

OPA1688 Super CMOY Build Instructions

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Background

The CMOY mint-tin headphone amplifier is named after Chu Moy, who first presented it on his Headwize.com forum a number of years ago. The classic CMOY uses a single op-amp for gain and output drive, and a virtual ground to “split” a single 9V battery.

The classic CMOY does amazingly well for so few parts, but has a few well-known shortcomings. One shortcoming is the vast majority of op-amps are designed to output a maximum of around 25mA. Another serious shortcoming is the distortion introduced by virtual grounds. Having the return currents from both channels pass through a virtual ground results in high THD, inter-modulation distortion (IMD), crosstalk, and noise. Used another op-amp for the virtual ground helps, but now that op amp would have to be able to handle 2x 20mA, which very few can.

The Super CMOY presented here solves both of the major shortcomings of the classic CMOY, while adding a few more nice features like a headphone relay for zero turn-on or turn-off thumps. The brand new OPA1688 headphone driver chip from TI supplies a full 75mA per channel of output current at very low THD and noise levels. A unique double solid-state-relay low battery protection circuit allows the use of two 9V batteries, one per supply rail, to for a true ground (as opposed to the classic virtual ground). True grounds do no introduce any distortion, IMD, crosstalk, or nose. Using two batteries also doubles the available voltage swing over a single-battery CMOY.

The features of the Super CMOY include:

- Ti's new OPA1688 headphone driver chip which supplies up to 75mA of output current on each channel at extremely low distortion levels.
- The OPA1688 is FET input which, along with an inherent low 500uV input DC offset, results in an extremely low output DC offset of around 500uV (0.5mV) per channel.
- Includes an input RF filter. The OPA1688 has a built-in ability to drive large capacitive loads, up to 600pF – headphones and cables – but requires a small 47uF compensation capacitor for stability. This results in a roll-off in the MHz region, so the RF filter is important to remove any input RF and prevent it from being amplified.
- Input DC blocking. The Super CMOY includes input 3.3uF film capacitor on each channel to block any source DC and keep it out of your expensive headphones! This also guarantees that the only DC output offset from the CMOY is that tiny inherent 500uV (0.5mV). Film capacitors don't have any significant effect on the sound. The 3.3uF value puts the low end corner frequency of the frequency response at just 0.9Hz, way below audible range.
- A unique power management circuit using two solid state relays that instantly cuts off both batteries if they drop below 7V. This feature is important since a single battery "disappearing" due to a broken wire, bad snap, or internal low battery cutoff (lithium rechargeables) would leave one power rail up and one down, resulting in large DC on the CMOY output. The SSRs have their internal LEDs wired in series which guarantees both switch on or off at exactly the same time. The SSRs are brand new types that have "on" resistances of just 0.0125 ohms, only slightly more than a wire!
- The comparator used in the power management circuit is a brand new chip from TI that pulls just 7uA of idle current. This allows the chip to be permanently connected to the batteries. It would take 35,000 hours for that chip to drain the batteries.
- The Super CMOY includes protection features such as battery reverse-polarity diodes and rail reverse voltage clamps.
- A headphone relay circuit which eliminates any turn-on or turn-off thumps. The same circuit I use in the O2 Booster Board and Inverting O2 headamp. A subminiature relay that pulls just 4mA of coil current. The relay circuit has a 3-second turn on delay to eliminate the turn-on thumps and to allow the power rails and amp chip to thermally stabilize. The turn-off is accelerated to eliminate turn-off thumps.

Assembly

Things to be careful about!

- The BOM has 499 ohm, 49.9K, and 499K resistors. Make sure you are using the right resistor! I would suggest soldering in all of one type first, then move on to the next bag. That will help with getting them mixed up.
- D1 and D2, which are underneath the TPS3701 adaptor, need to be touching each other and right over their PC board pad markings to make sure there is enough room around them for the adaptor board pins.
- Always use a grounded anti-static mat, grounded wrist strap, and ideally a grounded soldering iron tip when soldering to prevent static damage to parts.

Please refer to the layout diagram of the PC board at the project Google Drive link if you need to double-check the part number of any part that is sitting over their number.

Trim excess lead lengths with flush cutter pliers as you go.

Solder on the low-height parts that are not around the OPA1688 chip

This step gets a few of the low-height parts on before the static-sensitive OPA1688 chip and other semiconductors are installed. Doing things this way just helps reduce the amount of handling of the board while the OPA1688 is soldered on. We will omit parts around the OPA1688 for now to make soldering it on later easier. The low-height parts go on first to keep taller parts from blocking access to them for soldering.

Solder on R1, R2, R3, R4, R5, R6, R7, R8, R9, R12, R13, R14, C1, C2, C9, C10.

Solder on diodes D3 & D4. These are the small blue diodes. Double check that you are getting the banded end of these diodes lined up with the band on the silk screen marking.

Solder on diodes D1 & D2. D1 and D2, which are underneath the TPS3701 adaptor, need to be touching each other and right over their PC board pad markings to make sure there is enough room around them for the adaptor board pins. Double check that you are lining up the banded end of these diodes with the banded markings on the PC board. Please note that the banded ends of these two diodes go in opposite directions!

Solder on diodes D5 and D6. D6 is a zener diode. Make sure the banded end of these diodes matches up with the band marking on the PC board. The bands on both of these diodes point in the same direction.

Solder on the OPA1688 chip IC2

The orientation dot on the PC board is toward the relay end of the board. Make sure you line up the band or dot on the chip with the end of the IC pads that have the polarity dot.

First put a little solder on one corner's pad. Hold the chip by the sides with some right angle tweezers and re-heat the solder on the one pads while aligning the chip with all 8 pads. Re-heat the solder on the one pads as much as needed to get all 8 leads of the chip centered over the 8 PC board pads. A magnifying glass really helps with this, and with inspecting the solder joints!

Then go to the other side of the chip and solder the 4 leads one by one, or using the method of dragging a ball of solder across them briefly. You may bridge one or more pins with solder. Don't worry about this, some solder wick will be used later to remove the bridges.

Then go to the original side and solder up the remaining 3 pins, plus re-solder that original corner pad with a little fresh solder.

If you have solder bridges place some solder wick over the bridge and briefly heat with the soldering iron to remove the bridge.

Double check your soldering of all 8 leads by looking closely with a magnifying glass and a flashlight. Be sure to look at the leads from the side as well as the top, since this shows up solder bridges better.

Solder on the rest of the low-height parts

Solder on R11, C5, C6, C7, C8. Since the capacitors look similar I would suggest soldering on the two 47pF first, C7 & C8, then the two 0.1uF after, C5 and C6, to keep from getting them mixed up.

Solder on the medium-height parts

Solder on IC3 and IC4, making sure you have the notch in the chip lined up with the notch marking on the PC board. The notches on the two chips go in the same directions. If you are using the IC socket option on the BOM (recommended!) solder those on now. Make sure you get the notches in the sockets lined up with the notch marking on the PC board. Then insert

the Solid State Relay chips in the sockets, making sure once again you get the notches on the chips lined up with the sockets.

Solder on the depletion mosfet Q1. You will have to spread the transistor leads a little to line up with the holes on the PC board. This is by design, to make it easier to solder the leads without solder-bridging.

Solder on the voltage regulator IC5. You will have to spread the transistor leads a little to line up with the holes on the PC board. This is by design, to make it easier to solder the leads without solder-bridging.

Solder on the two n-channel enhancement mosfets Q2 & Q3. You will have to spread the transistor leads a little to line up with the holes on the PC board. This is by design, to make it easier to solder the leads without solder-bridging.

Solder on the relay K1. What I do is hold the relay in the holes with a finger while flipping the board over. I have a piece of solder sticking out from the roll, to allow using my other hand with the soldering iron. I then solder just one lead on the relay and turn over the board to check to make sure I have the relay level with the board. If not, resolder that one lead as much as necessary to move the relay around. Then flip the board over again and solder up all the other leads on the relay.

Solder on the solid organic polymer electrolytic capacitors C11 & C12. There is a very small “+” sign on the PC board marking on the holes closest to the PC board edge. The red band on the top of these capacitors marks the negative end, so it goes to the opposite hole of the “+” marking. As usual just solder one lead first, then flip the board over and make sure the capacitor is straight up and down. Resolder the one lead as needed to fix that. Then solder up the remaining lead.

Solder on some of the taller parts

Solder on the volume pot VR1. As usual solder just one lead first. Flip the board over to make sure the pot is sitting flat on the board and is aligned well with its marking on the PC board. Re-heat the one lead as necessary to get the pot lined up. Then solder up the remainder of the pot leads.

Solder on the film capacitors C3 & C4. There is no polarity to this type of capacitor, so either lead can go in either hole. Solder one lead then flip the board over and make sure the capacitors are sitting flat on the PC board, and also that they are right up against the pot body.

It is important to get them close to the pot so the output jack will have enough space when inserted.

Solder on the output jack J2. The input and output jacks are identical parts. Solder one lead, make sure the jack is flat against the PC board, then solder the rest of the leads.

Solder on the green power LED in either the forward or the rear marked position on the board. Make sure it sits flat on the board and right up against the pot body, to leave room for the input jack. The forward position will stick the LED through the mint tin, and it will come out very close to the nut on the pot. The rear mounting position will clear the mint tin. You can either leave it covered up that way or drill a small hole in the mint tin to let the light out. You can also leave the LED off entirely and jump jumper across either the forward or rear two LED holes (don't need to jumper both, just one or the other). Or finally you can use an external panel mount LED with wires and solder the wires into either the front or rear set of LED holes.

Solder in the input jack J1, making sure it is flat on the board.

Solder on the battery clips

Measure how long the wires on the battery clips should be for the side-by-side batteries in the mint tin and cut the wires, leaving room to strip them. The holes in the board are marked BAT1 and BAT2, with POS and NEG on each. Run the red wire from one battery clip (either one) to the POS on BAT1 and solder. Then run the black wire from that same clip to the NEG on BAT1 and solder. Then do the same with the other battery clip and the BAT2 holes.

When you are done your wires soldered into the board should go red, black, red, black. The Super CMOY includes protection diodes (D1 & D2) so that if you accidentally touch a 9V battery to the wrong terminals (I do that all the time!) it won't blow anything up.

Don't attach the batteries to the clips yet.

Testing

1. Make sure your on/off switch on the pot is off. Turn the pot until you hear the click.
2. Attach your batteries to the battery clips.
3. Turn on the switch on the pot. The green "power on" LED should light! If not, go through the troubleshooting steps below for the SSR control circuit.

4. Test the voltage on your board. Between the electrolytic capacitors and the edge of the board are 3 holes labeled V+, GND, and V-. With the power switch on and your DMM set to volts put your black meter probe on the GND and the red on V+. You should read the positive battery voltage for the type of batteries you are using.
5. Now do the same as in step 4 above but for the negative power rail. Put your red meter lead on GND and the black on V-. This is your negative battery voltage and it should be in the ballpark of your positive battery voltage from step 4. If not STOP right here and troubleshoot the problem.
6. With the board power still on, and nothing plugged into the input jack J1, measure the DC voltage from the GND hole to one of the output channels from your output jack J2. An easy way to do this is plug a 3.5mm plug with the cover off, and no wires attached, into J2. Another way is flip the board over and measure at the jack leads. The channels are the two jack PCB holes off to the side. The three down the center are grounds. You should have somewhere around 0.25mV (250uV) of DC output, not significantly more. This is so small that a lot of meters that only read down to 1mV will just show 0 volts. Please remember that the headphone relay delays turning on by about 3-4 seconds, so you need to wait that long before any voltage will come out. If you do measure significant voltage on the output pin, like 10mV, or 100mV or 1V or 9V, Stop right there and find the problem, which usually is one of the leads on the OPA1688 chip not being fully soldered. Look at those leads again with a magnifying glass. If the chip got static-zapped it can do this too.
7. Repeat the test above, but for the other output channel. Once again there shouldn't be anything much more than 0.25mV (250uV) of DC on the output.
8. Test your new amplifier!! Turn the pot volume down (but not so far as to turn the amp off with the switch) and connect the input jack J1 to a music source. Plus a set of cheap "test" headphones – something that wouldn't matter if they were damaged – into the output jack J2. Then slowly turn the volume pot up and listen for sound in both channels.
9. ENJOY!! 😊

Installing in a Mint Tin

The Super CMOY PC board installs in the end of a mint tin upside down. The board sits on the two 3.5mm jacks. Mark the position of the pot shaft first by placing the CMOY PCB inside a mint tin moving it forward so the pot shaft touches and end. Mark around that on the inside of the tin, then punch out or drill that hole. I use a handheld paper punch – Target and WalMart

have them in the US – to make the initial hole, then a round file from there to enlarge. The mint tin metal is so thin a paper punch will go right through.

Once the pot shaft goes through the hole mark the holes for the input and output 3.5mm jacks and cut those holes.

Drill a hole for the “power on” LED, if you are using the LED.

Install the nuts for the pot and 3.5mm jacks. These are what holds the CMOY board in place.

Finally install your batteries. Some foam is useful on one end of the batteries to keep them from rattling in the tin.

Operation

Once your batteries get low the power management circuit will either cut the sound off entirely, or it may turn the sound on and off about once every 3 seconds, the RC time delay of the headphone relay circuit. When that happens you need to remove your batteries and recharge them.

The OPA1688 chip has built-in short circuit protection, so plugging and unplugging your headphones won't affect it. Tip-Ring-Sleeve (TRS) jacks like this always short out the signals when the plug goes in and out.

Storage

The TPS3701 comparator chip is always being powered by the batteries when the batteries are installed. It only pulls 8 microamps of idle current though, so your amp could go for a year (or years depending on battery type) before the chips runs the batteries down. If you are planning on storing your Super CMOY for a long time it is best to remove the batteries.

Theory of Operation

Amplifier signal path

The first stage the signal goes into from the J1 input jack is the RF filter, composed of R1, C1, R2, and C2. This is filter with a corner frequency at $1/(2 \cdot \pi \cdot 274 \cdot 220\text{pF}) = 2.64\text{MHz}$ to keep radio frequency signals from broadcast stations out of the headphone amplifier. The OPA1688 chip itself also includes some RF EMI rejection features, according to the datasheet.

The signal then goes across a 10K audio-taper pot, which forms the input impedance the source “sees” when powering the Super CMOY. To be exact it is the pot plus that series 274 ohms for the RF filter, which is a total of 10,274 ohms. A 10K input impedance is the same that NwAvGuy chose for his O2 headphone amplifier, since it is essentially the lowest load that some output sources can drive without distorting.

The OPA1688 chip used in the Super CMOY has a FET (field effect transistor) input, which pulls extremely little current, just picoamps. That means unlike the O2 the Super CMOY could easily work with a larger value of pot that would load the source less, such as 50K or 100K, two standard values for input pots. Unfortunately the parts distributors don’t stock dual 9mm pots with switches in those values, although they are available for special order in quantity. If the Super CMOY board is being mounted in a larger case an external pot can be used and run to the CMOY board with twisted wires. A larger value of pot will introduce more Johnson/thermal noise, especially at mid-pot where half of the pot is in series with the signal.

The signal from the pot wiper then continue on through the 3.3uF coupling caps and 49.9K ground return resistors to the non-inverting input of the OPA1688. The coupling caps block any DC from the source to prevent it from appearing at the Super CMOY output, preserving that nice low 0.25mV DC output offset from the OPA1688 chip. In the other direction the coupling capacitor keeps the chip’s input bias current – although very small since it is FET input – out of the pot wiper which can cause scratchies in the sound as the pot is turned.

With the 3.3uF DC blocking capacitor in place the 49.9K ground return resistor has to be used to allow the chips input bias current a place to flow. Without that resistor the input bias current would charge the coupling capacitor up (or down) to one of the supply rails. If you are ever troubleshooting a headphone amplifier that has an output DC voltage near one of the rails, this is something to check for, that the ground return resistor is installed and the solder connections are good.

The 49.9K value for the ground return resistor is chosen to make it big enough not to load the pot, typically 5x to 10x the value of the pot. The pot in this case is 10K, so the ground return resistor is 5x at 49.9K.

The feedback network around the OPA1688 is taken from the datasheet, where they recommend a 47pF compensation capacitor to allow the output to drive large capacitive loads. The feedback resistors are lowest noise when kept under 860 ohms according to TI, so the resistors used are standard value of 825 ohms and multiples of that, 1.65K and 2.49K for 3x and 4x gain.

Power management circuit and solid-state relays

Headphone output relay