ELECTRICAL ENGINEERING DEPARTMENT

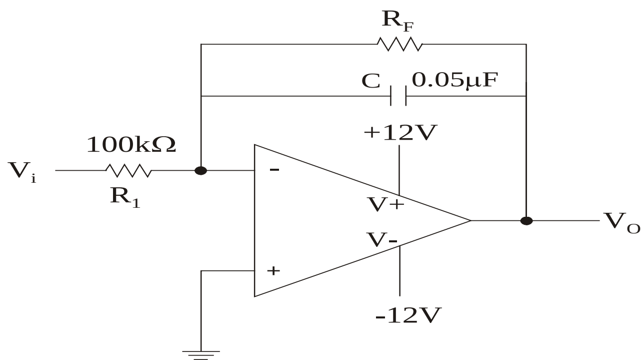
California Polytechnic State University

EE 361 | Operational Amplifier (Op-Amp) Circuits Part 2 | Pre-lab 5

Integrator, Active Low-Pass Filter,

Comparator Application – Continuity Tester

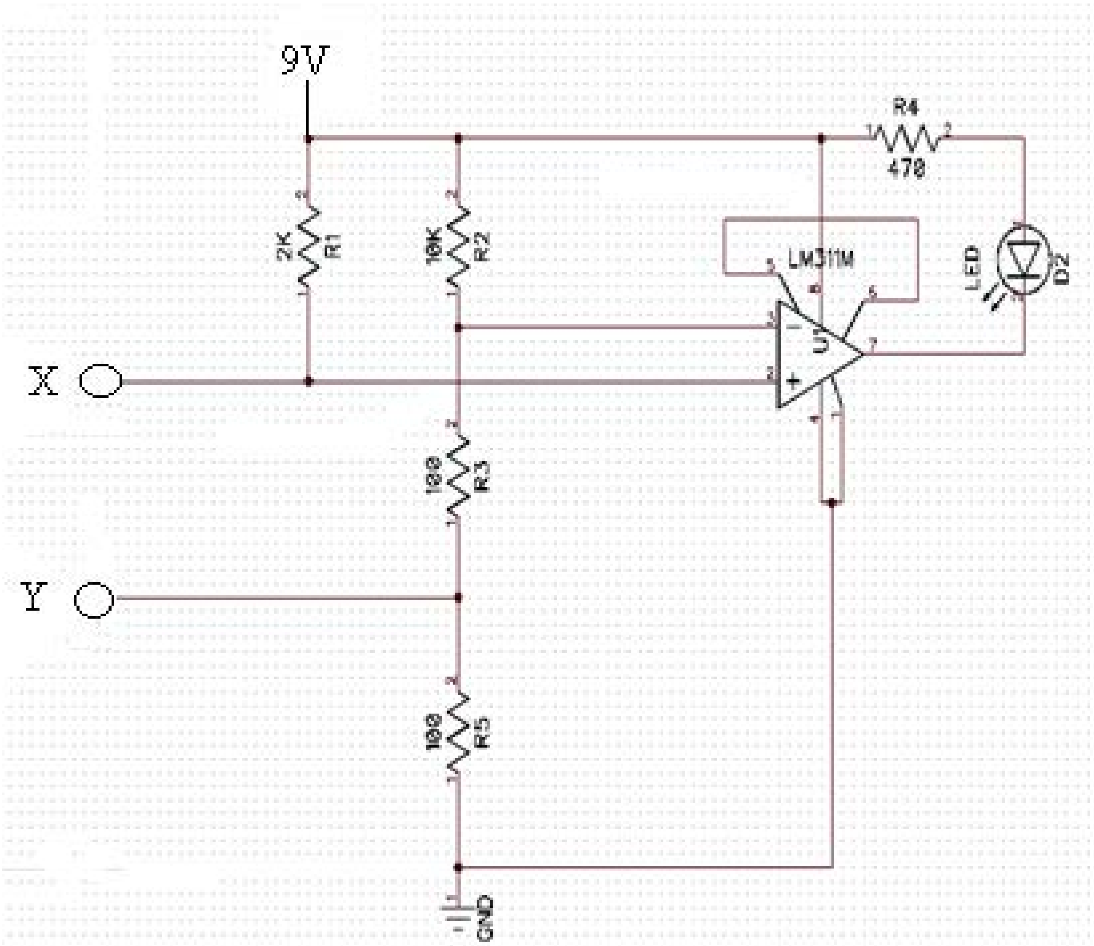
1. For the op-amp circuit below, <u>derive</u> V_o for $R_F = \infty\Omega$ (open), Vc(0) = 0V (capacitor initially uncharged. Sketch V_o for V_i = a square wave which varies between +10V and -10V at a f = 1KHz. Be certain to label, with numerical values, peak voltage and period.



2. For the op-amp circuit above, $V_i = \sqrt{2}\sin(\omega t)$ Volts and $R_F = 10K\Omega$. <u>Derive</u> the close-loop gain (V_o / V_i). In addition, determine the <u>magnitude</u> of V_o in V_{RMS} at the following frequencies; 0, 20, 40, 70, 100, 200, 300, 400, 700 1K and 2K Hz. Also, calculate cut-off frequency in Hertz.

3. The circuit shown is a comparator op-amp circuit used as a continuity tester.
   Note: +V = 9V and –V = 0V
   The test resistance is connected between nodes X and Y.
   Prove V_o = 9V (LED does not light) when there's an open between X, Y.
   Also, prove V_o = 0V (LED does light) when there's a short between X, Y.

   Note: Replace 2KΩ resistor with 2.2KΩ and 470Ω can be replaced with 680Ω.



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EE 361 — Operational Amplifier (Op-Amp) Circuits Part 2 — Lab 5
Integrator, Active Low-Pass Filter,
Comparator Application – Continuity Tester

Objective

Examine the characteristics and limitations of op-amps and to observe the operation of common op-amp circuits.

Workbench Equipment

- Digital Oscilloscope, Keysight InfiniiVision MSO-X2022A
- Function Generator, Agilent 33120A or Agilent 33220A
- Digital Multimeter, Agilent 34401A
- DC Power Supply, Agilent E3640A
- Dual-tracking DC Power Supply, TPS-4000

Check-out Equipment, 20-111 window

- Scope Probe (10:1), 2
- Banana to grabber 4 pair, 4red / 4black
- BNC to grabber lead
- Banana to Banana lead, 3

Background

General Closed-Loop Gain Equation for Integrator / Low-Pass Filter

KCL at node A of Figure 5-1: $i_{R1} = i_{RF} + i_{CF}$ (5-1)

Node-Voltage Equation: $$\frac{V_i - V_A}{R_1} = \frac{V_A - V_o}{R_F} + j(V_A - V_o)\omega C_F \quad (5\text{-}2)$$

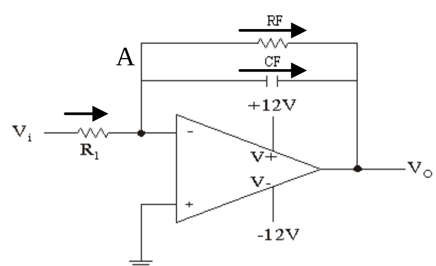

Fig. 5-1 Integrator / Low-Pass Filter

V_A = 0V since non-inverting input grounded and voltage across op-amp inputs equal zero.

$$\frac{V_i}{R_1} = \frac{-V_o}{R_F} - j(V_o)\omega C_F \quad (5\text{-}3)$$

General Closed-Loop Gain: $$\frac{V_o}{V_i} = -\frac{\frac{R_F}{R_1}}{1 + j\omega R_F C_F} \tag{5-4}$$

When ω = 0 (DC input): $$\frac{V_o}{V_i} = -\frac{R_F}{R_1} \tag{5-5}$$

Equation 5-5 is the closed-loop gain of an inverting amplifier since capacitor acts like an open to DC current.

Magnitude of equation 5-4: $$\left|\frac{V_o}{V_i}\right| = \frac{\frac{R_F}{R_1}}{\sqrt{1 + (\omega R_F C_F)^2}} \tag{5-6}$$

Writing equation 5-4 as: $$\frac{V_o}{V_i} = -\frac{\frac{1}{R_1}}{\frac{1}{R_F} + j\omega C_F} \tag{5-7}$$

If R_F is large, equation 5-7 reduces to: $$\frac{V_o}{V_i} = -\frac{\frac{1}{R_1}}{j\omega C_F} \tag{5-8}$$

Using Laplace transform: $$V_o = -\frac{1}{R_1 C_F}\int V_i dt \tag{5-9}$$

Equation 5-9 shows when R_F is large, ideally infinite, op-amp circuit is an integrator. In a practical integrator, R_F is a high resistance (for example 1 Meg Ω as used in this experiment). This feedback resistor is necessary to prevent output from saturating due to large DC gain.

Cut-off frequency, ω_{co}, is the frequency where magnitude of $$\frac{V_o}{V_i} = \frac{\frac{R_F}{R_1}}{\sqrt{2}} \tag{5-10}$$

As can be seen from equation 5-6: $$\omega_{co} = \frac{1}{R_F C_F} \tag{5-11}$$

<u>Comparator</u>

An op-amp without feedback can be used as a comparator. A comparator outputs one of two possible voltages dependant on the comparison of two input voltages.

Figure 5-2 is an example of a comparator.

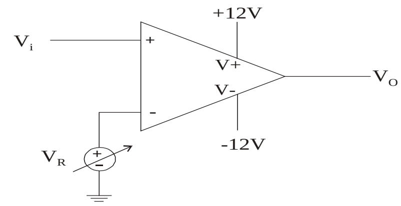

Fig. 5-2 Comparator Example

The output voltage of an ideal comparator equals either the positive rail voltage or the negative rail voltage. Which rail voltage the output equals depends on the input voltages (V_i and V_R in Figure 5-2). If the non-inverting input voltage (V_i) is > the inverting input voltage (V_R), then V_o equals the positive supply voltage (+12V). If the inverting input voltage (V_R) is > the non-inverting input voltage (V_i), then V_o equals the negative supply voltage (-12V).

Procedure 1: Integrator (prelab #1 circuit with R_F = 1MegΩ)

- Measure C_F on an impedance bridge.

C_F = ________________ Farads

- Measure both resistors with ohmmeter.

R_F = _____________Ω R_1 = _____________Ω

- Build the circuit of prelab #1.
- Use a function generator (Hi Z mode) to apply a square wave 10Vpp 500Hz at V_i.
- Observe V_o on scope, carefully measure Vpp of output with cursors and capture both V_o and V_i.
  - Vpp measurement of V_o is important for a postlab question.

Procedure 2: Low-Pass Filter (prelab #1 circuit with R_F = 10KΩ)

- Measure 10KΩ.

R_F = _____________Ω

- Remove square wave input and replace R_F with a 10KΩ resistor.
- Calculate and record the magnitude of V_o/V_i for each frequency listed in Table 5-1.
  - Use measured values for calculated magnitude of V_o/V_i.
- Apply a 1V RMS 20Hz sinusoid at V_i then measure and record V_o in RMS volts.
  - Use an AC voltmeter to measure V_o, an AC voltmeter displays RMS volts.
- Keep V_i at 1V RMS and change only frequency to each of the values listed in Table 5-1, record V_o.
- Plot magnitude of $\frac{V_o}{V_i}$ versus frequency for both experimental and calculated using Excel.
  - Plot both curves on one graph.
- Find cut-off frequency in Hertz from plot & compare to calculated f_{co}.
  - Use measured values to calculate f_{co}.

f_{co} plot = ___________ f_{co} calc = ___________ %Error = _________

f (Hz)	$V_{o\ rms}$ (V)	Experimental V_o/V_i	Calculated V_o/V_i
20	______________	______________	______________
40	______________	______________	______________
70	______________	______________	______________
100	______________	______________	______________
200	______________	______________	______________
300	______________	______________	______________
400	______________	______________	______________
700	______________	______________	______________
1000	______________	______________	______________
2000	______________	______________	______________

Table 5-1 Low-Pass Filter Plot Data

Procedure 3: Comparator Application – Continuity Tester

- Build the comparator (continuity tester) circuit of prelab #3.
    - **NOTE: Use op-amp LM311 NOT LM741.**
- Connect a wire between nodes X and Y, does the LED light?
- Does the LED light if there is an open between nodes X and Y?
- Obtain instructor verification of proper circuit operation.

Instructor Initials: __________

Discussion

1. Use equation 5-9 to calculate the peak-to-peak output voltage of the integrator circuit. Show your work! How does your calculated answer compare (%error) to the experimental output Vpp?
2. How well do the experimental and theoretical values in Table 5-1 compare? What are the significant causes of discrepancies?