An Autonomous Pulse Oximetry System for Dynamic Measurement of Vital Signs: Hardware Implementation

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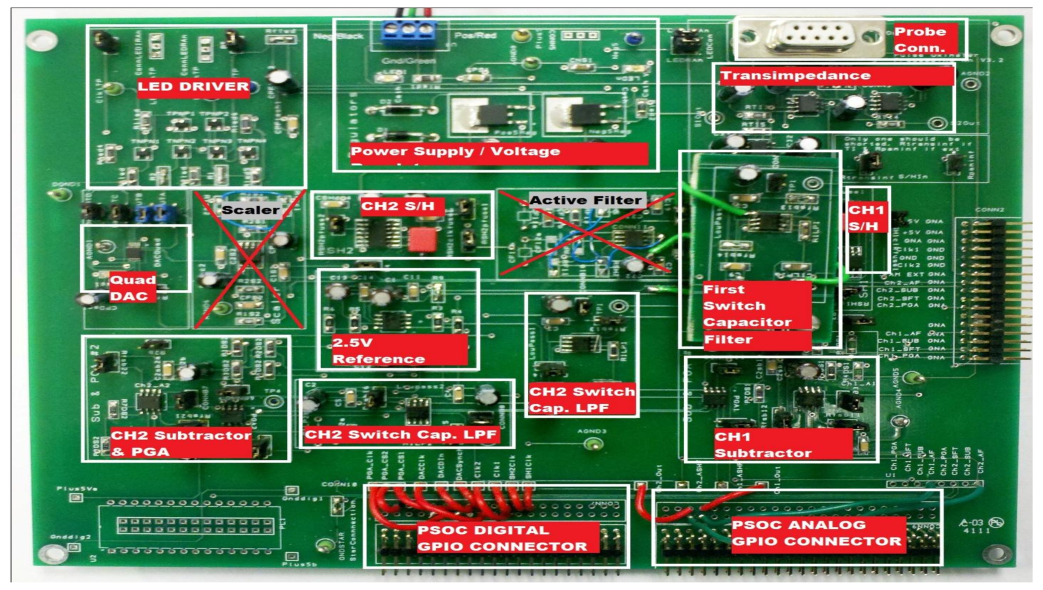
ABSTRACT

Accurate and reliable diagnostic tools are key to effective and low cost health care. We are building a clinical device to measure the oxygen saturation and pulse rate of patient in a noninvasive manner. The device automatically determines the appropriate settings for measurement and dynamically corrects for changes. Two LEDs, one red and one infrared, shine through a finger. The light is detected, and the difference in intensity due to optical absorption of hemoglobin in blood flowing in the veins is used to estimate the oxygen saturation and pulse rate. The intensity of the LEDs is determined automatically when a finger is inserted. A key challenge in implementing such a sensor is to compensate when the patient moves the finger such as when the patient is shivering. This disturbance complicates the measurement of the signals of interest. In order to address this issue, electronic control systems have been implemented to automatically compensate for movement changes to allow accurate and reliable measurements to be performed even under adverse conditions.

Hardware Overview

The pulse oximeter system is composed of these main stages: LED driver, Transimpedance Amplifier, Sample and Hold, Subtractor, and PGA.

Figure 1: Overview of Pulse Oximeter System Processing Protoboard

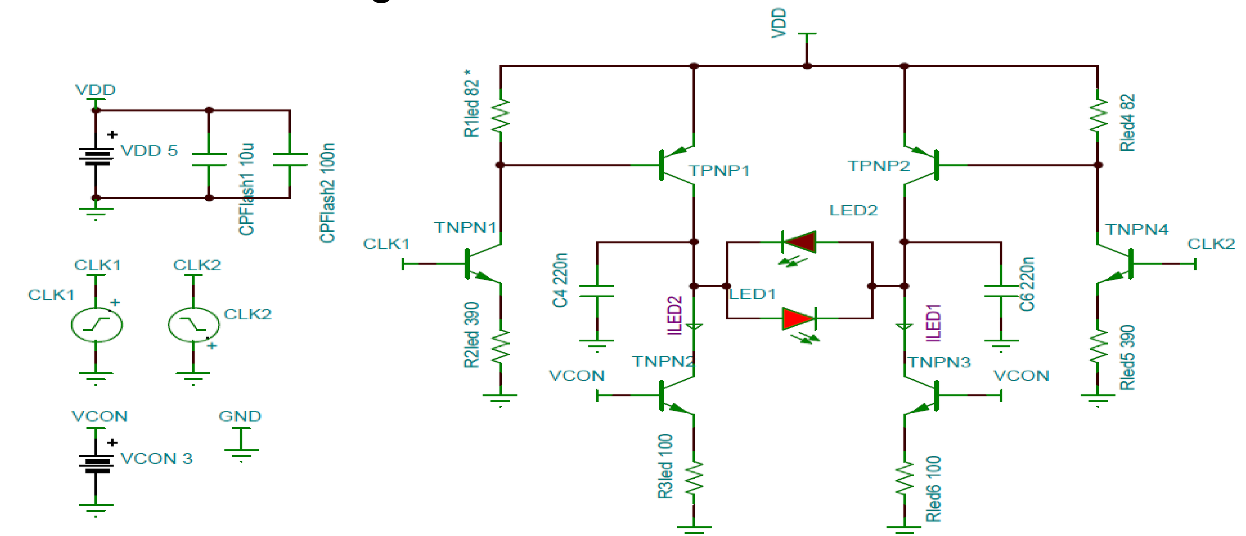


A finger is inserted into a probe. Two LEDs inside the probe shine red and infrared light onto the finger. An LED driver controls the amount of light produced by these LEDs. Digital to Analog Converters control the driver. The unabsorbed light passes through a photo detector, which generates a photo current. A differential transimpedance amplifier converts the photocurrent to a voltage so that the signal can be filtered. The transimpedance amplifier is designed to eliminate noise from the pulse oximeter signal. The signal then goes through a sample and hold circuit, followed by a switched capacitor filter, a DC subtractor to adjust the DC offset, and a programmable gain amplifier to compensate for the attenuation of the signal. Finally, a second switched capacitor filter cleans up the signal.

LED Driver

The LED driver stage of the pulse oximeter board is powered by two of the DACs on the protoboard and a set of PNP and NPN transistors that are configured to turn the red and infrared LEDs on and off. In order to turn the LEDs on and off, two external pulses from software are used.

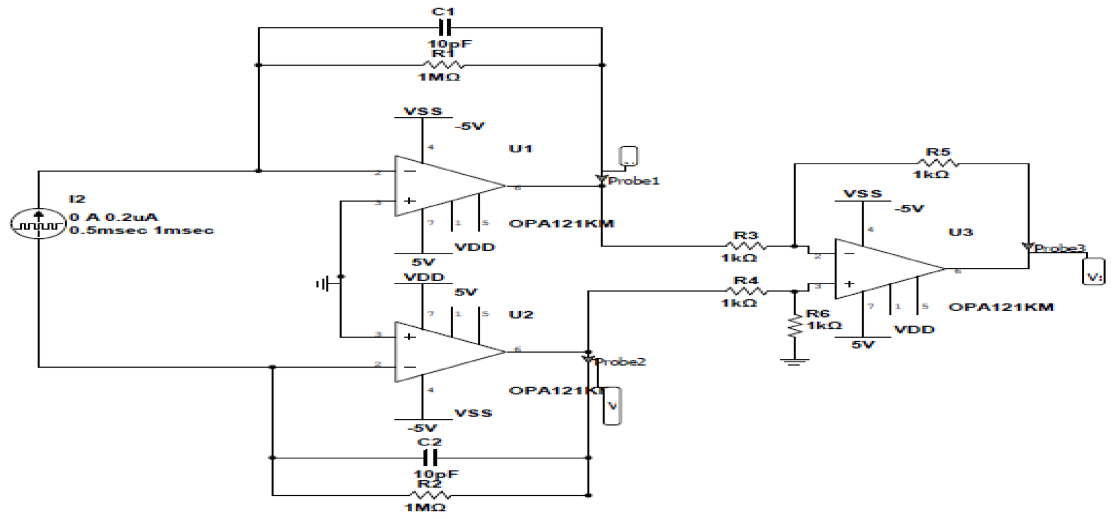
Figure 2: LED Driver Circuit



Transimpedance Amplifier

The resulting current from the photodiode is very small and must be converted into a voltage using a two-stage transimpedance amplifier in order for the signal to be used to calculate the SPO2 and heartbeat. The first stage consists of two transimpedance amplifiers in parallel, one adds gain and inverts the signal and the other just adds the same gain. They meet at a unity gain differential amplifier, which results in adding the signal from the two TIAs and subtracting common noise.

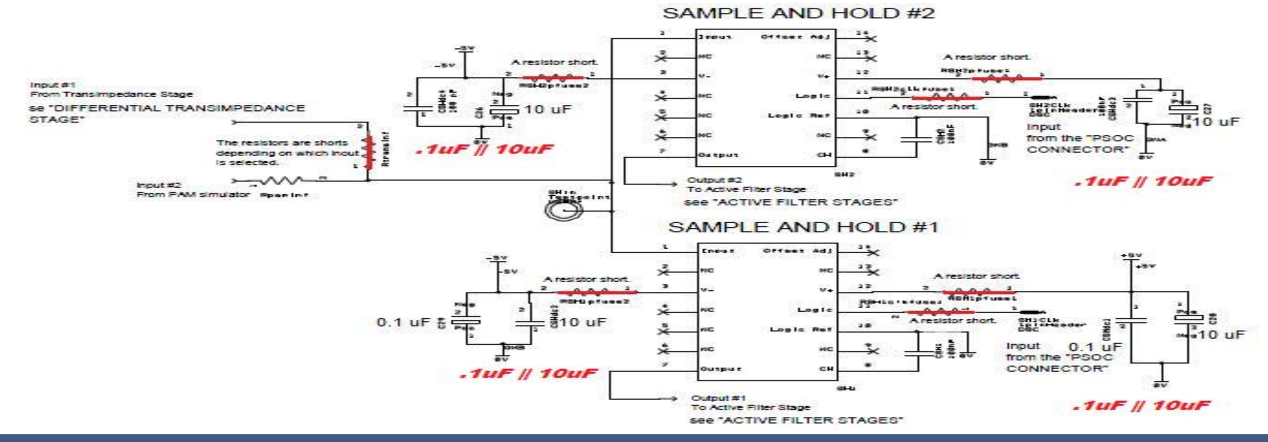
Figure 3: Transimpedance Amplifier Circuit



Sample and Hold Demodulation

The resulting signal from the transimpedance amplifier contains both the infrared and the red channel signals in one modulated signal. In order to extract the signal appropriately, a sample and hold stage for each channel is used. The sample and hold is timed to take a sample when the signal of its appropriate channel is on. This signal is held until the next sampling cycle and thus results in making the discrete signal continuous.

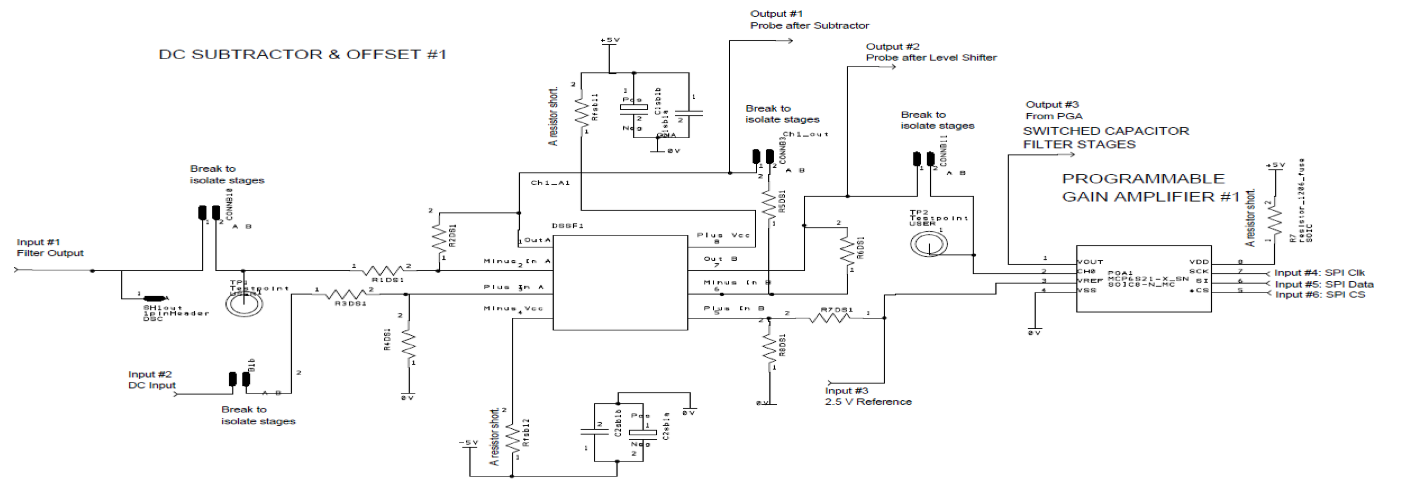
Figure 4: Sample and Hold Stage for Both Channels



Subtractor and Programmablle Gain Amplifier (PGA)

The resulting signal from the previous stages is very small, so the signal is amplified. This is done using Programmable Gain Amplifier. Before the signal comes into the PGA, the subtractor stage emoves the DC component of the signal. The PGA gives a variable gain, ranging from 1 to 32. The gain is set to maximize the signal out of the PGA without saturating PGA output.

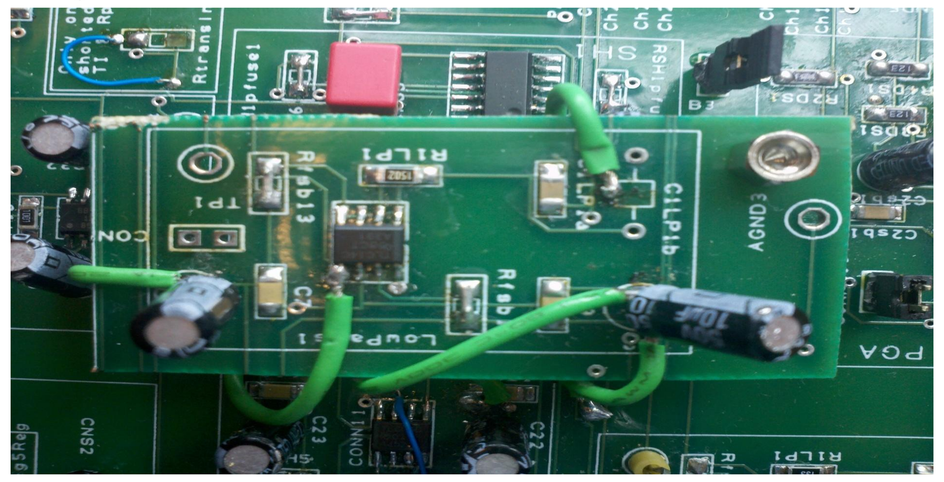
Figure 5: Subtractor and PGA Schematic



Switched Capacitor Filter

In the original implementation of the pulse oximeter board, a second order lowpass Butterworth active filter using the LMH6619 OP-AMP was used to suppress high frequency transient. However, visually this did not happen, the signal actually appeared to look much worse after having gone through the active filter and the heartbeat waveform was almost unrecognizable. For this reason, a switch capacitor low pass filter, like in the last stage of the board, was used to replace the active filter. The topology of the active filter was changed to match the topology of the switched capacitor filter by cutting traces and re-wiring connections on the board. A stand-off was made for the switched capacitor filter to keep it stable. Green Stranded wire was used for robustness and to maintain a reliable signal.

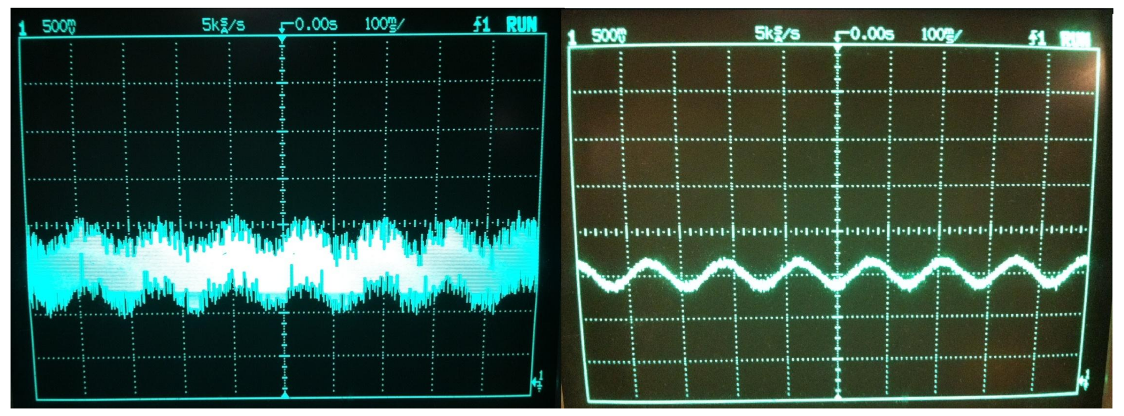
Figure 6: Modified Switched Capacitor Filter



Results

The signal coming out of the new switch capacitor filter was clean and allowed the heart beat signal to be quite distinguishable. The left part of Figure 7 shows the output signal of the original active filter and right part shows the output of the replacement switched-capacitor filter.

Figure 7: Output of Active Filter Vs. Output of Switched Capacitor Filter



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