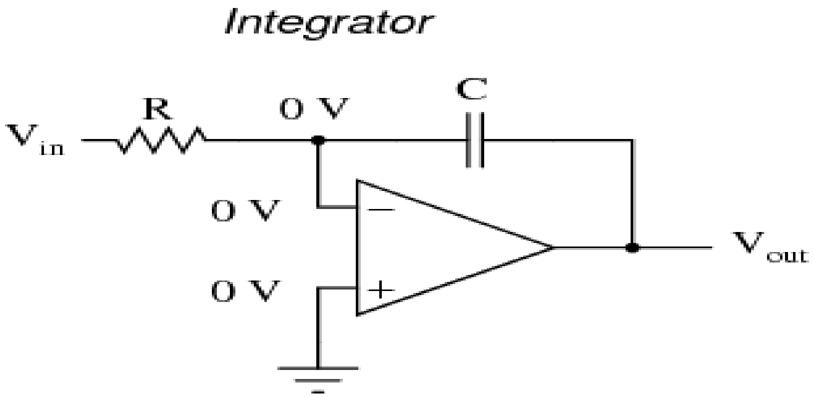
INTERGRATOR

The operational amplifier integrator is an electronic integration circuit. Based around the operational amplifier (op-amp), it performs the mathematical operation of integration with respect to time; that is, its output voltage is proportional to the input voltage integrated over time.



As before, the negative feedback of the op-amp ensures that the inverting input will be held at 0 volts (the virtual ground). If the input voltage is exactly 0 volts, there will be no current through the resistor, therefore no charging of the capacitor, and therefore the output voltage will not change. We cannot guarantee what voltage will be at the output with respect to ground in this condition, but we can say that the output voltage *will be constant*.

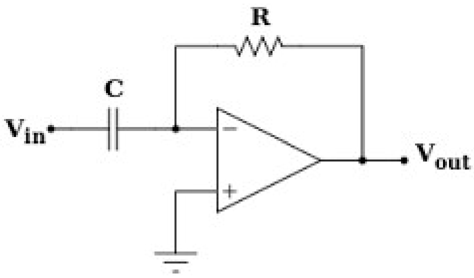
However, if we apply a constant, positive voltage to the input, the op-amp output will fall negative at a linear rate, in an attempt to produce the changing voltage across the capacitor necessary to maintain the current established by the voltage difference across the resistor. Conversely, a constant, negative voltage at the input results in a linear, rising (positive) voltage at the output. The output voltage rate-of-change will be proportional to the value of the input voltage.

The formula for determining voltage output for the integrator is as follows:

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

DIFFERENTIATOR

The differentiator (not to be confused with *differential*) produces a voltage output proportional to the input voltage's rate of change. In other words, We can build an op-amp circuit which measures change in voltage by measuring current through a capacitor, and outputs a voltage proportional to that current.



The right-hand side of the capacitor is held to a voltage of 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 won't cause a current through C, but a *changing* input voltage will.

Capacitor current moves through the feedback resistor, producing a drop across it, which is the same as the output voltage. A linear, positive rate of input voltage change will result in a steady negative voltage at the output of the op-amp. Conversely, a linear, negative rate of input voltage change will result in a steady positive voltage at the output of the op-amp.

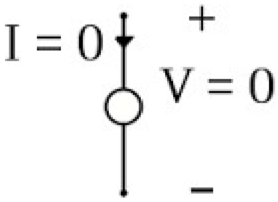
This polarity inversion from input to output is due to the fact that the input signal is being sent (essentially) to the inverting input of the op-amp, so it acts like the inverting amplifier mentioned previously. The faster the rate of voltage change at the input (either positive or negative), the greater the voltage at the output.

The formula for determining voltage output for the differentiator is as follows:

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

NULLATOR

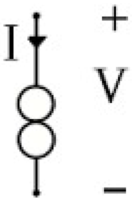
In electronics, a **nullator** is *defined* as having zero current and voltage across its terminals. Nullators are strange in the sense that they simultaneously have properties of both a short (zero voltage) and an open circuit (zero current). They are neither current nor voltage sources, yet both at the same time.



For example, the inputs of an ideal operational amplifier (with negative feedback) behave like a nullator, as they draw no current and have no voltage across them, and these conditions are used to analyze the circuitry surrounding the operational amplifier.

NORATOR

In electronics, a norator can have an arbitrary current and voltage between its terminals. A norator represents a controlled voltage or current source with infinite gain.



For example, the output of an ideal opamp behaves as a norator, producing nonzero output voltage and current that meet circuit requirements despite a zero input.