

Homemade Operational Amplifier

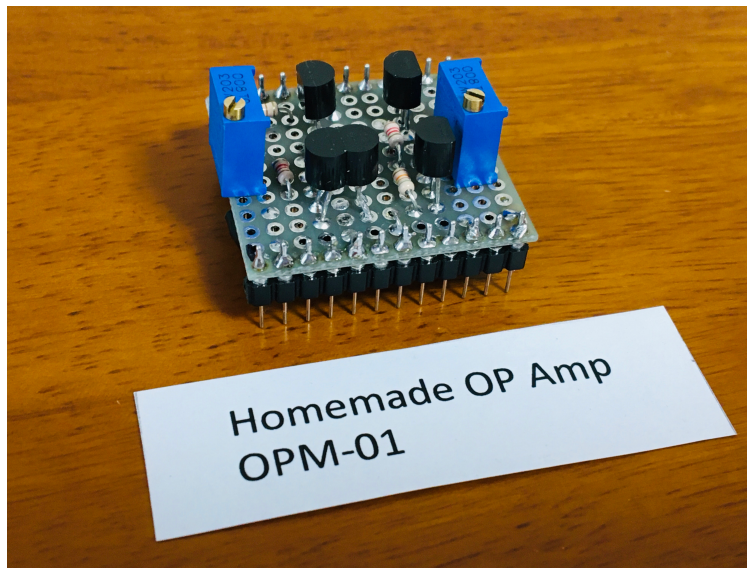
<https://hackaday.io/project/176860-homemade-operational-amplifier>

Homemade simple operational amplifier module and an audio amplifier using it.

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Description

Operational amplifiers (op-amps) are commercially available as monolithic ICs and are widely used as the basis of analog circuit elements. In 2010, I built my own simple op-amp with discrete transistors to properly understand the principle of the op-amp and experience the operation of the transistors, which allowed me to study the behavior of differential pair transistors and complementary emitter followers. Then I built a practical audio power amplifier with the homemade op-amps. In 2021, I decided to reproduce this op-amp module and publish it.



Details

1-1. Simple discrete op-amp

The inside of a commercially available op-amp consists of many monolithic transistors, but in this case, I decided on a circuit with only five transistors to make the operation as simple as possible as shown in Fig.1. The transistors used general-purpose NPN and PNP complementary pair transistors. This project used bipolar transistors, but an example of my own work using CMOSFETs is presented in another project CMOS Homemade Operational Amplifier [1]. I thought I had achieved at this circuit configuration by my own ingenuity, but when I searched the net again now, I found several similar circuits published. I guess the limitation of five transistors means that anyone can reach the same solution.

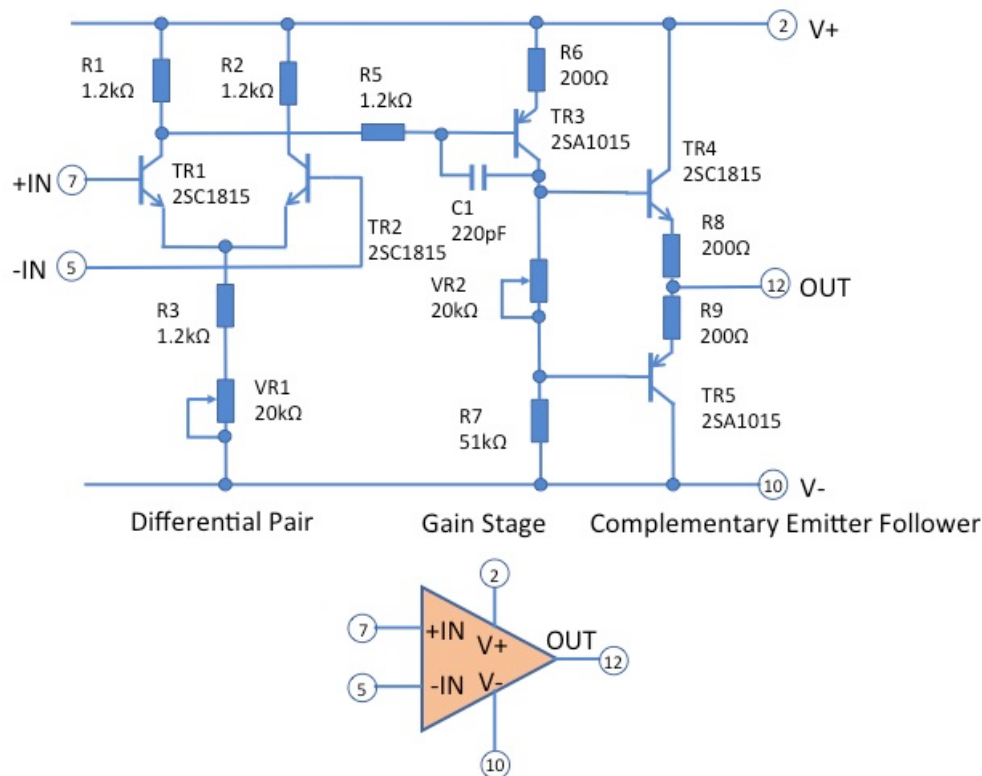


Fig. 1 Simple Discrete Operational Amplifier OPM-01

1-2. Differential pair

Shown in Fig.1, the differential pair consists of two transistors TR1 and TR2. Offset adjustment of the entire operational amplifier is done by VR1. This VR1 needs to be a multi-turn type. In commercial operational amplifiers, this is not necessary because each individual unit is laser-trimmed.

1-3. Gain stage

The gain stage consists only of a transistor TR3. The capacitor C1 is for phase compensation and is set to a large value for stability. If C1 is not used, a frequency characteristic of GB product = 4 MHz can be obtained, but it may cause micro oscillation.

1-4. Complementary emitter follower

The output stage of this op-amp is an ordinary complementary emitter follower by TR4 and TR5. This stage is no voltage gain but has current boosting. The VR2 is used to experiment with different biases to see the crossover distortion.

1-5. Result

Figure 2 shows an example of a non-inverting amplifier configuration and Fig. 2-1 shows input/output waveforms of the measurement. The oscilloscope's upper signal is 10 kHz 280 mVp-p sine wave input signal and the lower signal is the output signal. The measured resistances $R_{51} = 5.02 \text{ k}\Omega$ and $R_{52} = 50.4 \text{ k}\Omega$ gave a theoretical gain of 11.04x, while the measured gain was 10.96x with a gain error of 0.7 %. This was good enough for learning purposes.

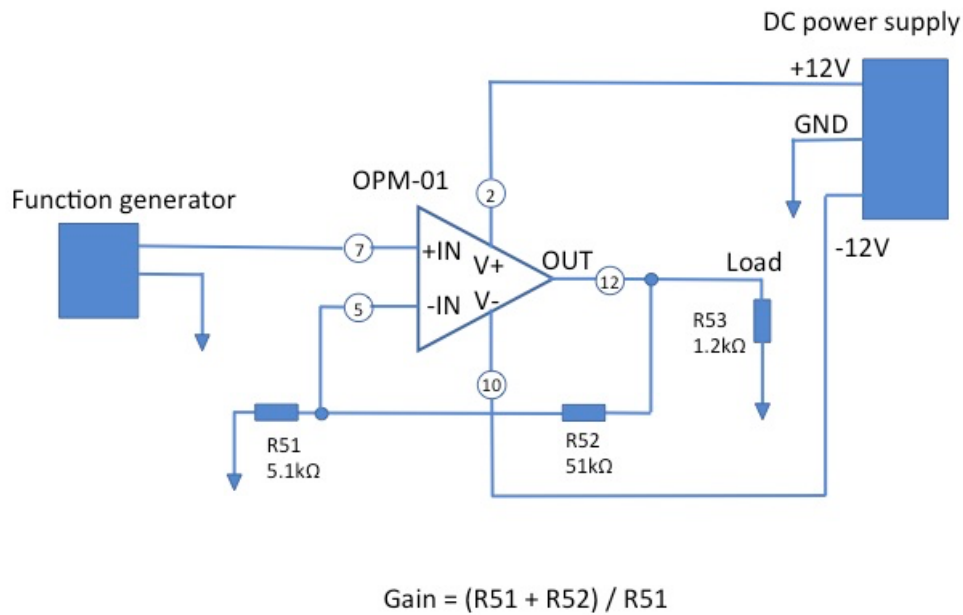


Fig. 2 Non-inverting amplifier configuration of OPM-01

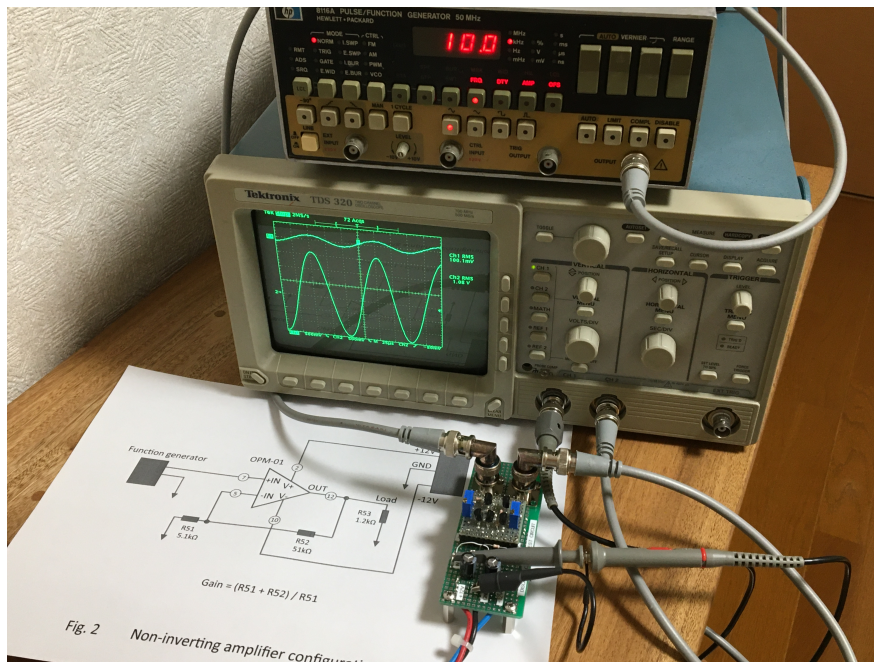
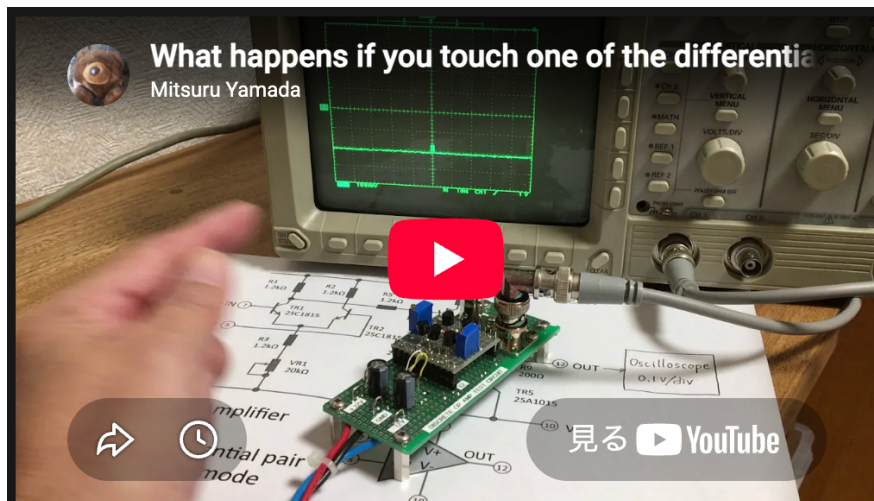


Fig. 2-1 Measurement of input/output waveforms of non-inverting amplifier configuration.

Following video shows an open loop drift,
 (00:00) if TR1 and TR2 are thermally uncoupled and the temperature changes by touching either of them, the output voltage can be seen to drift.
 (01:08) If TR1 and TR2 are subjected to the same changes, the output drift will cancel out and you will feel the differential circuit in action.



<https://www.youtube.com/watch?v=hyw-soufbXo>

Adjusting VR2 to zero ohms will cause TR4 and TR5 to operate in class B, resulting in crossover distortion; adjusting VR2 to around 5 k ohms will increase the bias voltage of TR4 and TR5, eliminating crossover distortion.

Figure 3 shows a modification to a power operational amplifier. With the emitter follower in Darlington configuration TR6 and TR7 attached, it can drive 0.35 A DC for an 8 ohms load. The stereo audio power amplifier shown in Fig. 4 is built with the power op amps. The output power is 1 watt, so I can listen to sound sources such as CD players through the speakers.

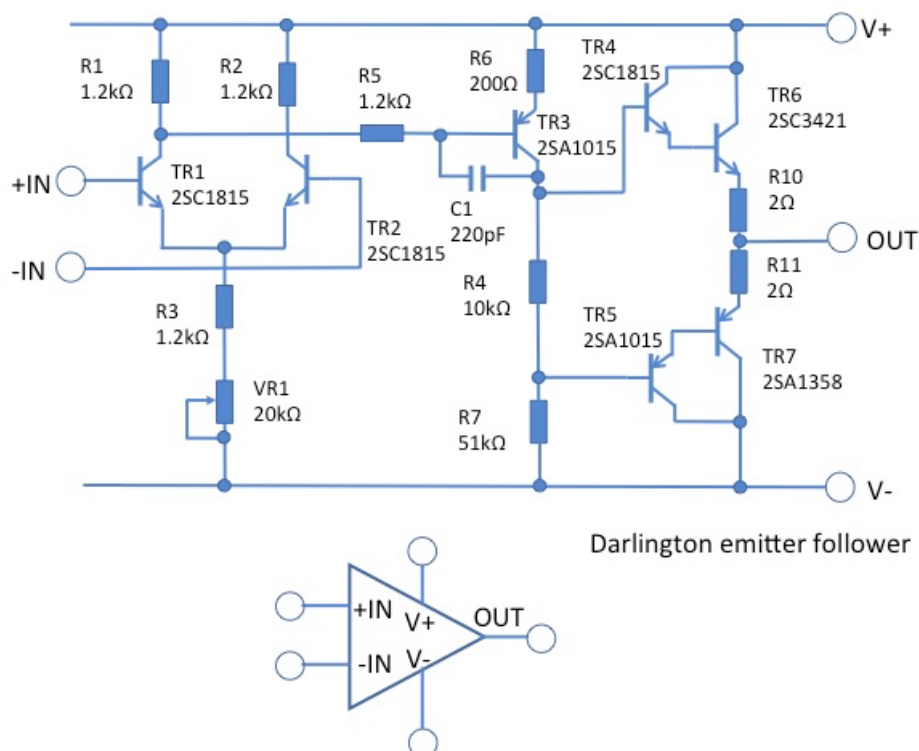


Fig. 3 Simple Discrete Power Operational Amplifier OPM-02

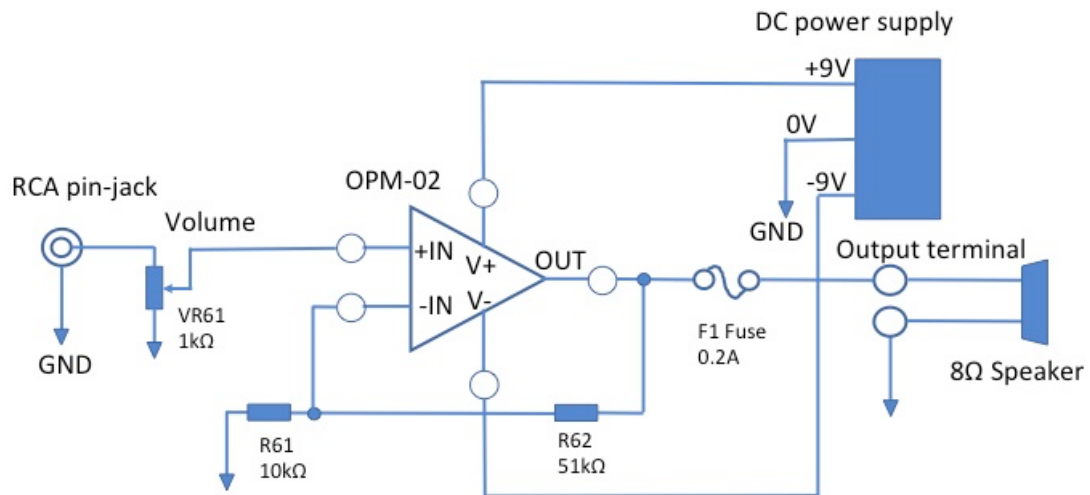


Fig. 4 Audio amplifier configuration of OPM-02

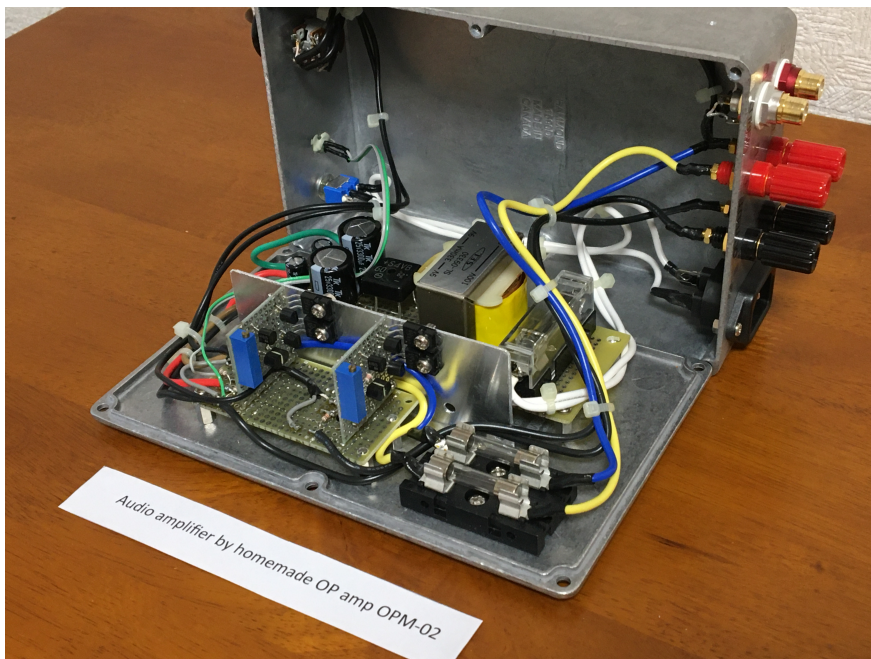


Fig. 4-1 Audio amplifier by using the homemade power operational amplifier OPM-02

Reference

[1] CMOS Homemade Operational Amplifier, <https://hackaday.io/project/191138-cmos-homemade-operational-amplifier>

(Posted on Jan. 16, 2021)

(Latest revision on Aug. 02, 2026)