# Circuit design – Fixed challenge 2019

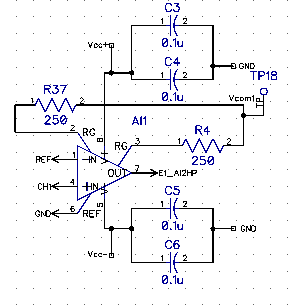
## Overview of the circuit

## Amplification

Electrical signals coming from the human body have weak amplitudes typically ranging from 1mV to 100mV. For the electroencephalogram (EEG), the voltage that can be measured at the surface of the brain is about 1-2mV whereas it decreases to microvolts (μV) when measured on the scalp with electrodes.[[1]](#footnote-1) Thus acquiring and visualizing EEG signals requires amplification of ~ 10 000. Such a gain allows the manipulation of the signals without saturating the operational amplifiers present in the circuit.

### Instrumentation Amplifier

The circuit to acquire EEG signals contain an operational amplifier placed directly after the electrodes to provide the signal with an initial gain before being filtered. The op amp used is Analog Devices’ AD8422, which is a high performance, low power, rail-to-rail precision amplifier. For the AD8422, the gain is determined by placing a single resistance RG across pin 2 and 3. PolyCortex decides the value of this resistance would be 2 times 250Ω, therefore inducing a gain of ### (Gain = 1 + 19.8kΩ/RG). Furthermore, the datasheet suggests placing bypass capacitors (C3, C4, C5 and C6) as close as possible to each supply pins.



*Figure 1 : Schematic of the in-op AD8422*

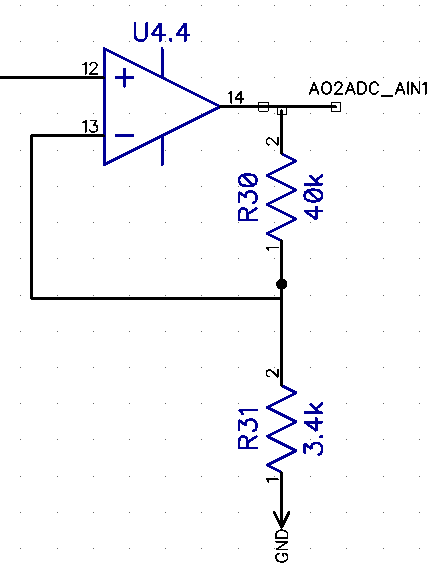
### Circuit Amplification

To obtain the expected gain of ~10 000, the different filtering layers can also be used to introduce a gain. The filters used in this EEG circuit are second order Butterworth active filters where two resistors (Rf and Ri) , R18 and R19 on figure 2, can be connected to the output signal without affecting the cutoff frequency. Consequently, the gain of the high pass and low pass filter is proportional to the ratio of these two resistors (Gain = 1 + Rf/Ri). During the design process, PolyCortex chose to introduce a gain of 8.9 in both filtering levels.



*Figure 2 : High pass filter with a gain (G = 1 + R18/R19) of 8.9*

After the signal has made its way through the amp-op and the filtering levels, it is amplified a final time with a non-inverting operational amplifier. For this configuration, the gain is once more proportional to the ratio of the chosen resistors (Gain = 1 + Rf/Ri) R30 and R31 on figure 3.

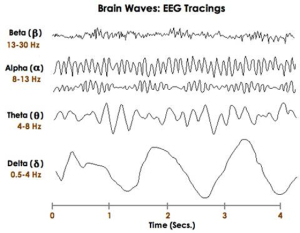


*Figure 3 : Final amplification level with a gain of 12.8 (G = 1 + R30/R31)*

The total gain produced by the cascading of the amp-op, the high pass and low pass filter and the non-inverter is thereby the multiplication of each individual gain, producing a final gain of ###.

## Filters

Due to their weak amplitudes, EEG signals are very susceptible to electromagnetic and common mode contamination. Additionally, EEG signals collected with electrodes may contain EMG information from the subject’s muscular activity and ECG signals from the polarizing cycles of heart cells. Is it thus important to filter the signal to isolate the frequency bands of interests for EEG analysis. The electroencephalogram is composed of 4 district waves ranging between 0.5 and 30Hz; the beta wave (13-30Hz), the alpha waves (8-13Hz), the theta waves (4-8Hz) and the delta waves (0.5-4Hz). PolyCortex therefore decided to filter outside of a bandwidth ranging from 0.3 to 35Hz to preserve all relevant EEG information.



*Figure 3 : Frequencies of EEG waves*

### High pass

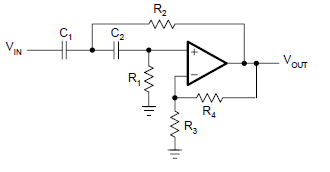
The first filtering stage is a high pass Butterworth filter of the second order.

Figure 4 : High pass filter configuration (left : Diptrace schematic, right: theorical configuration)

The cutoff frequency f of such a filter is determined by the value of R2 and the value of C1 following the equation with and . PolyCortex has chosen R1 = 75kΩ, R2 =37.4kΩ and C1 = C2 = 10µF, thus providing a cutoff frequency of 0.3Hz. The remaining resistor provide a gain to the filter, as explained in the Circuit Amplification section.

### Low pass

To insure the cutting off of EMG signals and other noise, the Butterworth low pass filter has a cutoff frequency of 35Hz. The cutoff frequency of this filter is given by the following equation referring to the right-side image of figure 5. In PolyCortex’s schematics (left-side of figure 5), these values have been set to R1 = 3.4Ωk, R2=60.4Ωk, C1= 0.1µF and C2= 1µF. Therefore, the cutoff frequency is 35Hz.

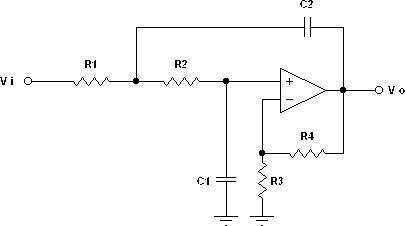
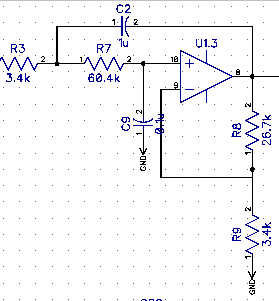


Figure 5 : Low pass filter configuration (left : Diptrace schematic, right: theorical configuration)

### Notch

When working near electrical power-lines, the electronic circuits will be affected by the mains hum, or electric hum, which is a noise associated with the alternating current of the power-line. In PolyCortex’s case, the fundamental frequency of the mains hum is 60Hz coming from Hydro-Quebec and has a maximum intensity of 30dB. It was considered wise to add a notch filter to the circuit to target this specific intense noise. For this specific configuration, the cutoff frequency is given by the equation with and (referring to the right-side of figure 6). To obtain a cutoff frequency centered around 60Hz with a gain of at least -30dB to eliminate the mains hum, PolyCortex chose values of R1 = R2 = 5Ωk, R3 = 10Ωk, R4 = R5 = 20Ωk, C1 = 94nF and C2 = 3 µF. These values produce a gain of about -36dB when simulated in LTspice (see simulation section).

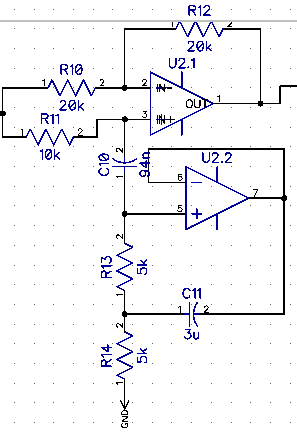


Figure 6 : Diptrace schematic for the notch filter (cut-off frequency of 60Hz)

### Common mode chokes

The circuit includes common mode chokes to eliminate a maximum of electromagnetic and radio frequency interferences from the power supply lines. The common-mode current creates a magnetic field when passing through the coil that opposes any increase on its intensity, thus blocking the common-mode current and passing differential current. PolyCortex chose CM4732V301R-10 by LAIRD, which works at a maximum current of 8,000mA and 30V.

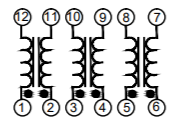
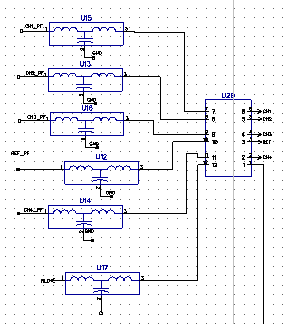


Figure 7 : Diptrace schematic of common mode chokes (left) and equivalent circuit (right)

## Right leg driver

According to Texas Instruments, the common-mode rejection (CRM) is one of the most important parameters in ECG and EEG systems. Therefore, a right leg driver (RLD) circuit was added to further decrease the common-mode interference. The RLD circuit sets the user’s common-mode voltage to increase the effective common-mode rejection ratio of the circuit.[[2]](#footnote-2) To do so, the RLD low-passes the common-mode voltage measured by the differential amplification stage.

## RF filters

Radio frequency (RF) filters were added to the circuit to remove high frequency (MHz-GHz) signals originating from broadcast and wireless communication. The filtering of these frequencies is important considering they could affect the envelop of the output signal. PolyCortex uses Bourns Inc.’s EMI103T-RC filter for their good noise filtering properties, which also attenuate the mains hum with a factor of about -50dB.

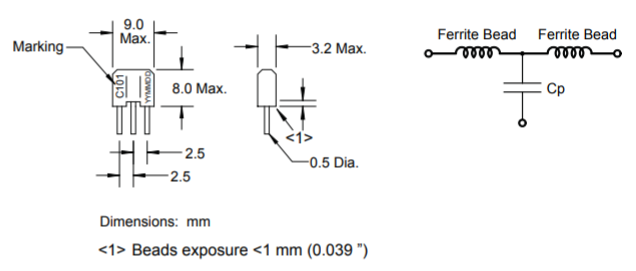
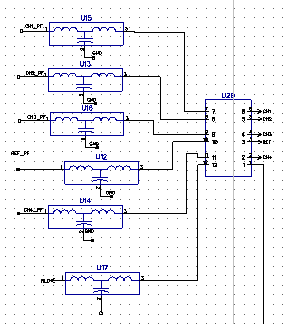
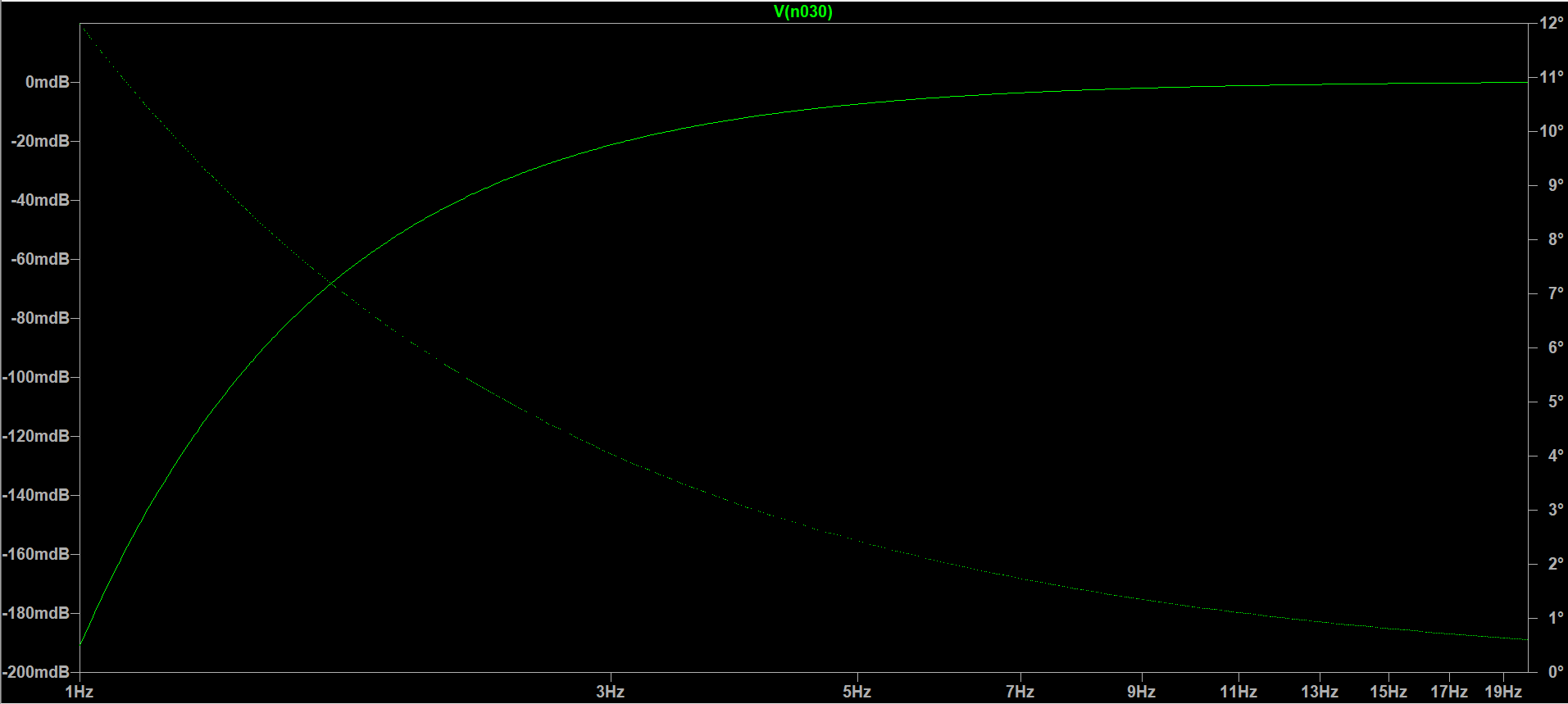
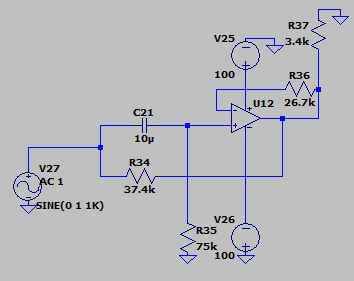


Figure 8 : Configuration of RF filter (left : Diptrace schematic, right : theorical configuration)

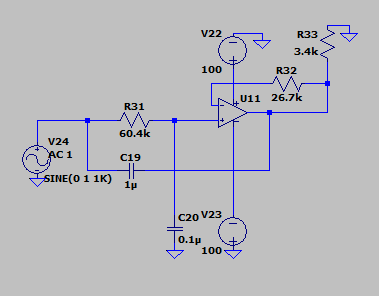
## Simulation

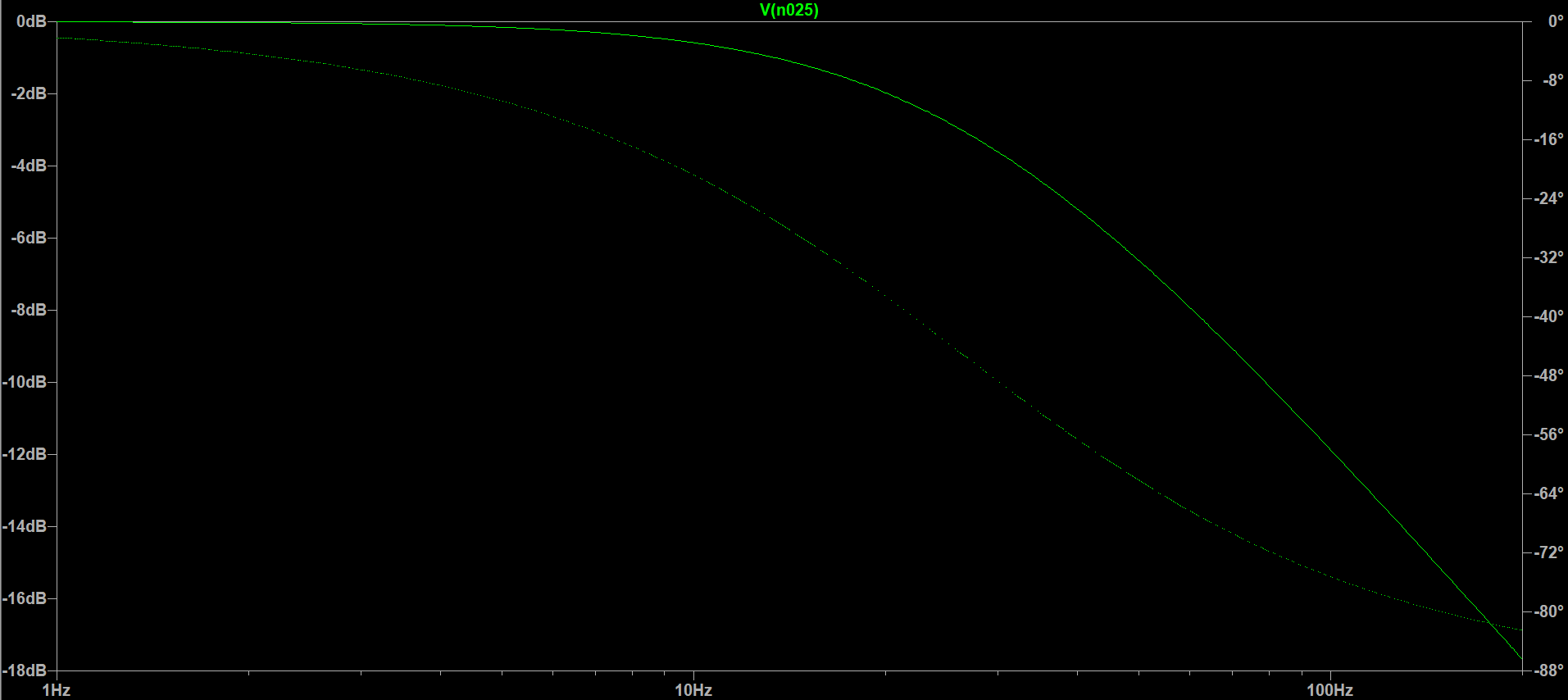
To insure the circuit behaves like it should, PolyCortex simulated every filtering stages with LTspice and tested the final amplification as well as the filtering capacities.

### High pass filter

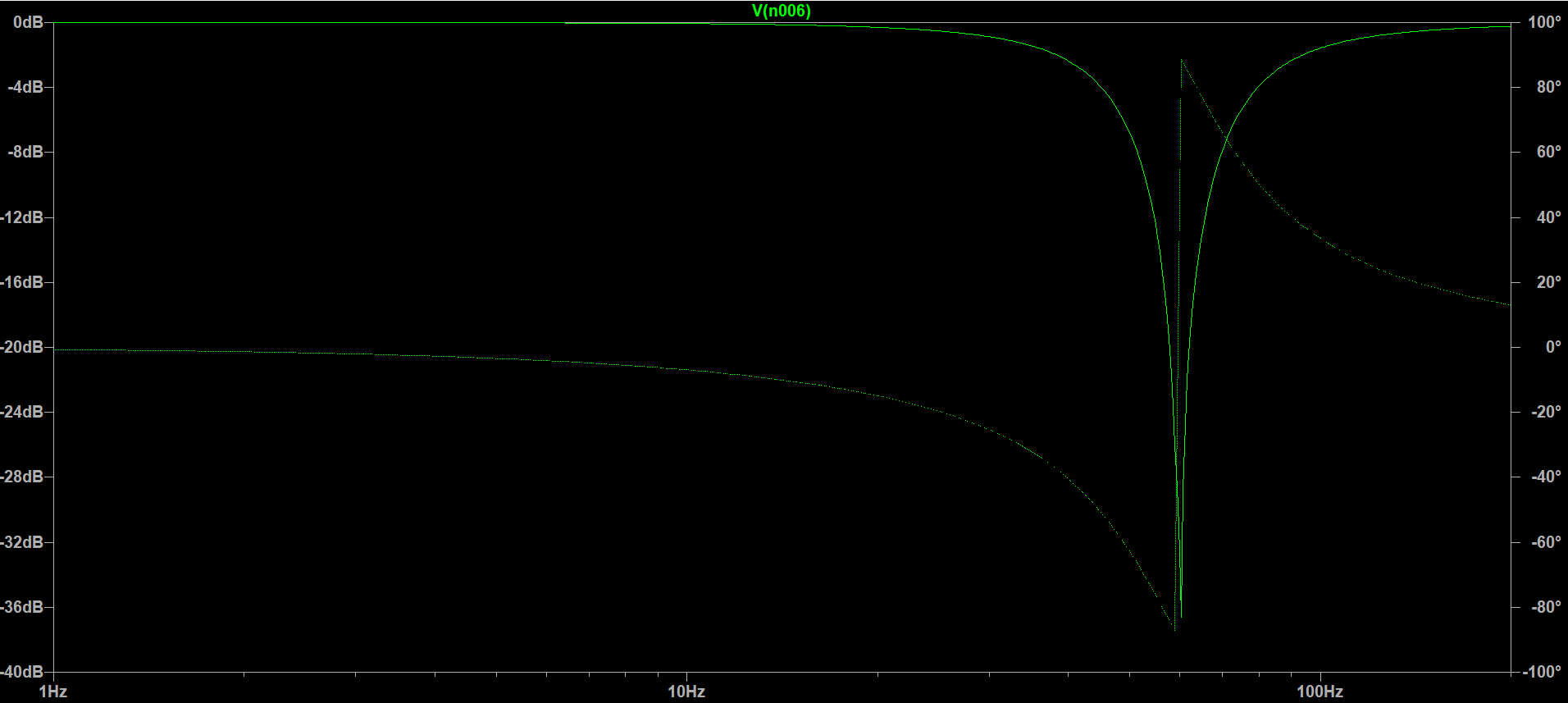


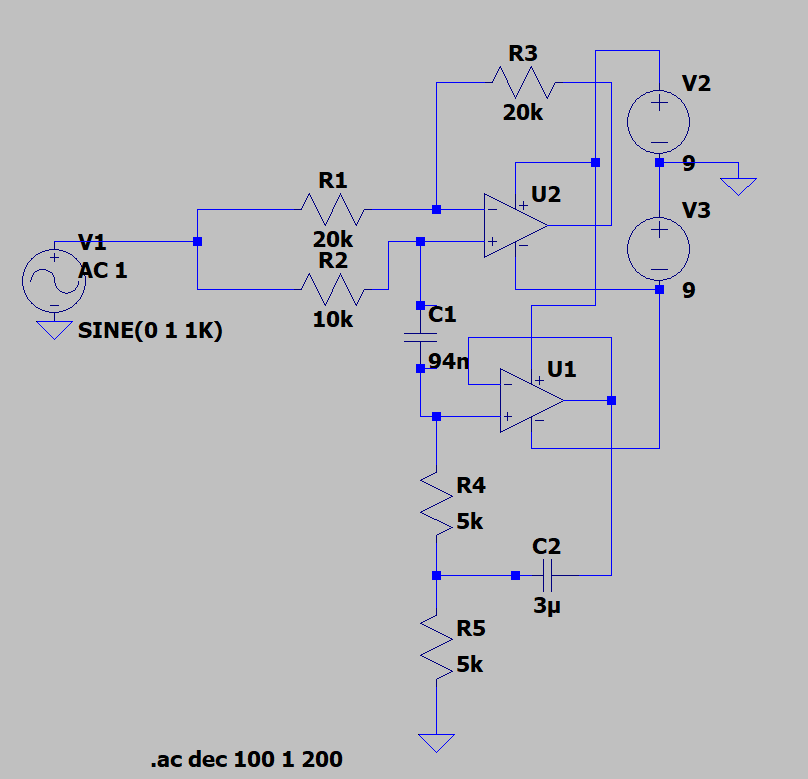
### Low pass filter





### Notch





## Components

### Power supply

### DC DC converters

### ADC

## Schematic, layout and routing

## Testing

## Board cost

1. [↑](#footnote-ref-1)
2. http://web.mit.edu/6.101/www/s2015/projects/narango\_Project\_Final\_Report.pdf [↑](#footnote-ref-2)