EXPERIMENT 11: LINEAR OP-AMP CIRCUITS (revised 11/20/07)

In this experiment we will examine the properties of operational amplifier circuits with various feedback networks. Circuits which perform four basic linear mathematical operations - addition, subtraction, integration, and differentiation - will be studied.

We will use a model μA741, operational amplifier. This is a general purpose, integrated-circuit op-amp with detailed specifications listed in the appendix to this experiment. The op-amp requires a ±15 V power source. We will use a small power supply that provides these voltages plus a zero to ±5 V variable DC output. The op-amp will supply a maximum output current of about 25 mA and has typical offset currents of about 20 nA. This implies that resistors in the range 1 kΩ to 100 kΩ should be used.

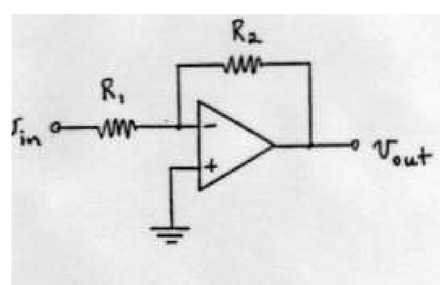
Use a scope for all measurements.

1. (a) Construct the operational feedback amplifier shown below with $R_1 = 1$ kΩ and $R_2 = 20$ kΩ with v_{in} grounded, adjust the pot on the circuit board for zero output voltage. Using sine waves from the function generator for v_{in} (with the amplitude set for 0.5 Volts peak-to-peak), measure and tabulate the amplitude and phase of v_{out} for 100 Hz $\leq$ f $\leq$100 kHz (take about 3 points/decade).

   (b) For a feedback amplifier the gain is given by:

$$A(\omega) = \frac{v_{out}}{v_{in}} = -\frac{R_2 A_0(\omega)}{R_1 A_0(\omega) + (R_1 + R_2)}$$

where $A_0(\omega)$ is the open loop gain and $A(\omega)$ is the closed loop gain. Use this formula and your measured values of $A(\omega)$ to find $A_0(\omega)$ at 20 kHz and 100 kHz. Assuming that $A_0(\omega)$ varies with frequency according to:



$$A_0(\omega) = \frac{A_0}{(1 + j\frac{\omega}{\omega_C})}$$

where $\omega_C = 10\pi$ radians/s, find the DC mid-band open-loop gain, A_0. Compare your result to the typical value given in the appendix.

2. Change R_2 to 10 kΩ and set f = 1 kHz. Increase the amplitude of v_{in} until v_{out} exhibits saturation at both positive and negative voltages. Sketch and determine the saturation voltages.

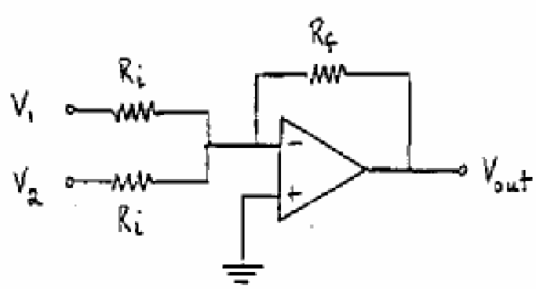
3. (a) The slew rate of the amplifier is defined as the maximum rate of change of the output voltage. Switch the input to square waves and set f = 10 kHz. Adjust the amplitude to obtain a peak-to-peak output voltage of 10 Volts. Measure the slew rate by observing dv_{out}/dt and compare your result to the typical value listed in the appendix.

   (b) Suppose you want to use the amplifier to produce a sine wave output with an amplitude of 10 Volts peak-to-peak. What is the maximum frequency you can use before the output wave begins to be distorted by the finite slew rate of the amplifier? Switch the input to sine waves and observe what happens when you exceed that frequency. Sketch the input and output waveforms.

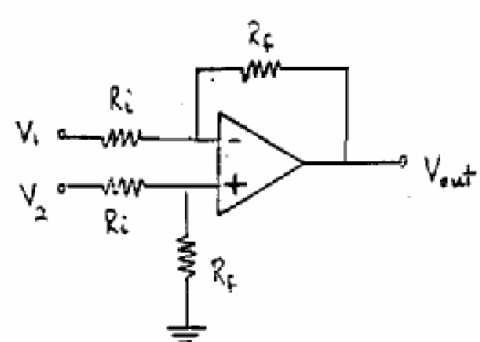
4. Set up the summing amp circuit shown below with $R_i = R_f = 10\ k\Omega$. Use the Lambda DC power supply for V_1, and the ±5 V supply for V_2. Measure V_{out} for three or four different values of V_1 and V_2 (using both positive and negative values of V_2) and verify that $V_{out} = -R_f(V_1 + V_2)/R_i$.

5. Set up the circuit shown below for subtracting two voltages. As in the previous step, use $R_i = R_f = 10\ k\Omega$. Measure V_{out} for three or four different values of V_1 and V_2, and verify that $V_{out} = R_f(V_2 - V_1)/R_i$.

adder or summing amp



subtractor



6. (a) Set up the differentiator circuit shown below with C = 100 nF and R = 2 kΩ. For the input use a 2 Volt peak-to-peak, f = 1 kHz triangle wave. Sketch the input and output waves and measure the magnitude of $v_{out.}$ Compare your measured value with the expected result, $v_{out} = -RC \times dv_{in}/dt$. Also, measure and tabulate the values of v_{out} (no sketches required) for f = 2 kHz with C = 100 nF, and for f =2 kHz with C= 50 nF.

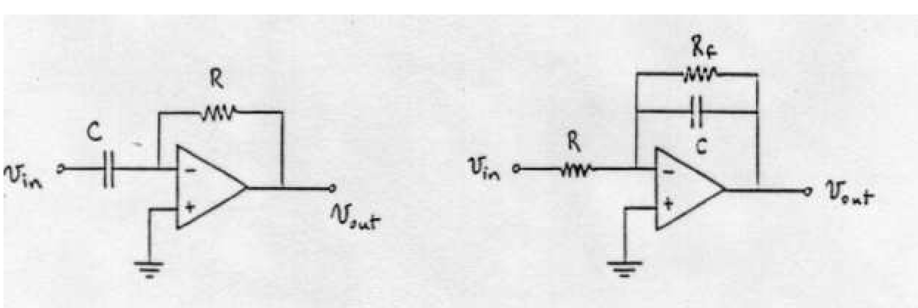
   (b) Switch the input waveform to square wave and sketch v_{in} and v_{out}. Explain why v_{out} looks the way it does.

7. (a) Set up the integrator circuit shown below, with C = 100 nF, R_F = 200 kΩ, and R = 10 kΩ. Use a 2 Volt peak-to-peak, f = 1 kHz square wave for v_{in}. Sketch the input and output wave forms and determine the magnitude of v_{out}. Compare your measurement with the expected result $v_{out} = -(1/RC) \times \int v_{in} dt$.

   (b) Observe what happens to the output voltage as you make R_F larger and smaller. What happens when R_F is removed? Explain why we need to have a feedback resistor in any integrating circuit.

   (c) Switch the input waveform to triangle wave and sketch the resulting input and output waveforms. In this case v_{out} looks quite similar to a sine wave. See if you can understand this result by writing down the Fourier expansion of a triangle wave and integrating this expression.

differentiator **integrator**



APPENDIX — Specifications for the μA741 op-amp

$V_{CC} = \pm 15V$, $T = 25^o C$

PARAMETER and CONDITIONS	MIN	TYP	MAX	UNITS
Input Offset Voltage $R_s = 10\ k\Omega$		1.0	5.0	mV
Input Offset Current		20	200	nA
Input Bias Current		80	500	nA
Input Resistance	0.3	2.0		MΩ
Input Capacitance		1.4		pF
Offset Voltage Adjustment Range		±15		mV
Output Resistance		75		Ω
Output Short Circuit Current		25		mA
Large Signal Gain $R_L \geq 2\ k\Omega$, $V_{out} \leq \pm 10$ V	$5x10^4$	$2x10^5$		
Output Swing (Vsat) $R_L = 2\ k\Omega$	±10	±13		V
$R_L = 10\ k\Omega$	±12	±14		V
Slew Rate $R_L = 2\ k\Omega$		0.5		V/μs
Transient Response Vin = 20 mV, $R_L = 2k\Omega$, $C_L \leq 20$ pF, unity gain				
Risetime		0.3		μs
Overshoot		5		%
Common Mode Rejection Ratio	70	90		dB
Power Supply Rejection Ratio		30	150	μV/V
Supply Current		1.7	2.8	mA
Power Consumption		50	85	mW