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# Summing Amplifier

The fact that the inverting input of the op-amp, when arranged in an inverting amplifier configuration, acts as a virtual ground allows one to inject several currents into that point without having any interaction between the signals. The signals sum cleanly and we can create an amplifier where the output voltage is related to a (perhaps weighted) sum of the input voltages.



Consider the circuit shown above. Let’s step through a quick analysis of this circuit to determine the output voltage $V\_{OUT}$ as a function of the input voltages $V\_{IN1}$, $V\_{IN2}, …, V\_{INn}$.

## Potential at inverting input.

Keeping in mind the op-amp golden rules, what is the potential at the inverting input (-) of the op-amp?

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## Input currents.

Using Ohm’s law, write expressions for the currents $I\_{1}$ thru resistor $R\_{1}$, $I\_{2}$ thru resistor $R\_{2}$, and $I\_{n}$ thru resistor $R\_{n}$. Your answers will depend upon the input voltages $V\_{IN1}, V\_{IN2},$ … $V\_{INn}$.

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## Feedback current.

Using Ohm’s law, write an expression for the current $I\_{f}$ thru the feedback resistor $R\_{f}$. Your answer will depend upon the output voltage $V\_{OUT}$. Be careful here to get the sign correct.

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## Op-amp input current.

Keeping in mind the op-amp golden rules, how much current is drawn at the inverting input of the op-amp?

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## Current relationship.

Using Kirchoff’s node rule and the previous answer, write an expression for the current thru the feedback resistor $I\_{f}$ in terms of the input currents $I\_{1}$, $I\_{2}$, … $I\_{n}$.

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## Voltage relationship.

Combining the previous results, write an expression for the output voltage $V\_{OUT}$ that only depends on the input voltages $V\_{IN1}, V\_{IN2},$ … $V\_{INn}$ and resistors $R\_{1}, R\_{2}, …R\_{n}, $and $R\_{f}$.

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# Averaging Amplifier

In the previous circuit, suppose that the feedback resistor is $R\_{f}=R$ and that there are $4$ inputs. What values (in terms of $R$) should be chosen for the input resistors $R\_{1}, R\_{2}, R\_{3}$, and $R\_{4}$ so that the output voltage $V\_{OUT}$ is equal to the (negative of the) **average value** of the inputs $V\_{IN1}, V\_{IN2}, V\_{IN3},$ and $V\_{IN4}$?

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# Digital to Analog Converter

A simple 4-bit digital to analog converter is shown in the adjacent circuit. This system can represent $2^{4}$, or $16$, different voltage levels depending on the state of the four switches. Take the common input voltage to be $V=5$ volts. Each input can be considered to be a simple high/low logic level that represents a 1 or 0 for that particular bit. Note that the input resistors vary by factors of 2. The gain for the lowest path is $R/R$, or unity. This input is used for the most significant bit of the input word (MSB). The next input shows a gain of $R/(2R)$, or $0.5$. The third input shows a gain of $0.25$, and the final (top) input shows a gain of $0.125$. The final input has the lowest gain and is used for the least significant bit of the input word (LSB). If the input word had a higher resolution (i.e., more bits), extra channels would be added, each having half the gain of the preceding input. To better understand the conversion process, let's consider a few representative inputs and outputs.

## Output for $0000$

The circuit above shows all $4$ of the switches connected to the $+5V$ source. Suppose instead that all of them are connected to ground. What will be the value of the output in this case?

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## Output for $0001$

Suppose that the topmost switch is connected to the $+5V$ source and the remaining three are connected to ground. What will be the value of the output in this case?

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## Output for 1111.

Suppose that all of the switches are connected to the $+5V$ source in the same manner as shown in the above figure. What will be the value of the output in this case?

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