ENGR-2300

Electronic Instrumentation

Quiz 2

Spring 2022

Print Name ________________ RIN ________________

Section ___

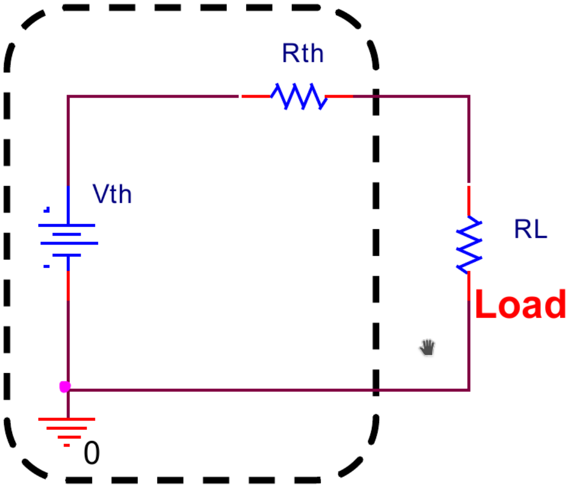
I have read, understood, and abided by the Collaboration and Academic Dishonesty statement in the course syllabus. The work presented here was solely performed by me.

Signature: ______________________________

Date: _________

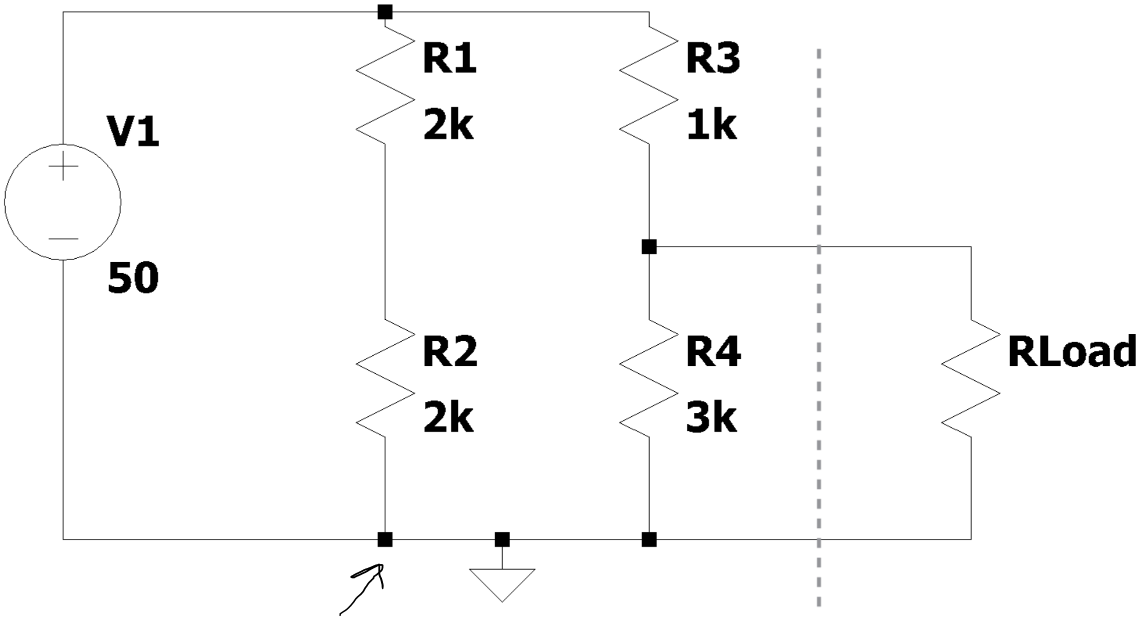
On all questions: SHOW ALL WORK. BEGIN WITH FORMULAS, THEN SUBSTITUTE VALUES AND UNITS. No credit will be given for numbers that appear without justification. Unless otherwise stated in a problem, provide 3 significant digits in answers. Read the entire quiz before answering any questions. Also it may be easier to answer parts of questions out of order.

I. Thèvenin Equivalent And Voltage Follower (20 points) As stated on the cover page: Round answers to 3 significant digits. Show formulas first and show your work. No credit will be given for numbers that appear without justification.

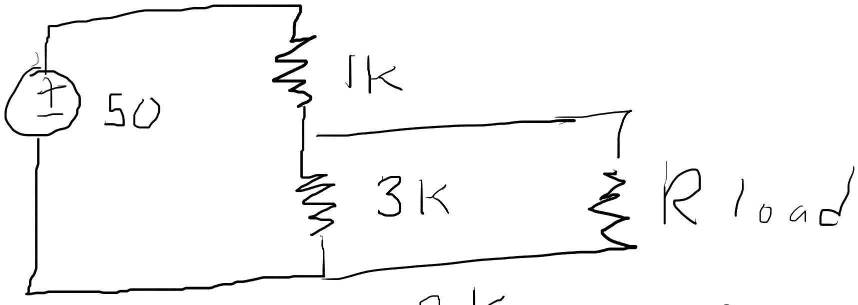


The Thevenin Equivalent Circuit consists of a voltage source in series with a resistor, which provides a very simple replacement for much more complex circuits. If we have this simple source, analyzing complex loads becomes quite easy.

a) (7 pts) Find the Thèvenin equivalent voltage and resistance for the circuit below. The load is to the right of the dashed line.



left branch does not affect Vth or Rth

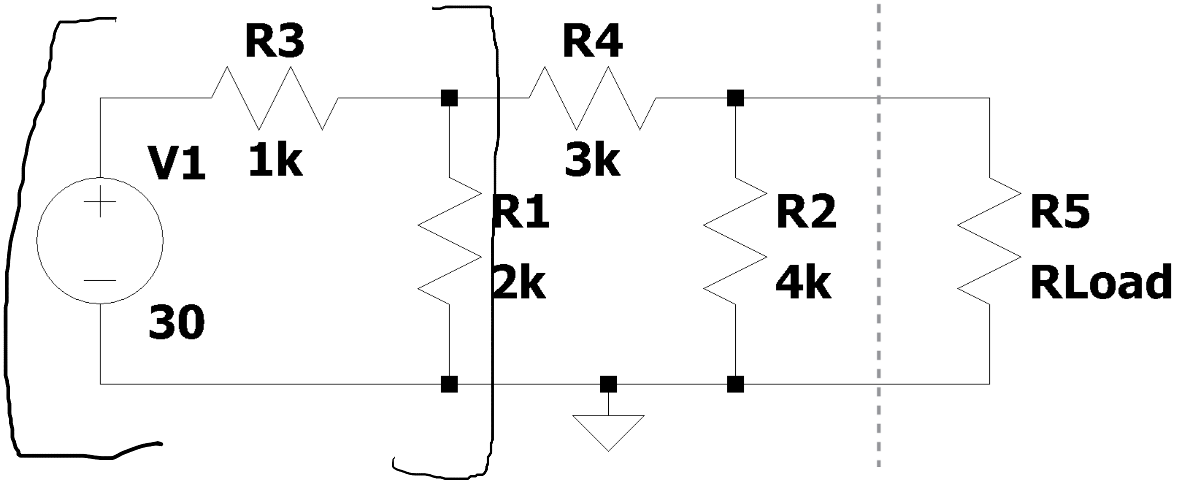


$$V_{th} = 50 \cdot \frac{3k}{1k+3k} = 37.5\ V$$

$$R_{th} = 1k \| 3k = \frac{1k \cdot 3k}{1k+3k} = 750\ \Omega$$

b) (7 pts) Now find the Thèvenin equivalent voltage and resistance for the circuit below. The load is to the right of the dashed line. *(Hint. It may be useful to do this in stages. Calculate the Thèvenin voltage and resistance of the voltage source and first two resistors, then add in R4 and R2.)*

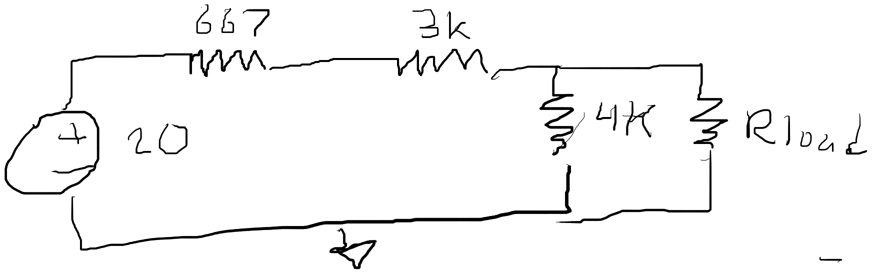
stage 1



For stage 1: $V_{th} = 30 \cdot \frac{2k}{1k+2k} = 20V$

$R_{th} = 1k \| 2k = 667\ \Omega$

Now redraw circuit:

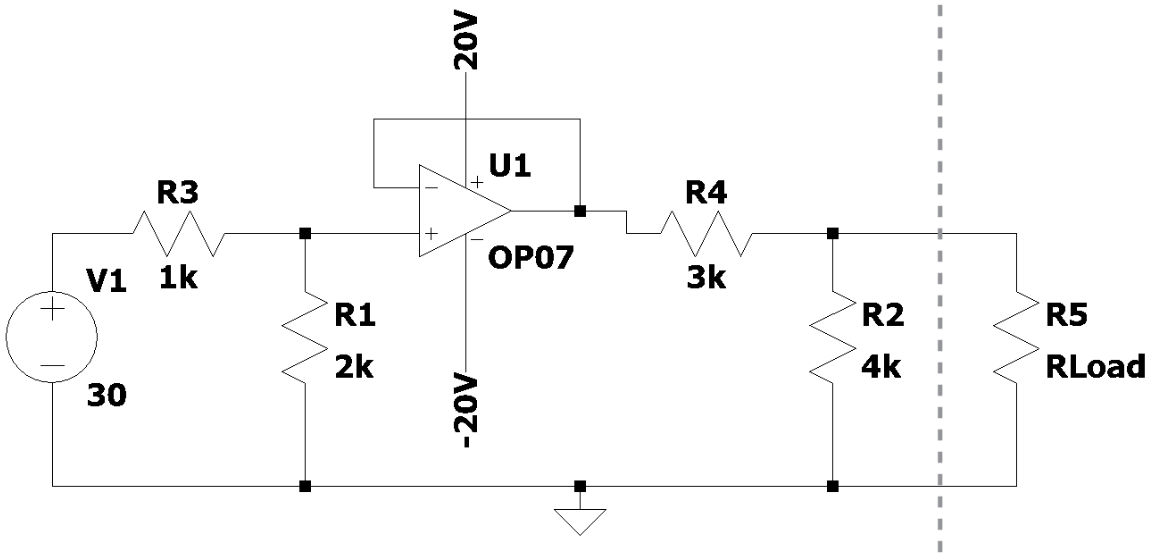


$R_{th} = 4k \| (3k + 667)$

$= \frac{(4000)(3667)}{4000 + 3667} = 1913\ \Omega$

$V_{th} = 20 \frac{4k}{667 + 3k + 4k} = 10.43\ V$

c) (4 pts) An ideal voltage follower is now placed between R1 and R4 as shown below. If we do not connect an RLoad resistor to the circuit, what is the voltage at the load resistor?

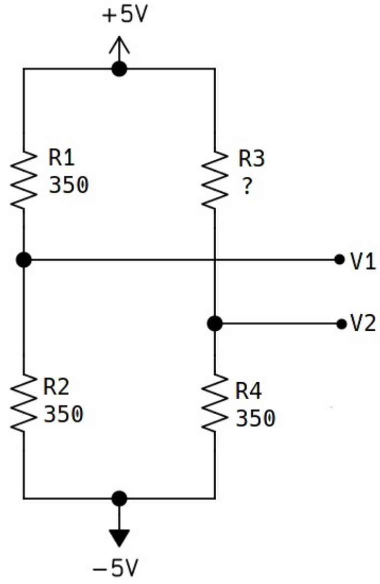


$30\,V \cdot \frac{2k}{1k+2k} = 20\,V$ (Vin of op amp)

$V_{out} = V_{in} = 20\,v$

$V_{load} = 20\,V \cdot \frac{4k}{3k+4k} = 11.42\,V$

II. Strain Gauges and Bridges (20 points)



←

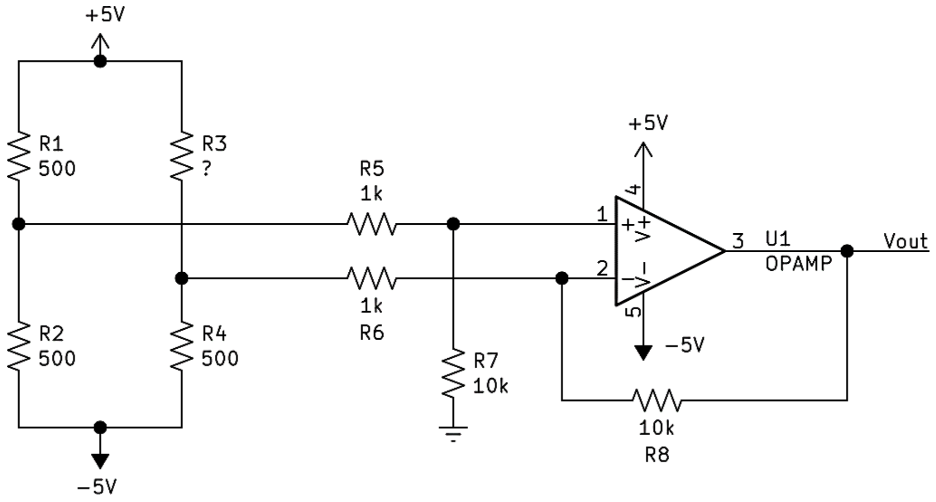
note that the left and right branches are each voltage dividers that divide a voltage starting at −5 V and increasing 10 V to +5 V

a. (3 pts) In the strain gauge above, suppose that R3 has a value of 370Ω. What is the differential voltage output (V1 – V2)?

$$V_1 = (-5) + (10)\frac{350}{350+350} = 0V$$

$$V_2 = (-5) + (10)\frac{350}{350+370} \approx -0.139\ V$$

$$V_1 - V_2 = 0.139\ V$$



b. (6 pts) Now we look at a new strain gauge connected to a differential amplifier as shown above. If the voltage Vout is 1.2V, find the value of R3. *(Assume that the op amp is a rail-to-rail chip, meaning that the output can reach the voltage of the power supplies; otherwise assume it is ideal.)*

$$V_{out} = \frac{R_8}{R_6}(V_2 - V_1) = \frac{R_7}{R_5}(V_2 - V_1)$$

$$1.2\ V = \frac{10k}{1k}(V_2 - V_1) \qquad (V_2 - V_1) = 0.12\ V$$

$$V_1 = 0\ V, \quad V_2 = 0.12\ V$$

$$(-5) + 10\frac{500}{R_3 + 500} = 0.12\ V$$

$$R_3 = 476.5\ \Omega$$

c. (6 pts) Suppose that the value of R3 in part b varies during normal operation. Assuming that you keep the values of R7 and R8 equal, what is the maximum resistance that R3 can have without saturating the op-amp? What is the minimum resistance it can have without saturating the op-amp?

Max $V_{out} = 5V$, $V_2 - V_1 = \frac{5V}{10} = 0.5V$

$V_2 = 0.5V$ $(-5) + 10\frac{500}{R_3 + 500} = 0.5V$, $R_3 = 409\,\Omega$

Min $V_{out} = -5V$, $V_2 - V_1 = -0.5V$, $V_2 = -0.5V$

$(-5) + 10\frac{500}{R_3 + 500} = -0.5V$ $R_3 = 611\,\Omega$

d. (3 pts) Name one change you could make to the differential amplifier circuit to increase its sensitivity (in other words, the amount of change in the output voltage for every ohm of change in R3. You answer should not be dependent on the current value of R3.)

Changing R_8 and R_7 to larger resistances will increase the diff amp gain and therefore the sensitivity.

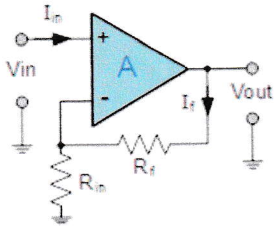
e. (2 pts) In Experiment 5 and Project 2, you were asked to consistently use the same cantilever beam and strain gauge each time you came to class or open shop. Why was this the case?

Changing beams would introduce measurement error and/or require you to recalibrate. strain gauge and beam deflection (and other factors) will cause each beam to respond differenty at zero deflection.

Soln

III. Operational Amplifier Applications (20 points)

a. For the circuits below, assume the op amps are ideal:



i. (2 pts)For the circuit on the left, given $R_f = 4k\Omega$ and $R_{in} = 1k\Omega$

1. Write an equation for Vout/Vin

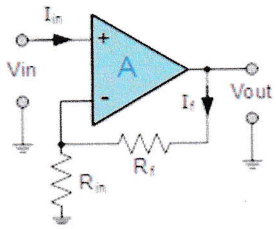
$A = \frac{-R_f}{R_{in}}$

$\frac{V_{out}}{V_{in}} = -4$

2. What is Vout if Vin=2V

$V_{out} = -8V$

Problem III.a.i. is the same as ii and the correct solution is A=5 and Vout=10V,



ii. (2pts) For the circuit on the left, given $R_f = 4k\Omega$ and $R_{in} = 1k\Omega$

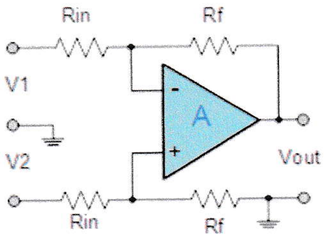
1. Write an equation for Vout/Vin

$A = 1 + \frac{R_f}{R_{in}} = 5$

$\frac{V_{out}}{V_{in}} = 5$

2. What is Vout if Vin=2V

$V_{out} = 10V$



iii. (2pts) For the circuit on the left, given $R_f = 3k\Omega$ and $R_{in} = 1k\Omega$

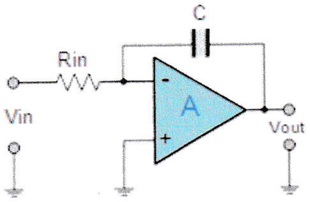
1. Write an equation for Vout as a function of V1 and V2.

$V_{out} = 3(V2 - V1)$

$A = \frac{R_f}{R_{in}}(V2 - V1)$

2. What is Vout if V1=3V and V2=1V

$V_{out} = 3(1-3) = -6V$



iv. For the circuit on the left, given Rin=10kΩ and C=1uF

1. (1pt) Write an equation for Vout(t) as a function of Vin(t)

$\frac{1}{RC} = 100$

$V_{out} = \frac{-1}{RC} \int V_{in}(t)\,dt = -100 \int V_{in}(t)\,dt$

2. (2pt) What is Vout(t) for t > 0 if Vin=0.2V (dc) and if Vout=0V when t=0.

$\int 0.2V\,dt = 0.2t$

$V_{out} = -20t$ (volts)

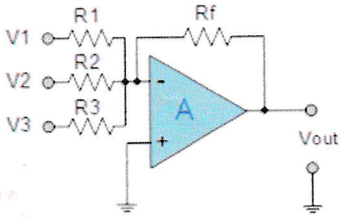
3. (2pts) For AC steady state, what is the magnitude and phase angle of Vout if Vin has a magnitude of 2V, a phase angle of 0° and a frequency of 10 Hz.

$V_{out} = V_{in} H(j\omega)$

$= (2V\angle 0°) \frac{-1}{j\omega RC} = (2\angle 0°)\left(\frac{j}{2\pi \cdot 10 \cdot 10^{-2}}\right)$ 90°

$\angle V_o = 90°$

$|V_o| = \frac{2}{2\pi\, 10^{-1}} = 3.18V$



v. (2pts) For the circuit on the left, given R1=1kΩ, R2=500Ω, R3=1kΩ, and Rf =1kΩ:

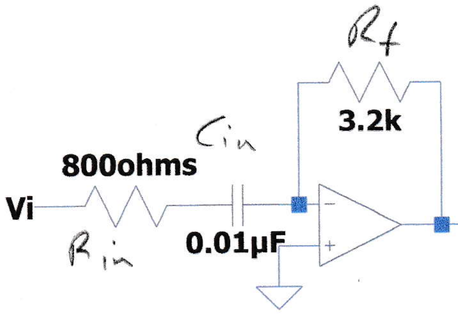
1.Write an equation for Vout/Vin

$V_{out} = -(V1) - 2V2 - V3$

2. What is Vout if V1=-2V, V2=2V and V3=0.5V

$V_{out} = +2 - 4 - 0.5 = -2.5V$

b. Answer the following questions based on the differentiator circuit show. For parts i. and ii. assume the op amp is ideal.



i. (2pts) For what range of frequencies will this circuit behave as a differentiator? Give your answer in Hz.

$f << 19.5\,KHz$ or $20\,kHz$

$w << \frac{1}{R_{in}C_{in}} \Rightarrow f << \frac{1}{2\pi \underset{800}{R_{in}} \underset{10^{-9}}{C_{in}}}$

ii. (2pts) For AC steady state, if Vi is a 5kHz sinewave with an amplitude of 2V and a phase angle of 0º, what is the amplitude and phase of Vo?

Consider 5kHz as << 20kHz $V_o(j\omega) = H(j\omega)V_i(j\omega)$ $H(j\omega) = -j\omega R_f C_{in}$

$|H(j\omega)| = (2\pi)(5\times10^3)(3.2\times10^3)(10^{-8}) = 1.01$

$\angle H(j\omega) = -90^\circ$

$\boxed{Amp(V_o) = Amp(V_i)\cdot|H(j\omega)| = 2V}$

$\angle V_o = \angle H(j\omega) + \angle V_i = -90 + 0$

$\boxed{\angle = -90^\circ}$

iii. (3pts) Now assume the op amp is ideal except that Vo is limited to be -4 < Vo < 4V, this limit is due to saturation of the op amp.
If Vi is a 4kHz sinewave, what is the maximum amplitude for Vi that won't result in saturation of the output stage of the op amp?

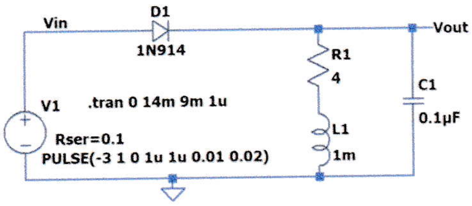
at 4kHz $|H(j\omega)| = 0.804 \sim 0.8$

$|max\ Amp\ V_{out}| = 4$ $|H(j\omega)| = 0.8$

$max\ Amp\ V_{in} = \frac{|max\ Amp\ V_{out}|}{0.8} = \underline{\underline{5V}}$

IV – Concepts, Troubleshooting and Data Analysis (20 points)

a. (4 pts) Real components compared to ideal: In Experiment 5 you built and modeled the circuit on the right.



i. For the LTspice model you included R1. But you didn't put a resistor there when you built the circuit. Why not? {1pt}

Real Inductors have resistance. R1 is the internal resistance of L1.

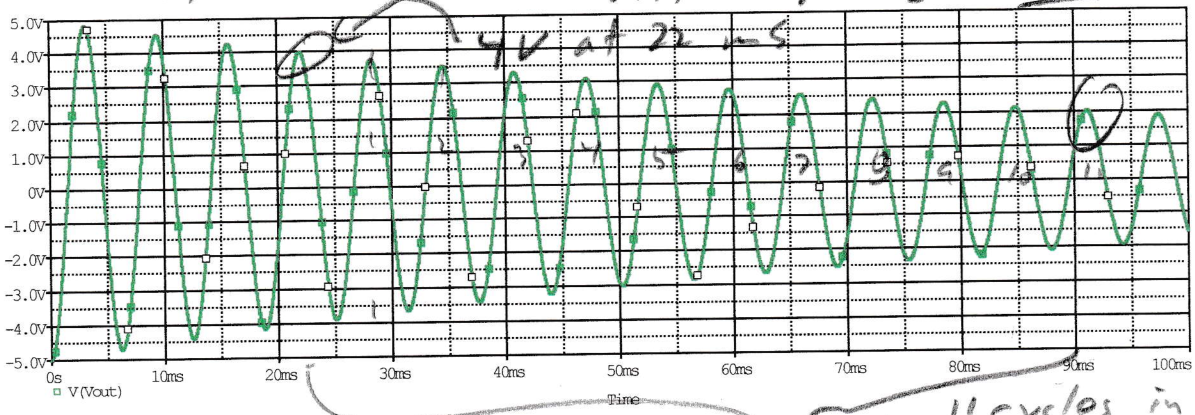
ii. Your partner wired the circuit with a 0.01uF capacitor rather than the 0.1uF capacitor called for in the experiment. Would the oscillation frequency go up or down and by what percentage (to the nearest 1%)? {3pt}

$$\omega_1 = \frac{1}{\sqrt{LC}} \qquad \omega_2 = \frac{1}{\sqrt{0.1 L \cdot C}}$$

$$\frac{\omega_2}{\omega_1} = \frac{1}{\sqrt{0.1}} = 3.16$$

frequency goes up by 216%

will accept f_2 = 316% of f_1



2V at 92ms

11 cycles in 70 ms

f = 157 Hz

$\boxed{\omega = 987\ Hz}$

b. (4pts) The plot above shows a damped oscillation. The horizontal scale is time (5ms per small division) and the vertical scale is voltage (0.5V per small division). The horizontal scale is from 0s to 100ms. The vertical scale is from -5V to 5V. Find the decay constant α and the angular frequency ω for this data. **You must mark the data points on the plot that you use for your answer.**

Any 2 points will work

@ t_1 = 22ms, V = 4V

@ t_2 = 92ms, V = 2

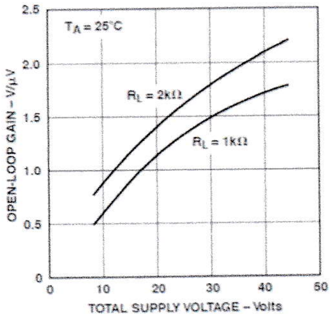
$$\frac{V e^{-\alpha t_1}}{V e^{-\alpha t_2}} = e^{-\alpha (t_1 - t_2)}$$

$$\frac{4}{2} = e^{-\alpha (22-92)\,ms}$$

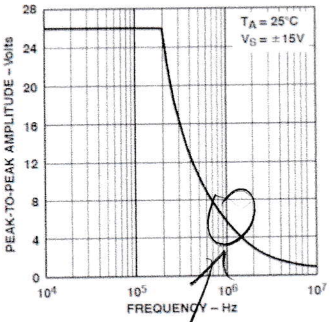
$$\ln(2) = -\alpha(-0.07) \qquad \boxed{\alpha = 9.9\ sec^{-1}}$$

ii

OP37

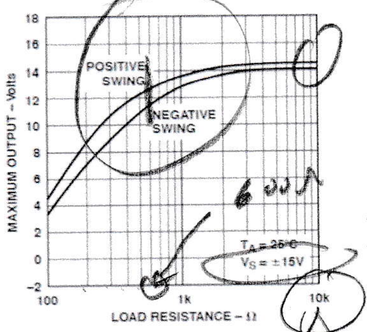


TPC 19. Open-Loop Voltage Gain vs. Supply Voltage



TPC 20. Maximum Output Swing vs. Frequency

iii

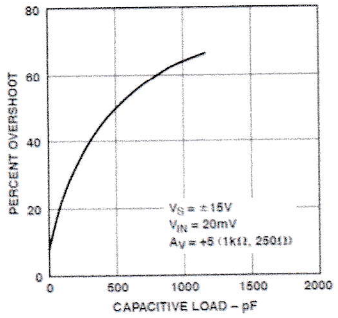


TPC 21. Maximum Output Voltage vs. Load Resistance

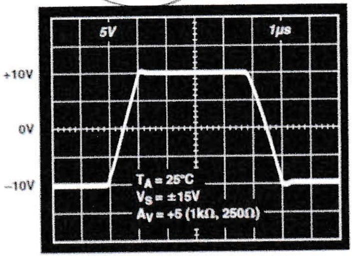
15V supply

i

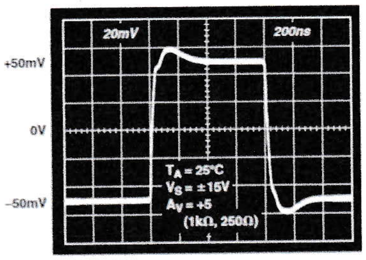
10k Load



TPC 22. Small-Signal Overshoot vs. Capacitive Load



TPC 23. Large-Signal Transient Response



TPC 24. Small-Signal Transient Response

c. (6 pts) The OP37 is included in the ADALP2000 kit of parts and a page of the data sheet is shown above. Use this to answer the following questions.

i. (2pt) If the OP37 is powered by ±15V supplies and has a 10kΩ load, what are the expected max and min output voltages that the OP37 can achieve?

1 Max and min output ≈ +14V, -14V

ii. (2pt) If the load is changed to 600Ω, what is the expected max and min output voltages?

max ≈ 13V, min ≈ -11V, will accept ±12, ±13, ±11 as valid

iii. (2pt) Staying with the OP37 and ±15V supplies, and using a high resistance load (greater than or equal to 10kΩ): if a 1MHz signal is applied, what is the maximum output voltage that the OP37 is expect to be able to provide?

½ pt if peak

At ~~[illegible]~~ 1MHz p-p output limited to ~6Vp-p

d. (2pts) Which of the following op-amp configurations works best to amplify the signal from a stain gauge bridge circuit? Circle one.

Voltage Follower   Inverting   Non-Inverting   [✓ Differential]

Adder   Integrator   Differentiator

e. (2pts) Explain in 25 words or less: Why does the Miller Integrator (practical integrator) have a resistor across the capacitor while the ideal integrator doesn't have one?

All op amps have dc errors. Given enough time an integrator will saturate due to op amp dc errors.
The Miller Integrator the gain of the circuit for dc + low frequencies.

Any parts of this count

f. (2pts) What is the likely capacitance of a capacitor with a label of 104 on the side?

$10 \times 10^4 = 10^5$

~~$10^5 \mu F$~~ – not likey

$10^5 nF \Rightarrow 100 \mu F$ – not likey but will allow

$10^5 pF \Rightarrow$ yes, 10nF