Introduction to Measurement system: Tarea 3
Heartbeat Measurement Circuit

LA-CoNGA physics

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1 Objective:

The objective of this Lab activity is to learn how to use a chain of amplifiers for gain and filtering, in a practical example, that aims to recover heartbeat information. The result of the system provides an relevant output that is displayed using Arduino & LabVIEW

2 Background:

A type of Heartbeat Measurement Device consists of an electronic circuit that monitors heartbeat by clipping onto a finger tip. It does this by shining light through your finger and measuring how much light is absorbed. This goes up and down as blood is pumped through your finger. For the operation as a optical heartbeat detector, a pair of IR LED and Phototransistor is used. The LED emits light through the finger and is detected by the phototransistor, which acts like a variable resistor conducting different amounts of current depending on the light received.

The voltage variations change with the heartbeat and are acquired from the collector of the phototransistor. The small signal obtained is used as input for the circuit, obtaining the behavior of a heartbeat detector.

In order to have a relevant output, the input signal is passed through multiple circuits:

- Preamplifier - the output signal from the heartbeat measurement setup is decoupled through the series capacitor and amplified using a negative feedback resistor.
- Low-Pass Filter - RC filter that cuts the high frequencies (noise).
- Voltage Follower - buffers the output of the low-pass filter and reproduces its voltage with a low impedance output.

- Inverting Amplifier with Low-Pass Filter - amplifies the voltage signal and cuts the high frequencies (noise)

3 Procedure

1. **Simulation** - Design the circuit of figure 1 in LTSpice.

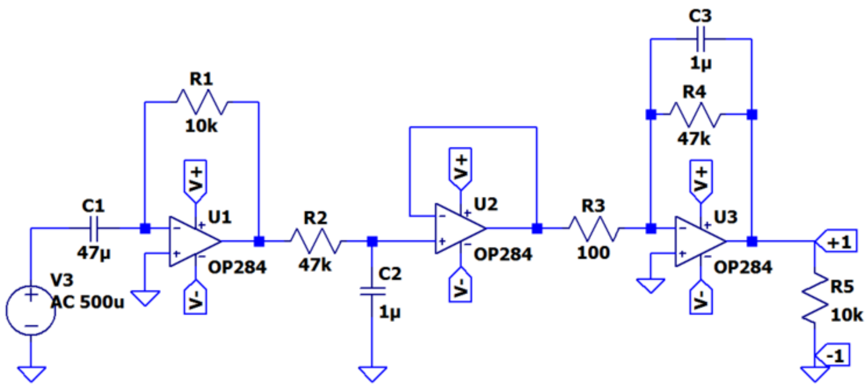


Figure 1: Heartbeat measuring circuit, the IR LED and Phototransistor are replaced by a signal generator

Two types of simulation are made:

- Transient - Connect at the input of the circuit a waveform generation source. Configure the source to generate a sine with amplitude of $500uV$, frequency $2Hz$ and $500mV$ offset. Observe the output signal amplitude in order to determine graphically the total gain of the circuit.
- AC Sweep - Connect at the input of the circuit a AC Source. Configure the source to have a magnitude of $500uV$. Observe the output signal in a chosen frequency domain $(100mHz - 1kHz)$ in order to determine graphically in which frequency range the output signal has the biggest amplification, an example is shown in figure 2

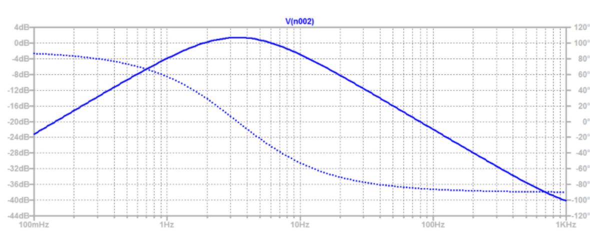
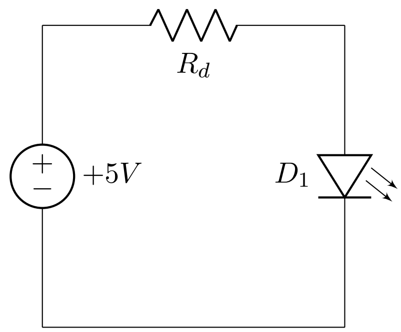


Figure 2: Output Voltage AC sweep simulation

2. **Analyzing the circuit** - The circuit can be divided in the following stages:

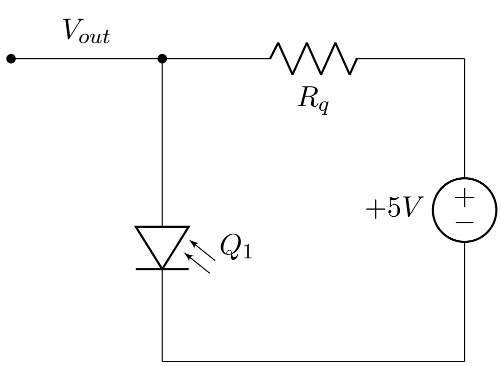
- **IR LED** - In order to have a proper current that will not damage the IR LED, a resistor needs to be added in series to limit the current. Varying the value between in the operating range will change the intensity of the emmited signal of the IR LED. Consider the circuit below:



  The following formula expresses the value of the forward current (I_F) through the LED, based on the positive voltage supply +5V (V_P), series resistance (R_1) and forward voltage drop on the LED (V_d):

$$I_F = \frac{V_P - V_d}{R_d} \tag{1}$$

- **Phototransistor** - To acquire information from the phototransistor (Q_1) when is in contact with the IR light, a common-emmiter amplifier circuit is designed. This circuit generates an output which transitions from a high state to a low state when light in the infrared range is detected by the phototransistor.



  The output is created by connecting a resistor (R_q), whose value was determined experimentally, between the voltage supply and the collector pin of the component.

- **Preamplifier** - The input signal from the heartbeat measurement setup is fed into a Differentiator Amplifier Circuit (C_1, U_1, R_1).

- **Active Low-Pass Filter** - Active Filters contain active components such as operational amplifiers, within their circuit design. They draw their power from an external power source and use it to boost or amplify the output signal. Active Low-Pass Filter principle of operation and frequency response is the same as of a simple RC Low-Pass Filter, the only difference being that that it uses an op-amp for amplification and gain control.

  This first-order low pass active filter (U_2, R_2, C_2), consists simply of a passive RC filter stage providing a low frequency path to the input of a non-inverting operational amplifier.

  The filter has the aim to cut the high frequencies that correspond to the noise signal. Taking into account that the heart rate does not exceed a value of 180 beats per minute (bpm) and the dependency between the bpm and the frequency is:

$$bpm = freq(Hz) \times 60 \tag{2}$$

  will result that frequencies that are higher than $3Hz$ should be cut.

- **Final Amplifier with Low-Pass Filter** - The configuration of the final stage represents a AC Op-amp Integrator with DC Gain Control. In simpler words, the circuit has the aim to low-pass filter (R_4, C_3) the signal from the remaining unnecessary frequencies that are higher than the maximum frequency of the heartbeat and amplify through the inverting amplifier the useful signal with a gain enough to display the heart beat in the Arduino.

3. **Signal simulation** -

   To test the circuit an input signal as show in figure 3 must be loaded in LTSpice using PWL function[1] (Use a voltage amplitude of tenths of milivolts).

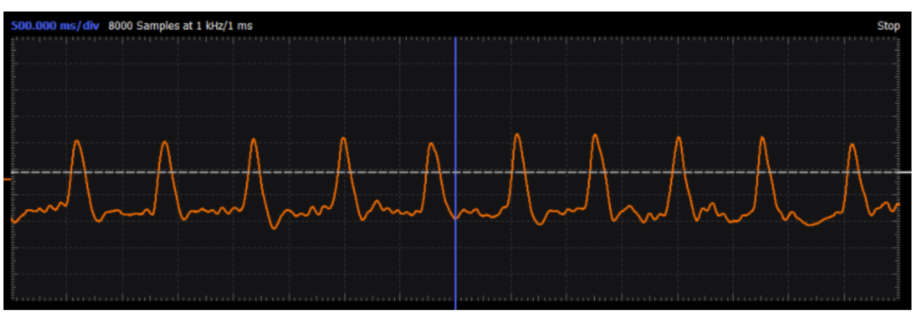


Figure 3: Heartbeat output waveform

Repeat the measurements made with the sine wave and figure out how to estimate band pass and response time of the circuit.

[1] Piecewise Linear function

4 Questions

Using the values of the components in the circuit and formulas provided in this guide compute the following parameters:

- Forward current through the IR LED. (use datasheet of the QED-123)
- Cut-off frequency of the high-pass filter.
- Cut-off frequency of the second stage low-pass filter.
- Cut-off frequency of the third stage low-pass filter.
- Gain of the third stage amplifier