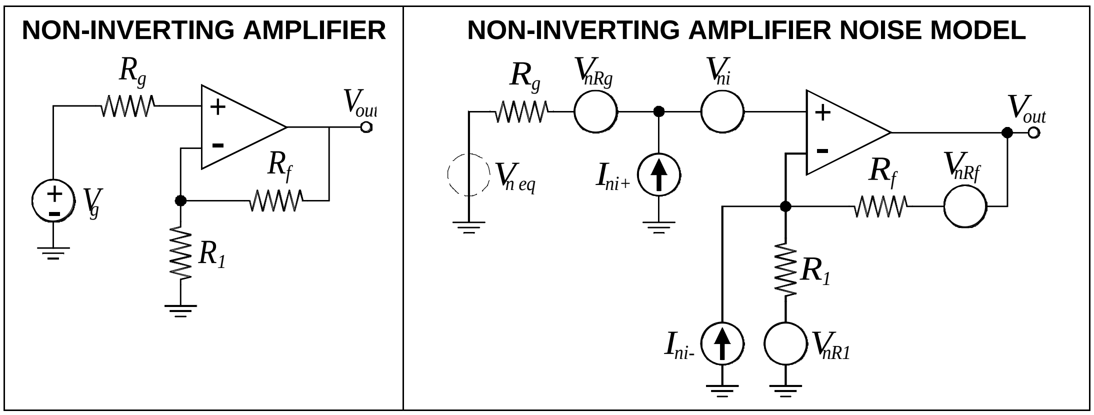
NOISE REFERRAL

To quantify noise in an op amp circuit, it is customary to give noise levels in terms of the equivalent input noise. So noise sources in various parts of the circuit are recalculated to the equivalent input noise that would produce the noise in question. The op amp circuit noise model has a noise voltage source for each resistor and one for one of the inputs. (The input voltage noise source V_{ni} may be placed on either input). Additionally, there is a noise current source on each input on the op amp.

In evaluating noise, the placement of V_{ni} and the distribution of input noise between I_{ni+} and I_{in-} are selected to give the worst case scenario.

The conversion formula for each noise source is derived by finding expressions for V_{out} resulting from 1) the noise source and 2) the equivalent input source. These expressions may then be set equal to each other and a conversion formula formed. Two examples follow:

EXAMPLE 1: The Non-Inverting Amplifier



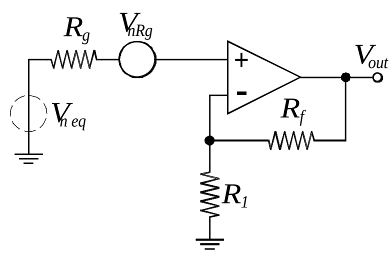
Finding the noise produced by each source:

Noise due to a resistor: $\boxed{V_n = \sqrt{4kTR}}$

k = 1.38×10^{-23} [J/K]
T = 300 [Kelvin]
R = resistance [Ω]

It is easier to visualize the problem if we take each source separately, find its value, and convert that value to an equivalent input noise. The sign of the result is not important since each value will be squared, making it positive.

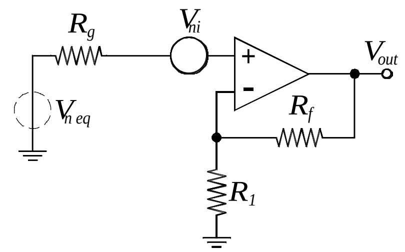
V_{nRg} Noise due to R_g



$$V_{nRg} = \sqrt{4kTR_g}$$

This noise will not need to be referred to the input because it is already at the input.

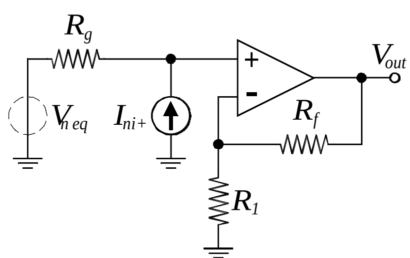
V_{ni} Noise due to V_{ni}



$V_{ni} = V_{ni}$

No calculations are required for this case. This noise will not need to be referred to the input because it is already at the input.

$I_{ni+}R_g$ Noise due to I_{ni+}

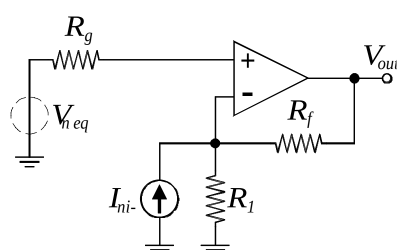


$I_{ni+}R_g$

Since all of the current from I_{ni+} flows through R_g to ground, the noise due to I_{ni+} in terms of voltage is I_{ni+} multiplied by R_g. This noise will not need to be referred to the input.

Noise due to I_{ni-}

The positive input is at ground potential due to the path through R_g. Under asymptotic conditions, the negative input of the op amp is also at ground potential and no current flows into it.



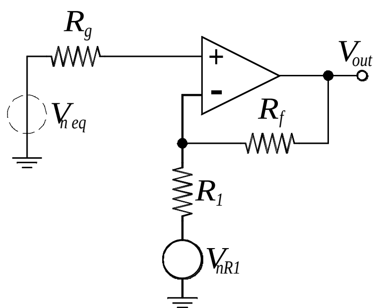
So no voltage drop exists across R_1 and there is no current flow through R_1. Therefore, all of the current from I_{ni-} must flow through R_f and the voltage at V_{out} will be $-I_{ni}R_f$.

To **refer the noise** to the input:

$$V_{n\,eq\,Ini-} \times \underbrace{\frac{R_1 + R_f}{R_1}}_{\text{gain of the amplifier}} = V_{out} = -I_{ni-}R_f$$

so that $$V_{n\,eq\,Ini-} = -I_{ni-} \times \frac{R_f R_1}{R_1 + R_f}$$

Noise due to V_{nR1}



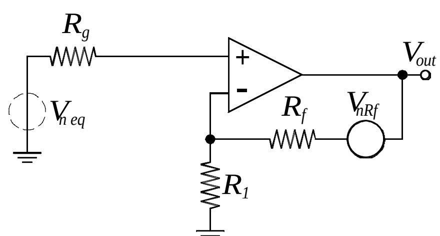
Under asymptotic conditions, the negative input of the op amp is at ground potential and no current enters the op amp, so all of the current generated by V_{nR1} (which is V_{nR1}/R_1) goes through R_f to create a voltage at the output ($-V_{nR1}R_f/R_1$).

To **refer the noise** to the input:

$$V_{n\,eq\,R1} \times \underbrace{\frac{R_1 + R_f}{R_1}}_{\text{gain of the amplifier}} = V_{out} = -\frac{R_f}{R_1} V_{nR1}$$

so that $$V_{n\,eq\,R1} = \frac{R_f}{R_1 + R_f}\sqrt{4kTR_1}$$

Noise due to V_{nRf}



In this case, the noise at the output due to V_{nRf} is simply V_{nRf}.

To **refer the noise** to the input:

$$V_{n\,eq\,Rf} \times \frac{R_1 + R_f}{R_1} = V_{out} = V_{nRf}$$

so that $$V_{n\,eq\,Rf} = \frac{R_1}{R_1 + R_f}\sqrt{4kTR_f}$$

Finding the Total Noise Referred to the Input of the Non-Inverting Amplifier

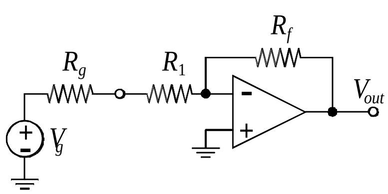
The noise sources and their input equivalences are listed at right. To find the total noise V_a at the input, sum the squares of each noise component (referenced to the input) and take the square root of the sum.

NOISE SOURCE	NOISE REFERRED TO INPUT
V_{nRg}	$\sqrt{4kTR_g}$
V_{ni}	V_{ni}
I_{ni+}	$I_{ni+}R_g$
I_{ni-}	$-I_{ni-} \times \frac{R_f R_1}{R_1 + R_f}$
V_{nR1}	$\frac{R_f}{R_1 + R_f}\sqrt{4kTR_1}$
V_{nRf}	$\frac{R_1}{R_1 + R_f}\sqrt{4kTR_f}$

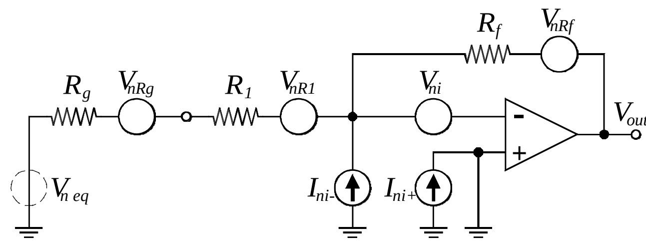
$$V_a = \sqrt{4kTR_g + (V_{ni})^2 + (I_{ni+}R_g)^2 + \left(I_{ni-} \times \frac{R_f R_1}{R_1 + R_f}\right)^2 + \left(\frac{R_f}{R_1 + R_f}\sqrt{4kTR_1}\right)^2 + \left(\frac{R_1}{R_1 + R_f}\sqrt{4kTR_f}\right)^2}$$

EXAMPLE 2: The Inverting Amplifier

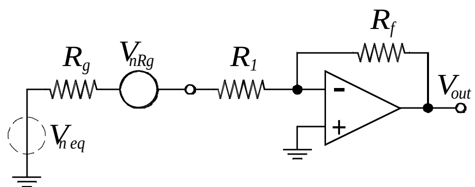
INVERTING AMPLIFIER



INVERTING AMPLIFIER NOISE MODEL



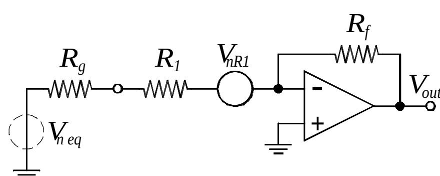
V_{nRg} Noise due to R_g



$$V_{nRg} = \sqrt{4kTR_g}$$

This noise will not need to be referred to the input because it is already at the input.

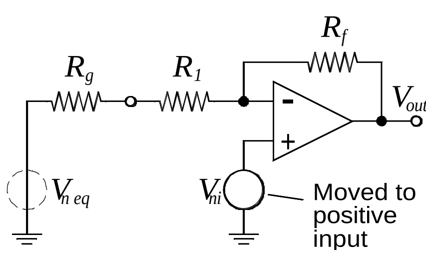
V_{nR1} Noise due to R_1



$$V_{nR1} = \sqrt{4kTR_1}$$

This noise will not need to be referred to the input because it is already at the input.

Noise due to V_{ni}

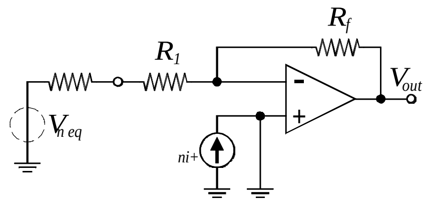


To **refer the noise** to the input:

$$V_{n\,eq\,Vni} \frac{-R_f}{R_g + R_1} = V_{out} = V_{ni} \frac{R_g + R_1 + R_f}{R_g + R_1}$$

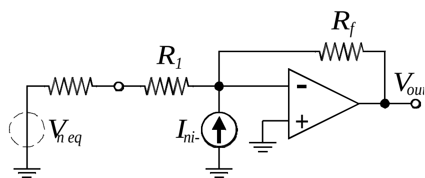
so that $V_{n\,eq\,Vni} = -V_{ni} \dfrac{R_g + R_1 + R_f}{R_f}$

Noise due to I_{ni+}



Since the positive input is connected to ground, I_{ni+} is not a factor.

Noise due to I_{ni-}



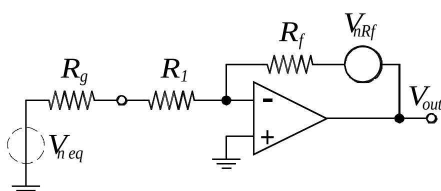
Under asymptotic conditions, all of the current from I_{ni-} flows through R_f and the voltage at V_{out} will be $-I_{ni}R_f$.

To **refer the noise** to the input:

$$V_{n\,eq\,Ini-}\frac{-R_f}{R_g+R_1}=V_{out}=-I_{ni}R_f$$

so that $$V_{n\,eq\,Ini-}=I_{ni-}\left(R_g+R_1\right)$$

Noise due to V_{nRf}



To **refer the noise** to the input:

$$V_{n\,eq\,Rf}\times\frac{-R_f}{R_g+R_1}=V_{out}=V_{nRf}$$

so that $$V_{n\,eq\,Rf}=\frac{-\left(R_g+R_1\right)}{R_f}\sqrt{4kTR_f}$$

Finding the Total Noise Referred to the Input of the Inverting Amplifier

The noise sources and their input equivalences are listed at right. To find the total noise V_a at the input, sum the squares of each noise component (referenced to the input) and take the square root of the sum.

NOISE SOURCE	NOISE REFERRED TO INPUT
V_{nRg}	$\sqrt{4kTR_g}$
V_{ni}	$-V_{ni}\frac{R_g+R_1+R_f}{R_f}$
I_{ni+}	0
I_{ni-}	$I_{ni-}\left(R_g+R_1\right)$
V_{nR1}	$\sqrt{4kTR_1}$
V_{nRf}	$\frac{-\left(R_g+R_1\right)}{R_f}\sqrt{4kTR_f}$

$$V_a=\sqrt{4kTR_g+\left(V_{ni}\frac{R_g+R_1+R_f}{R_f}\right)^2+\left[I_{ni-}\left(R_g+R_1\right)\right]^2+4kTR_1+\left(\frac{R_g+R_1}{R_f}\sqrt{4kTR_f}\right)^2}$$