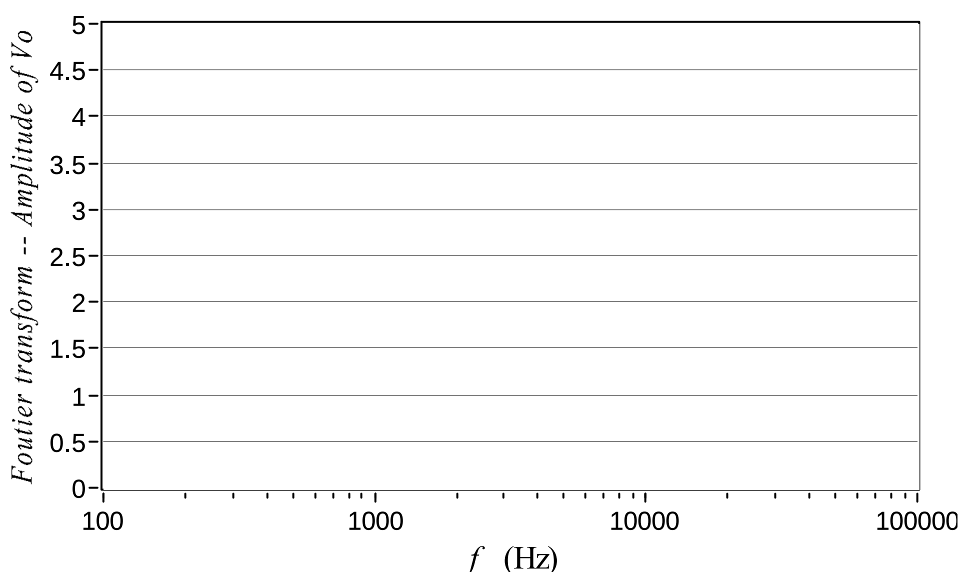
D. What is the role of:

Stage 1:__________________________
Stage 2:__________________________
Stage 3:__________________________

E. The frequency domain characteristics of input signal V_i is:



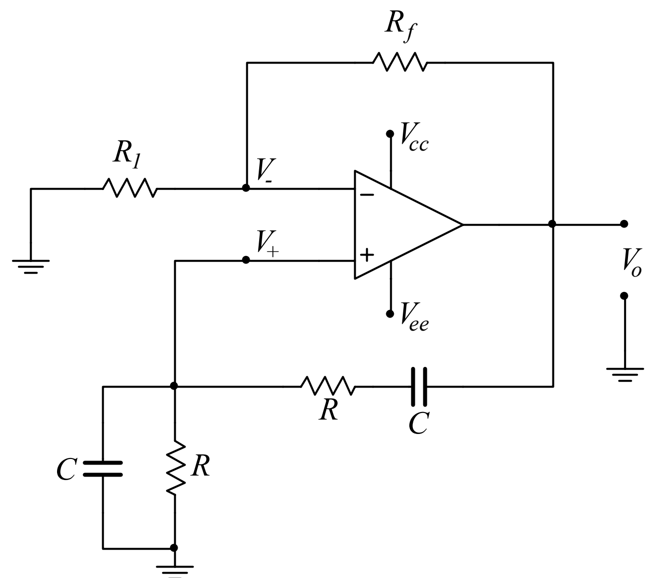
For $R=10k\Omega$, $C1=0.8nF$, $C2=1.6nF$, $R_1=10k\Omega$ and $R_f=20k\Omega$, draw the expected amplitude of the Fourier transform of V_o on the graph below. (Hint: $\frac{1}{2\pi} \simeq 0.16$)



Name:____

Problem 9 - (10 points)

The following circuit combines a positive feedback path to generate oscillations and negative feedback path to generate gain.



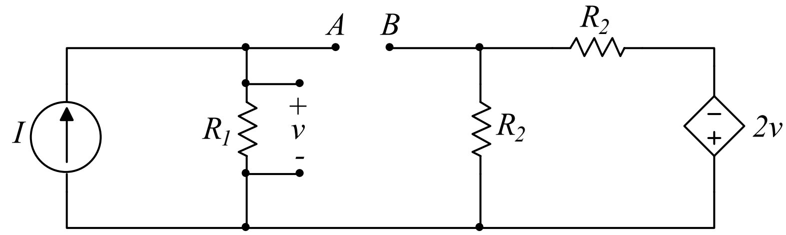
A. By considering the impedance of the elements calculate the voltage ratio $\frac{V_+}{V_o}$

B. Determine the condition for which the voltage V_o is in phase with the voltage V_+. What is the ratio $\frac{V_+}{V_o}$ at this condition? Hint: the phase, ϕ, of the complex number $a + jb$ is $\phi = \tan^{-1}\left(\frac{b}{a}\right)$. $b = 0$ gives $\phi = 0$

Name:____

Problem 10 - (10 points)

Find the Thevenin equivalent circuit across the port $A - B$



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