How To Choose The Right Op Amp

http://www.qooljaq.com/OpAmps.htm

There are two categories of requirements that relate to the performance of an op amp: General and Application Specific.

General requirements are the degree of mismatch between pairs of circuit elements within an op amp IC. The best matched op amp will have an offset of zero between all its inputs.

Application Specific requirements are trade-offs. For example, an op amp with the best input noise performance has high operating quiescent current. An op amp with the lowest operating quiescent current has the worse input noise.

Like the laws of quantum reality, the more control you exercise over one aspect of your life the less control you have over everything else. If you over-specify the General requirements, you restrict the potential performance of the Application Specific requirements.

The best way to select an op amp is to start by defining the minimum acceptable General requirements for a circuit application.

Op amps with the best General requirements have the lowest yields and/or require **post-manufacture trimming**.

General Category:

Input Offset Voltage

The voltage that must be applied directly between the input measuring terminals, with bias current supplied by a resistance path, to reduce the output indication to zero. Or the voltage that must be applied between the two input terminals of an operational amplifier to obtain zero output voltage.

Input Offset Voltage Match Dual or Quad Amps

Offset voltage will tend to introduce slight errors in any op-amp circuit. So how do we compensate for it? Unlike common-mode gain, there are usually provisions made by the manufacturer to trim the offset of a packaged op-amp. Usually, two extra terminals on the op-amp package are reserved for connecting an external "trim" potentiometer. These connection points are labeled offset null.

Input Offset Voltage Drift

Just because you trimmed out the offset voltage, doesn't mean all is tranquil on paradise island. The input offset voltage will drift with temperature; you have no control over this. But, knowing your overall error budget, you can select an op amp with a low enough offset drift for the intended temperature range.

Voltage Stability

The most stable circuits have the longest response times, lowest bandwidth, highest accuracy, and least overshoot. The least stable circuits have the fastest response times, highest bandwidth, lowest accuracy, and some overshoot.

Input Offset Voltage Shift Rail to Rail Amplifiers

The effect of reducing the power supply voltage is a shift in the amplifier's input offset voltage. The problem stems from the fact that most conventional op amps, with a typical operating range down to +-4.5 volts, are generally tested, and have their input offset trimmed, at a specific supply voltage, e.g., +-15 volts. Reducing the supply voltage can produce a shift in the input offset voltage. The shift in the offset voltage can be determined by looking at the "power-supply rejection ratio" (PSRR), or "power-supply sensitivity" of offset voltage specification; it provides a measure of the change in offset for a given change in supply voltage.

Input Offset Current

The difference between the two currents that must be supplied to the input measuring terminals of a differential instrument to reduce the output indication to zero (with zero input voltage and zero offset voltage). Or the difference in the currents into the two input terminals of an operational amplifier when the output is at zero.

Common Mode Rejection Ratio
Common Mode Rejection Ratio Match Dual or Quad Amps

A measure of an instrument's ability to reject an undesired signal that is common to both input terminals.

Also, CMRR describes the ability of a differential amplifier to reject interfering signals common to both inputs, and to amplify only the difference between the inputs.

Power Supply Rejection Ratio

Power Supply Rejection Ratio Match Dual or Quad Amps

This specification is the measure of how well the op amp rejects an AC signal riding on a nominal input DC voltage.

Power-supply rejection ratio is at a maximum at low frequencies, and begins to fall above 1kHz to 10kHz, depending upon the op amp design.

The only way to modify the basic rejection response of the regulator is to add an external network at the input of the op amp.

There are three methods to choose from:

1. One or more cascades of external RC filters. The additional attenuation adds to the inherent characteristic of the regulator. Typical values for the single RC and cascade RC filters range from R=1 to 10, and C=100µF to 10µF respectively. Choose the network -3dB frequency to coincide with that of the regulator PSRR characteristic.

2. An LC filter. The problem with using this type of filter is the lack of inherent damping at the output of the network (input of the op amp). The source impedance of the network is low. However, the op amp's VIN terminal presents a high impedance shunted with a small capacitor. (When the op amp is operated away from dropout with a constant load, its input current does not vary, to first order, when VIN is varied.) It is impossible to critically damp the LC network at the input of the regulator without significant DC loss in the shunt damping resistor. For example, a series 10µH inductor in combination with a shunt 100µF capacitor exhibits a turnover frequency of 5kHz; this combination requires a critical damping resistor of 0.32ohms between network output (op amp input) and ground.

3. An additional linear regulator. This method occupies a small PCB area and requires the least design time of the other methods. Using two linear regulators in series doubles the PSRR at any given frequency (assuming identical regulators). The "penalty" for this approach is the doubling of the dropout voltage and the need for an additional capacitor. A good design choice is to share the voltage drop

across each op amp. The total assembly requires three capacitors, one each at the input, output, and the intermediate position.

Application Specific:

Input Bias Current

Op-amp inputs usually conduct very small currents, called bias currents, needed to properly bias the first transistor amplifier stage internal to the op-amps' circuitry. Bias currents are small (in the microamp range), but large enough to cause problems in some applications.

Bias currents in both inputs must have paths to flow to either one of the power supply "rails" or to ground. It is not enough to just have a conductive path from one input to the other.

To cancel any offset voltages caused by bias current flowing through resistances, just add an equivalent resistance in series with the other op-amp input (called a compensating resistor). This corrective measure is based on the assumption that the two input bias currents will be equal.

Any inequality between bias currents in an op-amp constitutes what is called an input offset current.

It is essential for proper op-amp operation that there be a ground reference on some terminal of the power supply, to form complete paths for bias currents, feedback current(s), and load current.

Input Bias Current Shift Also General, Rail to Rail Amplifiers

As the input signal moves from one supply rail to the other, the amplifier shifts from one input pair to the other. At the crossover point, this shift can cause changes in the input bias current and offset voltage that affect both the magnitude and the polarity of these parameters. These offset-voltage changes typically worsen the distortion performance and precision specifications of rail-to-rail amplifiers (in comparison with ground-sensing types). To minimize offset-voltage shifts and smooth the transition from one input pair to another, Manufactures trims the offset of its rail-to-rail amplifiers at both the high and the low ends of the common-mode range.

To reduce offset voltages caused by input bias currents, the designer should match impedances at the op amp's inverting and non-inverting nodes. Because input bias currents are typically larger than input offset currents, this impedance matching is good practice for all types of op amps, not just rail-to-rail input amplifiers.

Output High Voltage / Output Low Voltage

The output of an op amp is required to swing rail-to-rail or as close as possible. The output swing is dependent on the amount of output loading.

The input-to-output linearity will degrade as the output swing approaches the voltage supply.

If the output is pushed to the rails, it will change the offset voltage of the op amp.

The output swing of the op amp can vary between +V and -V supply, and is controlled by the voltage difference between +In and -In. If the voltage at +In is positive with respect to -In, then the output of the op amp swings positive, toward the +V rail voltage. If the voltage at +In is negative compared to the voltage at -In, the output swings negative. It only takes a small difference in voltage between the two inputs to create a large change in the output voltage. This is known as the gain of the op amp.

Open Loop Voltage Gain

This is ratio of the input to the output voltage with no feedback applied. It is the D.C. gain of the amplifier or the gain at a frequency of 1 Hz. It is dependent on the output voltage swing and output load.

Common Mode Input Range

The range of input voltage for which the differential pairs behaves as a linear op amp. The upper limit is determined by one of the two inputs saturating. The lower limit is determined by the input bias current.

Input Noise Voltage / Input Noise Voltage Density
Input Current Noise / Input Current Noise Density

Op amp input noise specifications are usually given in terms of nV/H.z for noise voltage and pA/H.z or fA/H.z for noise current and are therefore directly comparable with resistor thermal noise. Due to the fact that noise density varies at low frequencies, most op amps also specify a typical peak-to-peak noise within a “0.1Hz to 10Hz or 0.01Hz to 1Hz bandwidth.

There are five types of noise in op amps and associated circuitry:

1) Shot noise
2) Thermal noise
3) Flicker noise
4) Burst noise
5) Avalanche noise

Some or all of these noises may be present in a design, presenting a noise spectrum unique to the system. It is not possible in most cases to separate the effects, but knowing general causes may help the designer optimize the design, minimizing noise in a particular bandwidth of interest. Proper design for low noise may involve a “balancing act” between these sources of noise and external noise sources.

Shot Noise

The name *shot noise* is short for Schottky noise. Sometimes it is referred to as *quantum noise*. It is caused by random fluctuations in the motion of charge carriers in a conductor.

Put another way, current flow is not a continuous effect. Current flow is electrons, charged particles that move in accordance with an applied potential. When the electrons encounter a barrier, potential energy builds until they have enough energy to cross that barrier. When they have enough potential energy, it is abruptly transformed into kinetic energy as they cross the barrier. A good analogy is stress in an earthquake fault that is suddenly released as an earthquake.

As each electron randomly crosses a potential barrier, such as a pn junction in a semiconductor, energy is stored and released as the electron encounters and then shoots across the barrier. Each electron contributes a little *pop* as its stored energy is released when it crosses the barrier.

Thermal Noise

Thermal noise is sometimes referred to as Johnson noise after its discoverer. It is generated by thermal agitation of electrons in a conductor. Simply put, as a conductor is heated, it will become noisy. Electrons are never at rest; they are always in motion. Heat disrupts the electrons’ response to an applied potential. It adds a random component to their motion.

Flicker Noise

Flicker noise is also called *1/f noise*. Its origin is one of the oldest unsolved problems in physics. It is pervasive in nature and in many human endeavors. It is present in all active and many passive devices. It may be related to imperfections in crystalline structure of semiconductors, as better processing can reduce it.

Flicker noise is found in carbon composition resistors, where it is often referred to as excess noise because it appears in addition to the thermal noise that is there. Other types of resistors also exhibit flicker noise to varying degrees, with wire wound showing the least. Since flicker noise is proportional to the dc current in the device, if the current is kept low enough, thermal noise will predominate and the type of resistor used will not change the noise in the circuit.

Reducing power consumption in an op amp circuit by scaling up resistors may reduce the 1/f noise, at the expense of increased thermal noise.

Burst Noise

Burst noise, also called popcorn noise, is related to imperfections in semiconductor material and heavy ion implants. It is characterized by discrete high-frequency pulses. The pulse rates may vary, but the amplitudes remain constant at several times the thermal noise amplitude. Burst noise makes a popping sound at rates below 100 Hz when played through a speaker — it sounds like popcorn popping, hence the name. Low burst noise is achieved by using clean device processing, and therefore is beyond the control of the designer. Modern processing techniques at Texas Instruments has all but eliminated its occurrence.

Avalanche Noise

Avalanche noise is created when a pn junction is operated in the reverse breakdown mode. Under the influence of a strong reverse electric field within the junction’s depletion region, electrons have enough kinetic energy that, when they collide with the atoms of the crystal lattice, additional electron-hole pairs are formed (Figure 10–4). These collisions are purely random and produce random current pulses similar to shot noise, but much more intense.

When electrons and holes in the depletion region of a reversed-biased junction acquire enough energy to cause the avalanche effect, a random series of large noise spikes will be generated. The magnitude of the noise is difficult to predict due to its dependence on the materials. Because the zener breakdown in a pn junction causes avalanche noise, it is an issue with op amp designs that include zener diodes. The best way of eliminating avalanche noise is to redesign a circuit to use no zener diodes.

Color Noise

While the noise types are interesting, real op amp noise will appear as the summation of some or all of them. The various noise types themselves will be difficult to separate. Fortunately, there is an alternative way to describe noise, which is called *color*. The colors of noise come from rough analogies to light, and refer to the frequency content. Many colors are used to describe noise, some of them having a relationship to the real world, and some of them more attuned to the field of psycho-acoustics.

White noise is in the middle of a *spectrum* that runs from purple to blue to white to pink and red/brown. These colors correspond to powers of the frequency to which their spectrum is proportional, as shown in the table below.

Color Frequency Content

Purple = frequencies squared
Blue = frequencies
White = 1
Pink = 1 / frequencies
Red Brown = 1 / frequencies squared

Gain Bandwidth Product

To determine the maximum gain that can be extracted from the circuit for a given frequency (or bandwidth) and vice-versa.

For example, if the GBW of an op-amp is 1 MHz, it means that the gain of the device falls to unity at 1MHz. Hence when the device is wired for unity gain it will work up to 1MHz (GBW product = gain x bandwidth, therefore if BW = 1 MHz, gain = 1) without excessively distorting the signal. The same device when wired for a gain of 10 will work only up to 100 kHz, in accordance with the GBW product formula. Further, if the maximum frequency of operation is 1 Hz, then the maximum gain that can be extracted from the device is 1 x 10 to the 6 power.

Slew Rate

This is the rate of change of the op amp's voltage output over time when its gain is set to unity (Gain =1).

-3dB Bandwidth

3dB bandwidth is defined as the frequency at which the signal intensity (or gain) has fallen to 0.5 of the zero frequency value.

The bandwidth is the difference between the upper 3dB frequency and lower 3dB frequency of a bandpass filter (High F-3dB – Low F-3dB).

Phase Margin

The phase margin is the difference between the phase of the response and -180° when the loop gain is 1.0. The frequency at which the magnitude is 1.0 is called the unity-gain frequency or crossover frequency. It is generally found that gain margins of three or more combined with phase margins between 30 and 60 degrees result in reasonable trade-offs between bandwidth and stability. The phase margin is the additional phase required to bring the phase of the loop gain to -180 degrees.

The system is unstable when the loop gain equals -1. That is, gain has a magnitude of one and a phase of -180 degrees. An unstable system oscillates. A system close to being unstable has a large ringing overshoot in response to a step input.

Full Power Bandwidth

Full Power Bandwidth (FPBW) is the frequency at which the reconstructed output fundamental drops 3 dB below its low frequency value for a full scale input.

Total Harmonic Distortion + Noise

THD is simply a measurement of how much RMS harmonic current is present in comparison to the amount of fundamental current. THD does NOT take into account frequency. It is the RMS value of ONLY the harmonics divided by the RMS value of the fundamental and is expressed in percent.

The RMS value of a sine wave regardless of frequency is simply the peak value of the sine wave divided by the square root of 2. (V means voltage)

Linear loads on a power system draw a load current that is a pure sine wave at the power frequency of 60Hz. Most everyone has seen the typical sine wave of 60Hz voltage that can be displayed on an oscilloscope. A linear load draws a current waveform of the same shape.

When a non linear load draws current from the power system (i.e. from the transformer), the current waveform is distorted from the mathematically perfect shape of a sine wave. A square wave or saw tooth waveform is an example of a distorted waveform.

The distorted waveform is actually a summation of the fundamental frequency sine wave and a variety of harmonics. Harmonics are actually pure sine waves themselves but each has a frequency that oscillates at a multiple of 60Hz (i.e. 3rd harmonic = 3 x 60 = 180Hz, 5th harmonic = 5 x 60 = 300Hz).

To find the total RMS value of any distorted wave, you have to take "the square root of the sum of the squares" of the RMS value of the fundamental and the series of harmonics. (admittedly it's easier to see this demonstrated than to explain it!!)

In this example the fundamental current is 10 amps. The harmonic RMS value is 5 amps.

5 / 10 x 100% = 0.5 x 100% = 50%

Therefore the THD is 50% regardless of the harmonic frequency.

In truth, THD is limited in its application. It is really only good for expressing harmonic limits on a feeder or that is produced by a load in a general way. It doesn't tell you which harmonics are present and how much of each harmonic (i.e. their RMS values) is present.

For that you need to perform a Harmonic Spectrum Analysis which is easily done with clamp on meters that are readily available. (Fluke has some hand held models that cost around $1500) These meters will tell you which harmonics are present, their respective RMS values, and even the phase angle between the harmonic and the fundamental.

(The phase angle is seldom used in any calculation or harmonic study.)

You must have a Spectrum Analysis performed at different points on your power system (such as at a non linear load, at the transformer, at capacitor banks, at the panelboard, etc.) before any solution to any harmonic problem can be undertaken.

Once the analysis is complete, and if the harmonics are causing you trouble (such as overheating transformers, blowing cap bank fuses, tripping breakers, causing telephone interference, etc.), the information can be used to apply harmonic filters, to size K rated transformers, or to install harmonic cancellation equipment.

Settling Time

This is the length of time for the output voltage of an operational amplifier to approach, and remain within, a certain tolerance of its final value. This is usually specified for a fast full-scale input step.

Operating Quiescent Current

Quiescent current is the current that flows in an electrical circuit when no load is present.

Differential Gain

The differential gain is the ratio of the difference of the outputs over the difference of the inputs.

In video it is the amount of change in the color saturation (amplitude of the color modulation) for a change in low-frequency luma (brightness) amplitude.

In fiber optics it's a type of distortion in a video signal that causes the brightness information to be incorrectly interpreted.

Differential Phase

In video it is the change in hue (phase of the color modulation) for a change in low-frequency luma (brightness) amplitude.