

PLECS

DEMO MODEL

Operational Amplifier Circuits

Last updated in PLECS 4.3.1

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1 Overview

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

2 Model

2.1 Multivibrator with comparator

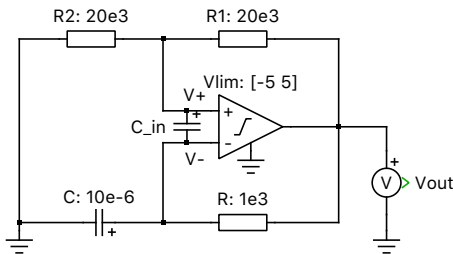


Figure 1: Multivibrator

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 $-\lambda V_{out}$ 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 $V = V_{out}$ and $q_0 = \lambda CV_{out}$,

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

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

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

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

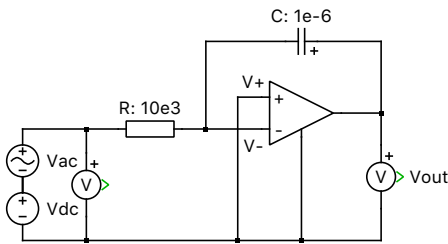


Figure 2: Inverting integrator

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

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

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:

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

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

$$i_C = C \cdot \frac{dv_C}{dt} = -C \cdot \frac{dV_{\text{out}}}{dt} = \frac{v_{\text{in}}}{R}$$

$$\frac{dV_{\text{out}}}{dt} = -\frac{1}{RC} \cdot v_{\text{in}}$$

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

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

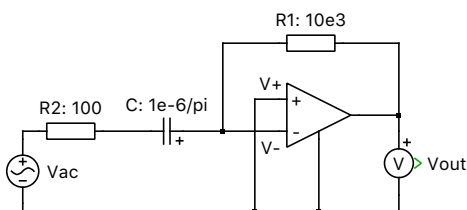


Figure 3: Inverting differentiator

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:

$$V_{\text{out}} = -RC \cdot \frac{dv_{\text{in}}}{dt}$$

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)

$$i_C = C \cdot \frac{dv_C}{dt} = C \cdot \frac{dv_{AC}}{dt} = -\frac{V_{\text{out}}}{R_1}$$

$$V_{\text{out}} = -R_1 C \cdot \frac{dv_{AC}}{dt}$$

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 μF 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 k Ω 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 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 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.

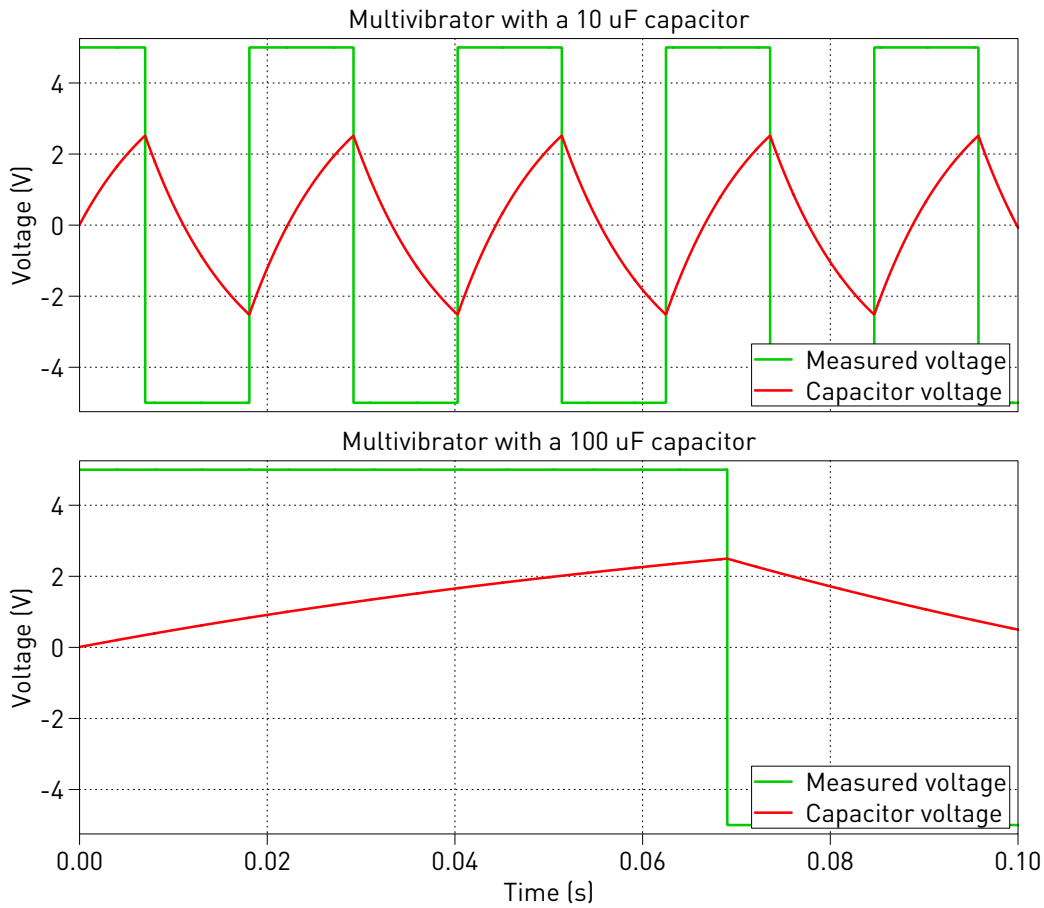


Figure 4: Multivibrator circuit simulations comparison

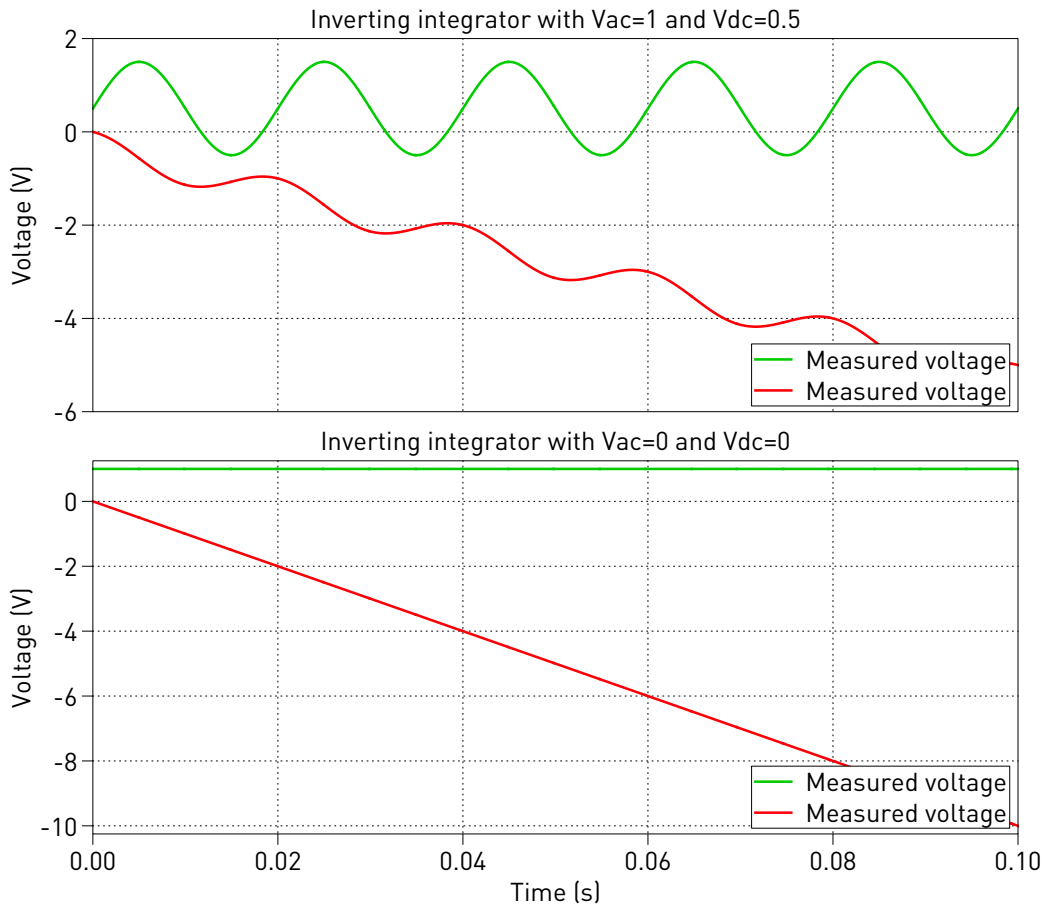


Figure 5: Inverting integrator circuit simulations comparison

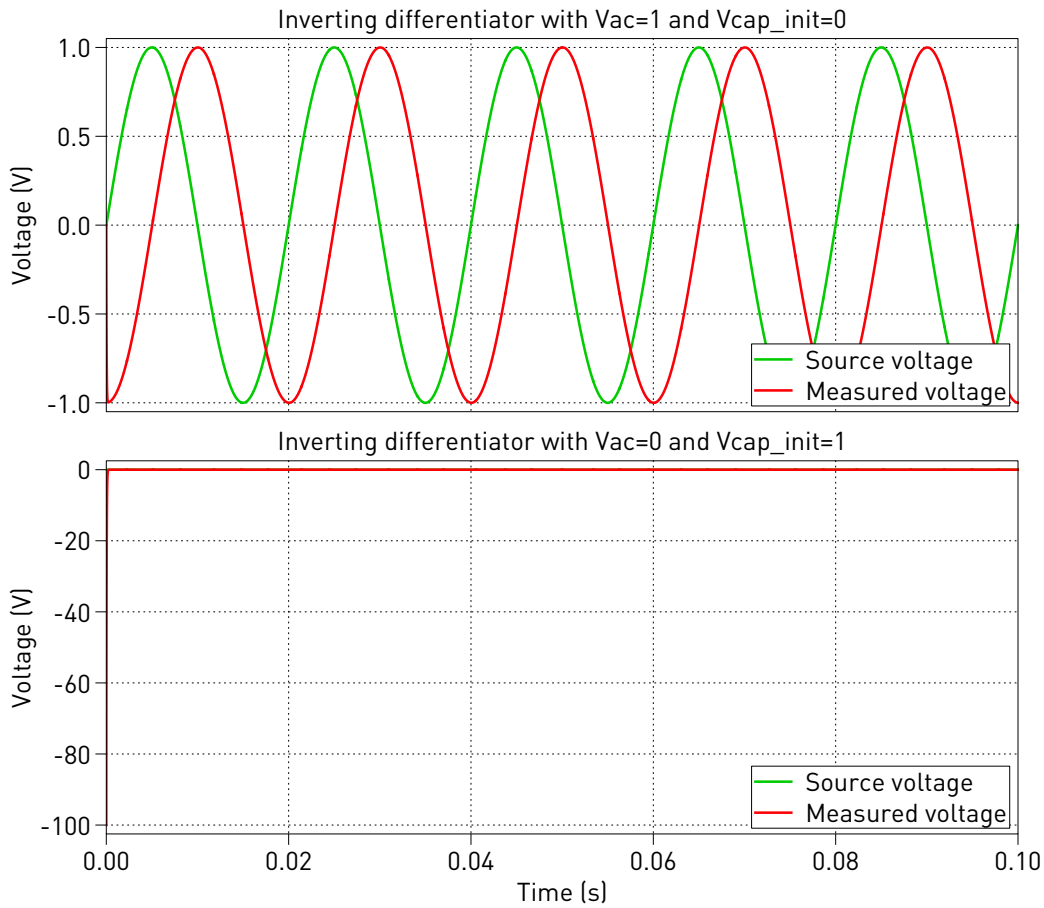


Figure 6: Inverting differentiator circuit simulations comparison

Revision History:

PLECS 4.3.1 First release

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