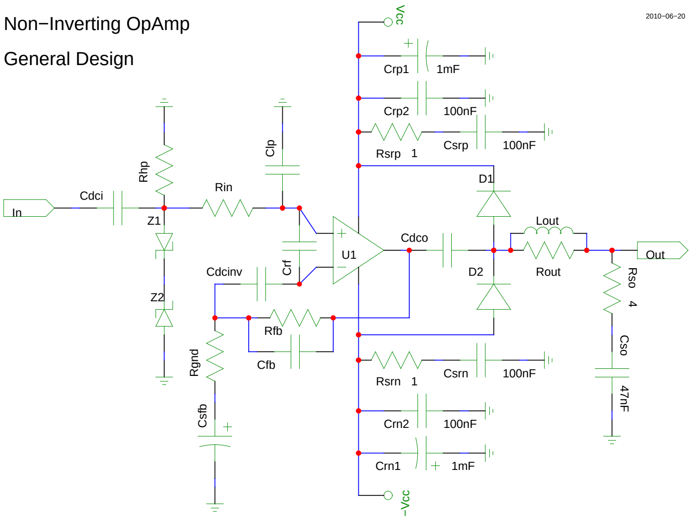
Non−Inverting OpAmp

General Design

2010−06−20



This is a generic op−amp circuit that can be adapted for both signal and power level usage.

Gain is set by 1+(Rfb/Rgnd). Rgnd should be >100ohm. Some op amps (mainly power) have a minimum gain ratio. Rfb can be split into an additional Rgnd + variable resistor combination (for minimum safety) for variable gain but will mess with the input impedances and DC offsets. Be warned that most manufacturers grossly over rate their power rating on power op−amps at 1−10% distortion (and they should be flogged for it). Obviously setting the gain to the manufacturer's full power rating will sound horribly bad (as in telephone or drive through window speaker bad). In the data sheet, look for a graph called "Power Vs. Distortion" (unfortunately sometimes not included in the data sheet). These graphs usually start out very flat then bend sharply up at some point. Do some ratio math and set the max gain somewhere before this knee point for optimum clarity. This point is usually 25−50% less than the advertised maximum power. Note that this is often why noobs whine that discrete transistor amps sound superior to chip amps.

Power Supply Rail Capacitors: Crp1, Crp2, Rsrp+Csrp, Crn1, Crn2, Rsrn+Csrn. These should be as close to the op amp's pins as possible. The configuration shown is for a lower power level op amp (<10watts). For higher power, increase the values of Crp1 and Crn1. The general rule is 1−3mF/ampere out. For signal level, Crp1 and Crn1 usually range from 10−100uF. The RsrX+CsrX Zobels are not needed if CrX1's are below 100uF (low ESL). If CrX1 is large, another middle value capacitor may be desirable (100−470uF for this example).

Option (not shown): sometimes a 470pF to 1nF capacitor is wired directly on the input connector from signal to ground to help block RF noise early on in the signal path. Do not go above 1nF to avoid excessive loading at the upper audio frequencies.

Option: Cdci blocks input DC offset. 1−10uF for signal levels. Use 22uF or higher if phantom power is on the input signal. Polarity warnings apply to electrolytics.

Option: Rhp can be used for both DC bias removal (some op amps need an impedance reference to ground on the input) and as a Cdci+Rhp high pass filter (bleeds the offset that accumulates in Cdci). If Rhp is moved after Rin, it will form a voltage divider and attenuate the input (useful in some buffers). Min −3db freq should be <1Hz. Rhp can be made variable with a volt meter to measure the DC bias on output.

Option: Rin+Clp can be used together to form a low pass filter. The −3db point should be set to at least 50kHz (100kHz preferred).

Option: Crf between the op amp input pins is used to block RF noise (typically 47−470pF).

Option: Z1+Z2 are input protection clamps and should be rated +2v higher than the highest input signal peak. If high signal and low gain are used, check the output to make sure that non−linear distortion on the signal peaks isn't being caused close the the zener voltage. These are mandatory if phantom power is on the input signal to prevent 48v pops appearing on the input.

Option: Rin should be the parallel values of Rfb+Rgnd to balance the input bias current and prevent DC offset on the output. Rin = (Rfb * Rgnd) / (Rfb + Rgnd)

Option: Cfb (typically low pF range) helps reduce HF noise. As frequency rises, the impedance of Cfb drops. Xc = 1/(2pi * freq * C). Parallel this value with Rfb and overall gain drops as frequency increases. Only use Cfb in unity gain stable op amps. Large cap can cause oscillation.

Option: Cdcinv (22−220uF) is used on single rail op amps to block DC from getting re−amplified or removed by CMRR.

Option: Csfb is DC decoupling for the inverting input. Ensures unity gain at DC levels (don't amplify DC offset). Csfb+Rgnd will form a high pass filter.

Option: Cdco blocks any DC on the output. This is mandatory for single supply rail op amps and more of a safety option for others (phantom power protect). Smaller power amps should have >100uF. Medium and higher power amps typically have 1−4mF. Note that electrolytics in the signal path produce phase distortion. Film caps in parallel have less phasing problems at this level. For signal level amps, 0.1−10uF is common. Be careful about Cdco + the output load forming an unintentional low pass filter. This filtering can be dynamic if the load is variable, such as an inductive speaker with a varying impedance based on frequency (causing bad capacitor coloration problems).

Option: D1+D2 are typically only needed when the op amp is pushed hard into poorly designed speakers. These protect against a heavily reactive load that might swing past the power rail voltages. This helps prevent over distortion and some op amps from being fried. The rail voltages "push" the diodes and keep them from conducting backwards on opposite output swings. When the output swings too high, the diode acts like a short and sinks the over voltage back into the power supply rails. The diodes also prevent the output from being pulled below ground at start up. Diodes often used: 1n4148, 1n4448, bat85, 1n400X.

Option: Rso+Cso Zobel/Snub. This helps stabilize the amp into inductive loads and is typically only needed for speakers and long cables. This forms a high pass filter to ground. It is calculated with the standard RC filter equation. Zobels act as a low impedance terminator (sink) for high frequency noise. Ideally the RC filter needs to be set to 150kHz, but this usually isn't practical and is often higher. Values for R and C need to be chosen carefully. Values too large or small can actually cause instability instead of helping to prevent it. Choose a high speed capacitor type (ceramic or film) to be effective at the high frequencies. Capacitave reactance (Xc) for a chosen capacitor needs to be calculated for the highest desired audio frequency (solve the RC filter equation for R; for given R and frequency, solve for C). Add this impedance to the zobel's R and Rout resistors then use Ohm's Law (I=V/R) and calculate for amperes. If the amperes are too high, it will cause a frequency drop, unnecessarily load the amp, cause higher output distortion, instability, and probably waste too much power. Signal level amps typically put out 5−30mA. If the calculated amperes is a significant portion of this, the C value needs to be reduced. Power level amps are far more tolerant but probably shouldn't exceed 100mA sunk. Some amps have a Frequency Vs. Impedance graph. The zobel impedance should be a little higher than the amp impedance at the desired upper audio frequency. Capacitor values are usually 1−100nF (smallest values with signal amps). Resistor values for power amps range from 1−8 ohms. Sources say to change the resistor to the resistance of the speaker. For signal level, this can get up to 100 ohms. Higher R value will lower the RC frequency. If R is too high it will block the sink and the zobel wont work. Put the resistor first to help block the capacitive load seen by the amp output. The resistor is usually a half watt or greater for power amps and is non−inductive. Zobels can also be used to help prevent RF from coming backwards into the op amp from a long output cable (antenna). If the receiving end also has a zobel, the extra loading may be too much for the driving amp.

Option: Rout. Signal Level (50−600ohm): used to help prevent overloading the input of sensitive or older equipment and some short circuit safety. Also adds reactive protection from long cables at high frequencies preventing oscillation problems. Power Level (0.1−10ohm, 1−10watt): protects amp from capacitance induced oscillation (mainly from poorly designed speakers or long cables). Equation for capacitive isolation (makes a pole to reduce phase shift at high frequencies). Freq[zero] = 1/(2*Pi*(Ru1+Rout)*Cload) + 1/(2*Pi*Rload*Cload). Cload is the capacitance in the cable and speaker. Ru1 is the output impedance of the op−amp itself (usually less than 1 ohm). Freq[zero] should be a decade below the closed loop bandwidth of the op−amp circuit. Small resistance is often used in paralleled output to help balance the load between multiple amps. Be sure to choose a non−inductive resistor. The resistor can go inside the feedback loop, but will mess with the gain equation slightly and will offer less protection (separation) for the op amp's inputs. Still, inside the feedback loop is usually preferred as the op−amp can control any interactions through the feedback loop. Rout adds output impedance, lowering the overall power output and also reducing the damping factor (higher values lead to flabby speakers, bad for HiFi, sometimes used for guitar amps).

Option: Lout (0.7uH). Some amps (mainly power) easily choke with capacitive output. If the amp is overly sensitive, set Rout to 10ohms in parallel with this inductor. The low frequencies will go through the inductor but it will force the high frequency problems through the resistor effectively decoupling the amp. This can be seen as excessive ringing with a square wave test.

Option (not shown): An 18k ohm resistor between output and negative rail to bias the op−amp into Class A mode (signal level). Care needs to be taken to not overload the amp and cause more distortion. This will force the op−amp to run constantly, hotter, and will use more power. A JFET cascode would be a better choice for constant current and cleaner sound.

Equation: RC Filters (−3db): freq = 1 / (2*Pi*R*C). Ohm's Law: V = I * R.

For best results, use star topologies for all grounds. If a speaker is on the output, be sure to return its negative termal to power ground and not signal ground. Sometimes isolating the main signal ground and power ground with a 1 ohm or smaller resistor can help reduce invasive ground noise. Keep resistor values below 50k in the signal path to help reduce Johnson Noise. Carbon resistors are the noisiest. Use metal foil or metal film resistors at 0.5−1wattrating to help keep noise down. Higher wattage resistors have less noise compared to the lower wattage ones. Capacitor Selection. Signal Path: polypropylene film for cleanest phase. Smaller (less than 1uF): ceramic (NP0, C0G) for lowest ESR/ESL and fast high frequency response.

Large: electrolytics with low ESR/ESL (sometimes multiple in parallel). Electrolytics in the signal path are not ideal because of phase linearity issues. This can be reduced by parallelling an electrolytic with the largest practical film capacitor. To help reduce the ESR of a capacitor, they can be split and paralleled to help mimic a more ideal capacitor. Values over 10uF can add a good high frequency rated ceramic (also sometimes being split and paralleled if you're paranoid).

Crosstalk Oddity. With multiple op−amps, the outputs are connected to ground through the feedback resistors. This can introduce ground crosstalk noise. It can be minimized with a good grounding topology, larger resistors, and a stable (non−bouncing) ground. For a dual op−amp socket with the chip out: Out−>Out = (Rfb+Rgnd)*2, −In −> −In = Rgnd*2, Out −> −In = Rfb+(Rgnd*2).

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