Heart rate monitor

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Introduction

* In this experiment, you will make a heart rate monitor circuit. This circuit is functionally similar to the one used in Apple watch and Fitbit etc.
* The principle of measurement of heart rate is based on PPG (photoplethysmogram). Read about this phenomenon (Wikipedia is a good starting point).
* PPG is used in a wide range of commercially available medical devices for measuring oxygen saturation, blood pressure, heart rate (pulse rate) and cardiac output, etc.
* We will use an IR (infrared) LED (light emitting diode)-phototransistor pair TCRT5000 to detect the PPG signal. The phototransistor output signal will be then appropriately conditioned by subsequent circuit stages.
* The main learning objectives today are to appreciate the application space of the devices that you will be using in this course, and to pique your interest to know more about these devices. The other learning objective is to write a good 1-page technical report on your experience.

Condensed review of PPG-1

* Photoplethysmography (PPG) is a simple and low-cost non-invasive optical technique that can be used to detect blood volume changes in the microvascular bed of tissue.

* During one cardiac cycle, the blood pressure varies in the artery from systolic (max pressure) to diastolic (min pressure). This is sensed as change in reflected optical signal due to change in optical absorption in the blood vessel/tissue.

* If the sensor is not tightly pressed against the skin, a pressure wave associated with the blood flow is also seen as a secondary peak in addition to the systolic and diastolic peaks.

Condensed review of PPG-2

There are two types of optical arrangements:

- Transmissive: In the transmissive type, the photodiode and the LED are placed on opposite sides of the human body part (typically, index finger is used). The photodiode detects the residual light after absorption from the various components of the body part.
- Reflective: In the reflective type, the photodiode and the LED are on the same side of the body part and the photodiode collects the light reflected from various depths underneath the skin.

Typical time-domain profile of PPG signal

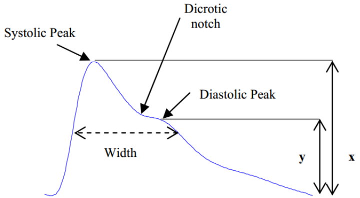

Figure: Typical reflection mode PPG profile. X-axis: time, and Y-axis: sensor output.

The figure shows systolic and diastolic peaks that would have corresponding maximum and minimum pressure values in one cardiac cycle. The heart rate can be calculated be measuring time difference between two systolic points (amplitude x) or two diastolic points (amplitude y).

To test your understanding, think about and sketch how the waveform would look like if the LED and phototransistor would be placed on opposite sides of the finger (i.e. transmission PPG instead of reflection).

Tips for the experiment

* Make sure you set the correct time scale (50 ms) on the oscilloscope. Use Autoset button as infrequently as possible.
* Your eyes cannot see IR light. Do not stare into the LED, as large IR power may damage your eyes. To test whether the IR LED is working, you may use your phone's camera.
* Make sure you limit the collector current before switching on the power. This is to protect eyes - yours, as well as those of everyone around you. And to protect the TCRT5000 from damage as well!
* The amplifier and filter stages can be tested independently of the sensor using function generator and oscilloscope (as you learnt in previous lab).
* The filter cut-off is designed to accommodate signals at frequencies beyond the average heart rate. This choice is justified because the PPG signal is not a sine wave, and contains other frequencies also. (Try FFT on oscilloscope.)
* Pressing the TCRT5000 too hard with your finger might lead to lesser volume variation in the artery and hence small amplitude variation in the PPG signal.

Sensor stage

* TCRT5000 (Vishay semiconductors) is an IR LED-phototransistor pair. Read the datasheet to know more about this device, and pose questions to your TA.
* Do not forget to limit the photo-current; this is done by connecting $10k\Omega$ resistor on the collector side as shown in the figure below.
* The IC pin numbers for TCRT5000 are not shown. Draw the circuit in your notebook and write down pin numbers before making connections and get it verified by your TA.

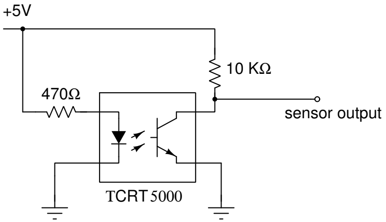

Figure: Sensor stage circuit connections

Filter stage

* Measure the sensor output directly on DSO. Typically, it has low amplitude and a lot of noise.

* We can suppress some noise in the sensor output by filtering out the frequency components which are not of our interest.

* This can be done by designing a band-pass filter that has pass-band to allow signal frequencies of 30 bpm and 120 bpm (bpm = beats per minute).

* Obtain the frequency range by converting units from bpm to Hz.

For a capacitor of 1 μF and R=330kΩ, we obtain cut-off frequency:

$$f_{HPF} = \frac{1}{2\pi \times 330k\Omega \times 1\mu F} = 0.483Hz \quad (1)$$

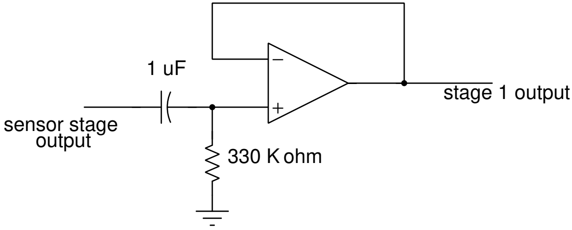

Figure: Schematic for high pass filter stage

This circuit looks different from a simple RC filter. Why have we included an op-amp connected as a source follower (unity gain buffer)?

Filter stage: Low pass filter

For a capacitor of 4.7 μF and R=10kΩ, we obtain cut-off frequency:

$$f_{LPF} = \frac{1}{2\pi \times 1k\Omega \times 4.7\mu F} = 3.38Hz \quad (2)$$

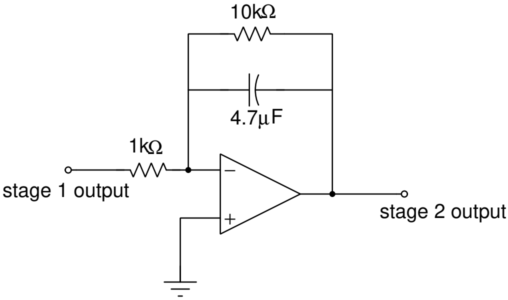

Figure: Schematic for low pass filter stage

This circuit is called an 'active filter'. Comment on the role of the op-amp in this circuit.

Inverting amplifier stage

* The final stage is an amplifier that amplifies the signal 22×.

* Connect all stages, and from the observed PPG waveform, calculate your heart rate. Verify by manually counting your pulse rate using a stop watch.

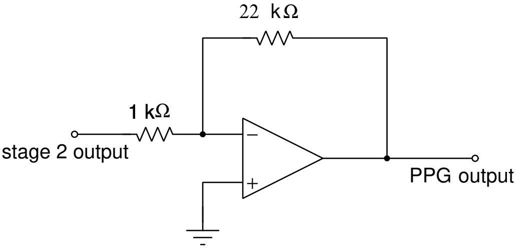

Figure: Inverting amplifier stage

A typical PPG waveform observed on DSO

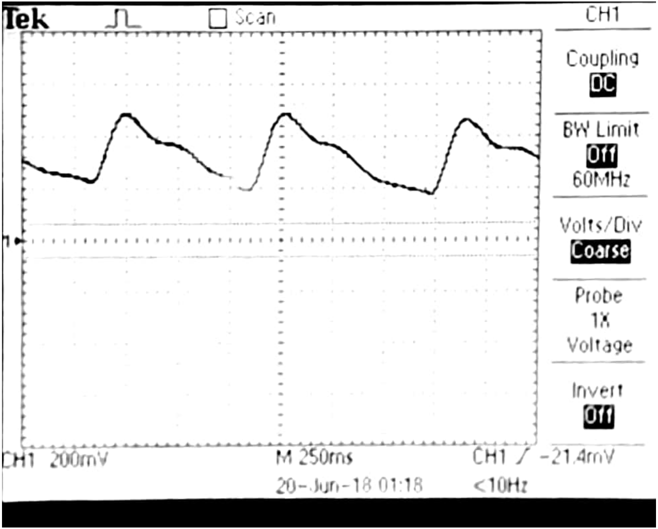

Figure: Typical PPG waveform captured on lab DSO