PLECS

DEMO MODEL

Operational Amplifier Circuits

Last updated in PLECS 4.3.1

1 Overview

This demonstration shows several op-amp circuits, including a multivibrator, integrator and differentiator.

2 Model

2.1 Multivibrator with comparator

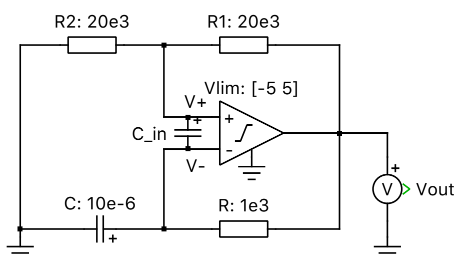

Figure 1: Multivibrator

The multivibrator amplifier is an astable oscillator which generates rectangular waveforms at the output using an RC network at the inverting input and a voltage divider at the non-inverting input of the amplifier.

This configuration switches between its two unstable states, with the time spent in each state controlled by the charging or discharging of the capacitor through a resistor.

Initially, the capacitor starts charging up to V_{out}. Once the voltage at the inverting terminal becomes equal to or greater than the voltage at the non-inverting terminal, λV_{out}, the op-amp output clamps to the negative supply rail, thus causing the capacitor charge go to zero and start charging to the new value of V_{out}. This goes on until the negative supply rail reaches the $-\lambda V_{\mathrm{out}}$ threshold, and the output changes state again, reinitiating the cycle. This produces a steady, continuous square wave pulse train at the output.

The RC time constant determines the rate of capacitor charge/discharge, or the period of the output waveform, and the voltage divider network sets the reference voltage level, λV_{out}.

A small capacitance C_{in} is required for decoupling of negative feedback.

Formula derivation

From voltage divider,

$$\lambda = \frac{R_1}{R_1 + R_2}$$

General charging equation for a capacitor with an original charge:

$$q = CV \cdot (1 - e^{\frac{-t}{RC}}) + q_0 \cdot e^{\frac{-t}{RC}}$$

For $V = V_{\mathrm{out}}$ and $q_0 = \lambda C V_{\mathrm{out}}$,

$$q = -CV_{\mathrm{out}} \cdot (1 - e^{\frac{-t}{RC}}) + \lambda C V_{\mathrm{out}} \cdot e^{\frac{-t}{RC}}$$

$$T = 2RC \cdot \ln\left(\frac{1+\lambda}{1-\lambda}\right)$$

This result is also obtained for the discharging period of the operation, assuming the magnitudes of the rails are equal, meaning $t_{\mathrm{charge}} = t_{\mathrm{discharge}}$.

Multivibrators are used in a variety of applications where square waves or timed intervals are required, such as a flashing light.

2.2 Inverting integrator

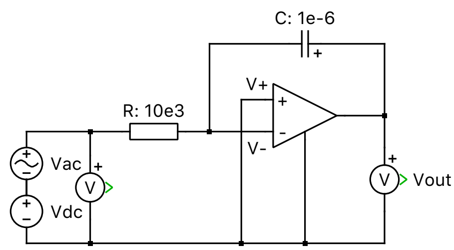

Figure 2: Inverting integrator

An integrator produces an output voltage, which is proportional to the integral of the input voltage.

$$V_{\mathrm{out}} = -\frac{1}{RC} \cdot \int_0^t v_{\mathrm{in}}\, dt$$

Formula derivation

Because of virtual ground and infinite impedance of the input terminals of the op-amp, all of the input current flows through R and C:

$$i_{\mathrm{in}} = \frac{v_{\mathrm{in}} - V_-}{R} = \frac{v_{\mathrm{in}}}{R} = i_R = i_C$$

$$v_C = V_- - V_{\mathrm{out}} = -V_{\mathrm{out}}$$

$$i_C = C \cdot \frac{\mathrm{d}v_C}{\mathrm{d}t} = -C \cdot \frac{\mathrm{d}V_{\mathrm{out}}}{\mathrm{d}t} = \frac{v_{\mathrm{in}}}{R}$$

$$\frac{\mathrm{d}V_{\mathrm{out}}}{\mathrm{d}t} = -\frac{1}{RC} \cdot v_{\mathrm{in}}$$

$$V_{\mathrm{out}} = -\frac{1}{RC} \cdot \int_0^t v_{\mathrm{in}}\, dt$$

An application for this circuit could be integrating water flow and measuring the total quantity of water that has passed by the flowmeter.

2.3 Inverting differentiator

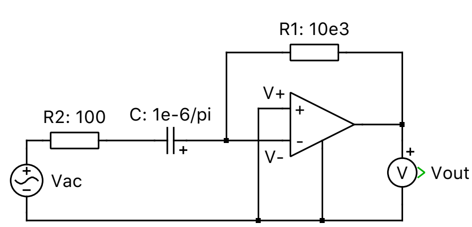

Figure 3: Inverting differentiator

The differentiator op-amp configuration produces an output voltage that is proportional to the rate of change of the input voltage by measuring the current through a capacitor:

$$V_{\mathrm{out}} = -RC \cdot \frac{\mathrm{d}v_{\mathrm{in}}}{\mathrm{d}t}$$

The right-hand side of the capacitor is held at 0 volts due to the virtual ground effect. Therefore, current through the capacitor is solely due to change in the input voltage. A steady input voltage will not cause a current through C, but a changing input voltage will. The faster the voltage changes, the larger the magnitude of the output voltage.

Formula derivation

Because of virtual ground and the infinite impedance of an op-amp, all current flowing through the capacitor also flows through R1:

$$i_C = i_{R_1} = \frac{V_- - V_\text{out}}{R_1} = \frac{-V_\text{out}}{R_1}$$

$$v_C = v_{AC} - i_C R_2 \approx v_{AC}$$

(the very small resistance R2 is needed for convergence purposes)

$$i_C = C \cdot \frac{\mathrm{d}v_C}{\mathrm{d}t} = C \cdot \frac{\mathrm{d}v_{AC}}{\mathrm{d}t} = -\frac{V_\text{out}}{R_1}$$

$$V_\text{out} = -R_1 C \cdot \frac{\mathrm{d}v_{AC}}{\mathrm{d}t}$$

An application for this circuit could be monitoring the rate of change of temperature in an environment where too high or too low of a temperature rise is detrimental and would, thus, trigger an alarm or a notification using additional circuitry on the output.

3 Simulation

3.1 Multivibrator with comparator

Increase the capacitance value to $100\,\mu\text{F}$ and observe the increase in the amount of time it takes to charge up the capacitor, as shown in Fig. 4. Increase the left-most resistor to $25\,\text{k}\Omega$ and observe the change in the output voltage switching frequency.

3.2 Inverting integrator

Set the amplitude and frequency of the AC voltage source to 0 and the DC voltage source to $1\,\text{V}$. The output should look like the one in Fig. 5. If a fixed voltage is applied to the input of an integrator, the output voltage will be a ramp with a constant slope of the negative input voltage multiplied by a factor of 1/RC.

3.3 Inverting differentiator

Set the amplitude and frequency of the AC voltage source to 0 and the initial capacitor voltage to $1\,\text{V}$. Observe the output after there is no change in the input voltage, as shown in Fig. 6. After the capacitor C discharges, do you see what you expected? If the input voltage is constant, dv/dt is zero and the output voltage is zero.

4 Conclusion

Operational amplifiers are a core part of analog electronics and can perform many different operations depending on the passive component configurations around them. For more op-amp examples, visit the Analog Electronics Academy page on Plexim's website.

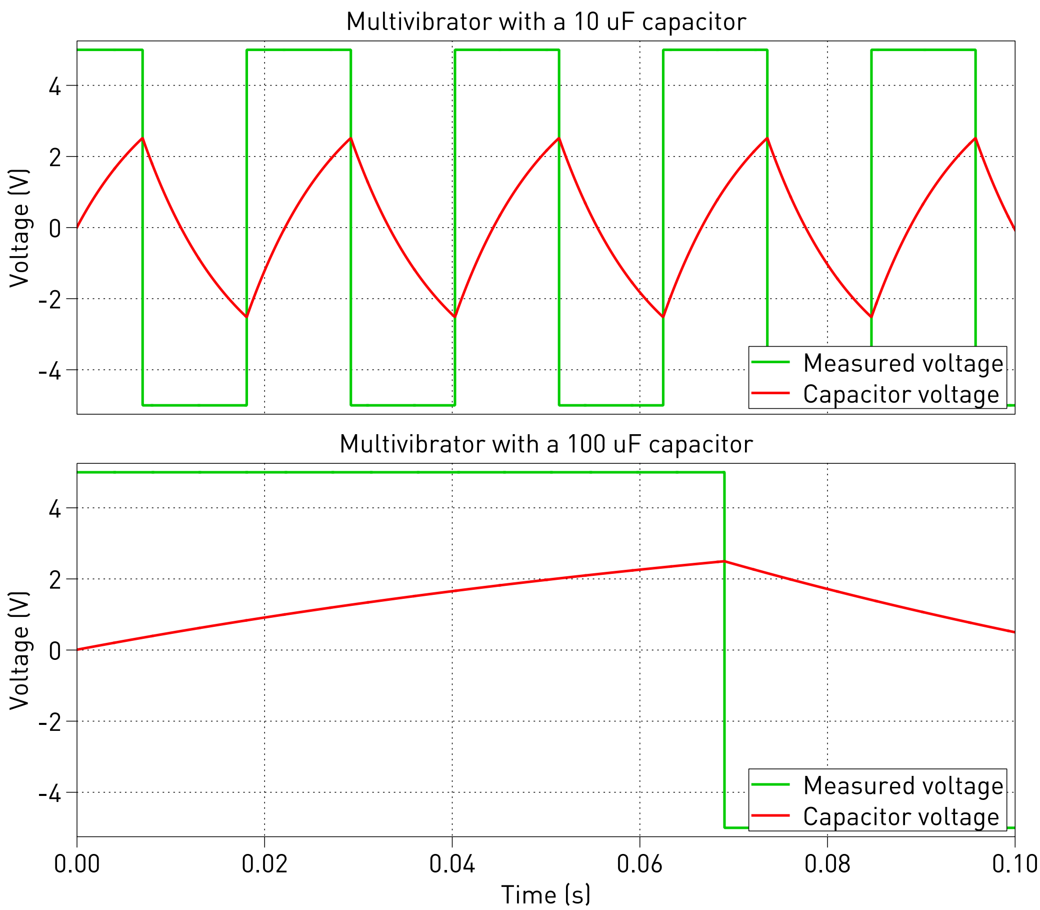

Figure 4: Multivibrator circuit simulations comparison

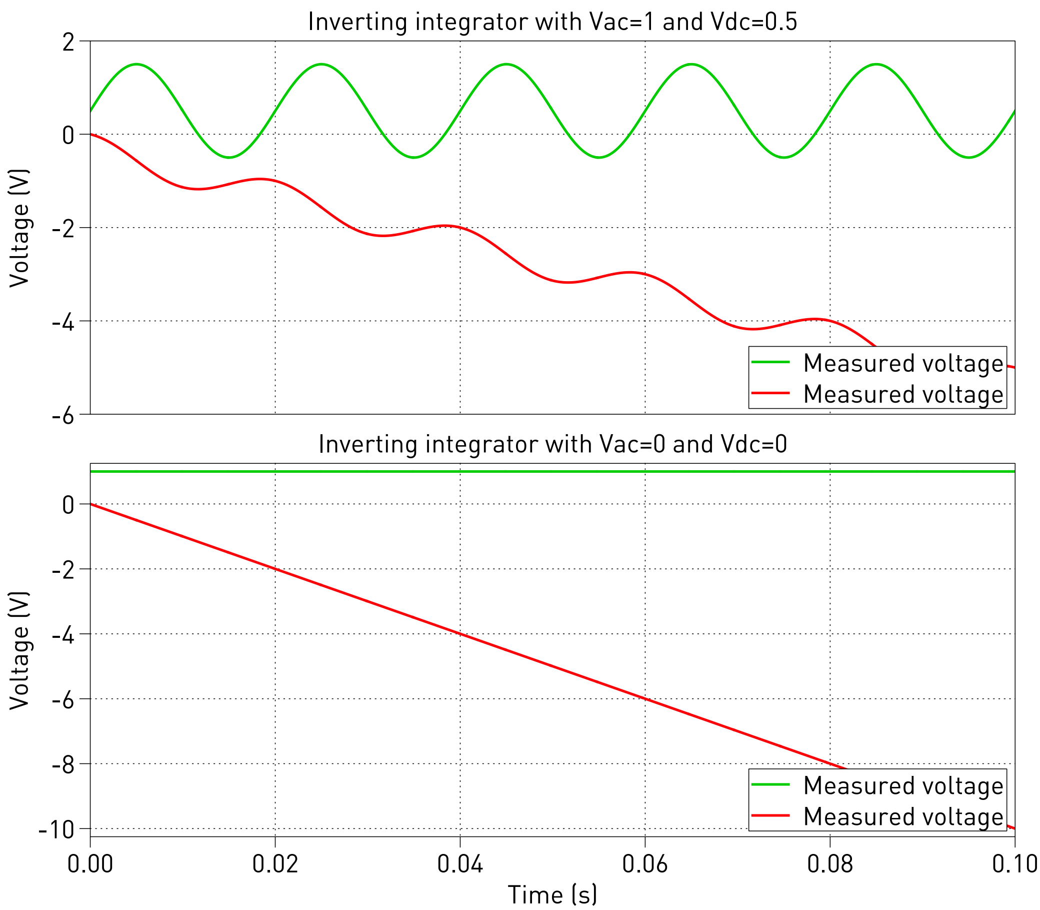

Figure 5: Inverting integrator circuit simulations comparison

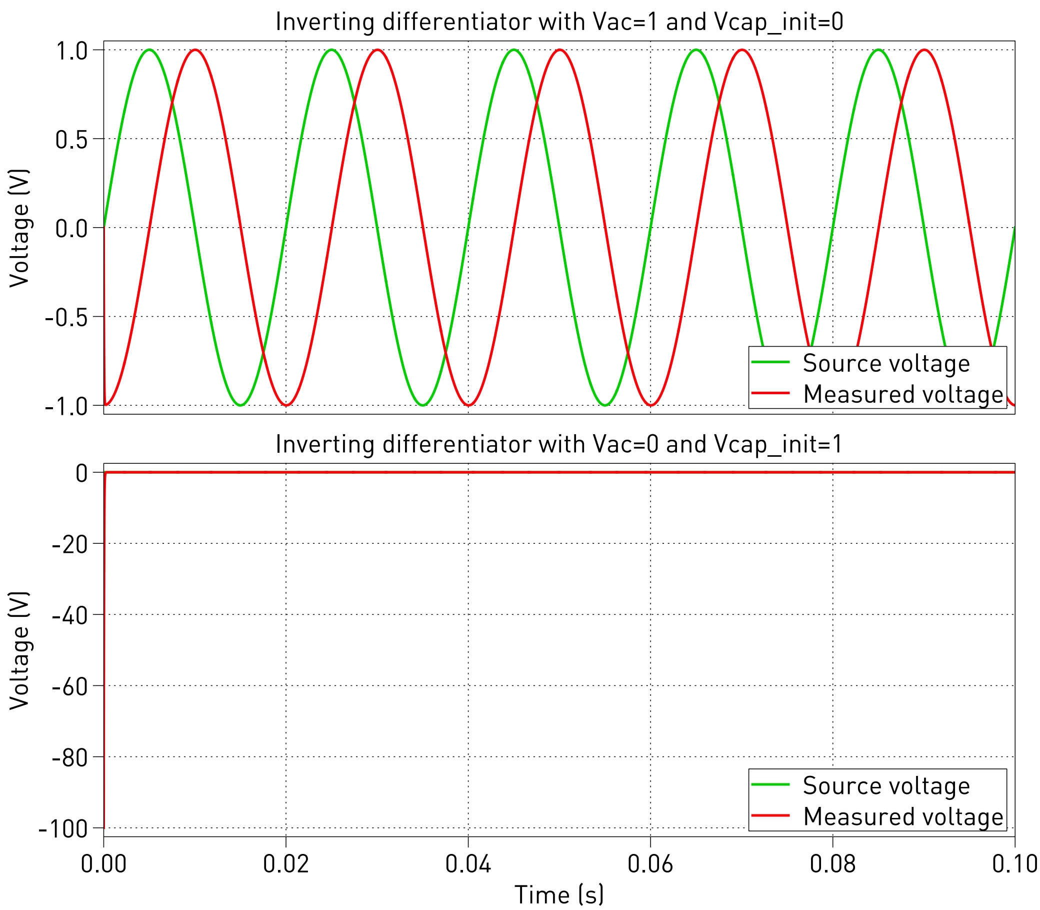

Figure 6: Inverting differentiator circuit simulations comparison

Revision History:

PLECS 4.3.1 First release

How to Contact Plexim:

☎ +41 44 533 51 00 Phone

+41 44 533 51 01 Fax

✉ Plexim GmbH
Technoparkstrasse 1
8005 Zurich
Switzerland Mail

@ info@plexim.com Email

http://www.plexim.com Web

PLECS Demo Model