EL 351 - Linear Integrated Circuits Laboratory
Testing Integrators and Differentiators

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Equipment:

- Agilent 54622A Deep-Memory Oscilloscope
- Agilent E3631A Triple-Output DC power supply
- Agilent 33120A Function Generator
- Agilent 34401A Digital Multimeter

Introduction:

The mathematical operations of integration and differentiation can be performed using operational amplifiers. In fact, that's where the name "op-amp" came from: the ability of a high-gain differential amplifier circuit to perform the mathematical operations of adding, subtracting, integrating and differentiating. With a bit of clever circuit design, multiplication and division can also be done. An integrator is made by putting a capacitor in the feedback path of an inverting amplifier.

DC integrators work wonderfully, until they saturate; once they saturate they are useless, and must be reset by discharging the integrating (feedback) capacitor. DC integrators saturate because the input bias current for the op-amp inverting terminal flows through the capacitor. A constant current flowing through a capacitor causes the output voltage to ramp upward until the op-amp output voltage can no longer grow; this is saturation.

AC integrators, on the other hand, have a feedback resistor in parallel with the capacitor, which provides a DC path for the input bias current. Due to the feedback path now containing a parallel RC, below a breakpoint frequency ($f_{BP} = 1/(2\pi RC)$), the integrator becomes a simple amplifier.

Procedure:

I. Measurement of DC Integrator Drift

1. Construct the inverting DC integrator circuit below, using a jumper wire to act as the switch across the feedback capacitor. Notice that the input voltage is 0.0 V, so the output voltage should not change (the integral of 0.0 is 0.0), even after the switch is opened.

2. Open the switch, and observe Vo. Carefully measure the time it takes for the output voltage to rise from 0 V to some convenient value (e.g. 2 V, 5 V or 10 V).

3. Based on the time you measured, calculate Ic, the current flowing from the output terminal through the capacitor (i = C dv/dt). This is the input bias current of the op-amp's inverting terminal.


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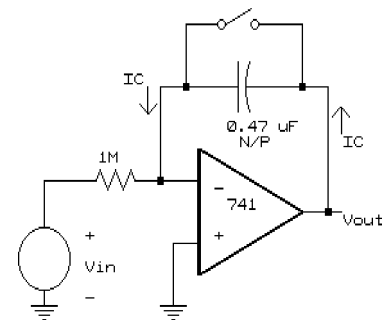
4. Repeat steps 2 and 3, for another 741 op-amp, and another op-amp with JFET or MOSFET input transistors (e.g. LF 351). Be prepared for a long wait; if you get bored, you can substitute a lower value of capacitance.

II. Integration of Square, Sine and Triangle Waveforms by an AC Integrator

1. Construct the inverting AC integrator circuit below. Calculate the breakpoint frequency of this integrator (above this frequency the circuit is an integrator, and below this frequency it is an amplifier with a gain of $-120\text{k}\Omega/10\text{k}\Omega = -12$ V/V).

2. Let Vin be a square wave, amplitude and frequency as shown. Make sure the average (or DC) value of Vin = 0.0 VDC. Record the waveforms of Vin and Vo.

3. Repeat step 2, with Vin changed to a sine wave (same frequency and amplitude).

4. What will happen if the frequency of Vin is increased to 400 Hz? Predict it, then try it, and record results.

5. Repeat step 2, with Vin = triangle waveform (4 Vpp, 200 Hz).

6. What is the shape of Vo when Vin is a triangle waveform? If you think Vo is a sine wave, carefully compare Vo waveforms with sinusoidal, and triangle, input voltage waveforms. If you have a spectrum analyzer available, you may gain some insights by looking at Vo in the frequency domain.
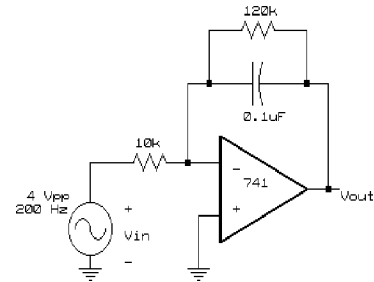
III. Uncompensated Differentiator, Tested with Sine, Triangle and Square Waveforms

1. Construct the uncompensated differentiator circuit below. It has two major problems:

   a) the input impedance is a capacitor, so Zin = $-jX_C$ Ω, which becomes smaller as the input frequency increases. As a result, the input impedance becomes very small at high frequencies; this is very undesirable (think of the effect on the source).

   b) the circuit gain magnitude = $(Z_{\text{feedback}}/Z_{\text{input}}) = (R_F/X_C) = (R_F/(1/(2\pi f\ C))) = (2\pi f\ R_F\ C)$, so as frequency increases, gain increases. This makes the circuit very susceptible to noise, which contains many high frequencies, and also makes it unable to accurately differentiate waveforms rich in harmonics (e.g. a squarewave).

2. Let V_{in} = 2 Vpp, 400 Hz sinusoid. Record the input and output voltage waveforms. Repeat with triangle and square waveforms.

3. Return to a sinusoidal input. Vary the frequency from 200 Hz. to 2 kHz, and clearly describe what happens to the output waveform as you do. Be qualitative and quantitative.
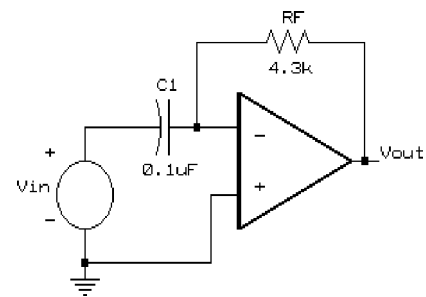
IV. Compensated Differentiator, Tested with 400 Hertz Sine, Triangle and Square Waveforms

1. Construct the compensated differentiator circuit below. Design it using the following algorithm, assuming this circuit is intended to differentiate signals with fundamental frequencies up to 400 Hz.

    let $f_{DESIGN} = 20(400 \text{ Hz}) = 8 \text{ kHz}$

    let $R_1 C_1 = 1/(2\pi f_{DESIGN})$, so $R_1 = 1/(2\pi f_{DESIGN} C_1)$

    let $R_F C_F = 1/(2\pi f_{DESIGN})$, so $C_F = 1/(2\pi f_{DESIGN} R_F)$

    At the design frequency of 8 kHz, the differentiator turns into an integrator, and this eliminates the two problems of the uncompensated differentiator.
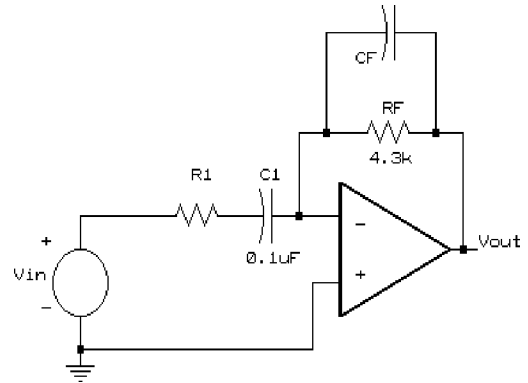
2. Repeat the measurements of procedure III.2

Lab Report:

1. In procedure I.1, what modification could be made to provide DC stability?

2. In III.2, for which input waveform was the output voltage the best inverted derivative of the input voltage? For which input waveform was it the worst?

3. In III.2, write a literal expression for output voltage, Vo, as a function of Vin, f, R and C. Then, substitute the numerical values for your circuit, and compare the result with the Vo you measured.

4. In IV.2, for which of the input waveform(s) was the output voltage a good inverted derivative of the input voltage? For which input waveform(s) was it the worst?

5. Only one of the two differentiators was able to produce output waveforms that were good derivatives of all input waveforms tested. Which one was it, and explain why this is so.