Audio chain for direct conversion receivers

Note: All pictures used in this article can be found in higher resolution at:
https://github.com/danielromila/Audio-chain-for-direct-conversion-receivers

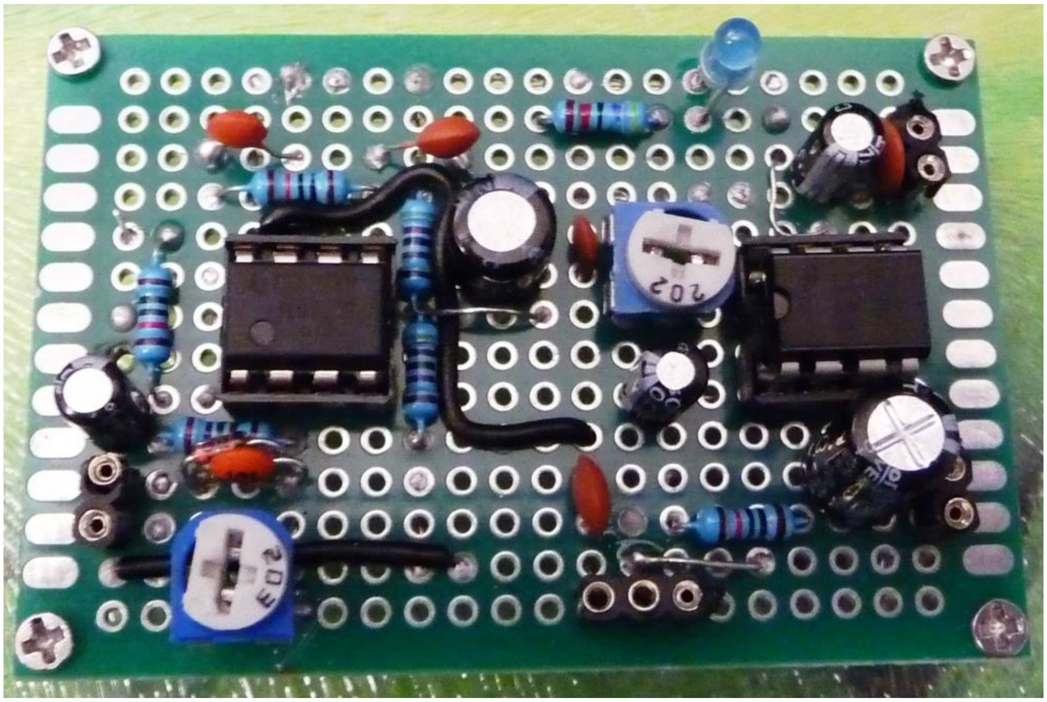
Playing with direct conversion receivers is fun. One of the problems with this type of receivers is that almost all sensitivity comes from the amplification given by the audio chain, from the mixing of the antenna signal with the local oscillator signal and up to the headphones/speakers. If we want to obtain 100 mV into headphones from a 1 microvolt signal resulted in the radio frequency mixer, we need 100,000 times amplification. Such an audio chain is susceptible to self-oscillation.

My initial goal was to reach a stable 4,000 times amplification and eventually to extend this to a 40,000 times amplification. Just for getting a grip on those numbers. I mention here that a class AB audio amplifier with 2 complimentary bipolar finals and a bipolar driver transistor has an amplification of around 20 times. A 4 transistors class AB amplifier has around 200 times amplification.

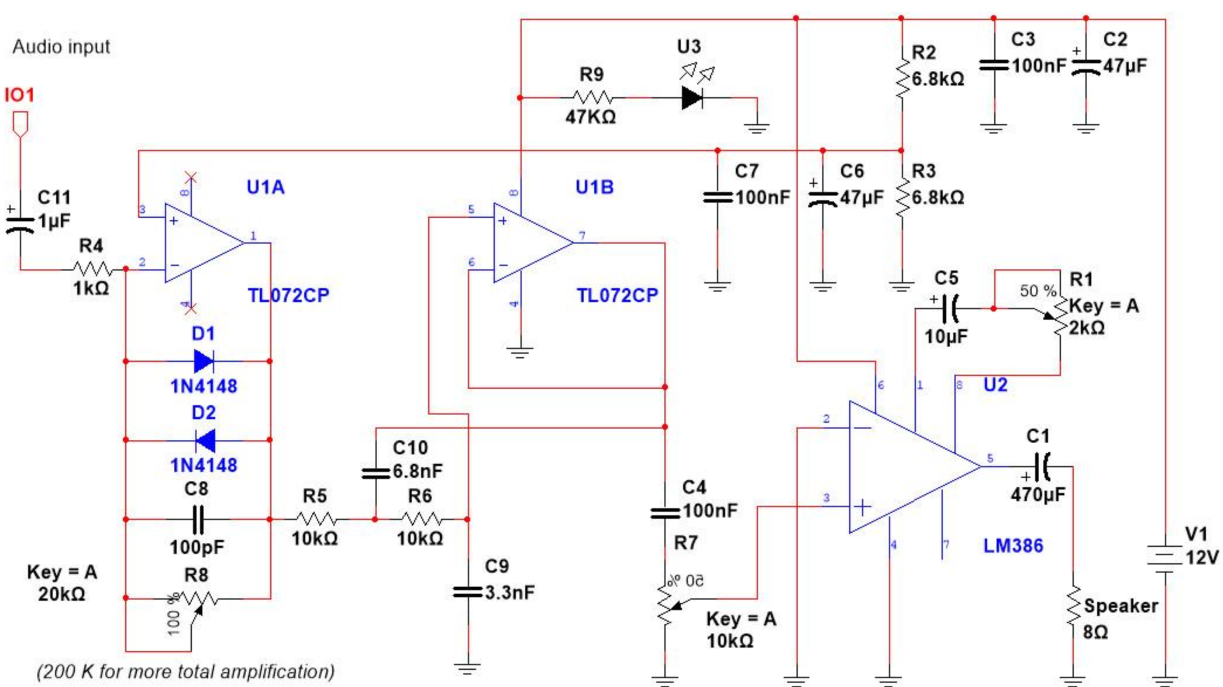
In order to obtain a big amplification:

- The input and output impedances should be low in all amplification blocks, to lower the chance of self-oscillation.
- The output final amplifier should be separated from the preamplifier and somehow the high audio frequencies should be cut somewhere in the middle, by a filter (self-oscillation happens mostly at higher frequencies).
- The first audio active element needs to have low noise. The noise of the first element is amplified by the whole audio chain and heard into the speakers/headphones.
- The amplification should be adjustable in various points of the amplifier, for future expansion from 4,000 times amplification towards 40,000 times amplification.

Following the above ideas, I made a final product on a 4 cm by 6 cm board that looks like this:

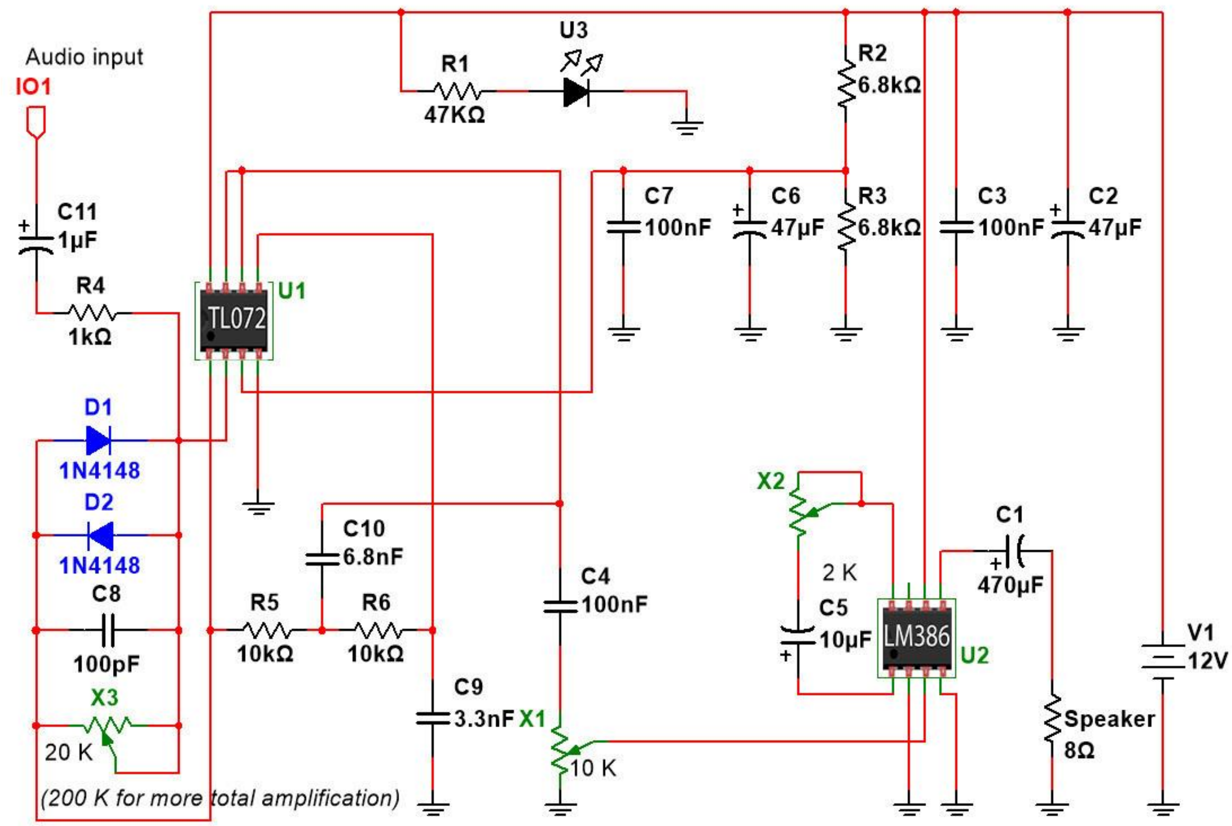


The schematics I got at is:

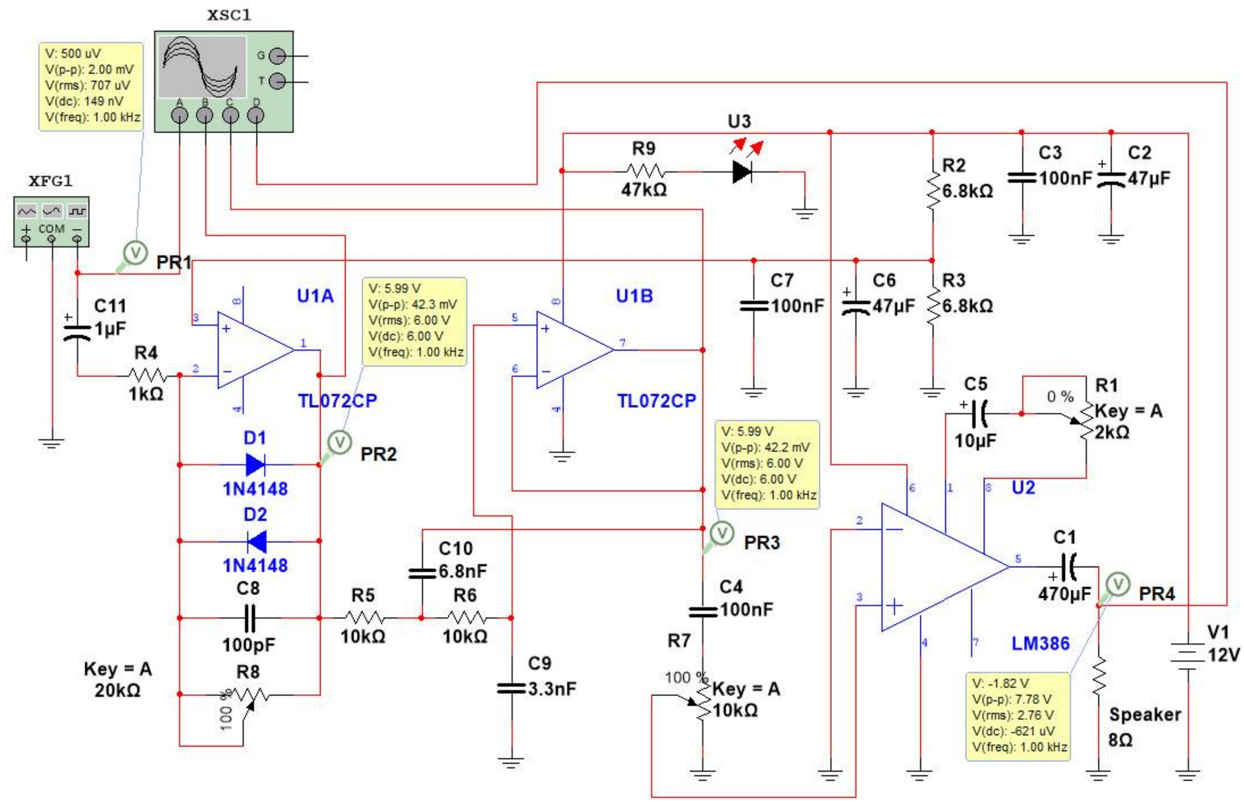


I use 8 pins integrated circuit TL072. The typical noise level is 15 nV/√Hz. TL072 is a high speed JFET input dual operational amplifiers incorporating well-matched, high-voltage JFET and bipolar transistors in a monolithic integrated circuit. The device features high slew rates, low input bias and offset current, and low offset voltage temperature coefficients. For comparison, the 741 operational amplifier family of circuits have the noise level 60 nV/sqrt(Hz), so 4 times bigger than TL072. Even better results can be obtained using the integrated circuit NE5532, which has an Equivalent Input Noise Voltage of 5 nV/√Hz, or LM833-N, with 4.5 nV/√Hz typical at 1 kHz.

At the moment of writing this article, March 2020, LM833-N can be bought with 22 cents by piece (shipping and taxes included), versus 11 cents for a TL072. NE5532, TL072, TL082, LM833-N, and OPA2134 have the same pinout and can be put in the above schematics without any modification. I also drawn the schematics having the real ICs put in it:



Before soldering everything on a double-sided perforated board I verified in a computer simulation. The setup for the computer simulation done with Multisim:

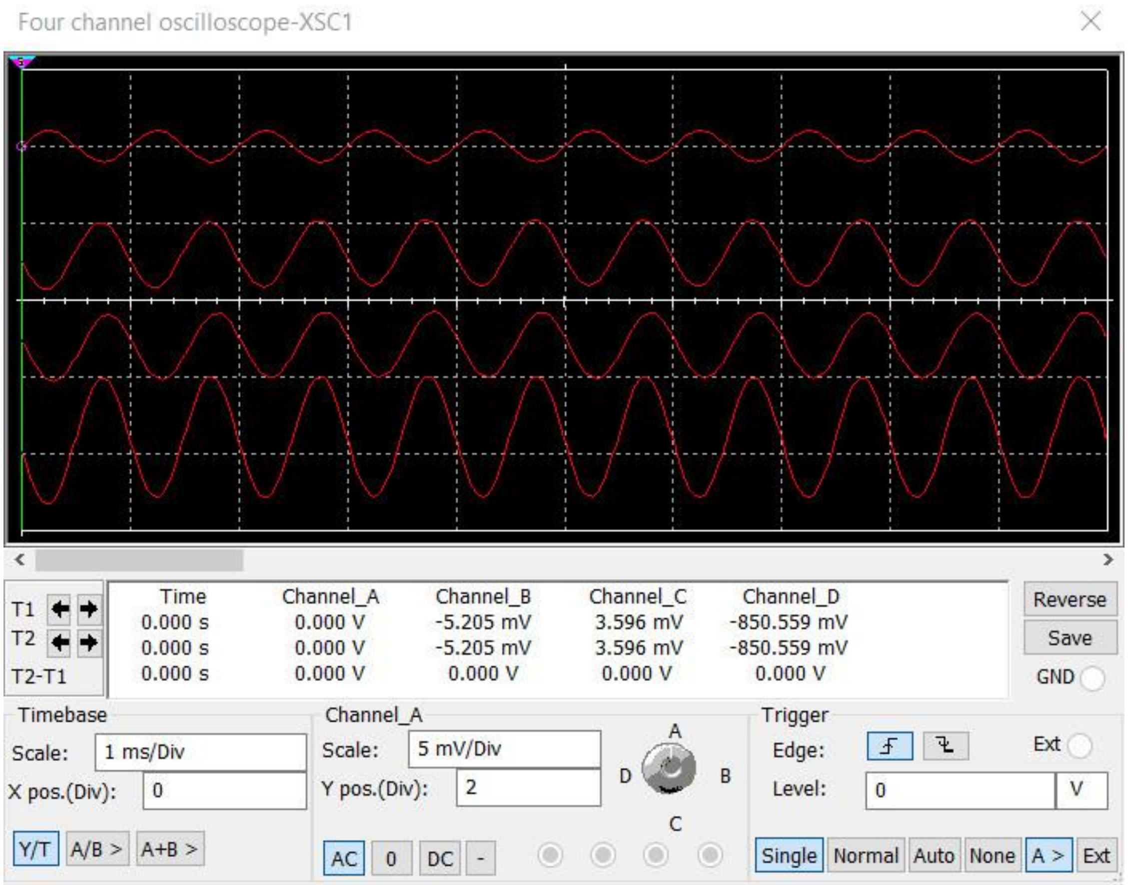


The first operational amplifier is connected in an inverter mode. The amplification is roughly dictated by R8/R4. The stronger the input signal, the stronger the effect of D1 and D2 diodes, which function in the nonlinear part of their characteristics diagram. Their equivalent resistance comes in parallel with R8, so the amplification becomes smaller for bigger input signals. R8 is an adjustable semi-pot with the value of 20 KOhm. This would give a maximum amplification for the first block of around 20 times. This R8 component can be increased to 200 KOhm (which I did) or even more. C8 capacitor, with a value of 100 pF is a kind of short-circuit for high frequencies, while having a big equivalent AC resistance (capacitive reactance) in audio frequencies. (TL072 amplifies up to 10 MHz, and I am not at all interested in amplifying RF with it, and it would eventually self-oscillate in RF.) In the above simulation, when the given input is 2 mV at 1 KHz peak to peak the output is 42.3 mV pp, for R8 being 20 KOhm. That is around 20 times amplification.

The second operational amplifier is a low pass filter. C10 is selected from a bunch of 6.8 nF capacitors to have the value as close as possible to 7 nF. C9 has the standard marked value of 3.3 nF, but it was also selected to be 3.5 nF. The cutoff frequency is around 3 KHz. The amplification of this second op amp block is 1, or a little under 1, as seen comparing the values from the input and output. I used the calculator from: http://www.calculatoredge.com/electronics/sk%20low%20pass.htm

As a final audio amplifier, I used LM386. This is not my favorite IC; TDA2003 offers lower distortion and higher amplification, for example. But LM386 is incredible stable (TDA2003 is not). LM386 is cheap and it can be bought in 8 pins capsule for around 7 cents by piece, shipping and taxes included. The normal amplification is 20 times. It can be forced to 200 times by connecting a 10 microF electrolytic capacitor between the pins 1 and 8 of the IC. I did this in my schematics, but I also inserted a semi-pot of 2 KOhm in series with the capacitor.

When the volume potentiometer R7 (10 KOhm) is set for maximum volume, and also the semi-pot is put at 2KOhm, the obtained amplification is 184 times in the LM386 block. The virtual 4 channels oscilloscope shows sinusoidal signals everywhere, even with such a big input signal, 2 mV pp.



In the simulation I obtained 7.78 V on the speaker with an input of 2 mV at 1 KHz. That is 3890 times total audio amplification. Practical, on the PCB, I immediately replaced the R8 semi-pot 20 KOhm with 200 KOhm and it continued to be stable (I had to lower the input signal.)

There are various versions of my schematics on the Internet; one op amp amplifier, one op amp low pass filter, LM386 final. My version has the advantage that is adjustable. So, it starts with a stable amplification, where the hobbyist can see the amplifier in function and from there it can improve towards bigger and bigger amplification. For example, VU2UPX made a direct conversion receiver by using a similar audio chain with what I did, and just several components around the integrated circuit NE612 in the RF part. VU2UPX forced the amplification of the first op amp at over 500 times. He did not even put any resistor at the non-inverting input, so I suspect he forced the full audio chain just up to the self-oscillating threshold.

https://www.qsl.net/va3iul/Homebrew_RF_Circuit_Design_Ideas/HF_DCR_VU2UPX.gif

Generally, the only possible source of problems is the R7 volume potentiometer. It is a big mechanic component which requires cables on the case, where it is supposed to be mounted. The pot can be soldered directly into the PCB and the whole audio and pot assembly to be together fixed somehow on the final case of the project (a receiver or transceiver, most probably). I also experimented with digital potentiometers, which require an IC planted on the PCB and a rotary encoder on the case. Only the digital IC is in the audio path, so long cables to the panel for the rotary encoder does not bring self-oscillation problems anymore.

LM386 is a low power amplifier integrated circuit. It is more suitable for listening into headphones than into a speaker. Whenever I use 3 terminals semi-pots in schematics that require 2 terminals semi-pots, I connect one of the extremes to the wiper. In this way it is less susceptible to collect noise and eventually to contribute to self-oscillations.