UNIVERSITY OF MIAMI
Department of Electrical and Computer Engineering
EEN 311

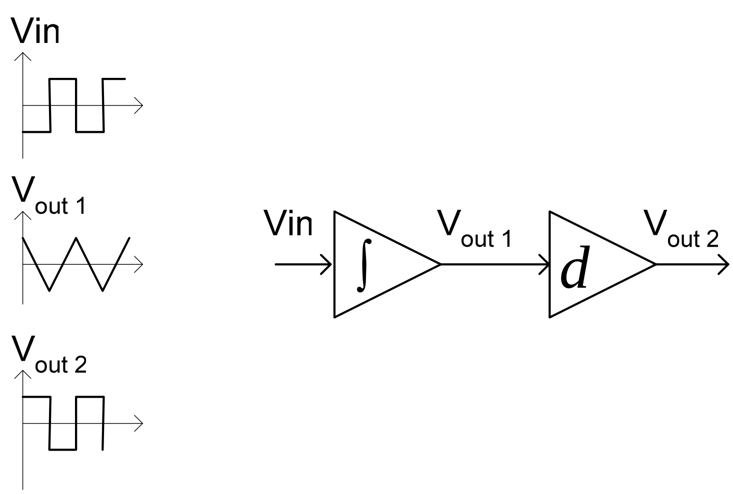
Name: ____________________
Section: ____________________
Date: ____________________

OPERATIONAL AMPLIFIERS / PART II

PURPOSE: The purpose of this experiment is to demonstrate the operation of some practical op-amp circuits; namely, the integrator, differentiator, comparator, and half-wave rectifier.

A *differentiator* is a circuit that calculates the instantaneous slope at every point on a waveform. On the other hand, an *integrator* computes the area underneath the curve of a given waveform.

The P*recision half-wave rectifier* can be used to rectify sinusoidal signals that can not be rectified by a simple diode half-wave rectifier; i.e. those waveforms with smaller amplitudes them 0.7_V needed to forward-bias the diode. Another name for this circuit is “A precision HW Rectifier”



Preliminary Work

1. INTEGRATOR

Shown in Fig.1 is an ideal integrator with its frequency response in Fig. 2.

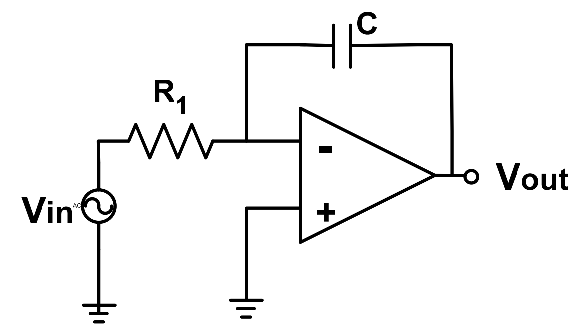


Figure 1: Ideal Integrator

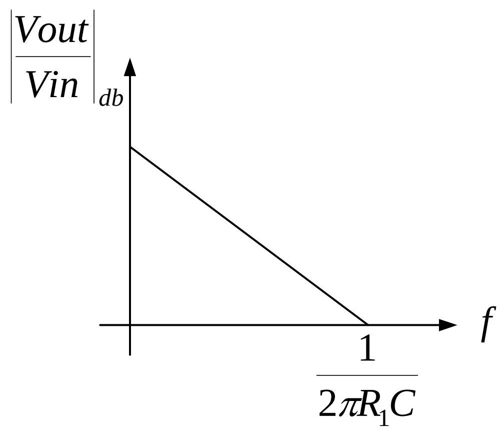


Figure 2: Frequency response of an Ideal Integrator

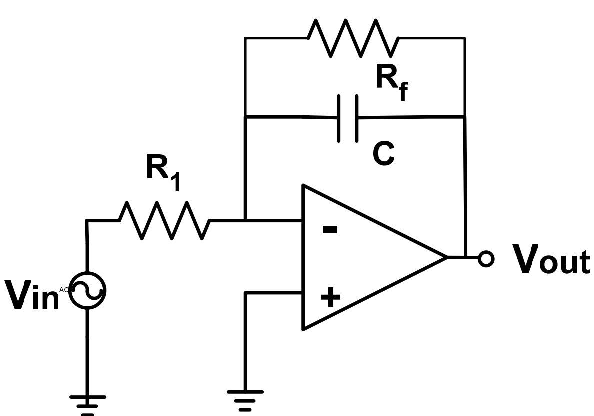
a. Derive the expression (assuming no initial voltage on the capacitor):

$$v_{out(t)} = -\frac{1}{R_1 C}\int v_{in(t)}dt$$

b. Derive the expression for the unity gain frequency given by:

$$f = \frac{1}{2\pi R_1 C}$$

c. As shown in Fig. 2, an ideal integrator will exhibit a very large gain at low frequencies since the capacitor acts as an open circuit (open loop gain). This fact causes problems with the offset voltages and currents of the Op-Amp. The capacitor may drive the output voltage to either the positive or negative saturation voltage. To fix this problem, a resistor is added in parallel to the capacitor as shown in Fig. 3. This circuit is called a practical integrator and its frequency response is shown in Fig. 4.



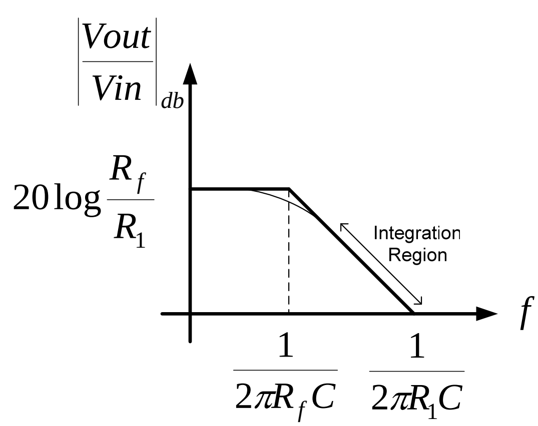


Figure 3: Practical Integrator

Figure 4: Frequency response of a practical Integrator

d. Derive the expression that shows that the practical integrator has a break frequency at:

$$f_H = \frac{1}{2\pi R_f C}$$

e. What is the gain of the practical integrator at low frequencies?

f. This practical integrator could be used as a simple **low pass filter** to frequencies up to the break frequency f_H or as an integrator for frequencies starting about a decade above the break frequency (as long as signals are integrated at the minus 20db/dec slope.

2. **Differentiator**

Shown in Fig. 5 is an ideal differentiator and its frequency response in Fig. 6.

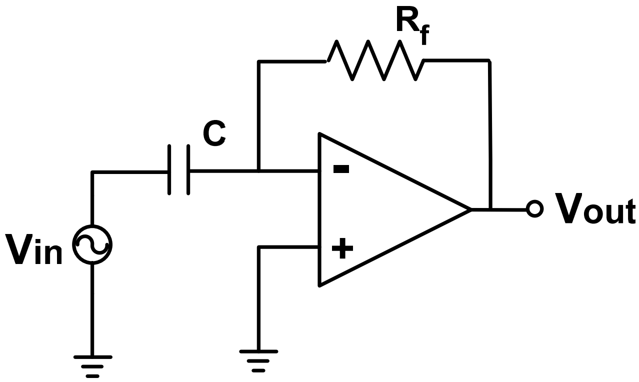


Figure 5: Ideal Differentiator

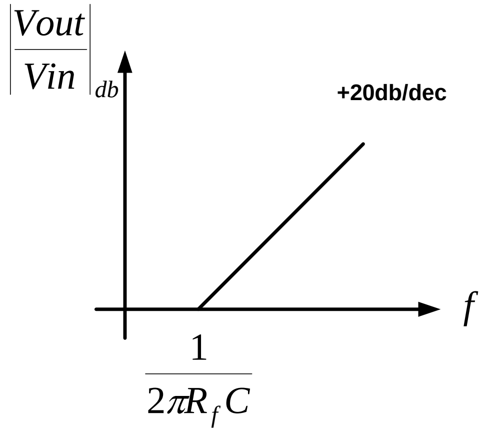


Figure 6: Frequency response of an Ideal Differentiator

a. Derive the expression (assuming no initial voltage on the capacitor):

$$v_{out(t)} = -RC\frac{dv_{in(t)}}{dt}$$

b. Derive the expression for the unity gain frequency given by:

$$f = \frac{1}{2\pi R_f C}$$

c. As shown in Fig. 6, an ideal differentiator will exhibit a very large gain at high frequencies since the capacitor acts as an open circuit. This fact may cause some oscillations at some high frequency. To fix this problem, a resistor is added in series to the capacitor as shown in Fig. 7. This circuit is called a practical differentiator and its frequency response is shown in Fig. 8.

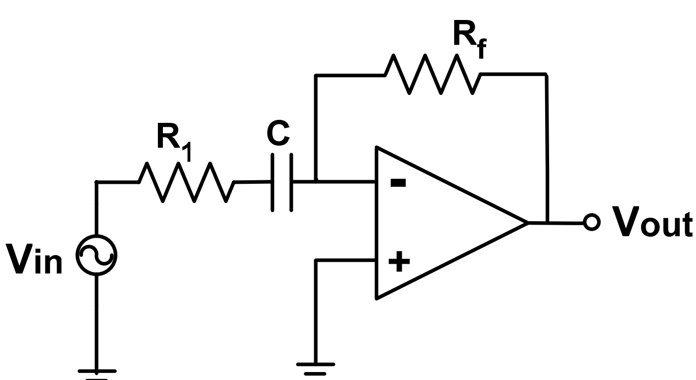


Figure 7: Practical Differentiator

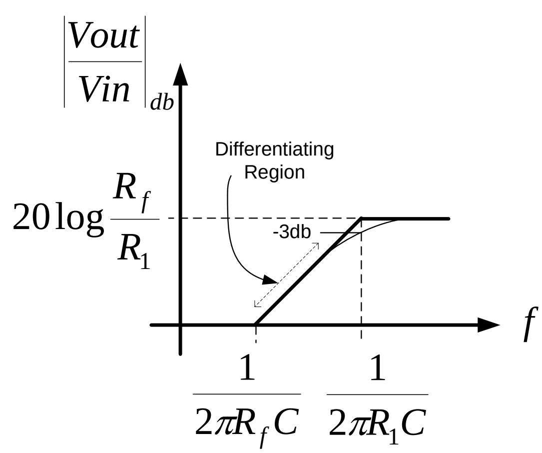


Figure 8: Frequency response of an Ideal Differentiator

d. Derive the expression that shows that the practical differentiator has a break frequency at:

$$f_L = \frac{1}{2\pi R_1 C}$$

e. What is the gain of the practical differentiator at high frequencies?

f. This practical differentiator could be used as a simple **high pass filter** to frequencies down to the break frequency f_L or as an differentiator for frequencies starting about a decade below the break frequency (as long as signals are differentiated at the plus 20db/dec slope.

Experimental Procedure

I. Integrator:

a. Calculate the DC gain and the break frequency f_H for the integrator of Fig.9?

DC gain = ________ f_H = _______

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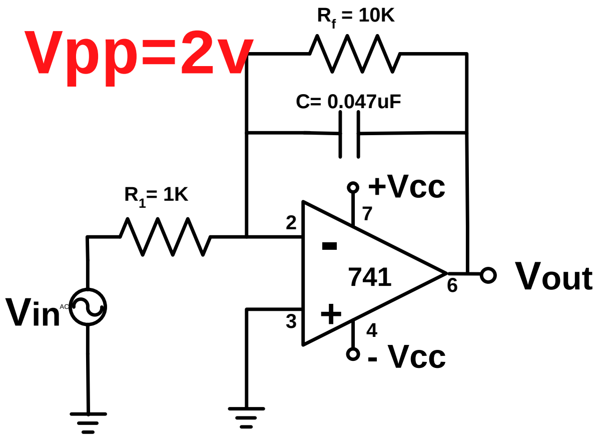


Figure 9: Practical Integrator

Values used:

R_1 = _____

R_f = _____

C = _____

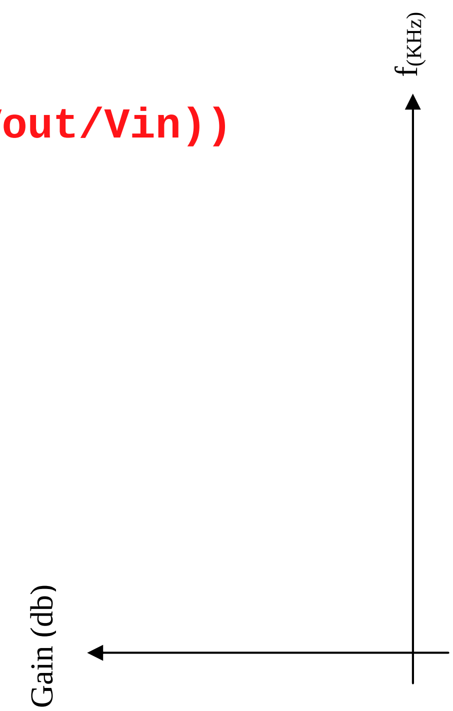
Expected DC gain =_________

Expected f_H=_________

b. **Frequency Response**.
Obtain the frequency response of the integrator of Fig 9 by varying the input signal from 50 Hz to 50KHz. Record in Table 1 Vin and Vout for each frequency and calculate the gain at each point. Make sure you obtain enough points around your expected f_H and plot it.
Use ± Vcc = ± 15V

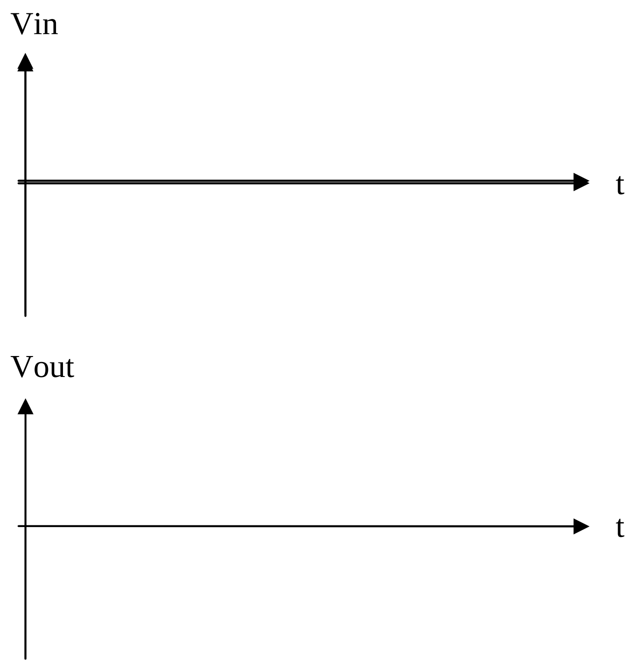
f	Vin	Vout	Av	Av in db's
50	1v	9.9	9.9	20log(abs(Vout/Vin))
100				
150				
300				
330				
340				
1KHz				
5KHz				
10KHz				
50KHz				

Table 1: Integrator's Frequency response

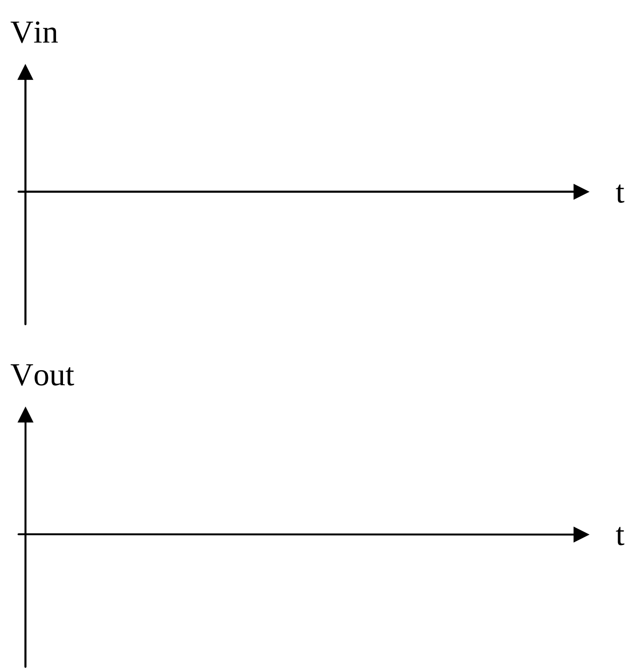


Integrator (Cont)

c. Apply a square wave at the input with a frequency f = 40 Hz. Displaying V_{in} and V_{out} on the oscilloscope simultaneously, sketch the waveforms with their phase relation shown clearly.



d. Increase the frequency of the input signal to f = 10 kHz. Repeat part b.



II. Differentiator:

a. Calculate the high frequency gain and the low break frequency f_L for the differentiator of Fig. 10?

High frequency gain = ________ f_L = _______

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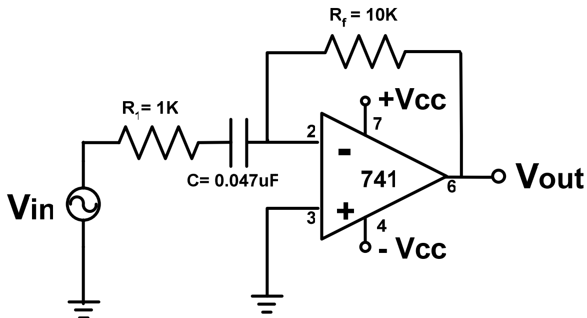


Figure 10: Practical Differentiator

Values used:

R_1 = ______

R_f = ______

C = ______

Expected High Frequency gain=_______

Expected f_H=_________

Pout=1/2*Pin
Vout=1/sqrt(2)*Vin

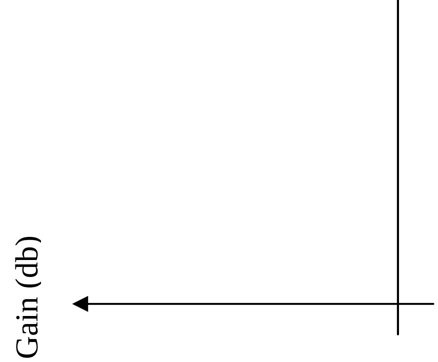
b. **Frequency Response**.
Obtain the frequency response of the differentiator of Fig 10 by varying the input signal from 50 Hz to 50KHz. Record in Table 2 Vin and Vout for each frequency and calculate the gain at each point. Make sure you obtain enough points around your expected f_L and plot it. Use ± Vcc = ± 15V.

Av

Vout=Vin*1/sqrt(2)
cuttoff f
20log10(1/sqrt(2))=-3dB

f	Vin	Vout	Av	Av in db's
100				
500				
1000				
10KHz				
10KHz				
50KHz				

Table 2: Differentiator's Frequency response



Differentiator (Cont)

c. Apply a triangle wave at the input with a frequency f = 300 Hz. Displaying V_{in} and V_{out} on the oscilloscope simultaneously, sketch the waveforms with their phase relation shown clearly.

d. Increase the frequency of the input signal to f = 30 kHz. Repeat part b.

III. Half-Wave Rectifier:

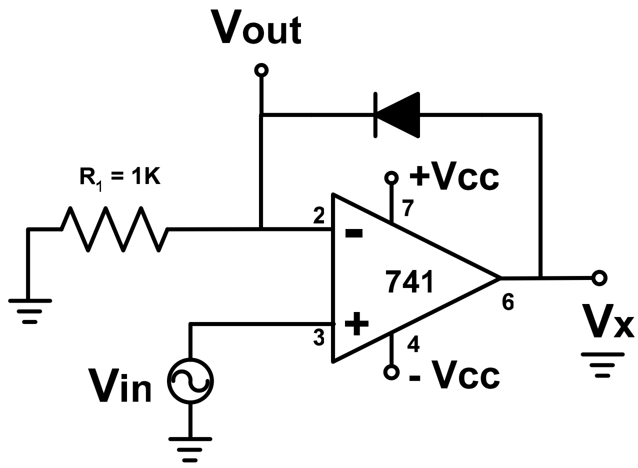


Figure 11: Precision half-wave rectifier

Set V_{CC} = ± 15 V. Apply a sinusoidal input signal of minimum amplitude and frequency 1kHz. Plot V_{in}, V_x, and V_{out} with their phase relations.

SPICE

Simulate the differentiator and integrator circuits of Figs. 9 and 10.

a. Plot the AC response of the two circuits up to at least 100 kHz.
b. Apply a square wave with a frequency of 10KHz to the integrator of Fig 9 and perform a transient analysis.
c. Apply a triangular wave with a frequency of 300Hz to the differentiator of Fig 10 and perform a transient analysis.

Discussion of the Results

1. Explain the results of Experimental Procedure Part I, (c) and (d).

2. Explain the results of Experimental Procedure Part II, (c) and (d).

3. Briefly explain the operation of the half-wave rectifier in Experimental Work Part III.

4. Comment on the Spice simulations.