MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Department of Electrical Engineering and Computer Science
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6.071J 22.071J Introduction To Electronics

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Heartrate Lab Solutions — TA

The goal of this lab is to transform a weak heartbeat signal into a 0-5V square wave. The circuit needs to be robust such that it can accommodate different people, and ambient conditions do not affect steady state circuit operation. Figure 1 shows the desired result and the final output of this suggested design solution in the following pages.

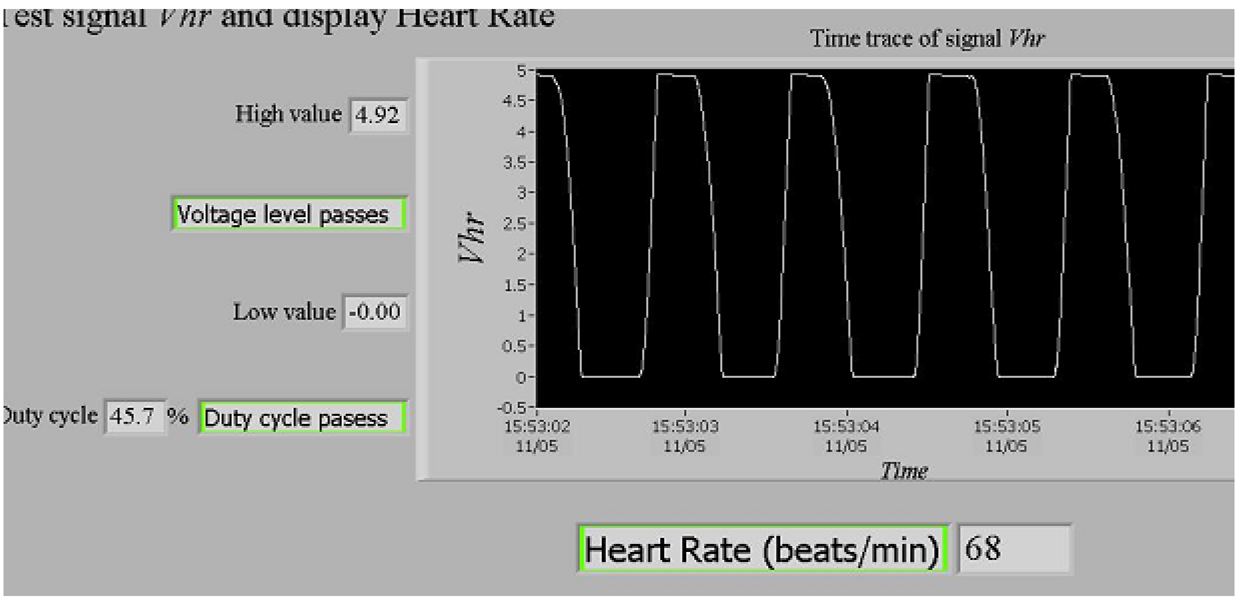

Figure 1: Final circuit output of a 0-5V square wave.

Figure 2 shows an intermediate output of the suggested solution and highlights the shape of the heartbeat signal. In figure 2, the unprocessed signal has already been amplified, low-pass filtered, and high-pass filtered. There still exists a slight DC-drift that is eliminated by the final part of the design solution. The challenges and objectives in processing the naked heartbeat signal with an infrared LED-phototransistor as sensors include:

(1) Keeping the circuit robust such that the circuit operates correctly with a wide range of sensor DC-operating conditions (caused by finger thickness variety).

(2) Eliminating 60Hz noise on the power supplies and 120Hz noise from ambient light.

(3) Eliminating low frequency noise (1/20-1/2Hz) from human body irregularities.

(4) Eliminating the "intermediate fake heartbeat", in between heart beats.

(5) Scaling the output into a 0-5V square wave without a rail-to-rail op-amp.

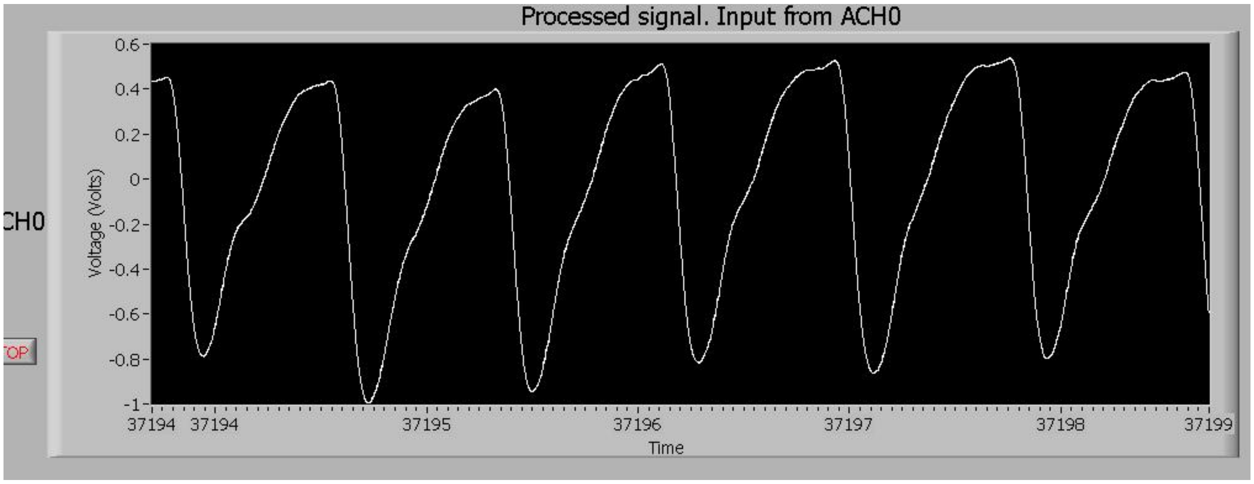

Figure 2: Intermediate circuit output of a heartbeart signal
that has gone through some cleaning.

Figure 3 shows the complete circuit. It consists of 5 main components (from left to right):

(1) The LED-phototransistor sensor array.

(2) A low-gain, all-pass stage that also acts as a buffer.

(3) A first order bandpass filter and amplifier.

(4) Another first order bandpass and amplifier with rectification.

(5) Voltage divider.

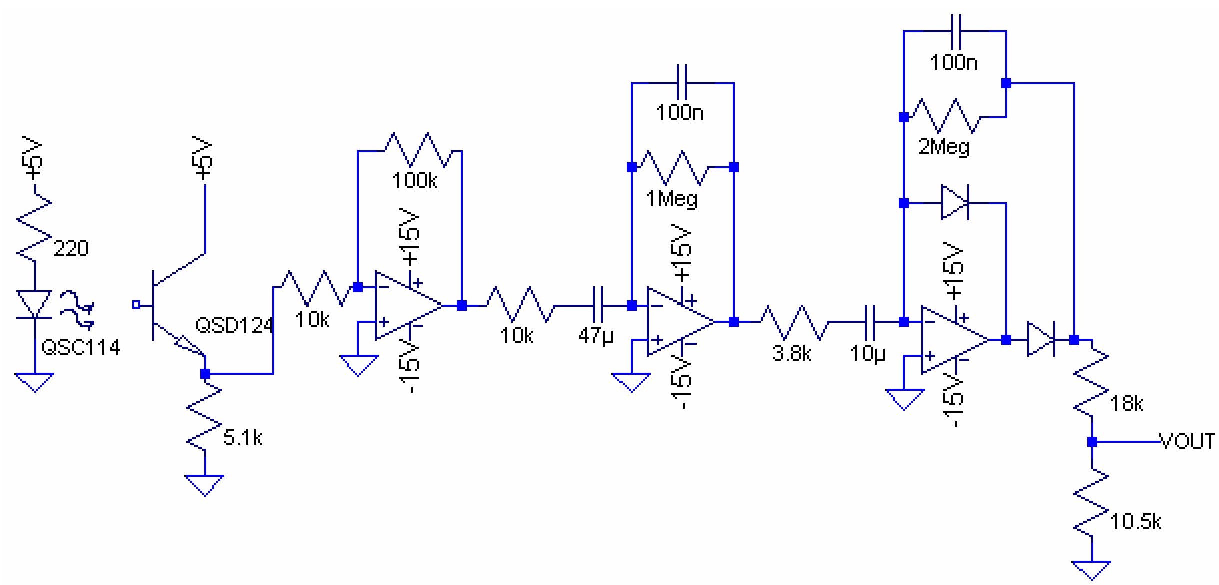

Figure 3: The complete heartrate monitor circuit.

In order to accommodate a wide range of finger thicknesses, the strength of the IR-LED and phototransistor should be adjusted such that the output of the phototransistor has a decent output voltage swing. With a 5V supply, 100 Ohm to 600 Ohm resistors in series with the IR-LED typically allows good input ranges by keeping the output of the phototransistor around 2.5V.

The first op-amp stage acts as a voltage buffer since its input resistance is 10k. The gain is kept low since there can be significant noise at this stage. AC-coupling the output of the phototransistor often causes charging delays since the phototransistor's quiescent current is small.

The second stage op-amp combines a first order low-pass filter and a first order high-pass filter. The low-pass filter has a 3dB frequency at 1.6Hz and eliminates 60Hz and 120Hz signals. The high-pass filter has a 3dB frequency at .34Hz and eliminates some DC drift.

The third stage op-amp combines another first order low-pass filter and a first order high-pass filter. The low-pass has a 3dB frequency at 3.2Hz and the high-pass has a 3dB frequency at .89Hz. The combination of the two filter stages significantly eliminates very low frequency drift. The third stage also rectifies the signal such that the output of the third stage swings from 0V to the high output swing of the op-amp.

The voltage divider that follows the third stage op-amp scales the output signal into a 0-5V signal. A helpful, but optional stage here, is a Schmitt Trigger, which eliminates fake heartbeats and fully amplifies the output into a near-perfect square wave. The above circuit can output a sufficiently decent signal.

Short leads significantly decrease both high frequency and low frequency noise, as in Figure 4 below.

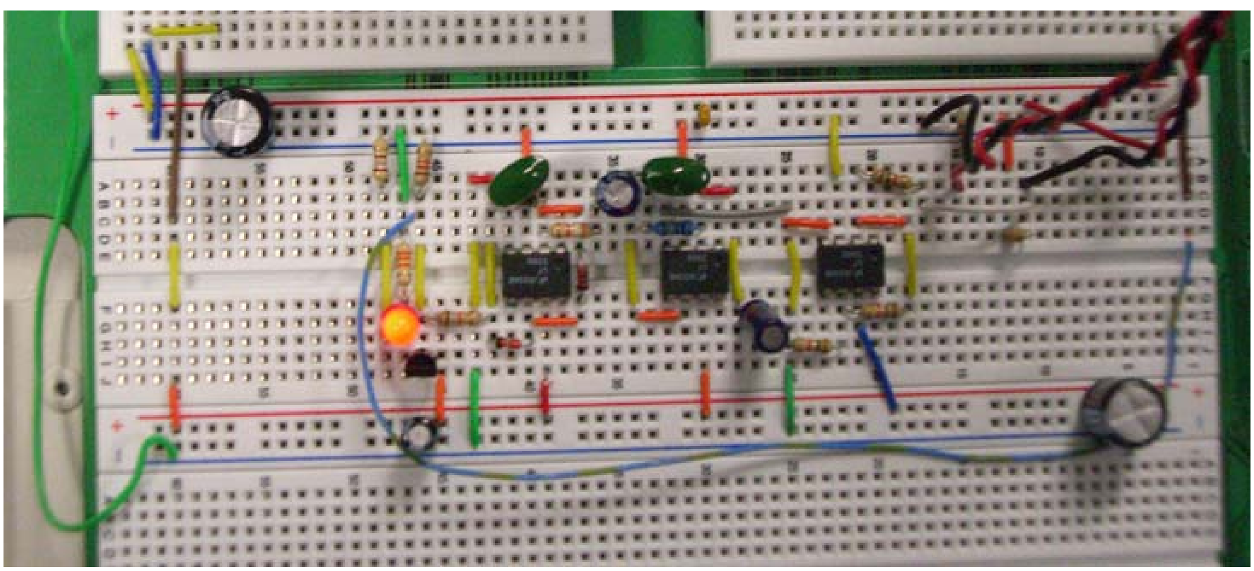

Figure 4: Photograph of the heartrate monitor circuit.