AN-28

Power Op Amp Specifications Discussion

Power Amp Design

Synopsis: The meaning of the performance specifications for power op amps is discussed with tips and insights.

Each power op amp datasheet will have a specifications page listing the model's performance specifications. For Power Amp Design op amp models the specifications are usually grouped by: INPUT, GAIN, OUTPUT, POWER SUPPLY, THERMAL and FAN. Each of the specifications will be discussed in turn as they appear in most op amp datasheets manufactured by Power Amp Design. Some familiarity with op amp theory is assumed, but a review of the specification discussions below may serve as a refresher course. For another op amp theory refresher you may refer to the first three pages of *AN-22 Single Supply Operation with Power Op Amps.*

INPUT

OFFSET VOLTAGE: In an ideal op amp the two inputs, via feedback, will assume the same voltage. The two inputs are the input nodes to a differential amplifier whose purpose is to amplify the difference of the two input voltages. One input is termed the inverting input (-) and the other the non-inverting input (+). The feedback of the amplifier from output to input is arranged so that the output voltage swings the proper amplitude and polarity so that the difference in voltage between the inputs is cancelled. But in practical op amps the input differential amplifier is not perfect and so some error voltage will exist. The offset voltage is this error, usually expressed in mV. Once the output of the amplifier has stabilized, a DC voltage can be measured between the two inputs and this is the offset voltage. Offset voltages between 1 and 5 mV are commonly specified and are assumed to be of either polarity. The voltage at the output of the amplifier with an input voltage of zero volts will be the dc gain of the amplifier times the offset voltage. For example, if the offset voltage is 1mV and the dc gain of the amplifier is 10 then 10mV will be measured at the output of the amplifier.

OFFSET VOLTAGE vs. temperature: The DC error of the input differential amplifier as discussed in the OFFSET VOLTAGE section above also has a temperature effect. The offset voltage can drift over temperature anywhere from 1 to 50 micro-volts per degree Centigrade (μV/^{O}C) of either polarity. Although the drift can be linear with temperature it usually is not. Either an "S" curve or "U" curve is usually noted as the offset voltage vs. temperature is plotted. However, the intent of the specification is to show that the change in offset between any two temperatures over the specified range will not change by more than the maximum specified drift per ^{O}C.

OFFSET VOLTAGE vs. supply: Yet another error specification related to offset voltage. The offset voltage as discussed above also changes with power supply changes. Op amps are designed to operate properly with a range of power supply voltages, both positive and negative. As the power supply voltages change the offset voltage will also change by some amount, usually expressed as micro-volts per volt of power supply change (μV/V). The offset change is usually different when the positive power supply voltage changes as when the negative power supply changes, but the specification takes the worst of the two changes into account.

BIAS CURRENT, initial: This specification also refers to the input differential amplifier and is a measure of the current required to operate the input differential pair of transistors. The bias current is often measured in pico-amps (pA). Power Amp Design power op amps use JFET transistors as the input differential pair and the bias current is exceedingly low. Although usually specified as 100pA maximum the bias current is usually much lower. Leakage to other circuit components is usually more than the actual bias current of the JFET transistors, but the bias current specified is the current that might be measured going into or out of the input pins, either positive or negative for each input pin.

BIAS CURRENT vs. supply: The bias current may change with the power supply voltage, usually specified as pico-amps of bias current change per volt of power supply voltage change (pA/V). This specification cites the maximum the bias current is likely to change as the power supply voltage changes.

OFFSET CURRENT, initial: The bias current to each input pin may not be the same value or polarity. The offset current is the difference between the two bias currents.

INPUT RESISTANCE, DC: The fact that some current flows into or out of the input pins means that the equivalent resistance of the inputs to the power op amp is not infinite as would be the case for an ideal amplifier. The equivalent resistance is specified in gig-ohms (GΩ). The JFET transistors connected to the inputs of the amplifier look like reversed biased diodes and have very high equivalent resistance, usually specified at 100 GΩ for Power Amp Design models.

INPUT CAPACITANCE: The signal inputs to the power op amp also have an equivalent capacitance specified in pico-farads (pF). The input capacitance for Power Amp Design models is usually specified as 4 pF. While in an ideal op amp the input and feedback resistances could be any value without an effect on the circuit, in a real world op amp the input capacitance forms a pole with the input and feedback gain setting resistors and therefore has an effect on the frequency response of the op amp circuit.

COMMON MODE VOLTAGE RANGE: This parameter specifies how closely the input voltages can approach the supply voltages in normal operation. Often there are two separate specifications, one specifying a voltage from the positive supply voltage and the other specifying a voltage from the negative supply voltage. For example, model PAD113 is specified as having a common mode voltage range of +Vcc-15V and –Vcc+7V. This means that the input pins in normal operation cannot be any closer than 15V from the positive supply voltage or any closer than 7V from the negative supply voltage. The common mode voltage range most often becomes a concern when one of the power supply voltages is minimum. For example, considering again the PAD113, the common mode voltage range to the negative supply voltage is –Vcc+7V. If the + input is grounded (as it often is for an inverting amplifier application) the negative power supply voltage could not be less than -7V (for example, -6V would not be allowed in this case). RRIO amplifier designs (rail to rail input and rail to rail output) like the PAD117, however, allow the input voltages to be the same as the power supply voltages. For a RRIO power op amp design the +input could be grounded and the negative power supply pin could also be grounded (single supply operation) and satisfy the common mode voltage range parameter.

COMMON MODE REJECTION, DC: As the input voltages move from near the negative power supply voltage to near the positive power supply voltage the offset voltage of the amplifier will change due to changing voltage drops across the internal components. How much the amplifier rejects any offset voltage changes is expressed in dB *down* from the original offset voltage value and is RTI (referred to input). Previously, under the offset voltage explanation, it was mentioned that the offset voltage is multiplied by the DC gain of the amplifier circuit, so that a 1mV offset between the inputs will result in a 10mV output for an amplifier circuit in a gain of 10. Therefore, when the gain of the amplifier circuit is known to be 10 and 10mV of output is observed the offset RTI (referred to input) is only 1mV (assumes a zero input voltage to the amplifier circuit). Although the gain of the circuit may change the output value, the RTI offset voltage does not change. Another specification that is related to Common Mode Rejection, DC, is Power Supply Rejection, DC. Although expressed differently as micro-volts per volt (µV/V), power supply rejection is virtually identical to common mode rejection. From the viewpoint of the amplifier's inputs there is no difference between moving the inputs relative to the power supply voltages and moving the power supply voltages relative to the inputs.

NOISE: Although an amplifier's noise can be expressed in several ways we specify the total noise within a brick-wall bandwidth of 100 kHz with a source impedance of 1kΩ. Since the source resistance itself is a noise source its noise will also be measured at the output of the amplifier. But in the real world some input resistance will be needed to set the gain of the amplifier and 1kΩ was chosen as a reasonable value for actual circuits.

GAIN

OPEN LOOP: Open loop gain is often abbreviated as Aol. It is the maximum gain that the amplifier produces at a stated frequency, often DC. The open loop gain is so stated because it is specified as the gain with no feedback elements that would set the overall amplifier circuit gain (closed loop gain). A graph of the open loop gain of the amplifier is given with a Bode plot which is provided in the data sheet in the typical performance graphs for each model. The Bode plot is important because it can graphically show the accuracy the amplifier can attain at any frequency within its range by plotting the closed loop gain (the gain determined by the external feedback elements) of the amplifier circuit on the Bode graph and taking the difference between the open loop curve and the closed loop curve. For example, say that at DC an amplifier has an open loop gain of 100dB. The amplifier circuit is in a closed loop gain of 10 (20dB). The difference between the open loop gain and the closed loop gain at DC is 80dB. Expressed linearly 80dB equals 10,000. So the gain accuracy you might expect from the amplifier due to open loop gain limitations would be 1 part in 10,000 or 0.01%. As the closed loop gain of the amplifier circuit goes up the corresponding gain accuracy goes down. In the example above let's say the DC gain of the amplifier circuit goes up to 100 from the 10 previously considered. The difference between the open loop curve for the amplifier and the DC gain curve is now only 60dB or 1000 and the corresponding gain accuracy we could expect drops to 1 part in 1000 or 0.1%. So, the higher the open loop gain at any frequency the better the expected gain accuracy at that frequency.

GAIN BANDWIDTH PRODUCT: is usually expressed in units of MHz (megahertz) at some specified frequency, often at 1Mhz. When the bode plot of the amplifier is examined to determine the gain at the specified frequency the gain bandwidth product is simply that gain multiplied by the stated frequency. For example, if the bode plot of the amplifier crosses zero dB (gain of 1) at 1 MHz then the gain bandwidth product of that amplifier is 1Mhz at 1Mhz. Another amplifier may have a gain of 20dB (gain of 10) at a frequency of 1MHz and therefore that amplifier would have a gain bandwidth 10MHz if the specified frequency is also 1 MHz.

PHASE MARGIN: For a feedback amplifier (such as an op amp) the worst case for a stable circuit occurs when the feedback ratio is 100% (unity gain follower). Amplifiers are usually designed to minimize phase shift so that there is at least 60^{O} of phase margin; that is to say the op amp's internal circuitry shifts the phase of the input signal by no more than 120^{O}. If the op amp is externally wired as unity gain follower and the phase shift were 180^{O} then that circuit would be sure to oscillate. A phase shift of 45^{O} is usually considered the minimum phase margin to insure stability. However, the amplifier's load also causes phase shift as it interacts with the closed loop output impedance of the amplifier and this is why it is desirable that the amplifier have as much phase margin as practical. Power op amps most commonly drive rather nasty loads when considering stability. It is therefore desirable to configure the gain circuit of the power op amp to have some gain greater than unity. As the gain increases the feedback percentage drops and makes an unstable circuit less likely. Power op amp loads are often not well defined, especially across a frequency band. A gain larger than unity helps insure a stable circuit. A gain of 10 or more is often recommended, especially for loads that are highly reactive (more common than not).

OUTPUT

VOLTAGE SWING: Specifies how closely the output of the amplifier can approach the power supply voltage feeding the amplifier when supplying a specified output current. The voltage swing depends on load current and is usually different for positive and negative output current. Even with no output load current most amplifiers are unable to drive the output voltage all the way the power supply voltage owing to the amplifier's internal bias considerations. However, so called RRIO (rail to rail input, rail to rail output) amplifiers come closest to achieving this.

CURRENT, continuous DC: usually the minimum output current capability of the amplifier. Power op amps usually can provide much more output current than specified as a minimum, especially with short term pulses, but the amplifier's limitation is usually the power dissipation while providing that current and it's the power dissipation capability that often sets the output current specification.

SLEW RATE: the maximum rate of change of voltage at the output of the amplifier between the 10% and 90% of the maximum output peak to peak voltage, specified as V/µS. A gain and a compensation capacitor value are also usually specified. As the compensation capacitor value decreases the slew rate increases. It is common for power op amps to have slew rates greater than that necessary to support their small signal bandwidths. This is easy to see via the square wave response of the amplifier where distinct rounding of an output square wave may be evident. However, common applications for power op amps involve driving sine wave outputs into loads and the higher slew rate translates into higher power bandwidths, a distinct advantage.

POWER SUPPLY

VOLTAGE: the power supply operating minimum and maximum voltages are given as a plus and minus value (±) since power op amps are usually operated from two power supply voltages. The amplifier can operate with supply voltages anywhere between these values. In addition the amplifier can operate with a single supply as long as common mode restrictions are met (see above under COMMON MODE VOLTAGE RANGE). If an amplifier's power supply voltage is rated from ±8V to ±50V it can also operate from a minimum single supply of 16V to a maximum of 100V either plus or minus and the other supply pin at zero (again, assuming common mode voltage range restrictions are met). The power supply voltages may also be unbalanced. For the amplifier specification of ±8V to ±50V power supply voltages of -10V and +90V also meet the power supply voltage specification.

CURRENT, quiescent: the various stages of the amplifier require some current to operate correctly and the sum of these currents is called quiescent current. This current varies over temperature and also with power supply voltage and graphs of these variations are plotted and presented in the typical performance graphs section of the datasheet. For power op amps most of the variation in quiescent current over temperature results from drift in the output stage bias current. In addition it is common for the quiescent current versus supply voltage variation to be more sensitive to one supply voltage variation than the other, but the worst of the two is specified.

THERMAL

RESISTANCE, AC, junction to air: measured in ^{O}C per watt (^{O}C/W) of power dissipated in the amplifier. Anytime an amplifier dissipates power the temperature of the amplifier's output transistors will rise. The lower the thermal resistance of the heat path of output transistors the lower the temperature rise. Lower operating temperature is essential to high reliability. If the temperature rises too much the output transistors will be destroyed. In the case of AC thermal resistance each of the two output transistors share the load─ each of the two output transistors conducting current on alternate half cycles. Since the temperature of each output transistor affects the temperature of the other transistor the AC thermal resistance is not one half of the DC thermal resistance. As the frequency rises from DC, the AC thermal resistance drops until it reaches its minimum point at about 60Hz.

RESISTANCE, DC, junction to air: similar to AC thermal resistance as above, but considers the thermal path of only one of the two output transistors since only one transistor at a time can conduct current.

TEMPERATURE RANGE, ambient air: the ambient air temperature is the temperature of the air immediately surrounding the amplifier's environment. The environment temperature is affected by the heat generated by the amplifier as it dissipates power. It is therefore important that some means is employed to remove the air with elevated temperature. The fan intake must have a continual source of fresh cool air to maintain the amplifier within its operating temperature range. The ambient air temperature specification is limited by the operating specifications of the fan. The amplifier itself is capable of operating over a wider temperature range. Due to the thermal drop across the heat sink, the temperature of the amplifier's substrate is higher than the temperature of the fan. So while the fan is limited to a temperature range of -40 to +70 ^{O}C, the amplifier substrate can operate over a temperature range of -40 to +105 ^{O}C.

TEMPERATURE, *shutdown*, *substrate*: the amplifier is equipped with a precision sensor that monitors the temperature of the amplifier's substrate. When the substrate temperature exceeds 110 ^{O}C the sensor circuit activates a shutdown signal that turns off the output stage of the amplifier. The substrate temperature must fall by 10 ^{O}C before the amplifier's output stage is enabled once again. The sensor measures average substrate temperature and so it is possible that an overload of the output transistors might occur so quickly that the output transistors may be destroyed before substrate has had time to heat up to the point that shutdown will occur. However, the sensor will protect the amplifier against slow thermal overloads and fan circuit failures.

FAN

OPERATING VOLTAGE: the nominal operating voltage for the fan that produces the thermal resistance specifications as above. The nominal voltage is 12V but the entire range of the fan is 7-17V. Running the fan at a voltage above the nominal does not improve the thermal rating of the amplifier.

OPERATING CURRENT: the current required to operate the fan at the nominal voltage. The fan is operated by a brushless motor controller inside the fan housing. The controller is a switching circuit and can produce voltage noise due to the current pulses from the switching circuits. It is recommended that a 47µF electrolytic capacitor be used to filter the current pulses. The bypass capacitor should be placed directly at the point where the wires leading to the fan connect to the 12V power supply for the fan.

AIR FLOW: this is the rated air volume for the fan used before it is attached to the heat sink. Due to the resistance that the heat sink fins provide the air flow will drop when the fan is mated to the heat sink. This is a useful specification to have should the fan ever need to be replaced.

RPM: this is the rated revolutions per minute of the fan used before it is attached to the heat sink. Due to the resistance that the heat sink fins provide the RPM will drop when the fan is mated to the heat sink. Another useful specification to know should the fan ever need to be replaced.

NOISE: this is the audible noise the fan generates. As the RPM drops the noise drops as well.

L10, life expectancy, 50 ^{O}C: L10 refers to the time it takes for 10% of a population of fans to fail. Lower ambient temperature increases fan life. This is a different specification than mean time to failure. Mean time to failure requires that 50% of a population of fans fail. While the L10 failure time is 45k hours for the fans we use an equivalent mean time to failure is 200k hours.

Although some amplifiers may have additional specifications the above discussion covers all of the common specifications you will find in our power op amp datasheets. Our application engineers are always available to answer questions about our products and are happy to assist you with your application circuit development. In addition, each amplifier product has a companion evaluation kit available to help you rapidly develop your circuit without having to research supporting components and construct a circuit board.