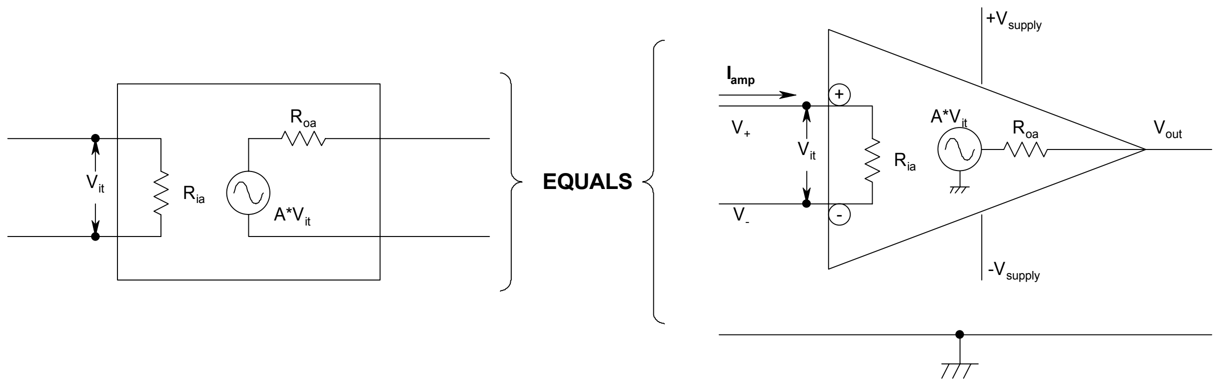
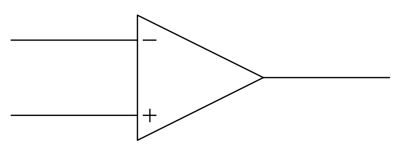
OPERATIONAL AMPLIFIERS

INTRODUCTION

Fundamentally, ***operational amplifiers*** are normal amplifiers usually represented with a ***3-terminal*** symbol. The relation between the 3-terminal representation and the 4-terminal version we have used is indicated below:



From the diagram, it is clear that the connections labeled "+" and "-" are opposite ends of the input, and that $V_{it} = (V_+ - V_-)$. As well, $V_{out} = A * V_{it} = A * (V_+ - V_-)$, which we will refer to as the ***basic amplifier relation.*** (Of course, this means that the "+" and "-" **do not** refer to power connections!!!) The usual form of the operational amplifier circuit symbol , shown in the inset, also omits the power connections shown above and labeled "$+V_{supply}$ and $-V_{supply}$.



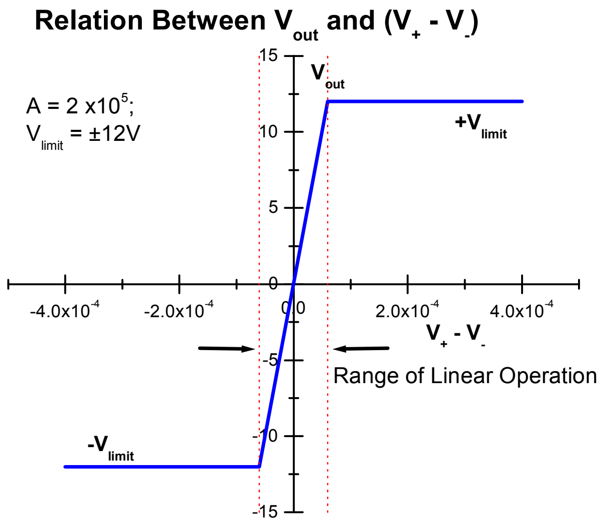
Standard Op Amp Representation

MAIN PROPERTIES

The two main properties of operational amplifiers are:

1. $R_{ia} \rightarrow \infty \;\Rightarrow\; I_{amp} \rightarrow 0$
2. $A \rightarrow \infty \;\Rightarrow$ Needs discussion

Property #2, A going to infinity, seems to say that V_o also will become infinite. However, V_o is limited to finite values by practical matters such as power supply voltage. For example, the supply voltages are typically ±15V, meaning that there's no way *V_o*can exceed 15V! Thus $A \rightarrow \infty$ really means that the output is ***limited*** by the power supply (or other internal characteristics) for values $\left|(V_+ - V_-)\right| \geq \dfrac{|V_{limit}|}{A}$. Moreover, $\dfrac{|V_{limit}|}{A} \rightarrow 0$ as $A \rightarrow \infty$. The actual consequence of A 6 4, then, is that V_{out} responds to changes in the input only if $\left|(V_+ - V_-)\right| \leq \dfrac{|V_{limit}|}{A}$ or when $|V_+ - V_-| \approx 0$.



The graph to the left illustrates the relation between the input and output for typical values of A and V_{limit}. This point is important for amplifier applications since the main purpose of an amplifier is for the output to be a faithful copy of the input. Thus we can conclude that $V_+ \sim V_-$ for ***amplifier applications.*** However, it is also important to note that *V_+ - V_-* can easily be non-zero. If so, the output is simply "stalled" at the "power supply limit." While this can be desirable, it is not an amplifier application.

Summary of Op Amp Properties and Their Consequences

(For example, a general-purpose operational amplifier type such as the one used in the lab experiments has $R_{ia} \sim 2 \times 10^6$ ohms and $A \sim 2 \times 10^5$. Both values are large but finite. The data sheet for this amplifier type, the "741," is appended as is that of the type LF356.)

1. $R_{ia} \rightarrow \infty \Rightarrow I_{amp} \rightarrow 0$
2. $A \rightarrow \infty \Rightarrow V_+ \cong V_-$ (only for amplifying applications)

OPERATIONAL AMPLIFIERS IN AMPLIFYING APPLICATIONS

Standard Inverting Configuration. The inverting configuration is sketched in the circuit below; following the circuit is an analysis of the circuit leading to the expression for V_{out} / V_{in}, referred to as "Gain." (Gain means the same as amplification, but is not the same as A of the operational amplifier itself.)

The following relations describe the inverting circuit:

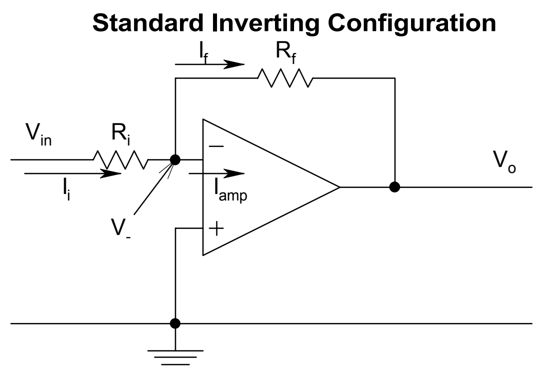
$$V_- = V_+ = 0 \quad \text{(amplifier circuit)}$$

$$I_f = I_i + I_{amp} = I_i \quad (I_{amp} = 0)$$

$$I_i = \frac{V_{in} - V_-}{R_i} = \frac{V_{in}}{R_i}$$

$$I_f = \frac{V_- - V_o}{R_f} = -\frac{V_o}{R_f}$$

$$I_i = I_f = \frac{V_{in}}{R_{in}} = -\frac{V_o}{R_f} \Rightarrow G = \frac{V_o}{V_{in}} = -\frac{R_f}{R_i}$$

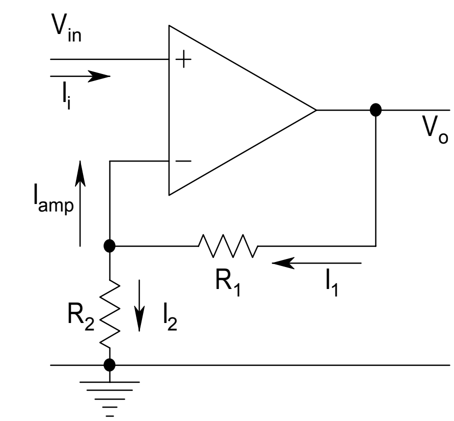


From this result, we see that the "gain" depends only on the ratio of the two resistors, R_f and R_i. (R_i and R_f are sometimes called the "input" and "feedback" resistors, respectively.)

Standard Non-inverting Configuration. The non-inverting configuration is shown in the inset, with the analysis following.

The following relations describe the non-inverting circuit.

Standard Non-inverting Configuration



$$V_- = V_+ = V_{in}$$

$$I_2 = I_1 + I_{amp} = I_1$$

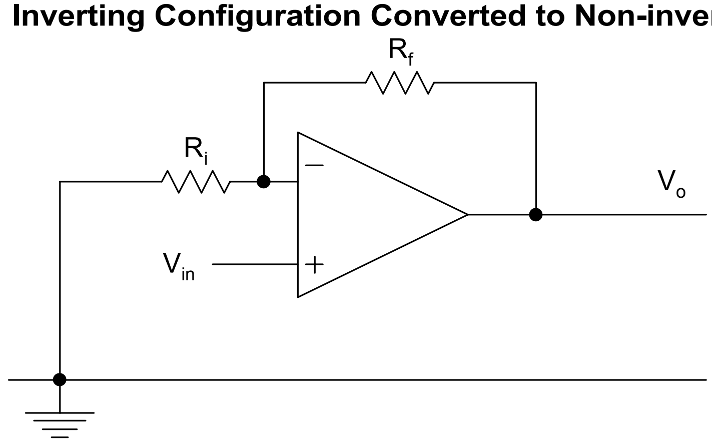
$$I_1 = I_2 = \frac{V_0}{R_1 + R_2}$$

$$V_{in} = V_- = I_2 R_2 = R_2\left(\frac{V_o}{R_1 + R_2}\right)$$

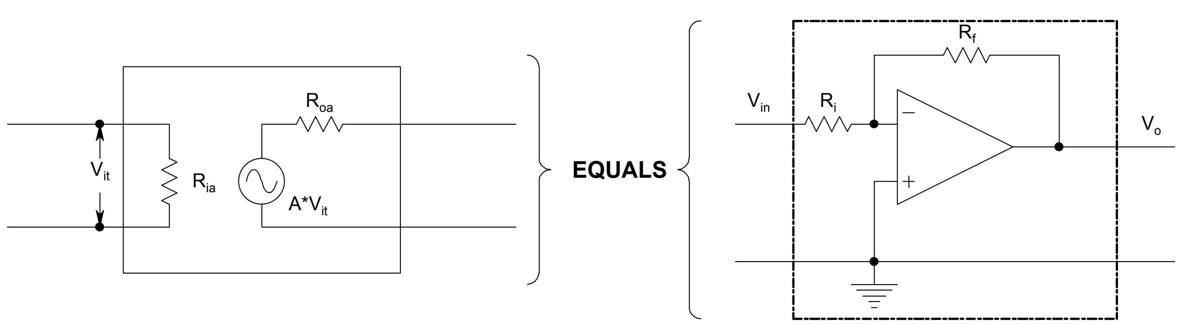
$$\frac{V_o}{V_{in}} = \frac{R_1 + R_2}{R_2} = 1 + \frac{R_1}{R_2} = G$$

As before, the gain depends only on the two resistors. Also, the non-inverting character is clear from the overall positive value of the expression. Finally, the non-inverting circuit can be derived from the inverting configuration by simply "swapping" the input connections as shown in the inset.

Inverting Configuration Converted to Non-inverting



Equivalent Input Resistance of the Standard Circuits. As before, the procedure is to "connect" an input voltage and develop an expression for the resulting input current. The ratio, V_{in} / I_{in} gives the equivalent input resistance of the amplifier. In this case, we need to recall that the "amplifier" under examination is that of the inverting or non-inverting circuit developed above. This is illustrated below for the inverting configuration:

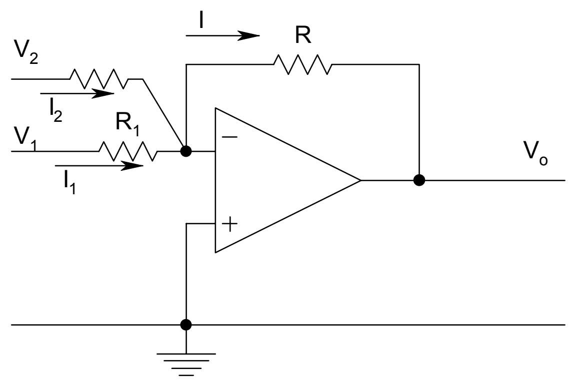


As developed above for the inverting circuit, V_{in} causes $I_{in} = V_{in} / R_i$; thus $V_{in} / I_{in} = R_i$! ***In other words, the effective input resistance of the inverting circuit is established by R_i, and is equal to R_i.***

The result for the non-inverting circuit will be less exact. However, referring to the circuit diagram above we can see that the only current path for V_{in} is ***through the amplifier***. Thus, ***the effective input resistance of the non-inverting circuit is at least as high as that of the operational amplifier itself***.

(We will not consider for now the effective output resistance of the circuits as we will describe this in general more completely in the discussion of feedback, to follow.)

Operational Amplifier Summing Circuit (Based on the Inverting Configuration). Sketched below is a multi-input circuit in the inverting arrangement:



Analysis:

$I = I_1 + I_2 \qquad (I_{amp} = 0)$

$V_- = V_+ = 0$

$$I_1 = \frac{V_1 - V_-}{R_1} = \frac{V_1}{R_1}$$

$$I_2 = \frac{V_2 - V_-}{R_2} = \frac{V_2}{R_2}$$

$$I = I_1 + I_2 = \frac{V_1}{R_1} + \frac{V_2}{R_2}$$

$$I = \frac{V_- - V_o}{R} = -\frac{V_o}{R}$$

$$-\frac{V_o}{R} = \frac{V_1}{R_1} + \frac{V_2}{R_2} \Rightarrow \mathbf{V_o = -\left(\frac{R}{R_1}V_1 + \frac{R}{R_2}V_2\right)}$$

From a straightforward perspective, we can see that the output has a linear dependence on the two input voltages. While these may be constant voltages, in general they will be variable–a voice signal, for example. Thus the circuit can function as a signal combining or “mixing” circuit.

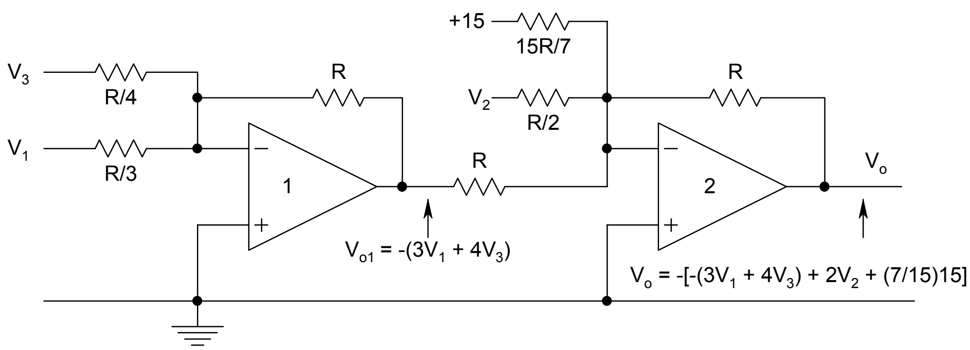
From a different view, keeping the concept of the voltages as “variables,” this circuit creates a linear combination of the “variables,” weighted by the resistance ratios. Thus, the circuit can implement the linear algebraic function $y = ax_1 + bx_2$. In fact, this circuit type was the cornerstone of the ***analog computer***.

Note that the adding (or summing) character of the circuit was the result of V_- being *virtually* at ground. In fact, we can extend this by connecting any number of input voltages to the inverting input (the “summing point”). Each will contribute the amount $I_k = V_k / R_k$ (where k = 1 to n) to the current through R, and the contribution of each will appear in the linear combination as the term $V_k (R / R_k)$.

(Note also that the simple combination came from the fact that $V_- = 0$. Since this is not the case for the non-inverting circuit, that circuit does not permit such simple combinations.)

EXAMPLE 1: Given the variable voltages V_1, V_2, V_3, and the constant voltage +15, create the combination $V_o = 3V_1 - 2V_2 + 4V_3 - 7$ using ***no more than 2 operational amplifiers***.

Solution: The key is that one amplifier gives a "-" sign; however sending that to a second amplifier provides an additional "times -1." Thus two amplifiers are needed to create a ***positive*** coefficient. In addition, there will be an infinite set of resistors capable of giving the result. Consider the circuit below as a practical solution:



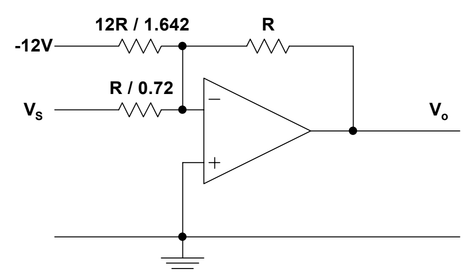
EXAMPLE 2: Many types of sensors give voltage outputs, and often it is necessary to re-scale the output voltages to provide convenient readings. For example, consider a temperature sensor with the characteristics that its output voltage is a function of temperature in centigrade (Celsius) according to ***$V_s = (0.5 - 0.1T_C)$ volts***, where ***T_c*** is the temperature in Celsius units. Devise a circuit to transform this voltage to one in terms of Fahrenheit degrees according to ***$V_o = (0.04T_F)$ volts***, where ***T_F*** is the temperature in Fahrenheit. (Assume availability of ±12V as power supply voltages and for deriving any constant voltage values.)

Solution: Since the relation between Fahrenheit and Celsius is $T_C = 5(T_F - 32)/9$, the sensor voltage can be transformed into $V_s = 0.5 - (0.1)\frac{5}{9}(T_F - 32) = 2.28 - .0556T_F$. Similarly, the "target" V_{out} is related to T_F according to $T_F = V_o / 0.04 = 25V_o$.

Thus, by substitution,

$$V_S = 2.28 - 0.0556\,(25\,V_o) = 2.28 - 1.389V_o\text{, or}$$

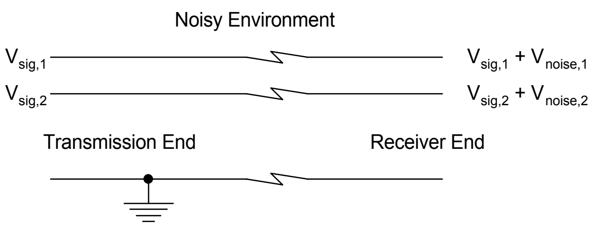
$$\mathbf{V_o = (2.28 - V_s)/1.389 = 1.642 - 0.72\,V_s}$$



and the appropriate circuit is as shown to the right.

Differential Amplifier Using Op-Amp's:

Differential Amplifiers, which amplify the *difference* between two voltages, are commonly used in cases where sensitive signals need to be amplified, where signal-carrying cables may pass through noisy environments, where signal-carrying cables may be extremely long, *etc.* The idea for noisy environments, as sketched below, is that each signal connection may be affected by noise or "pick-up," but if they closely follow the same path (being twisted together, for example), they will pick up the same amount of noise. Integrity of sensitive or low-level signals may be compromised by use of the general "ground" as one "side" of the signal connection. This possibility arises since conductors are not perfect; thus sharing a ground path with a high-current or "noisy" signal will add a varying voltage only onto the ground side of the signal. If the added signal is comparable to the signal, the overall transmission is significantly degraded. In this case, the use of differential signal transmission avoids using the "noisy" ground. In summary therefore, taking the difference in voltages between the two wires will maintain the desired signal while canceling the noise as indicated in the relations below.



Model of Signal Transmission

Starting Signal:

$$V_2 - V_1 = (V_{sig,2} - V_{sig,1})$$

Result of Noise Pickup:

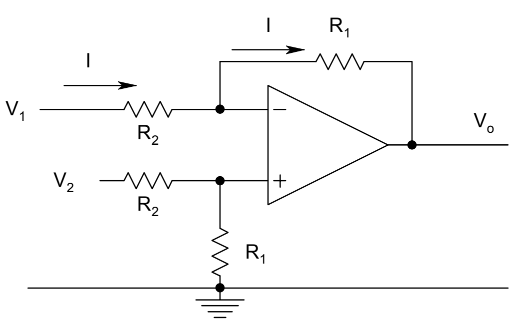
$$V_1 = V_{sig,1} + V_{noise,1}$$

$$V_2 = V_{sig,2} + V_{noise,2}$$

Result of Differential Amplifier:

$$V_2 - V_1 = (V_{sig,2} - V_{sig,1}) + (V_{noise,2} - V_{noise,1})$$

Fundamentally, operational amplifiers are "differential amplifiers." Consequently, we can create differential circuits with appropriate use of resistors based the ideas presented and discussed above for the basic amplifier circuits; the standard differential configuration is shown and analyzed below.



Differential Amplifier Circuit

$$V_+ = R_1\left(\frac{V_2}{R_1 + R_2}\right) = V_-$$

$$I = \frac{V_1 - V_-}{R_2} = \frac{V_- - V_o}{R}$$

$$\frac{V_1}{R_2} + \frac{V_O}{R_1} = V_-\left(\frac{1}{R_1} + \frac{1}{R_2}\right) = V_-\left(\frac{R_1 + R_2}{R_1 R_2}\right)$$

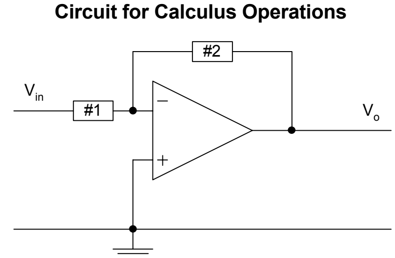
$$\frac{V_1}{R_2} + \frac{V_O}{R_1} = V_-\left(\frac{R_1 + R_2}{R_1 R_2}\right) = R_1\left(\frac{V_2}{R_1 + R_2}\right)\left(\frac{R_1 + R_2}{R_1 R_2}\right)$$

$$\frac{V_1}{R_2} + \frac{V_O}{R_1} = \frac{V_2}{R_2} \Rightarrow \quad \mathbf{V_O = \frac{R_1}{R_2}(V_2 - V_1)}$$

Calculus Operations

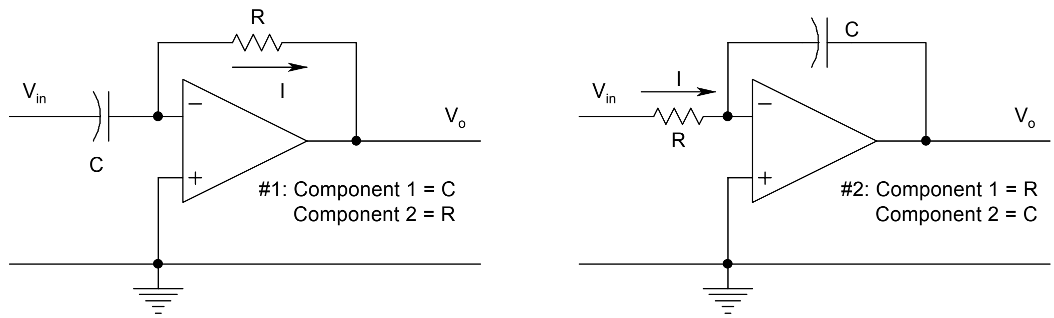
The general form of the circuit is shown in the inset with components 1 and 2 being a resistor and a capacitor. (Of course, this means there are two variations on the circuit.)

Circuit for Calculus Operations



Technically, viewing the circuits from the standpoint of *calculus operations* describes their *time-dependence*, and is sometimes referred to as the *time-domain* analysis. Alternately, the circuits may be examined for their *frequency dependence*; this is a *frequency-domain* analysis. We will analyze them from both perspectives. To set up the analyses, the two variations of the circuit configuration are sketched below.

RC-Based Circuits for Calculus Operations



Circuit #1, Frequency Domain Analysis

Since the circuit is the standard Inverting configuration, we can use the result from before with R's replaced by Z's.

$$\frac{V_o}{V_i} = -\frac{Z_2}{Z_1} = -\left(\frac{R}{{}^{-j}\!/_{\omega C}}\right) = -j\omega RC \text{ (high-pass character)}$$

Circuit #2, Frequency Domain Analysis

$$\frac{V_o}{V_i} = -\frac{Z_2}{Z_1} = -\left(\frac{{}^{-j}\!/_{\omega C}}{R}\right) = {}^{j}\!/_{\omega RC} \text{ (low-pass character)}$$

Circuit # 1, Time-Domain Analysis

Following previous procedures,

$$V_- = V_+ = 0$$

$$I = \frac{V_- - V_o}{R} = -\frac{V_o}{R} \Rightarrow V_o = -IR$$

$$\frac{Q}{C} = V_C = V_{in} - V_- = V_{in} \Rightarrow Q = CV_{in}$$

$$I = \frac{dQ}{dt} = C\frac{dV_{in}}{dt} \Rightarrow \mathbf{V_o = -IR = -RC\frac{dV_{in}}{dt}}$$

Circuit # 2, Time-Domain Analysis

Following previous procedures,

$$V_- = V_+ = 0$$

$$I = \frac{V_{in} - V_-}{R} = \frac{V_{in}}{R}$$

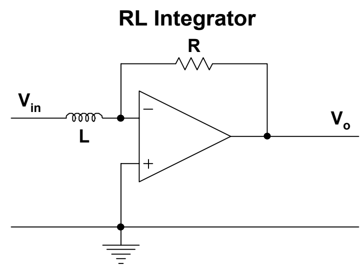
$$\frac{Q}{C} = V_C = V_- - V_o = -V_o \Rightarrow V_o = -\frac{Q}{C}$$

$$Q = \int I\,dt \Rightarrow \mathbf{V_o = -\frac{Q}{C} = -\frac{1}{RC}\int V_{in}\,dt}$$

In summary, therefore, the ***differentiator*** circuit has *high-pass* character, while the ***integrator*** has *low-pass* character.

Example: In the “calculus” circuits described above, only resistors and capacitors were used. However, the same set of operations can also be implemented (in principle) with resistors and inductors. (Inductors are usually not used since real capacitors are more nearly “ideal” than real inductors.) With the same general configuration used for RC-based circuits, develop RL-based differentiation and integration circuits.

Solution: Consider first the RC differentiator arrangement with the C replaced by an L. Since $V_{in} = V_L$ and $V_L = L\frac{dI}{dt}$, we see that $I = \frac{1}{L}\int V_L dt = \frac{1}{L}\int V_{in}dt$. Also, since V_o = -IR, the result is $V_o = -IR = -\frac{R}{L}\int V_{in}dt$. Therefore, replacing the C in the RC differentiator circuit with an L creates an integrating circuit.



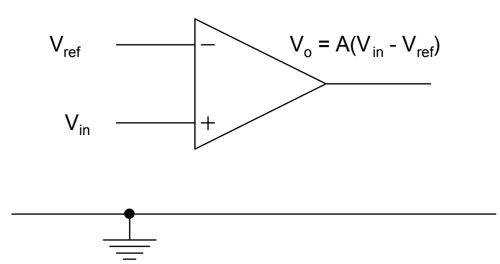
It is straightforward to show that replacing the C with an L in the RC integrator circuit yields the RL differentiator circuit.

Non-Amplifying Applications of Operational Amplifiers

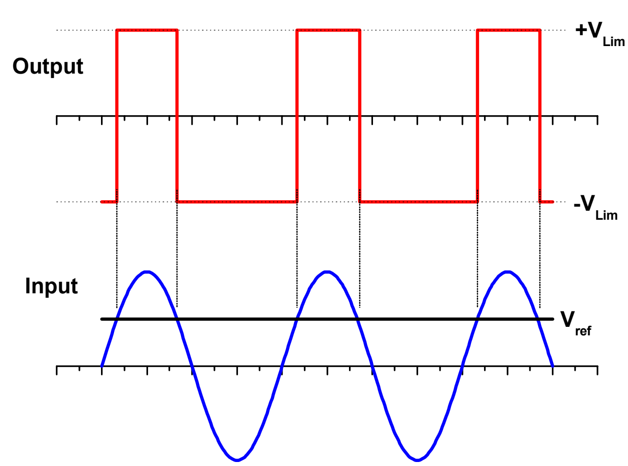
In analyzing the amplifying applications described above, we took V_+ as being virtually equal to V_-. This was appropriate in those cases since the objective was to have the output change continuous with changes in the input. However, V_+ is not *automatically* equal to V_-. As described above, ***when V_+ and V_- are "much" different, the output is limited by the power supply (or other pactical considerations).*** We will now examine useful applications where this *non-linear* application of operational amplifiers is the goal.

Voltage Comparator. The voltage comparator function can be implemented by using the "bare" amplifier as sketched in the inset. The basic idea is that the large value of A means the output will be limited by the power supply (or other internal factors) unless V_{in} is within a very small range of V_{ref}. Effectively, therefore, V_o will be at the positive limiting value when $V_{in} > V_{ref}$ and will be at the negative limiting value when $V_{in} < V_{ref}$ (or $V_{ref} > V_{in}$). In other words, the output will be a binary indicator of which is greater: V_{in} or V_{ref}.

Operational Amplifier as Comparator



Sketched to the side is a graph illustrating this behavior for a sine wave V_{in} and a constant V_{ref}. The vertical dotted lines show the correspondence in time and voltage between the two patterns.



Operational Amplifier as Comparator

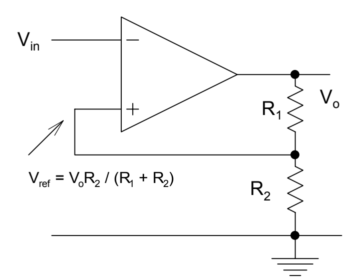
In addition to its value as the cornerstone of additional circuits, this is a useful type of circuit with several of applications in its own right. For example, a temperature control system can use sensors providing a voltage proportional to the temperature. In this case, the V_{ref}

value could be the voltage corresponding to the set point. When the measured temperature is too low, a heater can be switched on, while cooling can be switched on if the temperature is too high. Closely related to this example is that of an overheat alarm system: if the measured temperature (V_{in}) exceeds the "danger" set point (V_{ref}), an alarm can be switched on.

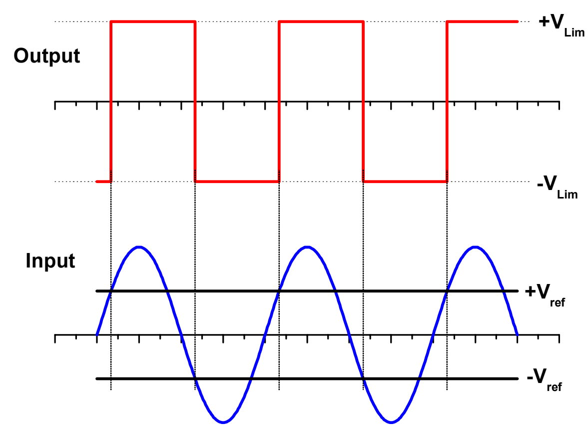
Schmitt Trigger. The Schmitt Trigger circuit can be derived directly from the voltage comparator. The basic modification is to derive the V_{ref} value from the output, thereby meaning there is only one "input," the signal. Making this modification means that tha V_{ref} will not always be the same value. However, if the output is always at one or the other power-supply limited states, there will be only two such values. In effect, therefore, the input will be compared to a voltage derived from the positive limit in one case, and to a voltage derived from the negative limit in the next case. This behavior introduces a range of values over which sequential + to - limit transitions cannot occur, and is the behavior known as ***hysteresis.***

The Schmitt trigger circuit as derived from an operational amplifier is sketched to the side. The circuit is deceptively like that of the non-inverting amplifier; however, it is not the same. Note that the connection derived from the output is to the non-inverting input. The corresponding connection in the non-inverting amplifier was to the inverting input. In fact, the difference between to two circuits is that one employs negative feedback (the amplifier), while the other employs positive feedback (the trigger). We will return to this point briefly when we discuss the topic of feedback. The main thing to note about the Schmitt Trigger is that the "trigger level" is a fraction of the voltages established as the output limits (V_{limit}). For operational amplifiers, these may be taken as symmetrical (equal + and - values). Thus, the trigger points are controlled by the fraction $R_2 / (R_1 + R_2)$.

Operational Amplifier as Schmitt Trigger



In the illustration, $\pm V_{ref}$ is the value $\pm V_{limit} {}^{*} R_2/(R_2 + R_1)$, indicating the ***two different values*** to which the input is compared. This also shows the hysteresis, the values between the two trigger levels.



Operational Amplifier as Schmitt Trigger

Concluding remarks.

Operational amplifiers are versatile building blocks for many analog and interface circuits. Appended to this set of notes, along with the two data sheets from general purpose operational amplifiers is a collection of useful operational amplifier circuits from the National Semiconductor website (www.national.com).

National Semiconductor

August 2000

LM741
Operational Amplifier

General Description

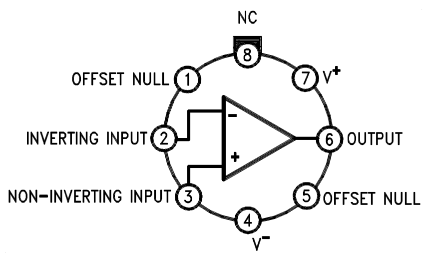
The LM741 series are general purpose operational amplifiers which feature improved performance over industry standards like the LM709. They are direct, plug-in replacements for the 709C, LM201, MC1439 and 748 in most applications.

The amplifiers offer many features which make their application nearly foolproof: overload protection on the input and output, no latch-up when the common mode range is exceeded, as well as freedom from oscillations.

The LM741C is identical to the LM741/LM741A except that the LM741C has their performance guaranteed over a 0˚C to +70˚C temperature range, instead of −55˚C to +125˚C.

Connection Diagrams

Metal Can Package

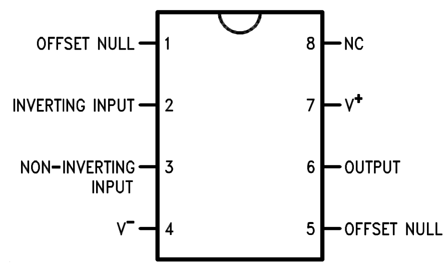


DS009341-2

Note 1: LM741H is available per JM38510/10101

Order Number LM741H, LM741H/883 (Note 1), **LM741AH/883 or LM741CH**
See NS Package Number H08C

Dual-In-Line or S.O. Package



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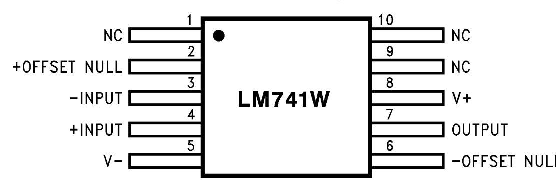
Order Number LM741J, LM741J/883, LM741CN
See NS Package Number J08A, M08A or N08E

Ceramic Flatpak



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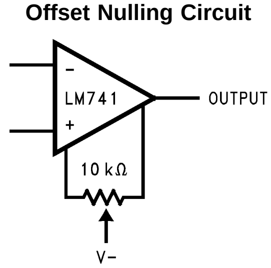
Order Number LM741W/883
See NS Package Number W10A

Typical Application

Offset Nulling Circuit



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Absolute Maximum Ratings (Note 2)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/ Distributors for availability and specifications.

(Note 7)

	LM741A	LM741	LM741C
Supply Voltage	±22V	±22V	±18V
Power Dissipation (Note 3)	500 mW	500 mW	500 mW
Differential Input Voltage	±30V	±30V	±30V
Input Voltage (Note 4)	±15V	±15V	±15V
Output Short Circuit Duration	Continuous	Continuous	Continuous
Operating Temperature Range	−55˚C to +125˚C	−55˚C to +125˚C	0˚C to +70˚C
Storage Temperature Range	−65˚C to +150˚C	−65˚C to +150˚C	−65˚C to +150˚C
Junction Temperature	150˚C	150˚C	100˚C
Soldering Information			
N-Package (10 seconds)	260˚C	260˚C	260˚C
J- or H-Package (10 seconds)	300˚C	300˚C	300˚C
M-Package			
Vapor Phase (60 seconds)	215˚C	215˚C	215˚C
Infrared (15 seconds)	215˚C	215˚C	215˚C

See AN-450 “Surface Mounting Methods and Their Effect on Product Reliability” for other methods of soldering surface mount devices.

	LM741A	LM741	LM741C
ESD Tolerance (Note 8)	400V	400V	400V

Electrical Characteristics (Note 5)

Parameter	Conditions	LM741A			LM741			LM741C			Units
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Input Offset Voltage	$T_A = 25˚C$										
	$R_S \leq 10\ k\Omega$					1.0	5.0		2.0	6.0	mV
	$R_S \leq 50\Omega$		0.8	3.0							mV
	$T_{AMIN} \leq T_A \leq T_{AMAX}$										
	$R_S \leq 50\Omega$			4.0							mV
	$R_S \leq 10\ k\Omega$						6.0			7.5	mV
Average Input Offset Voltage Drift				15							μV/˚C
Input Offset Voltage Adjustment Range	$T_A = 25˚C, V_S = \pm 20V$	±10				±15			±15		mV
Input Offset Current	$T_A = 25˚C$		3.0	30		20	200		20	200	nA
	$T_{AMIN} \leq T_A \leq T_{AMAX}$			70		85	500			300	nA
Average Input Offset Current Drift				0.5							nA/˚C
Input Bias Current	$T_A = 25˚C$		30	80		80	500		80	500	nA
	$T_{AMIN} \leq T_A \leq T_{AMAX}$			0.210			1.5			0.8	μA
Input Resistance	$T_A = 25˚C, V_S = \pm 20V$	1.0	6.0		0.3	2.0		0.3	2.0		MΩ
	$T_{AMIN} \leq T_A \leq T_{AMAX}$, $V_S = \pm 20V$	0.5									MΩ
Input Voltage Range	$T_A = 25˚C$							±12	±13		V
	$T_{AMIN} \leq T_A \leq T_{AMAX}$				±12	±13					V

Electrical Characteristics (Note 5) (Continued)

Parameter	Conditions	LM741A			LM741			LM741C			Units
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Large Signal Voltage Gain	T_A = 25˚C, R_L ≥ 2 kΩ										
	V_S = ±20V, V_O = ±15V	50									V/mV
	V_S = ±15V, V_O = ±10V				50	200		20	200		V/mV
	T_{AMIN} ≤ T_A ≤ T_{AMAX},										
	R_L ≥ 2 kΩ,										
	V_S = ±20V, V_O = ±15V	32									V/mV
	V_S = ±15V, V_O = ±10V				25			15			V/mV
	V_S = ±5V, V_O = ±2V	10									V/mV
Output Voltage Swing	V_S = ±20V										
	R_L ≥ 10 kΩ	±16									V
	R_L ≥ 2 kΩ	±15									V
	V_S = ±15V										
	R_L ≥ 10 kΩ				±12	±14		±12	±14		V
	R_L ≥ 2 kΩ				±10	±13		±10	±13		V
Output Short Circuit	T_A = 25˚C	10	25	35		25			25		mA
Current	T_{AMIN} ≤ T_A ≤ T_{AMAX}	10		40							mA
Common-Mode	T_{AMIN} ≤ T_A ≤ T_{AMAX}										
Rejection Ratio	R_S ≤ 10 kΩ, V_{CM} = ±12V				70	90		70	90		dB
	R_S ≤ 50Ω, V_{CM} = ±12V	80	95								dB
Supply Voltage Rejection	T_{AMIN} ≤ T_A ≤ T_{AMAX},										
Ratio	V_S = ±20V to V_S = ±5V										
	R_S ≤ 50Ω	86	96								dB
	R_S ≤ 10 kΩ				77	96		77	96		dB
Transient Response	T_A = 25˚C, Unity Gain										
Rise Time			0.25	0.8		0.3			0.3		µs
Overshoot			6.0	20		5			5		%
Bandwidth (Note 6)	T_A = 25˚C	0.437	1.5								MHz
Slew Rate	T_A = 25˚C, Unity Gain	0.3	0.7			0.5			0.5		V/µs
Supply Current	T_A = 25˚C					1.7	2.8		1.7	2.8	mA
Power Consumption	T_A = 25˚C										
	V_S = ±20V		80	150							mW
	V_S = ±15V					50	85		50	85	mW
LM741A	V_S = ±20V										
	T_A = T_{AMIN}			165							mW
	T_A = T_{AMAX}			135							mW
LM741	V_S = ±15V										
	T_A = T_{AMIN}					60	100				mW
	T_A = T_{AMAX}					45	75				mW

Note 2: "Absolute Maximum Ratings" indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is functional, but do not guarantee specific performance limits.

Electrical Characteristics (Note 5) (Continued)

Note 3: For operation at elevated temperatures, these devices must be derated based on thermal resistance, and T_j max. (listed under "Absolute Maximum Ratings"). $T_j = T_A + (\theta_{jA} P_D)$.

Thermal Resistance	Cerdip (J)	DIP (N)	HO8 (H)	SO-8 (M)
θ_{jA} (Junction to Ambient)	100˚C/W	100˚C/W	170˚C/W	195˚C/W
θ_{jC} (Junction to Case)	N/A	N/A	25˚C/W	N/A

Note 4: For supply voltages less than ±15V, the absolute maximum input voltage is equal to the supply voltage.

Note 5: Unless otherwise specified, these specifications apply for V_S = ±15V, −55˚C ≤ T_A ≤ +125˚C (LM741/LM741A). For the LM741C/LM741E, these specifications are limited to 0˚C ≤ T_A ≤ +70˚C.

Note 6: Calculated value from: BW (MHz) = 0.35/Rise Time(µs).

Note 7: For military specifications see RETS741X for LM741 and RETS741AX for LM741A.

Note 8: Human body model, 1.5 kΩ in series with 100 pF.

Schematic Diagram