Pulse Oximeter Prototype Testing

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The design process implemented by Pulse Laboratories involved the fabrication, integration, and testing of two prototype pulse oximeters. Both prototypes involved the use of a light-emitting diode to transmit light waves through the translucent tissue of a human finger. For the first prototype, a Wheatstone bridge circuit was assembled, using a photo-sensitive resistor. National Instruments' MyDAQ components were used to provide a 5Vdc voltage through the circuit, as well as measure the change in voltage across the bridge. This voltage change is directly proportional to the amount of light passing through the blood. The second prototype involved the use of a photo-generating diode that produces a current proportional to its level of illumination. The diode was wired to a transimpedance amplifier, which was used to convert this current to a measurable voltage. It was found that the photo-generative circuit produced the cleanest signal, and is therefore the more reliable instrument. The average resting heart rate among members of the design team was approximately 74 beats per minute. It was shown, using the T-test comparison, that there is no statistical difference between these results and those obtained from a national study performed by the U.S. Department of Health and Human Services.

Table of Symbols

R1, R2	10 kΩ Resistors (Wheatstone Bridge Circuit)
R4	*Elenco* Box Adjustable Resistor (Wheatstone Bridge Circuit)
V_{ex}	5 Volt Direct Current Excitation Voltage (Wheatstone Bridge Circuit)
$R_{ph.max}$	Maximum resistance of photo-resistor
$R_{ph.min}$	Minimum resistance of photo-resistor
$P(R_a, R_b, V_{ex})$	Function used to express power dissipation across a resistor, R_a, that is in series with $R_b$on a leg of a Wheatstone bridge
R	1.0 MΩ Resistor used in feedback loop of photo-generative circuit
V_{out}	Maximum voltage measured when photo diode was directly exposed to red LED light source

I. Introduction

A pulse oximeter prototype was designed for the purpose of monitoring a subject's oxygen level. The light absorption and reflection indicate the properties of the hemoglobin. The light absorption can be associated with the wavelength of light by using a relation known as the Lambert-Beer Law. This method works because most body tissue is almost opaque to light. Fingers are semi-transparent and that is why the pulse oximeter prototype uses the finger to take its measurements. The Light Emitting Diode illuminates the tissue and measures how much of the light is absorbed by the tissue. This prototype uses a red LED (650 nm).

In order to take these readings a light source is placed on one side of the finger and a detector is placed on the opposite side of the finger. When the light goes through the tissue and is detected, its signal is passed to the circuit which will produce an output voltage. This signal will be high when the arteries are filled with relatively higher amounts of blood and low when the opposite is true. We used a photo-sensitive resistor. There were two methods that could have been used to collect the data. First, a Wheatstone bridge circuit and second, a voltage divider circuit. Our team decided to use the Wheatstone bridge circuit for resolution reasons. It was important that the wattage for each component didn't exceed the limits specified by the manufacturer.

We also used a photo-generation sensing circuit. This concept uses a photo-diode to produce an output current that changes corresponding to the illumination level. A transimpedance amplifier can be used to convert this current into voltage output. This output will be negative because nothing flows to the op-amp. This also means that the voltage drop across our photo-diode will be zero. It is important in this instance to match the source of the light to the photo-diode so that it will be optimally sensitive to the signals it is detecting. Similar to the photo-sensitive resistor method, it is still important to maintain the limits set by the manufacturer so that the wattage drawn is not too high for the components.

The key software used for this testing and processing was LabVIEW and signals were acquired using the NI MyDAQ unit. This was very useful in presenting the signals that were read through the detector in an understandable and clear way. Readings could be taken to show accurate measurements of the heart rate of each member of the team. One of the emphasized concepts of this experiment was the importance of having a system that would filter the voltage data to only show the significant and pertinent readings. Noise can often get in the way of taking accurate measurements if not reduced and filtered. A range was given of about 50 to 240 beats per minute as the reasonable possible readings. The values within this range are the values that are desirable and of interest. The filter can take out the noise of unreasonable signals to show only what is most likely the heart rate of the subject. This allows the heart rate to be enhanced and recordable. Between different members of the team, different filtering settings were required to find the right setting for each circumstance, giving the most accurate possible reading.

II. List of Team Members and Roles

1) Gage Salerno was the chief engineer and he built the circuits, helped analyze circuits, and helped with the statistical analysis.
2) Lisa Montierth was the systems engineer, she compiled the report and participated in the heart rate study.
3) Jacob Forsyth was in charge of hardware, his contributions included purchasing the hardware, assembling the finger clips, making the team logo, and participating in the heart rate study.
4) David Stringham performed software development and analysis tasks as well as the circuit testing and analysis. He also had a substantial contribution to the final written report, including provision of background theory and measurement requirements.
5) Chase Halverson led the analysis calculations and was in involved in the pre-circuit analysis, construction of the pulse oximeter and circuit.
6) Karson Halverson developed the software, performed pre-test circuit analysis, was heavily involved in circuit troubleshooting, and was instrumental in writing the final report.
7) Landon Terry was in charge of the presentation, he compiled and presented the work in an oral report.

III. Background Theory and Measurement Requirements

In this section, three important subjects will be discussed regarding the development of the two prototype heart rate monitors. First, a brief explanation of the science behind pulse oximetry will be given. Second, the salient features of photo-resistive and photo-generative circuits will be addressed. Finally, the LabVIEW software used for monitoring a human heart rate will be examined in detail.

A. Pulse Oximetry[1][2]

Transmissive pulse oximetry is a non-invasive method used to measure the level of oxygen saturation in the bloodstream. Because this technique is photo-based, it involves a light-emitting source and a photo-sensor. Most body tissue is not translucent to light, meaning that the majority of wavelengths are either absorbed or reflected. However, the extremities (e.g. fingertips, toes, earlobes) of the human body are semitransparent, allowing the transmission of certain wavelengths of visible light. The tissue of a fingertip, for example, can be illuminated using a light emitting diode (LED) on one side, while a light-sensitive component is placed on the opposite side.

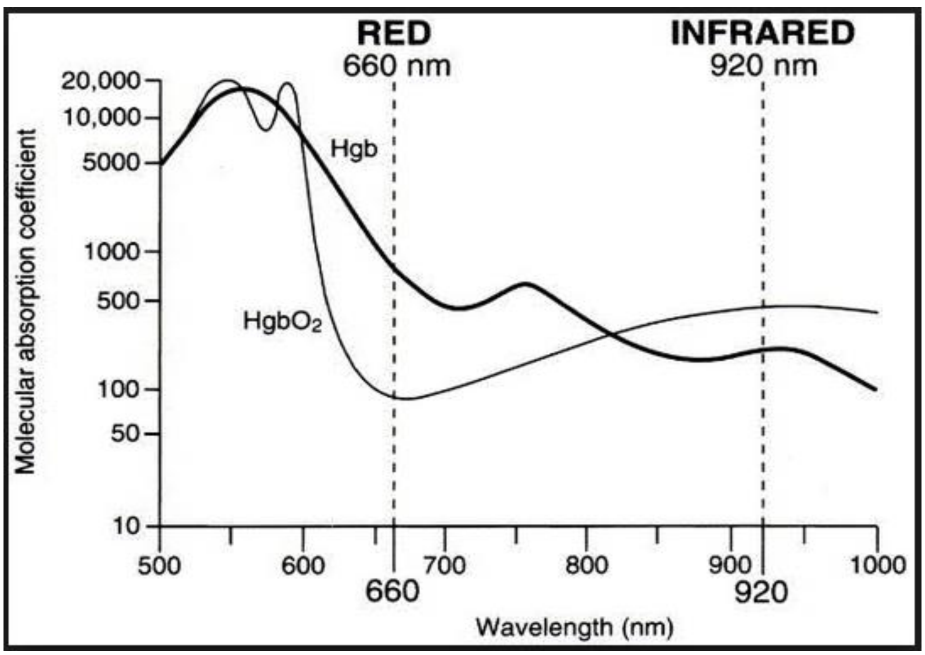

Figure 1: Molecular absorption coefficient as a function of light wavelength for oxygenated and deoxygenated hemoglobin [3].

In order to understand the application of pulse oximetry, it is necessary to review the relationship between light wavelength and absorption. This relationship is defined using the Lambert-Beer Law [4], which states that the amount of light emerging from a sample is diminished by three physical phenomena: 1) The concentration of light-absorbing material in throughout the length of the path, 2) the distance the light must travel through the sample, and 3) the probability that the photon of the specified wavelength will be absorbed by the material (absorption coefficient). Figure 1 shows the relationship between the molecular absorption coefficient and wavelength for oxygenated and deoxygenated hemoglobin. The maximum difference in absorption coefficients occurs at approximately 660 nm, which corresponds to visible red light. Due to this large difference in hemoglobin absorbance at this wavelength, it is expected to be the optimum wavelength at which a reliable heart rate measurement can be made.

The photo-sensor on the opposite side of the finger is able to detect the amount of light transmitted through the semitransparent tissue, which fluctuates according to the level of oxygenation in the blood. The signal received by the sensor is then passed through a signal conditioning circuit in order to produce an output voltage, which can be easily measured. This voltage measurement is proportional to the level of blood absorbance, which is high when the arteries contain the maximum amount of blood, known as the systolic cardiac cycle. The output voltage will read "low" as the blood returns during the diastolic cardiac cycle.

B. Signal Conditioning Circuits

In order to obtain a sensible voltage output, a signal conditioning circuit must be attached to the photo-sensitive component of the pulse oximeter. There are a number of possible schemes that could be implemented to produce this desired output voltage. The prototypes that were fabricated and tested involved the application of two of these schemes, which will be discussed.

The first circuit involved the use of a photo-resistor as the light-sensitive element, which was connected as part of a Wheatstone bridge circuit. The resistance of a typical photo-resistor varies immensely with depending on the level of light impingement on its top surface. Figure 2 shows the design of a standard photo resistor.

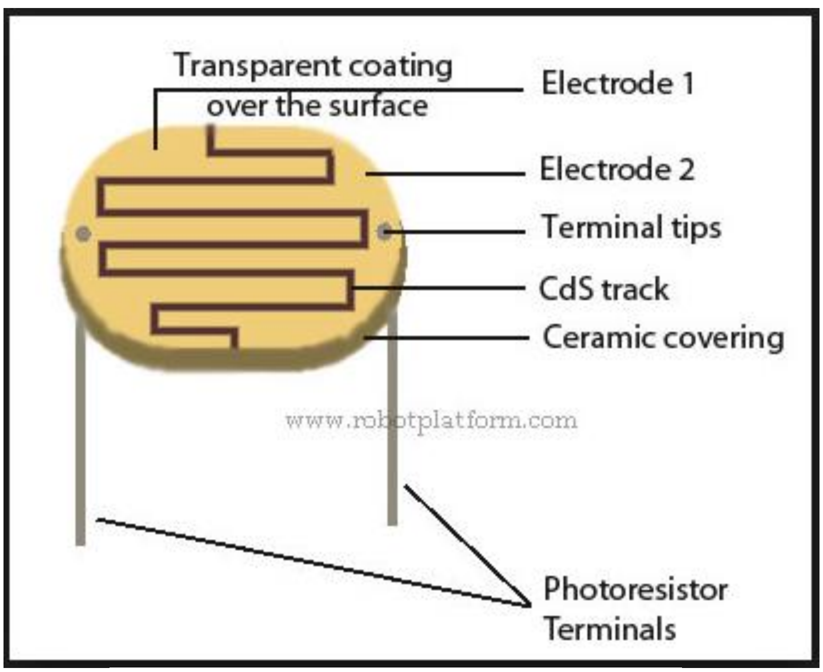

Figure 2: Standard Photo-Resistor Layout [5]

As mentioned previously, the optimum light wavelength used for differentiating between oxygenated and deoxygenated hemoglobin is that of red visible light. To ensure that maximum sensitivity is achieved, it is imperative that the photo-resistor be well matched to this wavelength of light. Figure 3 shows that for red visible light, with a wavelength of ~660 nm, the CdS (Cadmium Sulfide) photo-resistor has a relative response of approximately 50%. According to this figure, maximum sensitivity is achieved at 540 nm, which corresponds to yellow or orange visible light. However, red light was used in this prototype due to the fact that the maximum difference in hemoglobin light absorption occurs at a wavelength of roughly 660 nm, which would provide a signal that is easier to interpret.

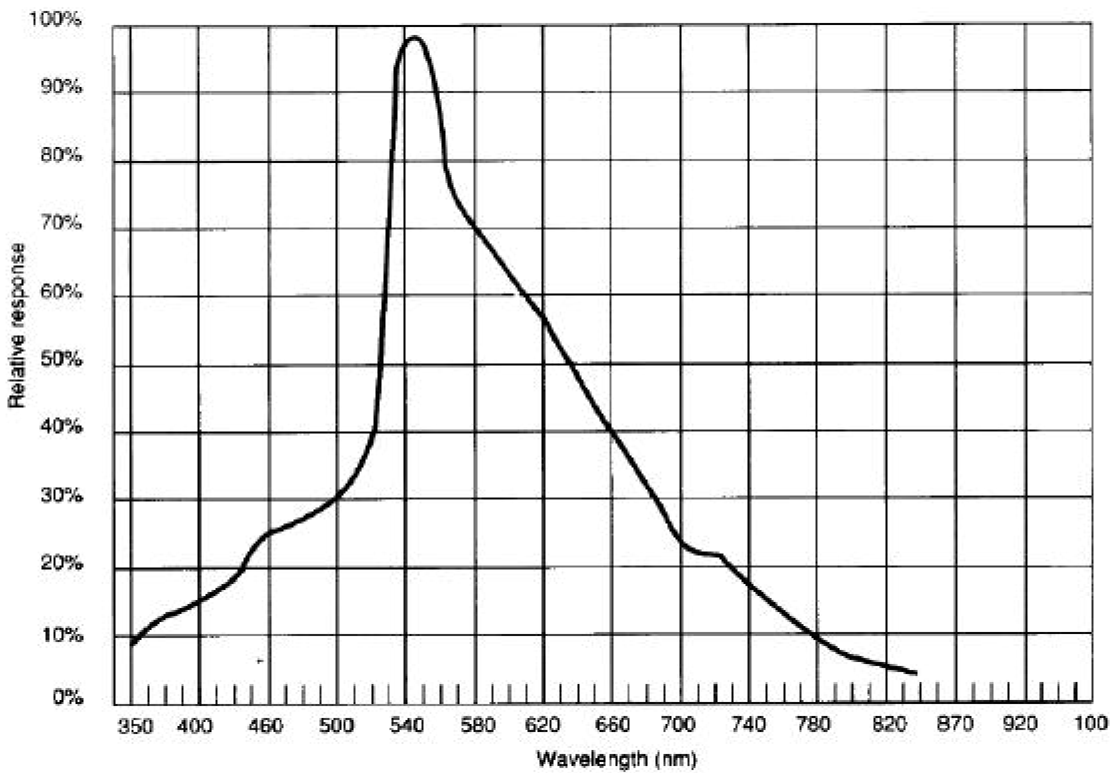

Figure 3: Light Spectrum Sensitivity of CdS Light-Dependent Resistor [6]

In order to produce a viable output signal, the photo-resistor was wired to the fourth leg of a Wheatstone bridge. The Wheatstone bridge is an extremely useful electrical circuit configuration used to measure an unknown resistance by balancing two legs of the "bridge"[7]. The term "balancing" refers to obtaining a voltage output value of zero across the two legs. This was achieved by using an *Elenco* adjustable resistor box in place of R_4 (See Figure 4). The two resistors, R_1 and R_2, used in the circuit have nominal values of 10 kΩ each. In this case, the unknown resistance is that of the light dependent resistor. A diagram of the Wheatstone bridge circuit used for signal conditioning of the photo resistor is shown in Figure 4.

The second prototype involved the utilization of a photo-diode that produces an output current proportional to the amount of light impingement. When a highly energized photon strikes the diode, an electron-hole pair is created. This process is known as the inner

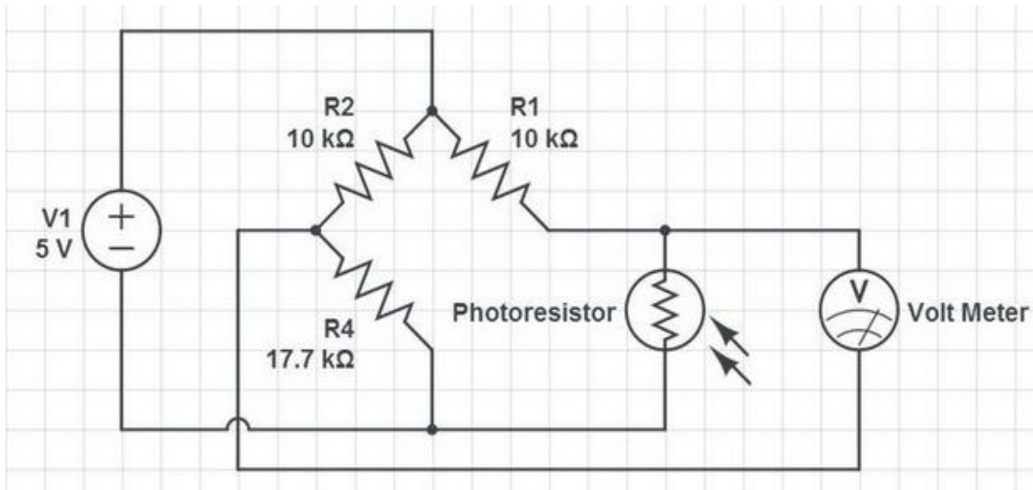

Figure 4: Photo-Resistive Circuit Diagram

photoelectric effect. The electrons move toward the cathode and the holes move toward the anode, resulting in the production of a photocurrent. This current flows in opposition to the current within a normal diode. In other words, the photo-diode becomes a “current sink”. The electric current produced by the diode is converted to a sensible output voltage using an operational amplifier. The op-amp acts as a transimpedance amplifier, which allows the voltage drop across the photo-diode to be zero. A diagram of this photo-generative circuit is given in Figure 5. When light hits the diode, as shown in the figure, the generated electrical current flows through the 1.0 MΩ resistor, and directly to the output terminal of the amplifier. The voltage drop across the diode is zero due to the fact that no current flows into the op-amp. When the circuit is arranged in the manner shown in Figure 5, the output voltage is linear for 5-10 orders of magnitude of diode illumination.

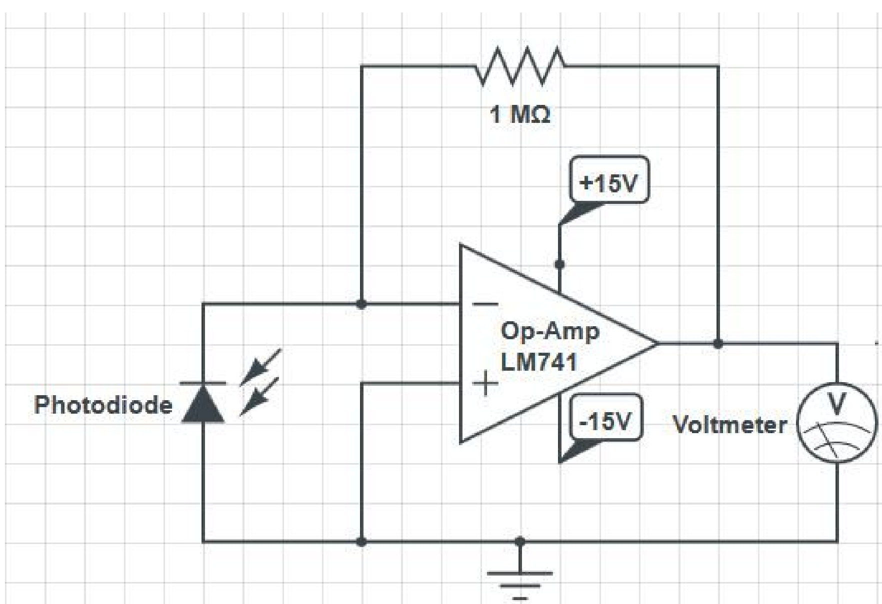

Figure 5: Photo-Generative Circuit Diagram

Once again, it is crucial that the wavelength provided by the light source be well matched with the response of the photo-diode in order to obtain maximum sensitivity. Figure 6 shows the spectral response of a typical photo-diode as a function of the impinging light wavelength. From the figure, it is clear that the maximum sensitivity is achieved for a wavelength of approximately 950 nm, which corresponds to infrared light. However, a red LED was used for the photo-generative circuit as well, because the red light produces a signal that is more easily interpreted when passing through the tissue of a human finger. From Figure 6, it can be seen that for red light, with a wavelength of ~660 nm, the relative spectral sensitivity is around 45%, which was found to be sufficient to give a reliable voltage output.

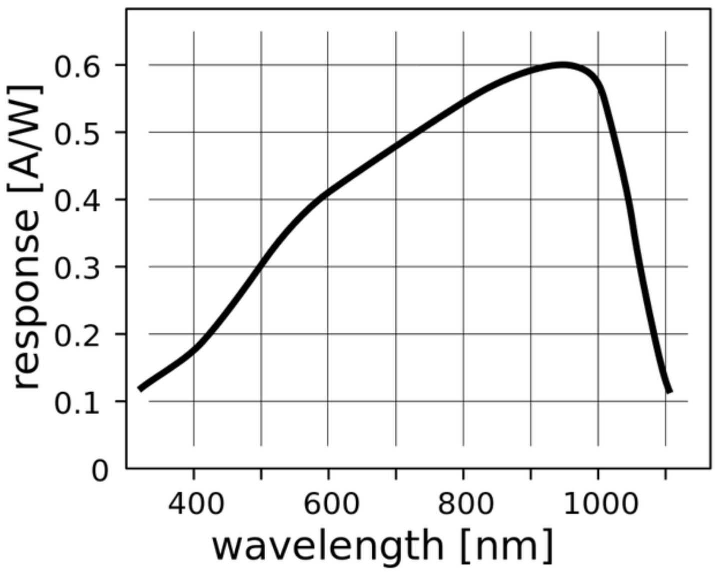

Figure 6: Light Spectrum Sensitivity of a silicon photo-diode [8]

C. Software[9]

In order to represent data in a manner that can be easily interpreted and analyzed, National Instruments' LabVIEW was used to write a functioning heart rate monitor program. The software for this project uses the design flow of collecting data, processing data, and displaying the data to the user. These three processes will be discussed in detail in this section.

The data collection portion of the code is capable of reading in two pieces of information from the user. A stop button can be used to stop the program execution, and the "Simulate Heart Beat?" control is used to determine if the program will collect data from the MyDAQ or if it will produce a simulated heart beat signal. The three major parameters that are configured to enable data collection from the sensor include: The sampling mode, the sampling rate, and the number of samples to read. In order to prevent loss of data, the sampling mode was set to continuous acquisition. The sampling rate was set to 10,000 samples per second in order to provide a signal that is visually appealing when displayed on the waveform chart. The number of samples was configured such that the DAQ Assistant would only wait up to 100 ms for new data. Furthermore, as a part of the data collection portion of the code, a signal filter was added in order to eliminate any noise that could be sensed by the MyDAQ. The signal was filtered such that the normal range for a heartbeat fell just within its bound. After several tweaks, it was found that the optimum filter setting was the range of 1 to 3 Hz.

The data processing section of the code involves the application of different processing techniques to the filtered signal data in order to extract important information. The Detect Peak VI detects signal peaks using a minimum threshold that auto-calibrates during program execution. If the Detect Peak VI finds a peak in the data, a timestamp is generated for the moment in time when that peak occurred, and it is then passed to the BPM VI. This VI calculates the difference between the current timestamp and the previous timestamp and determines the period of the signal. Within the BPM VI, the period is then converted into units of Beats per Minute (BPM). If the BPM VI determines that a true heartbeat was detected, then a string is generated from the heart rate, and the value for the minimum threshold is reconfigured to closely match the amplitude of the detected peak. Finally, the data display section is used to display the results to the user. The filtered signal is plotted against a simulated signal that shows the value of the threshold when the peak was detected. Figure 7 shows the block diagram for the heart rate monitor program, with each of the aforementioned sections highlighted.

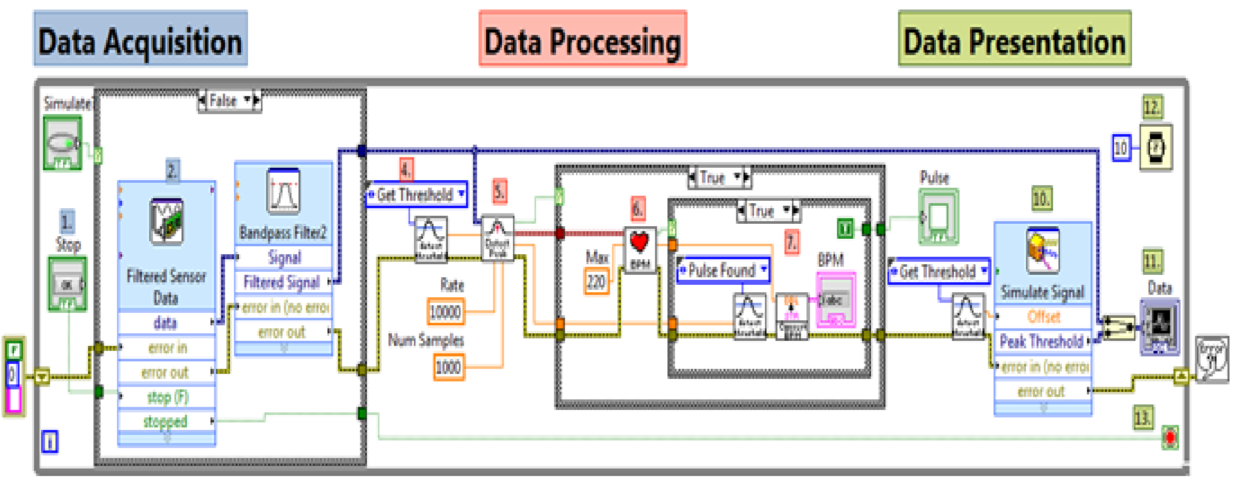

Figure 7: Block Diagram for Heart Rate Monitor Program [9]

IV. Design Schematic and Analysis

Photo-Resistive Circuit:

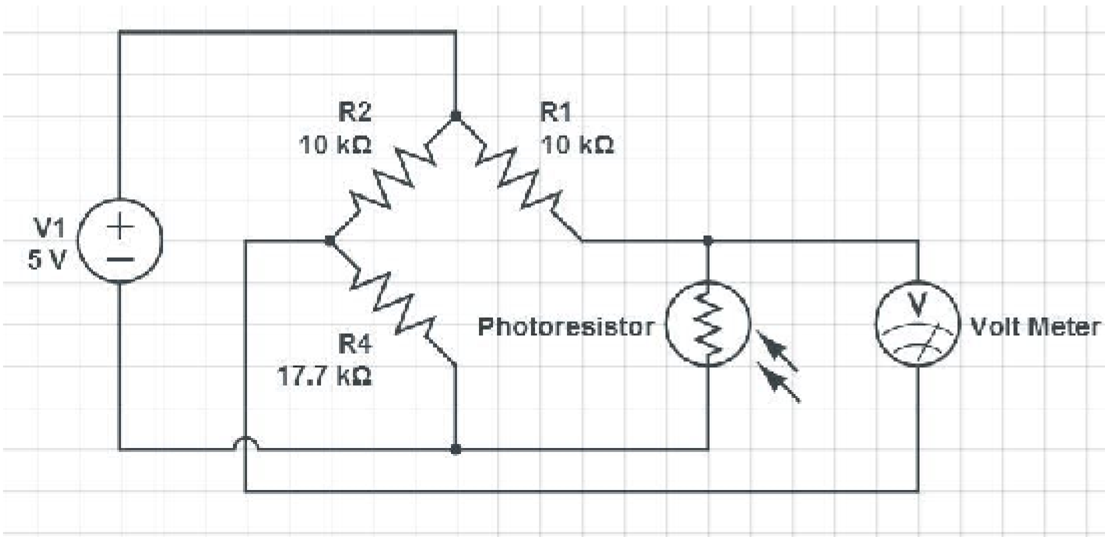

Figure 4: Photo-Resistive Circuit Diagram

The ohmmeter was used to test the minimum and maximum resistance values of the photo-resistor. When exposed to light, the value was found to be 1.70 kΩ. When the photo-resistor was covered by a human finger, the value jumped up to an average resistance of 17.50 kΩ when exposed to the LED through translucent tissue.

For optimum sensitivity, R1 and R2 were selected based on the average resistance value of the photo-resistor when exposed to red visible light transmitted through a finger. The resistance values are given below:

$R_1 := 10000 \ \Omega$ $R_2 := 10000 \ \Omega$ $R_{ph.max} := 17500 \ \Omega$ $R_{ph.min} := 1700 \ \Omega$

$R_4 := 17700 \ \Omega$ $V_{ex} := 5 \ Vdc$

The following equations were used to perform a circuit analysis, to ensure that wattage limits were not exceeded. It will be assumed that the resistance of the photo-resistor is at it's minimum value, as defined above. If this is the case, it will result in the maximum power dissipation, which is not to exceed 0.25 Watts.

The power dissipated across each resistor is given by the following equation:

$$P(R_a, R_b, V_{ex}) := R_a \cdot \left[\frac{V_{ex}}{(R_a + R_b)} \right]^2$$

Using the equation defined above, the power dissipated across R1 is:

$$P_1 := P(R_1, R_{ph.min}, V_{ex}) = 1.826 \times 10^{-3} \text{ Watts}$$

The power dissipated across R2 is:

$$P_2 := P(R_2, R_4, V_{ex}) = 3.258 \times 10^{-4} \text{ Watts}$$

The power dissipated across R4 is:

$$P_4 := P(R_4, R_2, V_{ex}) = 5.767 \times 10^{-4} \text{ Watts}$$

The power dissipated across the photo-resistor is:

$$P_{ph} := P(R_{ph.min}, R_1, V_{ex}) = 3.105 \times 10^{-4} \text{ Watts}$$

It is clear that, even for the worst case scenario, the circuit power dissipation will never exceed the 0.25 Watt limit.

Photo Generative Circuit:

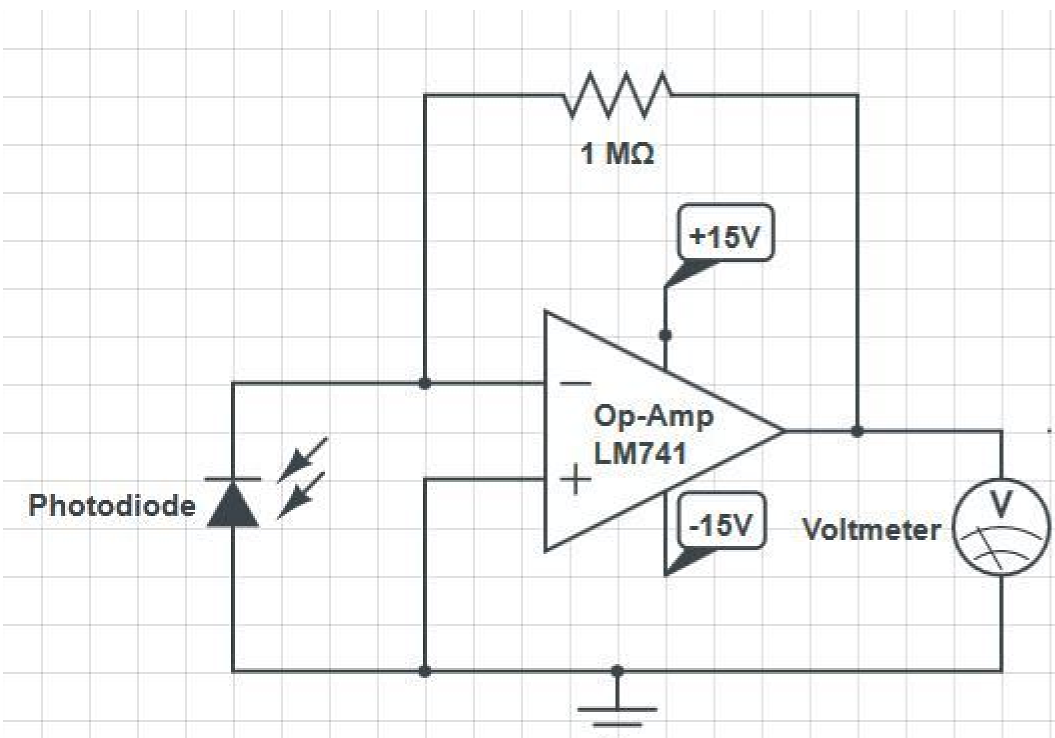

Figure 5: Photo-Generative Circuit Diagram

When the circuit was connected as shown above, the voltage drop across the photo-diode is zero. The diode serves as a "current sink", which results in power dissipated across the single resistor in the feedback loop. With this circuit configuration, the voltmeter measured a maximum of 13.0 Vdc when the photodiode was directly exposed to the red LED. The resistance value of the resistor in the feedback loop was chosen to optimize resolution from the heartbeat monitor. The selection involved a process of trial and error with varying resistance values until sufficient resolution was obtained.

$$R := 1000000 \ \Omega \qquad V_{out} := 13 \ \text{Vdc}$$

$$\text{Power} := \frac{V_{out}^{2}}{R} = 1.69 \times 10^{-4} \ \text{Watts}$$

Once again, it is clear that the limit of 0.25 Watts across the resistor will not be exceeded, even if the maximum voltage is reached.

V. Parts and Components List

ITEMS	Symbol	Test condition	Min.	Typ.	Max.	Unit
Forward Voltage	V_F	I_F=20mA	1.8	---	2.2	V
Wavelenength (nm) or TC(k)	$\Delta\lambda$	I_F=20mA	620	---	625	nm
*Luminous intensity	I_V	I_F=20mA	150	---	200	mcd
50% Viewing Angle	2θ1/2	I_F=20mA	40	---	60	deg

Figure 8: LED – Basic Red 5 mm

Light Resistance at 10Lux (at 25℃)	8~20KΩ
Dark Resistance at 0 Lux	1.0MΩ(min)
Gamma value at 100-10Lux	0.7
Power Dissipation(at 25℃)	100mW
Max Voltage (at 25℃)	150V
Spectral Response peak (at 25℃)	540nm
Ambient Temperature Range:	- 30~+70℃

Figure 9: Mini Photocell

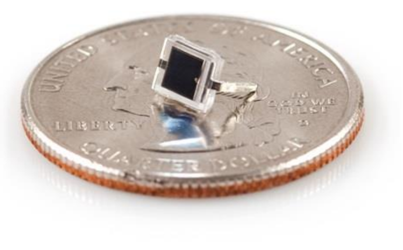

Figure 10: Miniature Solar Cell

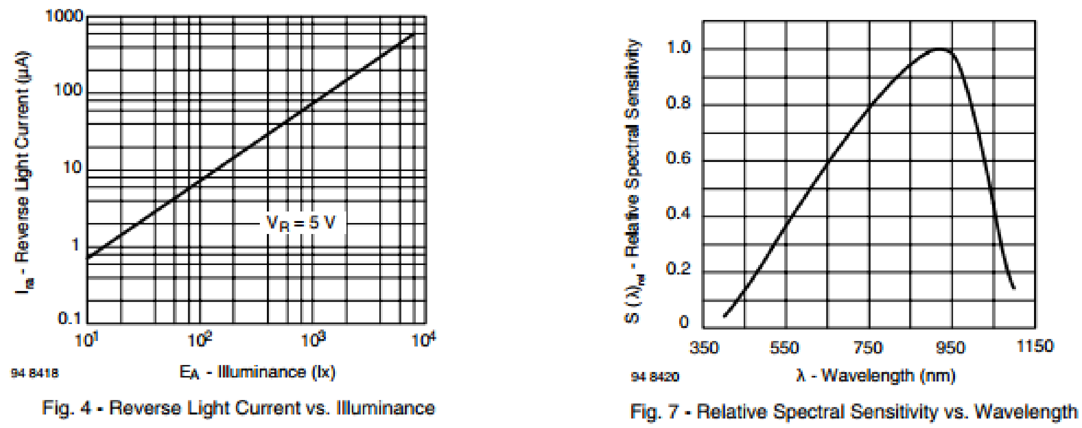

Figure 11: Plots describing Solar Cell Behavior (see Appendix A)

Other Structural Parts Include:

- Clothes Pins
- PVC Pipe
- Screws
- Spray Paint
- Super Glue
- Blister Pads
- Telephone Wire

VI. Assembly Images

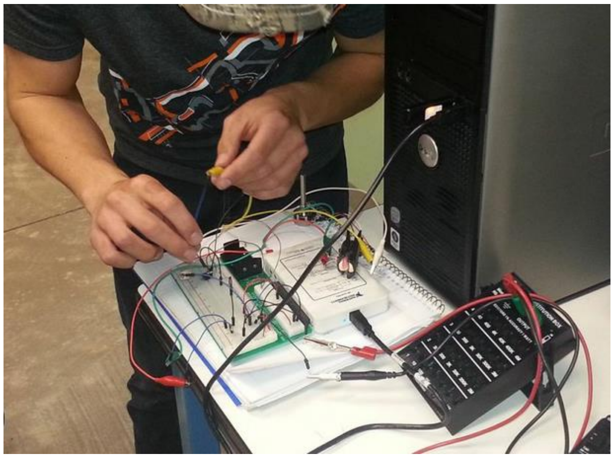

Figure 12: Photo-Resistive Circuit Construction

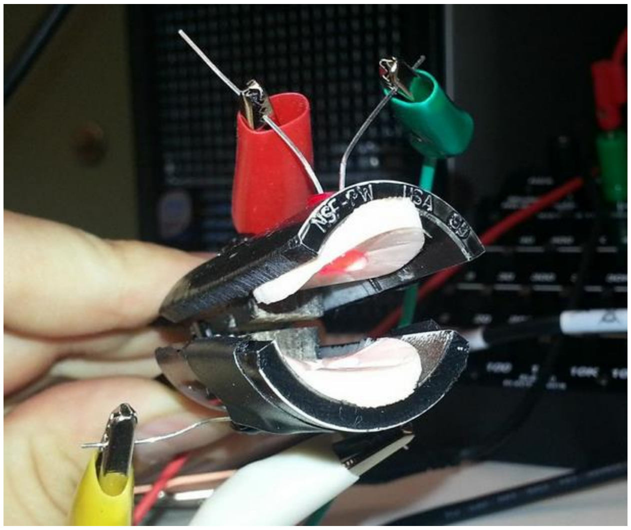

Figure 13: Pulse Oximeter

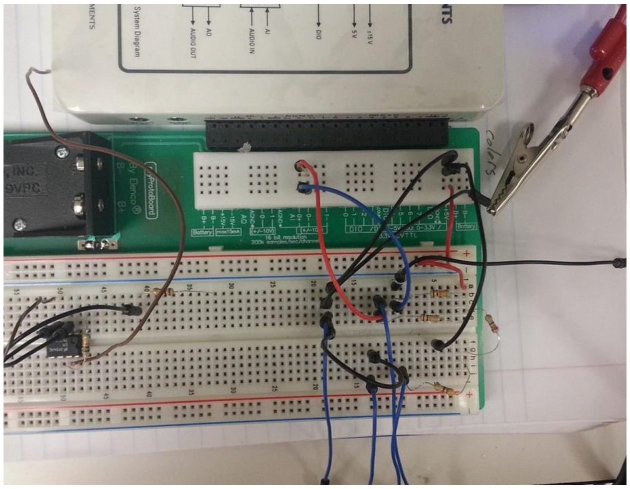

Figure 14: Photo-Resistive Wheatstone Circuit

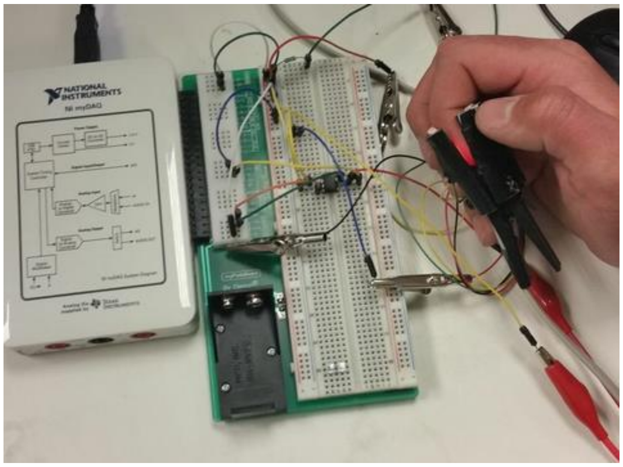

Figure 15: Constructed Photo-Generative Circuit

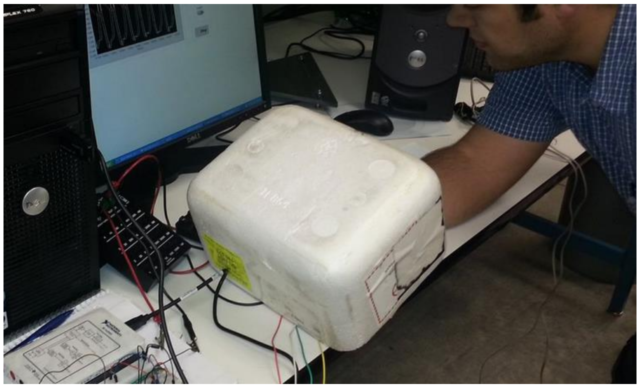

Figure 16: Utilize Foam Box

VII. Test and Analysis

A. Circuit Analysis

The pre-test circuit analysis matched the post-test analysis. The circuit analysis is covered in section IV of the report. Refer to the preceding analysis for our full procedure.

B. Results and discussion

Our team decided to use a Wheatstone bridge for our *Photo-Resistive Sensing Circuit*. The biggest reason for using the Wheatstone bridge was so that the output readings were easily centered around 0 Volts. Once the general design was chosen calculations were made to first, select the appropriate components, and then verify that the wattage drawn by each component were within the specified limits (reference section IV. Design Schematic and Analysis). A prototype pulse oximeter was fashioned out of a clothespin and PVC pipe (see figure 13). A red LED and a photo resistor were fastened on either side directly opposite each other. Small foam pads on the inside both made for a comfy fit for the patient and helped to dampen sound and ambient light that could alter our readings. Once the *Photo-Resistive Sensing Circuit* was built and working as tested by the digital multimeter, a Labview program that had previously been designed to read, graph, and count voltage pulses was downloaded from National Instruments [9] and altered to be compatible with our pulse oximeter. After verifying that our *Photo-Resistive Sensing Circuit* was working, several calibration tests were run to verify the accuracy of the model. During calibration we found that our sensor was very sensitive to sounds in the room and even more so to movement. In order to account for this potential bias, the team's heart rates were measured while holding as still as possible, in complete silence, and by placing the device under a foam box (see figure 16). This technique of measuring improved the accuracy of our *Photo-Resistive Sensing Circuit* tremendously. The results for both the resting heart rate and the heart rate measured after running to the top of the stairs can be seen in Table 1.

The *Photo-Generation Sensing Circuit* proved to be more complex that the *Photo-Resistive Sensing Circuit* but in the end it was agreed that the *Photo-Generation Sensing Circuit* was less susceptible to false readings due to movement or other nearby sounds. Much like the *Photo-Resistive Sensing Circuit,* the *Photo-Generation Sensing Circuit* required that measurements be made to determine which components would be used. Once components were selected calculations were done to ensure that the wattage drawn by each component was acceptable (reference section IV. Design Schematic and Analysis). A prototype pulse oximeter was also made for the *Photo-Generation Sensing Circuit* out of a clothespin and PVC pipe (see figure 13). A red LED and a photodiode were fastened on either side directly opposite each other. The same Labview code that was used for the *Photo-Resistive Sensing Circuit* was used for the *Photo-Generation Sensing Circuit*. Once the model had been calibrated each team member's resting heart rate was measured. Each team member in turn ran to the top of the stairs and then has his/her heart rate read again. While the resting heart rates for both the *Photo-Generation Sensing Circuit* and *Photo-Resistive Sensing Circuit* coincided, the heart rates after running to the top of the stairs appeared to be biased in one of the models. After calibrating the circuits at the heightened heart rates it was discovered that the *Photo-Generation Sensing Circuit* generated a cleaner signal. The *Photo-Resistive Sensing Circuit* is so sensitive to movement that the increased heart rates and heavy breathing caused a bias in the readings that was not completely accounted for. The results for both the resting heart rate and the heart rate measured after running to the top of the stairs can be seen in Table 2.

Data was gathered for both resting heart rate and active heart rate from each of the functioning pulse oximeters. Then t-test comparisons were done to evaluate whether the mean of our group's resting heart rate and active heart rate were statistically significant compared to the national mean for resting heart rate and active. First the degrees of freedom were calculated using the following equation:

$$v = \frac{\left[\left(S_1^2/n_1\right)+\left(S_2^2/n_2\right)\right]^2}{\dfrac{\left(S_1^2/n_1\right)^2}{n_1-1}+\dfrac{\left(S_2^2/n_2\right)^2}{n_2-1}}$$

The t-value corresponding to the degrees of freedom and at a 95 percent confidence level calculated was found using a LabView VI created by Dr. Whitmore as shown [10].

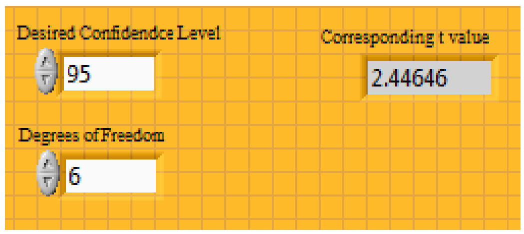

Figure 17: Labview VI parameters

In order to compare our data to the national data the following t value was calculated using the mean and standard deviation from our data and from the national data.

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\left(S_1^2/n_1\right)+\left(S_2^2/n_2\right)}}$$

Then a t-test was done to find the 95 percent confidence interval using the following equation. The t- value ended up being the same because the degrees of freedom were the same as the previous test.

$$\bar{x} - t_{c/2,v} \cdot \frac{S_x}{\sqrt{n}} \le \mu_x \le \bar{x} + t_{c/2,v} \cdot \frac{S_x}{\sqrt{n}}$$

The data used for these calculations and results are tabulated in tables 1-12.

Team Member Name	**Resting (BPM)**	**Active (BPM)**
Gage Salerno	72	140
Karson Halverson	68	160
Chase Halverson	79	160
Lisa Montierth	74	160
Jacob Forsyth	72	163
Landon Terry	76	160
David Stringham	79	170
Mean	74.28571429	159
Standard Deviation	4.029652	9.146948489
Number of Samples	7	7

Table 1: Photo Resistor Pulse Oximeter Data

Team Member Name	**Resting (BPM)**	**Active (BPM)**
Gage Salerno	68	128
Karson Halverson	75	130
Chase Halverson	74	130
Lisa Montierth	80	140
Jacob Forsyth	82	132
Landon Terry	73	136
David Stringham	77	135
Mean	75.57142857	133
Standard Deviation	4.649628761	4.203173404
Number of Samples	7	7

Table 2: Photo Generative Pulse Oximeter Data

Mean (BPM)	73
Standard Error	0.2
Standard Deviation	16.13195586
Number of Samples	6506

Table 3: National Data for Average Resting Heart Rate [11]

Mean (BPM)	154
Standard Deviation	20
Number of Samples	4633

Table 4: National Data for Average Active Heart Rate [12]

v=Degrees of Freedom (calculated)	6.208703128
Round Degrees of Freedom Down	6
Confidence Level (percent)	95
t value at 0.95/2 and v=6	2.446
Calculated t	0.836976967

Table 5: t-Test Comparison Results for Photo Resistor (Resting Heart Rate)

The results in this table show that the calculated t value is less than the look up value therefore our data at a 95 percent confidence level is statistically insignificant compared to the national data.

Degrees of Freedom For t test	6
t value at 0.95/2 and v=6	2.446
Confidence Interval (low side BPM)	70.56029658
Confidence Interval (high side BPM)	78.011132

Table 6: **Confidence Interval using t-Test for Photo Resistor (Resting Heart Rate)**

v=Degrees of Freedom (calculated)	6.086993775
Round Degrees of Freedom Down	6
Confidence Level (percent)	95
t value at 0.95/2 and v=6	2.446
Calculated t	1.441052761

Table 7: t-Test Comparison Results for Photo Resistor (Active Heart Rate)

The results of this table show as well that at a 95 percent confidence level our data is statistically insignificant.

Degrees of Freedom For t test	6
t value at 0.95/2 and v=6	2.446
Confidence Interval (low side BPM)	150.5436361
Confidence Interval (high side BPM)	167.4563639

Table 8: Confidence Interval using t-Test for Photo Resistor (Active Heart Rate)

v=Degrees of Freedom (calculated)	6.150751704
Round Degrees of Freedom Down	6
Confidence Interval (percent)	95
t value at 0.95/2 and v=6	2.446
Calculated t	1.453820777

Table 9: t-Test Comparison Results for Photo Generative (Resting Heart Rate)

This table also shows that because the calculated t value is less than the look up value, it cannot be said with a 95 percent confidence level that our data is statistically significant.

Degrees of Freedom For t test	6
t value at 0.95/2 and v=6	2.446
Confidence Interval (low side BPM)	71.27284166
Confidence Interval (high side BPM)	79.87001548

Table 10: Confidence Interval using t-Test for Photo Generative (Resting Heart Rate)

v=Degrees of Freedom (calculated)	6.417520527
Round Degrees of Freedom Down	6
Confidence Level (percent)	95
t value at 0.95/2 and v=6	2.446
Calculated t	12.99830845

Table 11: t-Test Comparison Results for Photo Generative (Active Heart Rate)

This table on the other hand does show that at a 95 percent confidence level our data is statistically significant.

Degrees of Freedom For t test	6
t value at 0.95/2 and v=6	2.446
Confidence Interval (low side BPM)	129.1141616
Confidence Interval (high side BPM)	136.8858384

Table 12: Confidence Interval using t-Test for Photo Generative (Active Heart Rate)

C. Description of Lessons Learned

As a direct result of this project, there were several valuable lessons learned pertaining to the design process as a whole. The most important lesson was that of persistence. On many occasions, a trial and error process was required in order to obtain accurate results from the two heart rate monitors. For example, the design team spent several hours in an attempt to construct a functioning heart rate monitor using a photo generative circuit. Tedious adjustments were made, changing one thing at a time. Alterations included adjusting the band filter, adjusting circuit connections, and at one point, the circuit was completely disassembled and reassembled in an attempt to solve the problem. In the end, the team was made aware that the photo-diode has a prescribed polarity to it, and will therefore only function if the poles are wired in the correct fashion. Once that change was made, the circuit worked perfectly, generating a clear, visually appealing signal that provided an accurate heart rate measurement.

VIII. Conclusion

The two circuits that were designed and built were photo-resistive and photo-generative. For a photo-resistive circuit (using a Wheatstone bridge), an ohmmeter is used to test resistance values at maximum and minimum values. When exposed to light, the resistance was 1.7 kΩ. A finger placed over the photo-resistor changed this value to 17.5 kΩ. R1 and R2 were selected to be compatible with a red LED. A circuit analysis was performed, with caution that wattage limits were not exceeded. Power dissipated through R1 and R2 did not exceed .25 Watt limit. In testing for accuracy, it was found that our sensor was sensitive to surrounding sounds and movements. This prompted the practice of taking measurements under a foam box, holding still and not speaking. This improved the accuracy of our readings significantly.

For the photo-generative circuit, the voltage drop across the photo-diode was zero. The diode served as a current sink which dissipates power across the resistor. The maximum reading on the voltmeter was 13 Vdc when directly exposed to the red LED. The resistor value was chosen to optimize the resolution from the heartbeat monitor. This circuit was also analyzed to make sure that the power dissipated did not exceed .25 Watts. This circuit was found to be more reliable in its accuracy because it was not noticeably affected by sounds and movement like the photo-resistive circuit. The model consisted of a red LED on one side of the pulse oximeter and a photodiode on the other side. Measurements were taken from each team member.

In comparison, both the photo-resistive and photo-generative gave similar readings for resting heart rates. However, in taking readings for an active heart rate, it was found that the results were not coinciding. The photo-generation sensing circuit was providing cleaner signals. The photo-resistive sensing circuit appeared to be so sensitive that an active heart rate signal was causing a significant bias in the results. Data was gathered from each group member for resting and active heart rates, once for the photo-resistive and once for the photo-generative circuits. A Student-t test statistical analysis was performed to determine whether our results were statistically significant from national averages. A t-value was calculated from the mean and standard deviation found from our data. The t-test was then performed to find that our data is statistically insignificant from the national data.

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13. Appendix A – Spec Sheets

深 圳 市 昱 申 科 技 有 限 公 司

CHINA YOUNG SUN LED TECHNOLOGY CO., LTD.

TEL: (86) 755-28079401 28079402 28079403 28079404 28079405
FAX: (86) 755-28079407 E-mail: info@100LED.com Web: www.100LED.com

Model No.: YSL-R531R3D-D2

Applications:

- Decorations
- Bill Insperctor
- Incetícidal Lights
- Medical Appliance

Absolute Maximum Ratings: (Ta=25℃).

ITEMS	Symbol	Absolute Maximum Rating	Unit
Forward Current	I_F	20	mA
Peak Forward Current	I_{FP}	30	mA
Suggestion Using Current	I_{SU}	16-18	mA
Reverse Voltage (V_R=5V)	I_R	10	uA
Power Dissipation	P_D	105	mW
Operation Temperature	T_{OPR}	-40 ~ 85	℃
Storage Temperature	T_{STG}	-40 ~ 100	℃
Lead Soldering Temperature	T_{SOL}	Max. 260℃ for 3 Sec. Max. (3mm from the base of the expoxy bulb)	

Absolute Maximum Ratings: (Ta=25℃)

ITEMS	Symbol	Test condition	Min.	Typ.	Max.	Unit
Forward Voltage	V_F	I_F=20mA	1.8	---	2.2	V
Wavelenength (nm) or TC(k)	$\Delta\lambda$	I_F=20mA	620	---	625	nm
*Luminous intensity	I_V	I_F=20mA	150	---	200	mcd
50% Viewing Angle	$2\theta 1/2$	I_F=20mA	40	---	60	deg

Address: 5/F, Building B, Anzhilong Indl., Qinghua East Road., Longhua Town, Shenzhen CHINA. 518109

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FAX: (86) 755-28079407 E-mail: info@100LED.com Web: www.100LED.com

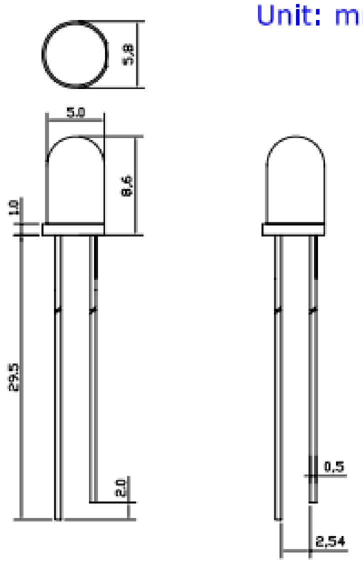
Light Degradation in mcd: (I_F=20mA)

Hours / Colors	Light Degradation in mcd after Different Hours					
	216 Hrs	360 Hrs	792 Hrs	1104 Hrs	1992 Hrs	2328 Hrs
Red	1.52%	-1.22%	-3.10%	-4.68%	-5.72%	-8.27%
Yellow	-1.71%	-2.97%	-5.93%	-8.13%	-8.90%	-11.10%
Blue	3.13%	-0.33%	-3.84%	-8.23%	-21.32%	-24.92%
Green	-8.02%	-9.78%	-14.25%	-17.37%	-20.79%	-22.30%
Hours	48 Hrs	168 Hrs	336 Hrs	360Hrs	720 Hrs	1008 Hrs
Cool White	10.56%	6.72%	-2.29%	-7.68%	-17.32%	-22.48%
Pure White	13.66%	8.22%	-1.45%	-8.50%	-19.52%	-25.26%
Warm White	3.02%	-4.38%	-15.18%	-21.15%	-27.19%	-29.97%

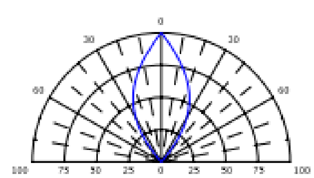
Mechanical Dimensions:

- All dimension are in mm, tolerance is ±0.2mm unless otherwise noted
- An epoxy meniscus may extend about 1.5mm down the leads.
- Burr around bottom of epoxy may be 0.5mm Maximum

Unit: mm



Viewing Angle Drawing

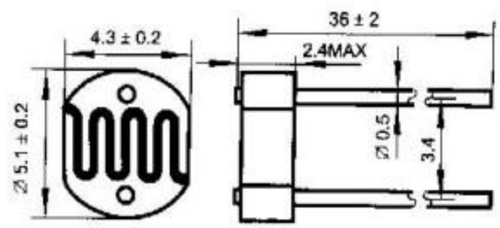


CdS PHOTOCONDUCTIVE CELLS | GL5528

- ▲ Epoxy encapsulated
- ▲ Quick response
- ▲ Small size
- ▲ High sensitivity
- ▲ Reliable performance
- ▲ Good characteristic of spectrum

Light Resistance at 10Lux (at 25℃)	8～20KΩ
Dark Resistance at 0 Lux	1.0MΩ(min)
Gamma value at 100-10Lux	0.7
Power Dissipation(at 25℃)	100mW
Max Voltage (at 25℃)	150V
Spectral Response peak (at 25℃)	540nm
Ambient Temperature Range:	- 30～+70℃

Outline



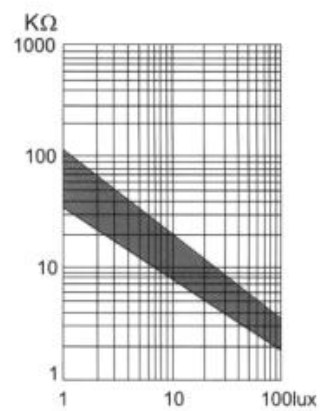
Measuring Conditions

1. Light Resistance:
   measured at 10 lux with standard light A (2854k color temperature) and 2h pre-illumination at 400-600 lux prior to testing.
2. Dark Resistance:
   measured 10 seconds after pulsed 10 lux.
3. Gamma Characteristic:
   between 10 lux and 100 lux and given by

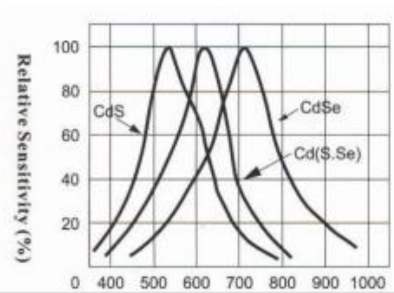
   $$T = \frac{\log (R10/R100)}{\log (100/10)} = \log (R10/R100)$$

   R10, R100 cell resistance at 10 lux and 100 lux.
   The error of T is +0.1.
4. Pmax:
   Max. power dissipation at ambient temperature of 25°C.
5. Vmax:
   Max. voltage in darkness that may be applied to the cell continuously.

Illuminance Vs. Photo Resistance



Spectral Response



Silicon PIN Photodiode, RoHS Compliant

FEATURES

- Package type: leaded
- Package form: top view
- Dimensions (L x W x H in mm): 5.4 x 4.3 x 3.2
- Radiant sensitive area (in mm^2): 7.5
- High photo sensitivity
- High radiant sensitivity
- Suitable for visible and near infrared radiation
- Fast response times
- Angle of half sensitivity: $\varphi = \pm 65°$
- Lead (Pb)-free component in accordance with RoHS 2002/95/EC and WEEE 2002/96/EC

DESCRIPTION

BPW34 is a PIN photodiode with high speed and high radiant sensitivity in miniature, flat, top view, clear plastic package. It is sensitive to visible and near infrared radiation.
BPW34S is packed in tubes, specifications like BPW34.

APPLICATIONS

- High speed photo detector

PRODUCT SUMMARY

COMPONENT	I_{ra} (µA)	φ (deg)	$\lambda_{0.1}$ (nm)
BPW34	50	± 65	430 to 1100
BPW34S	50	± 65	430 to 1100

Note
Test condition see table "Basic Characteristics"

ORDERING INFORMATION

ORDERING CODE	PACKAGING	REMARKS	PACKAGE FORM
BPW34	Bulk	MOQ: 3000 pcs, 3000 pcs/bulk	Top view
BPW34S	Tube	MOQ: 1800 pcs, 45 pcs/tube	Top view

Note
MOQ: minimum order quantity

ABSOLUTE MAXIMUM RATINGS

PARAMETER	TEST CONDITION	SYMBOL	VALUE	UNIT
Reverse voltage		V_R	60	V
Power dissipation	$T_{amb} \leq 25$ °C	P_V	215	mW
Junction temperature		T_j	100	°C
Operating temperature range		T_{amb}	- 40 to + 100	°C
Storage temperature range		T_{stg}	- 40 to + 100	°C
Soldering temperature	$t \leq 3$ s	T_{sd}	260	°C
Thermal resistance junction/ambient	Connected with Cu wire, 0.14 mm^2	R_{thJA}	350	K/W

Note
T_{amb} = 25 °C, unless otherwise specified

BASIC CHARACTERISTICS						
PARAMETER	**TEST CONDITION**	**SYMBOL**	**MIN.**	**TYP.**	**MAX.**	**UNIT**
Breakdown voltage	I_R = 100 µA, E = 0	$V_{(BR)}$	60			V
Reverse dark current	V_R = 10 V, E = 0	I_{ro}		2	30	nA
Diode capacitance	V_R = 0 V, f = 1 MHz, E = 0	C_D		70		pF
	V_R = 3 V, f = 1 MHz, E = 0	C_D		25	40	pF
Open circuit voltage	E_e = 1 mW/cm^2, λ = 950 nm	V_o		350		mV
Temperature coefficient of V_o	E_e = 1 mW/cm^2, λ = 950 nm	TK_{Vo}		- 2.6		mV/K
Short circuit current	E_A = 1 klx	I_k		70		µA
	E_e = 1 mW/cm^2, λ = 950 nm	I_k		47		µA
Temperature coefficient of I_k	E_e = 1 mW/cm^2, λ = 950 nm	TK_{Ik}		0.1		%/K
Reverse light current	E_A = 1 klx, V_R = 5 V	I_{ra}		75		µA
	E_e = 1 mW/cm^2, λ = 950 nm, V_R = 5 V	I_{ra}	40	50		µA
Angle of half sensitivity		φ		± 65		deg
Wavelength of peak sensitivity		λ_p		900		nm
Range of spectral bandwidth		$\lambda_{0.1}$		430 to 1100		nm
Noise equivalent power	V_R = 10 V, λ = 950 nm	NEP		4 x 10^{-14}		W/√Hz
Rise time	V_R = 10 V, R_L = 1 kΩ, λ = 820 nm	t_r		100		ns
Fall time	V_R = 10 V, R_L = 1 kΩ, λ = 820 nm	t_f		100		ns

Note
T_{amb} = 25 °C, unless otherwise specified

BASIC CHARACTERISTICS

T_{amb} = 25 °C, unless otherwise specified

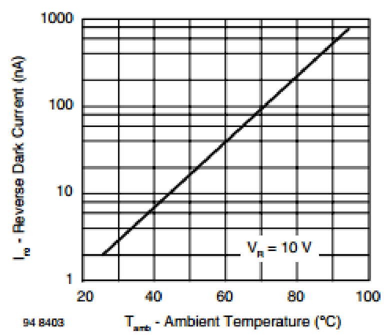


Fig. 1 - Reverse Dark Current vs. Ambient Temperature

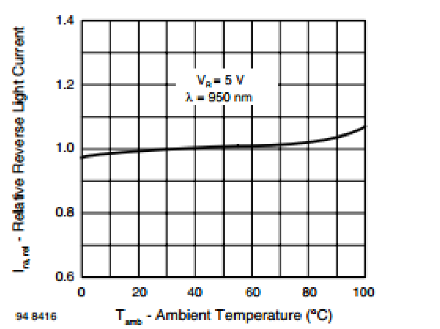


Fig. 2 - Relative Reverse Light Current vs. Ambient Temperature

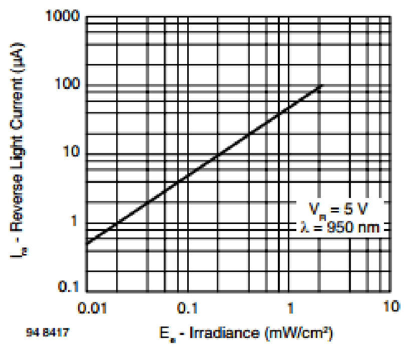


Fig. 3 - Reverse Light Current vs. Irradiance

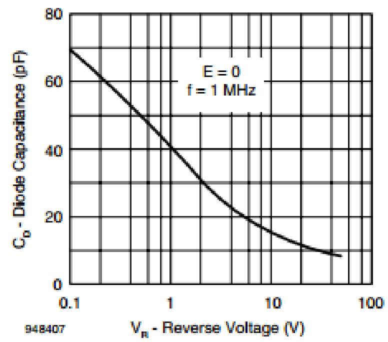


Fig. 6 - Diode Capacitance vs. Reverse Voltage

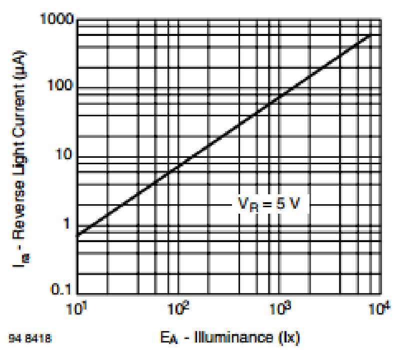


Fig. 4 - Reverse Light Current vs. Illuminance

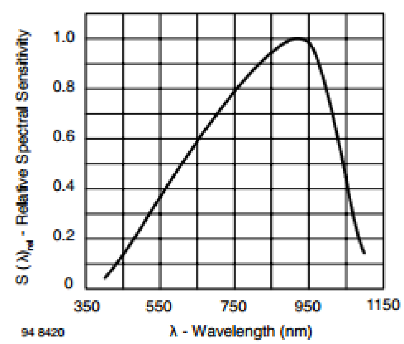


Fig. 7 - Relative Spectral Sensitivity vs. Wavelength

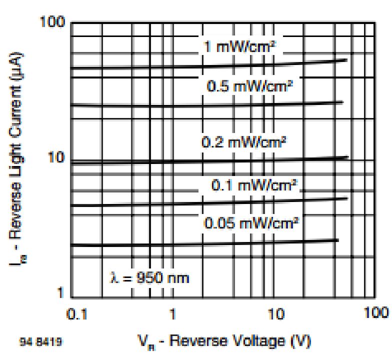


Fig. 5 - Reverse Light Current vs. Reverse Voltage

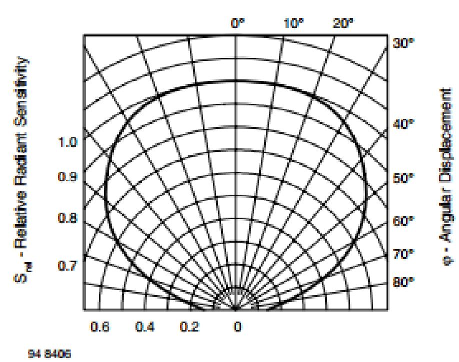
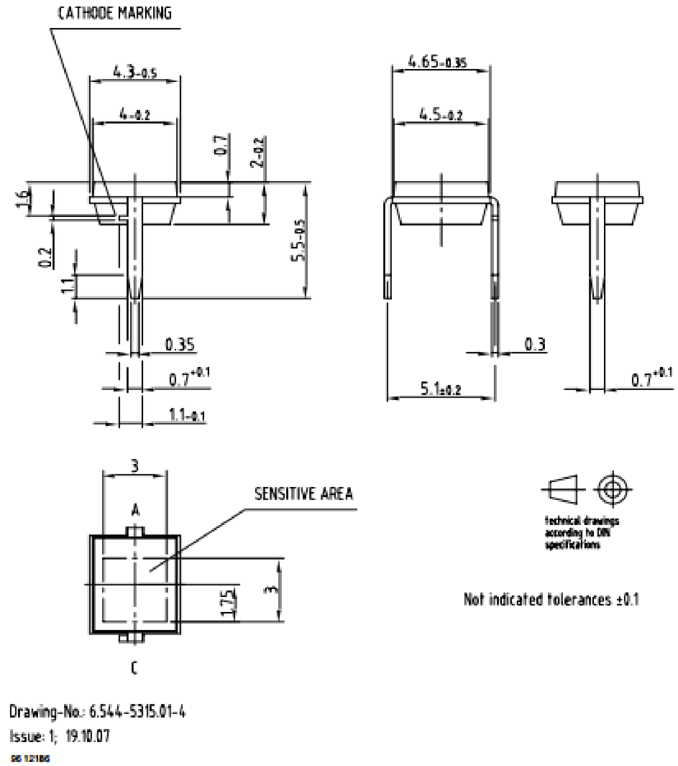


Fig. 8 - Relative Radiant Sensitivity vs. Angular Displacement

PACKAGE DIMENSIONS in millimeters



TUBE PACKAGING DIMENSIONS in millimeters