Op-Amps in Audio Circuits – A Quick 12 Point Check List

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Many audio DIYers like to experiment with op-amps, often swapping out devices in an existing design in order to 'improve the sound'. There is a lot of commentary on the internet about *the sound of opamps*. Listed below are some simple guidelines to make sure the change in sound you are hearing isn't because of oscillation, ringing, TID or any other problems. These points are not an exhaustive list, but paying attention to them will solve most problems when you find things don't quite sound the way you'd hoped.

And, if you are designing an op-amp based circuit from scratch, these guidelines should also prove just as useful.

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1. First of all, we are going to limit this discussion to **Voltage Feedback Amplifier** (VFA) opamps. VFA's come in 3 flavors:-

    - **Compensated** – these have the comp cap on the chip and require no additional compensation of the actual op-amp. However, your circuit may well need overall loop compensation, but that is a different discussion which will not be addressed here. There are no dedicated compensation pins brought out on the device connections.
    - **De-compensated** - these types have some compensation fitted internally (either through a comp cap, degeneration, or some combination of these), but not enough to guarantee stability at gains below a certain specified amount.
    - **Uncompensated** - these devices bring the compensation cap connections out on pins. For stable operation, they will require an external com cap to be fitted. The pins usually used are 1 and 8 or 8 and 5, and which pair of pins depends upon the specific opamp.

2. Never try to run a de-compensated opamp at unity gain, or at a gain that is less than the minimum specified in the data sheet. If you do, the circuit will ring, or oscillate. Check out the op-amp data sheet and make sure you comply with this important boundary condition. Furthermore, if you are using a de-compensated opamp, make sure that capacitance (either

stray, or fitted as part of the design) across the feedback resistors is not lowering the gain at HF to below the minimum recommended level. This will cause ringing or oscillation.

3. Don't run an uncompensated opamp without a comp cap, or too small a comp cap. Uncompensated op-amps do not fit the miller integration cap around the VAS stage on the chip – this has to be added externally (see point 4 below). If a compensation cap is not fitted, you are likely to get oscillation or ringing.

4. Make sure you fit the comp cap across the correct pins in an uncompensated op-amp (i.e. pins 1-5 instead of pins 1-8 and vice-a-versa). For this reason, in circuits where a comp cap is fitted, just swapping the op-amp out without checking this point, can lead to changes in audible performance and problems.

5. Always fit an isolation resistor (47 or 50 Ohms) in series with the output when driving a real world load - like a cable for example, or a capacitive load. Locate this resistor as close as possible to the output pin, just after the feedback resistor or feedback network take off point. Why is this good practice? A capacitive load on any amplifier causes HF poles to migrate downwards in frequency but up in magnitude (i.e. gain). If the gain of these poles as a result is >unity, the amplifier will ring or oscillate. The series resistor (and in the case of a power amplifier, usually an inductor of 1-2uH), ensures that the output of the op-amp sees a primarily resistive load, thus minimizing or avoiding the pole shifting problem.

6. Ensure that the junction of the feedback network (i.e. the upper leg from the output and the lower leg which normally will go to ground, or in an inverting configuration, to the preceding stage) is located physically very close to the op-amp feedback input pin (usually the inverting input). In the non-inverting configuration, any noise voltage appearing between the junction of the feedback resistor network and the inverting input on the op-amp, will be amplified by the *closed loop gain* of the op-amp. In the inverting configuration, where the inverting input to the opamp forms a summing junction, the same rules apply, but the noise is amplified by the full *loop gain* of the opamp. In a well laid out board, the virtual earth capacitance to the surrounding circuitry can be kept to a few pF. However, fast rising signal edges can couple more easily into the virtual earth and cause output noise. If the non-inverting pin, which is usually connected to ground, sees a high impedance (for example a bias current balancing resistor), this issue may be exacerbated.

7. Locate any input filter as physically close as possible to the op-amp input (usually the non-inverting input). In this scenario, any noise signal induced on the connection between the non-inverting input and the filter will be amplified by the closed loop gain of the amplifier.

8. Decouple the supply rails adequately and close to the op-amp supply pins. Typically, 0.1uF to 1uF ceramic from the supply pins to ground will prevent any oscillation or instability. Also, make sure you do NOT use the signal ground for the decoupling capacitor ground return – you should use a separate power supply ground return for this purpose.

9. Avoid using opamps not characterized for audio usage. Typical examples are uA741 (an early 1970's relic), TL072 (ok for DC work, but not high quality audio), LF355,356, 357 - also relics from the late 1970's. Low supply rail, low power op-amps are also generally not good for audio, unless specifically designed for this purpose, as is the case for battery powered portable applications. Look for devices with the following minimum general characteristics:-

   - Slew rate of at least 10V/us
   - Full Power bandwidth of 50KHz or better
   - Low frequency PSRR of >80dB (some modern VFA op-amps do >120dB) on both +ve and –ve rails; HF PSRR should be better than 70dB, but on older devices, this may not be achievable, with 50-60dB a realistic
   - 600 Ohm 1KHz 10Vpk output distortion of 20ppm or better. At these levels, modern devices will achieve low ppm figures at 20KHz and low single digit ppm at 1KHz into 600 Ohms. For more realistic output levels of 2Vpk, figures of <5ppm from DC-20KHz into 600 Ohms are the norm.
   - Ensure the noise performance is adequate for your application, taking into consideration both the input noise voltage and input noise current

10. Scope your physical design out . . . it's always possible, despite your best efforts, to have your op-amp design or swap out, oscillating at some high frequency. HF oscillation or ringing will definitely affect a circuits sound for the worse.

11. Make sure you understand how the opamp behaves under input and output overload conditions. You'd be surprised how otherwise reasonably specified devices misbehave under these conditions. Some op-amps suffer output phase reversal if the input signal goes within a volt or two of the supply rails for example. Look out for rail sticking when the output clips, and slewing when driving a large square wave signal (a problem with the LF355 family for example).

12. If your application allows it, operate the opamp output stage in class A. This can be done by loading the output to either the + or – rail with a resistor slightly lower in value than the expected load resistance the opamp will drive. For example, if the opamp will drive a 2k potentiometer, then connect a 1.8k resistor between the output to either the + or – rail with a 1.8k resistor. Operating the opamp in class A (1) completely removes output stage cross over distortion and (2) minimizes half wave class B artifacts (which are full of harmonics) on the supply rails, reducing noise and possible distortion through the coupling of these extraneous signals into sensitive circuit nodes.

Document History: Para 6 updated 8th Feb 2012 – noise gain wrt to loop gain and closed loop gain. Added point 12. Spelling and grammar corrections.