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# Non inverting op amp gain equation

This calculator calculates the gain of an inverting op amp based on the input resistor value, RIN, and the output resistor value, RF, according to the formula, Gain= RF/RIN. To use this calculator, a user just inputs the value of resistor, RIN, and resistor, RF, and clicks the 'Submit' button and the answer is automatically computed and shown below. A user can specify each resistance value as either ohms (â„¦), kilohms (Kâ„¦), or megohms (Mâ„¦). The output resultant value does not any units. It's a unitless result. It's simply the factor by which the input signal is multiplied by to produce the amplified output voltage. The gain of an op amp signifies how much greater in magnitude the output voltage will be than the input. For example, an op amp with a resistor, RIN, of 1Kâ„¦ and a resistor, RF of 10Kâ„¦, will have a gain of 10. This means that the output will be ten times greater in magnitude than the input voltage. So, for example, if the input voltage is 5V in magnitude, the output voltage will be 50V in magnitude. Calculating the gain of an op amp is very important because many circuits such as audio amplifiers and volume control circuits need to utilize op amp gain in order to function correctly. Knowing the formulas for calculating the gain of op amps is crucial to having high-precision amplifier circuits. Noninverting Op Amp Gain Calculator This calculator calculates the gain of a noninverting op amp based on the input resistor value, RIN, and the output resistor value, RF, according to the formula, Gain= 1 + RF/RIN. To use this calculator, a user just inputs the value of resistor, RIN, and resistor, RF, and clicks the 'Submit' button and the answer is automatically computed and shown below. A user can specify each resistance value as either ohms (â„¦), kilohms (Kâ„¦), or megohms (Mâ„¦). The output resultant gain value does not have any units. The gain of an op amp signifies how much greater in magnitude the output voltage will be than the input. For example, an op amp with a resistor, RIN, of 20Kâ„¦ and a resistor, RF of 100Kâ„¦, will have a gain of 6. This means that the output will be 6 times greater in magnitude than the input voltage. So, for example, if the input voltage is 9V in magnitude, the output voltage will be 54V in magnitude. Related Resources What is an Ideal Op Amp? Why Does an Op Amp Need a High Input Impedance and a Low Output Impedance? Why Does an Op Amp Need a Power Supply? Voltage Divider Calculator Capacitor Voltage Divider Calculator Voltage RMS Calculator Peak-to-Peak Voltage (VPP) Calculator Peak Voltage (VP) Calculator Potential Energy Calculator Electric Potential Energy Calculator One of the most common amplifiers in Analog Design is the non-inverting amplifier. Figure 1 Its transfer function is (1) How do you derive this function? Let’s first note that we can consider this Op Amp as ideal. As such, the current in the inverting input is zero (I = 0A, see Figure 2) and the currents through R1 and R2 are equal. (2) Figure 2 Next, we can write an equation for the loop made by Vout, R2, V and Vin. (3) From equation (3) the I2 expression is (4) In a similar way we can determine the expression for I1. Equation (5) is the loop equation for R1, V1 and Vin. (5) and (6) Being an ideal Op Amp, we can consider that the non-inverting input is at the same potential as the inverting input, so V = 0V. This is due to the high gain of the ideal Op Amp. When the output is at a level of a few volts, the differential input can be at a level of some tens of microvolts. Hence, V is very close to zero. Replacing I1 and I2 in equation (2) and eliminating V, we can write this equation: (7) Therefore, the transfer function of the non-inverting amplifier is (8) Q. E. D. Operational amplifiers can be used in two basic configurations to create amplifier circuits. One is the inverting amplifier where the output is the inverse or 180° out of phase with the input, and the other is the non-inverting amplifier where the output is in the same sense or in phase with the input. Non-Inverting Amplifier Circuit Basic: The basic non-inverting amplifier circuit using an op-amp is shown below. In this circuit the signal is applied to the non-inverting input of the amplifier. However the feedback is taken from the output via a resistor to the inverting input of the operational amplifier where another resistor is taken to ground. It is the value of these two resistors that govern the gain of the operational amplifier circuit. Non-Inverting Amplifier Circuit The gain of the non-inverting amplifier circuit for the operational amplifier is easy to determine. The calculation hinges around the fact that the voltage at both inputs is the same. This arises from the fact that the gain of the amplifier is exceedingly high. If the output of the circuit remains within the supply rails of the amplifier, then the output voltage divided by the gain means that there is virtually no difference between the two inputs. As the input to the op-amp draws no current this means that the current flowing in the resistors R1 and R2 is the same. The voltage at the inverting input is formed from a potential divider consisting of R1 and R2, and as the voltage at both inputs is the same, the voltage at the inverting input must be the same as that at the non-inverting input. This means that Vin = Vout x R1 / (R1 + R2). Hence the voltage gain of the circuit Av can be taken as: Non-inverting Operational Amplifier Configuration: In the previous Inverting Amplifier tutorial, we said that for an ideal op-amp “No current flows into the input terminal” of the amplifier and that “V1 always equals V2”. This was because the junction of the input and feedback signal ( V1 ) are at the same potential. In other words the junction is a “virtual earth” summing point. Because of this virtual earth node the resistors, Rƒ and R2 form a simple potential divider network across the non-inverting amplifier with the voltage gain of the circuit being determined by the ratios of R2 and Rƒ as shown below. Equivalent Potential Divider Network: Then using the formula to calculate the output voltage of a potential divider network, we can calculate the closed-loop voltage gain ( A V ) of the Non-inverting Amplifier as follows: Then the closed loop voltage gain of a Non-inverting Operational Amplifier will be given as: We can see from the equation above, that the overall closed-loop gain of a non-inverting amplifier will always be greater but never less than one (unity), it is positive in nature and is determined by the ratio of the values of Rƒ and R2. If the value of the feedback resistor Rƒ is zero, the gain of the amplifier will be exactly equal to one (unity). If resistor R2 is zero the gain will approach infinity, but in practice it will be limited to the operational amplifiers open-loop differential gain, ( Ao ). We can easily convert an inverting operational amplifier configuration into a non-inverting amplifier configuration by simply changing the input connections as shown. non-inverting amplifier Input-impedance of non-inverting amplifier: It is often necessary to know the input impedance of a circuit. The input impedance of this non-inverting amplifier circuit is very high, and may typically be well in excess of 10^7 ohms. For most circuit applications this can be completely ignored. This is a significant difference to the inverting configuration of an operational amplifier circuit which provided only a relatively low impedance dependent upon the value of the input resistor. AC coupling the non-inverting op-amp circuit: In most cases, it is possible to DC couple the circuit. However. in this case it is necessary to ensure that the non-inverting has a DC path to earth for the very small input current that is needed. This can be achieved by inserting a high-value resistor, R3 in the diagram, to ground as shown below. The value of this may typically be 100 k ohms or more. If this resistor is not inserted the output of the operational amplifier will be driven into one of the voltage rails. Basic non-inverting operational amplifier circuit with capacitor coupled input When inserting a resistor in this manner it should be remembered that the capacitor-resistor combination forms a high-pass filter with a cut-off frequency. The cut-off point occurs at a frequency where the capacitive reactance is equal to the resistance. Op amp as a voltage follower: A non-inverting amplifier using an op amp forms an ideal voltage follower. The very high gain of the op-amp enables it to present a very high impedance to the signal source whilst being able to accurately follow the voltage waveform. An op amp is configured in its non-inverting amplifier format, linking the output directly to the inverting input and applying the input signal to the non-inverting input. From the gain equation. it is possible to see that the voltage gain of this circuit is unity. Av = 1 + R2 / R1. R2 is zero and R1 is infinity, so the term R2/R1 is zero and this means that Av = 1. Non-inverting amplifier used as a voltage follower Non-inverting amplifier using single supply: Normally op amps are configured to use dual supplies – the chips are intended for use in this way. However, this is not always feasible if only one rail is present. To enable the op amp to run with just one power rail, the positive and negative rails have to be simulated by operating the amplifier half way between the rail and ground, and ensuring the decoupling is sufficient in all the required areas. This is often referred to as a virtual ground technique. To create the virtual ground, two resistors form a voltage divider so that the half the rail voltage, Vcc/2 appears at the non-inverting input of the op-amp. Non-inverting amplifier using a single voltage rail This circuit works well, but when using it a few design issues must be remembered: Resistors R3 & R4: These two resistors form the bias for the non-inverting amplifier, setting the input voltage and operating point. Typically they are set to provide half the supply voltage and therefore they will be equal in value. Values of around 100kΩ are typically chosen because they determine the input impedance. To incoming signals they are in parallel with each other and the input impedance of the op-amp itself is normally much higher and is often ignored – although check for the given op amp. Assuming this and each resistor being 100 kΩ, then the resistance in parallel is 50Ω Capacitor C2 value: The value of this capacitor must be chosen to give a low impedance at low frequencies. It is typically chosen to be equal in impedance to R1 at the lowest frequency required – this will give a -3dB fall at this frequency. Capacitor C2 type: It is important that this capacitor must be a low leakage type. If not the leakage could cause the output to hit the voltage rail if there is some gain in the circuit. Typically ceramic or tantalum types are best. Electrolytic types have a higher leakage and may not be suitable. Operating range: Dependent upon the requirements for the non-inverting amplifier, it may be necessary to choose an op amp that is able to operate with its output voltage close to either voltage rail. In this way, the maximum output voltage swing can be obtained. This type of circuit is often very useful when only one supply line is available. Often it is more convenient to adopt this approach that provide an additional supply rail. Feedback is important to us. The voltage signal applied to an op-amp can either be supplied to its non-inverting input (+) or the inverting input (-). These different configurations are simply known as a non-inverting op-amp, and inverting op-amp. In this tutorial, we focus on the non-inverting configuration and present its details. An overview of the non-inverting op-amp will be given in the first section through the concept of the ideal amplifier. In the second section, real non-inverting configurations are discussed, we demonstrate the equations describing the gain and the input/output impedances. Finally, examples of circuits based on the non-inverting configurations are given in the last section. Ideal non-inverting op-amp The goal of this section is to properly demonstrate and explain the ideal characteristics of the non-inverting configuration such as its input/output impedance and gain. The circuit representation of an ideal non-inverting op-amp is given in Figure 1 below. Note that the symbol “∞” highlights the fact that the op-amp is here to be considered ideal. We highly recommend the reader to refer to the tutorial Op-amp basics for this section. fig 1: Ideal non-inverting op-amp circuit In this ideal model, the input impedance defined by the contribution of the resistance linking the inverting and non-inverting inputs (Ri in Figure 3) and the resistors R1 and R2, is infinite. Moreover, for an ideal circuit, Ri is supposed to be infinite, as a consequence, no currents can enter the op-amp through any input because of the presence of an open circuit. This observation can also be summarized by saying that the node interconnecting the inverting input and resistances R1 and R2 is a virtual short. For this same reason, all the feedback current across R1 (I) is also found across R2. For the ideal model, the equality V+=V–=Vin is assured by the fact that the differential signal V+-V– can only be equal to 0 in order to produce a finite output Vout when multiplied by an infinite open-loop gain. We can see the branches connected to the inverting input acting as a voltage divider circuit: fig 2: Inverting branches seen as a voltage divider circuit According to the voltage divider formula, we can express the inverting voltage V– as a function of the output voltage and the resistances: eq 1: Voltage divider formula for V– Since V–=Vin, after some simplification, we prove the expression of the gain in closed-loop ACL of an ideal non-inverting configuration: eq 2: Closed-loop gain of an ideal non-inverting op-amp We can note that the ideal gain presented in Equation 2 is strictly positive and higher than 1, meaning that the output signal is amplified and in phase with the input signal. Real non-inverting op-amp In a real op-amp circuit, the input (Zin) and output (Zout) impedances are not idealized to be equal to respectively +∞ and 0 Ω. Instead, the input impedance has a high but finite value, the output impedance has a low but non-zero value. The non-inverting configuration still remains the same as the one presented in Figure 1. fig 3: Internal equivalent circuitry of a real op-amp Note that Ri and Ro can be described to be respectively the input and output impedances of the op-amp without any feedback loop (open-loop configuration). Closed-loop gain For a non-inverting configuration, Equation 1 still applies for V– , moreover, we have V+=Vin. However, since a low current can flow from the non-inverting input to the inverting input, the voltages are not equal anymore: V+≠V–. We also need to remind that the inputs V+ and V– are linked with the output through the open-loop gain formula: eq 3: Open-loop gain formula The equations for V+ and V– can be injected in Equation 3. After regrouping the terms “Vout” on one side of the equation and the terms “Vin” on the other, we get: Finally, the closed-loop gain ACL for a real non-inverting configuration is given by Equation 4: eq 4: Closed-loop gain of a real non-inverting configuration For a real configuration, the gain not only depends on the resistor values but also on the open-loop gain It is interesting to note that if we consider the op-amp to be ideal (AOL→+∞), the denominator is simplified to one term: AOLR2/(R1+R2). As a consequence, Equation 4 is simplified back to Equation 2. Output impedance We start by assuming the equality of the currents across the resistances: IR1=IR2. Even if for real op-amps, a small leaking current enters the inverting input, it is several orders of magnitude smaller than the feedback current. The current I0 across R0 (see Figure 3) can be expressed as a function of the voltage drop across R0 and the same value of the impedance R0: Since V– is described by Equation 1, the output current Iout can be expressed as the sum of I0 and the current flowing in the feedback branch given by Vout/(R1+R2): Finally, after rearranging the equation to obtain the ratio Zout=Vout/Iout, we can write the expression of the output impedance for a real non-inverting configuration: eq 5: Expression of the output impedance for a real non-inverting configuration We can note that in the case of an ideal op-amp, that is to say when AOL→+∞, we observe indeed Zout→0. A simplified version for the expression of Zout is given by the following Equation 6: eq 6: Simplified expression of the output impedance for a real non-inverting configuration The term β is known as the feedback factor and is given by the ratio R1/(R1+R2). With that simplified version, we can still see that Zout→0 for an ideal op-amp situation. Input impedance The input impedance of a non-inverting configuration can be defined by the ratio V+/Iin (see Figure 3). For the input loop, we can write Kirchoff’s voltage law such as V+-Vin+IR2R2=0 with IR2 being the current across the resistor R2. It can be shown that the expression of the input impedance can also be written as a function of the feedback factor: eq 7: Expression of the input impedance for a real non-inverting configuration Again, when the ideal situation is satisfied (AOL→+∞) we find that Zin→+∞ such as specified in the first section. Non-inverting op-amp examples Buffer circuits The most simple designs for non-inverting configurations are buffers, which have been described in the previous tutorial Op-amp Building Blocks. In this configuration, R1=0 and R2→+∞ as we can present in Figure 4 below: fig 4: The buffer circuit This buffer (or voltage follower) has a unity gain and does not invert the output, meaning that Vout=Vin. Its high input impedance and low output impedance are very useful to establish a load match between circuits and make the buffer to act as an ideal voltage source. Example We consider a real non-inverting configuration circuit given in Figure 5: fig 5: Example of real non-inverting configuration


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