EOG Design to Measure REM Sleep Patterns At Home

Trisha Ahuja, Erin Barry, Scott Skalak, Kaitlyn Strandberg, and Melina Tsotras

Abstract – **Rapid Eye Movement (REM) sleep is one of the main stages of sleep and accounts for a quarter of a person's nightly sleep. Deprivation of REM sleep could lead to a variety of health disorders. Thus, the main goal of this paper is to propose a solution to easily track and analyze the amount of REM sleep a person gets in one night. An electrooculogram (EOG) can be utilized to non-invasively track a person's sleep by recording eye movement. The circuit design of an EOG includes 3 electrodes – 2 placed laterally next to each eye, a reference electrode near the cheek, and an instrumentation and operational amplifier to create a band-pass and high-gain circuit. A connected Arduino can be used to record and analyze the signals from the circuit, which can then be sent to an app on a user's smartphone. The user would be able to see the amount of REM sleep and number of cycles of REM sleep they had throughout the night. An improvement to this project would be to add an electroencephalogram (EEG) in addition to the EOG to obtain more accurate readings. Overall, tracking REM sleep is important to prevent serious health conditions and can help the user improve their quality of sleep.**

I. INTRODUCTION

REM sleep stands for rapid eye movement sleep. Normal human sleep is composed of REM sleep and non REM sleep. Our sleep begins in non-REM and 80 to 100 minutes later progresses through to REM. This cycles throughout the night as the person sleeps and goes through various stages of REM and non-REM. In young adults, REM sleep accounts for 20-25% of their total nights sleep (8). REM sleep is characterized by bursts of episodic horizontal rapid eye movement; this makes an EOG particularly useful to track REM sleep. Furthermore, the motivation behind our project is to track and analyze the amount of REM sleep and inform the user via a smartphone app. The tracking of REM sleep is extremely important because REM sleep deprivation can lead to a variety of health disorders and physiological effects. These effects range from decreased neurotransmitter levels to impaired memory and a greater risk for depression and anxiety (9).

Anywhere that there is muscle activity leads to electric potentials. Some of the strongest signals among these electric potentials consist of Electrocardiography (ECG), Electromyography (EMG), and our focus: Electrooculography (EOG). The reason we chose to model our project after an EOG is because of its simplicity in tracking REM cycling during sleep. In short, EOG allows the usage of electrodes to detect movement of the eyes. This is possible because the eye can be modeled as a dipole with the cornea as the positive potential and the retina as negative. The EOG signal is then generated from the potential difference between the cornea and the retina (1). The main eye movements that are detectable with EOG are saccades, fixations, and both voluntary as well as involuntary blinks (2). Depending on whether one intends to measure vertical or horizontal saccades the electrode placement in the periocular region will vary. For horizontal measurements (the focus of our project), electrodes would be placed on the lateral side of each eye with the reference electrode on either cheek. Once electrodes are in place, if the user's eyes move from a central location to a peripheral location the retina will then approach one electrode while the cornea approaches the other. This change in dipole orientation can then be observed as a change in the measured EOG signal (3).

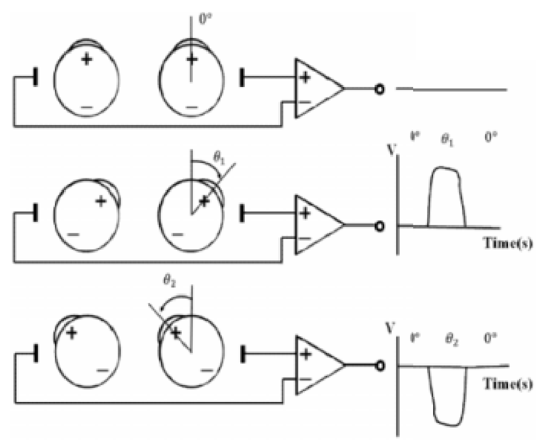

Figure 1. Voltage of EOG signal resulting from no eye movement, looking right, and looking left. From Reference 1.

If the horizontal electrodes are defined to have the positive input at the right eye and the negative input at the left eye as seen in Figure 1, then the measured voltage will increase in magnitude and be positive when one looks right. This is because the cornea gets closer to the positive input. The opposite occurs when looking left, the magnitude increases but is negative since the cornea nears the negative input (1). The voltage of a typical EOG signal can range from 100 to 3500 microvolts (4).

II. METHODS

In order to record voltage changes that arise from horizontal eye movement electrodes would be placed on the lateral side of both eyes with the reference electrode on the cheek. This placement can be visualized in figure 2.

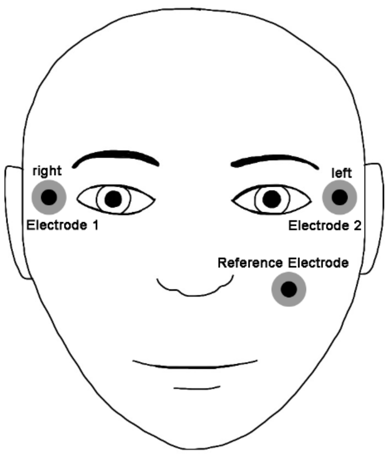

Figure 2. Electrode used placement for horizontal EOG signals.

As mentioned in the introduction, the EOG signal is in the magnitude of hundreds to a few thousand microvolts so we needed to amplify it. The first stage of our circuit as seen in figure 3 carries out the necessary amplification and also includes a bandpass filter.

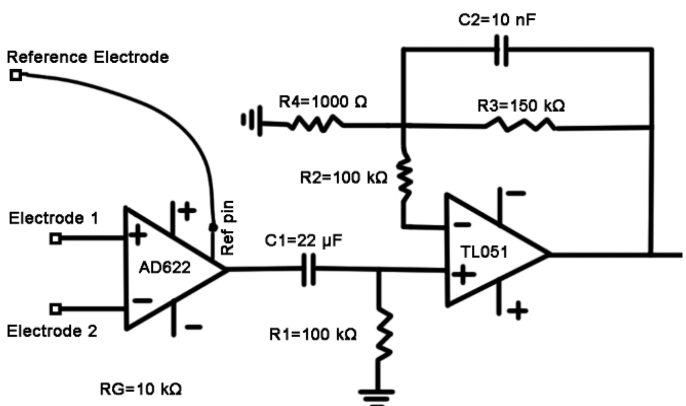

Figure 3. First stage of circuit that amplifies and filters the signal.

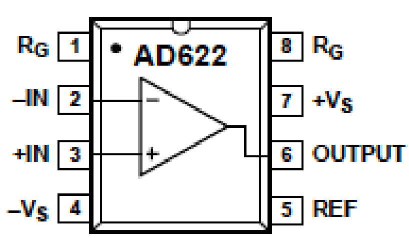

Figure 4. Pinout diagram of the AD622 Instrumentation Amplifier. From reference 5.

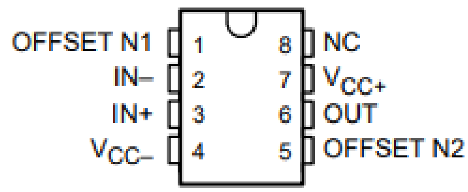

Figure 5. Pinout diagram of the TL051 operational amplifier. From reference 6.

The two electrodes that are placed laterally to each eye go into both the positive and negative inputs of the AD622. The reference electrode that was placed on the cheek connects to the reference pin of the AD622, which is grounded. The gain of the AD622 is set by the resistor R_G, this resistor is connected from pin 1 to pin 8 which can be seen in figure 4. Equation 2 is the gain equation for the AD622; by setting R_G to 10 kΩ we obtain a gain of 6.05 V/V.

As opposed to the AD622, the TL051's gain is not determined by a gain resistor but instead by R_3 and R_4 through the relationship shown in equation 3. Using said equation and the values of R_3=150 kΩ and R_4=1000 Ω we can find the gain of the TL051 to be 151 V/V. The sole purpose of R_4 is to be able to easily change this gain, similarly to how changing R_G can change the AD622 gain. The total gain of the circuit is then equal to the gain of the AD622 times the gain of the TL051. With the two gains being 6.05V/V and 151V/V respectively, by multiplying them we calculate our total gain of 913.55V/V or 59.2 dB.

After the AD622, C_1 and R_1 create a high pass filter that has a cutoff frequency given by equation 1. Using equation 1 with our values of C_1 = 22 µF and R_1 = 100 kΩ we get a cutoff frequency of 0.07 Hz. The purpose of this filter is to block DC drift. Next, R_3 and C_2 form a low pass filter. Once again, using our values shown in figure 3 along with equation 3 we can calculate the cutoff frequency to be 53 Hz. The main purpose of this filter is to block common mode 60 Hz noise and remove any high frequency noise that may affect the EOG recording. The last component of this first stage is the resistor R_2 which is intentionally equal in value to R_1. The purpose of this is so that any bias current will have equal voltage affects and get eliminated by the differential amplifier. Overall, stage one of the circuit has a bandpass filter from 0.07 Hz to 53 Hz and amplifies our EOG signal with a gain of 913.55V/V.

In order to input a signal into Arduino the signal must be between 0 and positive 5 volts. To get our signal in this desired range, stage two of our circuit is a level shifting circuit. This level shifting circuit as seen below in figure 6 will make the signal centered at 2.5 volts.

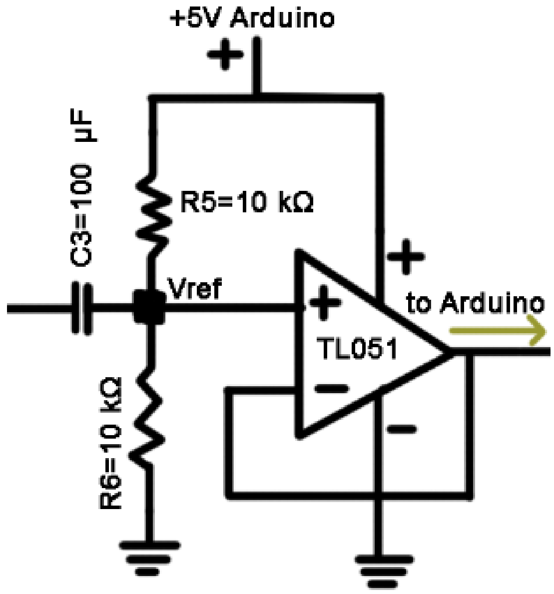

Figure 6. Second stage of the circuit whose purpose is to shift the signal so that it is solely between 0 and +5 volts.

The input to this stage is the signal leaving the first stage that has been amplified and filtered as described above. Since both of the resistors, R_5 and R_6, are equal, this makes Vreference equal to 2.5 volts which makes the average input to the TL051 2.5 volts thanks to the positive 5 volts from Arduino. This results in the output signal being centered at 2.5 volts, very suitable for Arduino. The capacitor, C_3, is used to make a high-pass filter along with two equal resistors. Using $R_{effective}=\frac{R5}{2}$ and equation 3 again, we can calculate the cutoff of this filter to be 0.3 Hz. The goal of this filter is to simply block any super low frequencies from passing through. Once the signal has been properly shifted it is sent to an Arduino Mega 2560, which can be seen in figure 7 below.

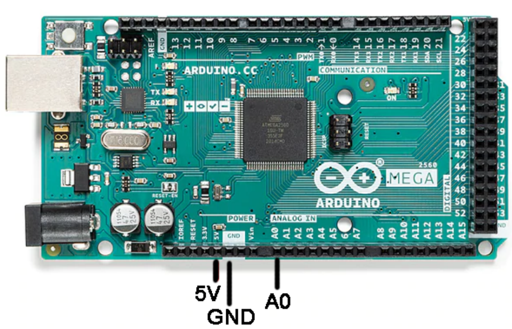

Figure 7. Arduino Mega 2560 image/pinout. From reference 8.

The output from stage two of our circuit is input into an Arduino using the pin A0. The 5 volts from Arduino that can be seen in figure 6 will come from the 5V pin seen in figure 7. It is also extremely important to note that the ground used for the entire circuit comes from the Arduino, specifically the GND pin marked in figure 7.

Figure 8 seen below, shows the diagram of the entire circuit.

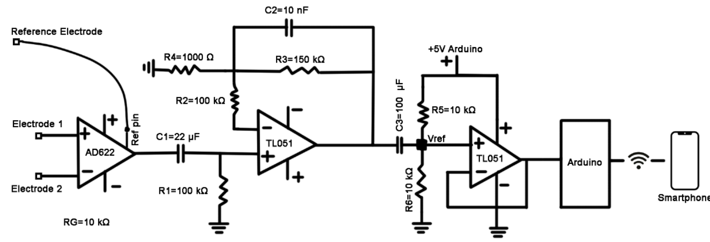

Figure 8. Diagram of the circuit used to amplify, filter, shift, and utilize Arduino to record and analyze EOG signal while reading.

Once the electrodes were connected and the circuit built as described, the EOG signal would be recorded using Arduino while the subject slept. After the signal was recorded, in Arduino we would perform analysis to determine the amount of total time spent in REM sleep and the number of REM cycles the individual goes through while sleeping.

First, the mean of the data would be subtracted from each data point to center the signal at 0V. This is necessary because the input signal will be centered at 2.5V as Arduino only accepts voltage in the range 0V-5V. Next, we would find the absolute value of the signal. This is because we want to analyze when the magnitude of the signal is above a certain threshold. Our input signal into Arduino would have a max magnitude of around 1V, so we chose a threshold value of 0.5V. This means when the signal was ever above 0.5V, we assumed the individual was in REM sleep.

Using this technique to categorize the subject's sleep, we would determine the number of periods they go through REM sleep and how long each of these periods of REM sleep are. Finally, this information would be sent to the subject's phone through what, in the future, we would imagine to be a wellness application.

III. RESULTS

Using Simulink, we simulated what the outputs of each stage of this circuit would look like on an oscilloscope, using an randomized input signal that somewhat resembles EOG. The randomized input signal is shown in Figure 9. Noting the scale on the y-axis, it has a maximum voltage of 1mV and minimum voltage of -1mV. Figure 10 shows the signal after it has been amplified with a gain of 913.5 V/V. It has a maximum voltage of around 0.9V and minimum voltage of around -0.9V. Finally, in Figure 11, the output of the level-shifting circuit can be seen. The maximum voltage now becomes 3.4V and the minimum voltage is around 1.6V.

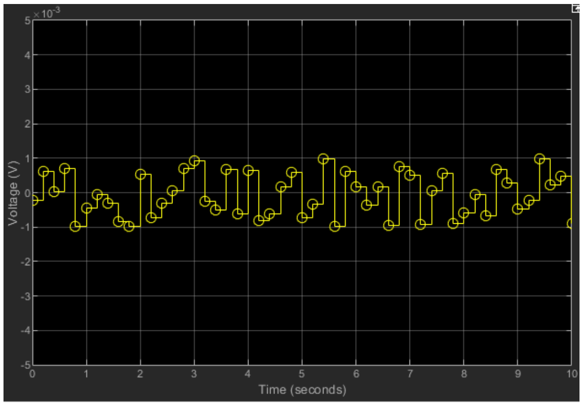

Figure 9. Randomized input signal used to test the circuit that somewhat resembles EOG.

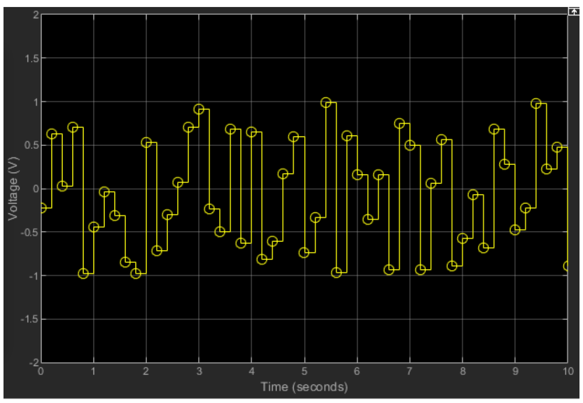

Figure 10. Signal after passing through stage 1 of the circuit. The signal has been filtered and amplified.

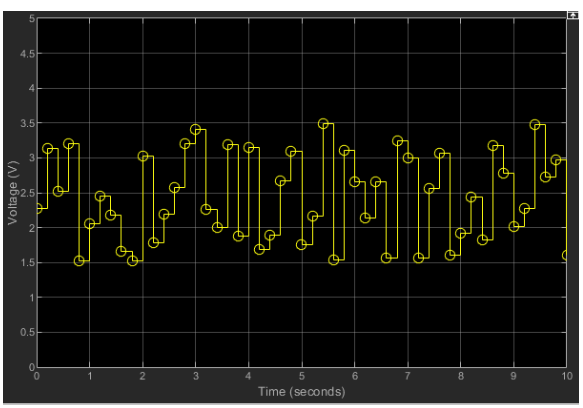

Figure 11. Signal after passing through stage 2 of the circuit, the level shifter. The signal has been shifted so that it is centered at 2.5 volts.

IV. Discussion

Analysis of results:

As previously discussed, it can be assumed that a patient is in REM sleep when the absolute value of the amplitude at a certain time is above a 0.5V on the Arduino. Looking at Figure 11, we see that for most spikes in the time range, the amplitude is well above 0.5 volts, therefore we can assume that the patient is currently in REM sleep. The pseudo code for the Arduino would be as follows:

1. Find when the signal is above a threshold value of 0.5 volts (note: signal is centered at 2.5V)
2. Measure the duration of time each period of REM sleep occurs based on when the signal is above the threshold value
3. Count the number of times the patients experiences REM sleep throughout the night
4. Output number of times and duration of REM sleep to an app on the patient's phone

For our results, we see that the maximum voltage reached is 3.4V, and the minimum to be 1.6V, that peak would have an amplitude of about 0.9V matching our gain. Looking at figure 11 and using the known maximum amplitude, we can assume that for this sample (t = 10 seconds) the patient is experiencing REM sleep, given some variation in amplitude is slightly less than the threshold. Although there are some time data points in which the amplitude is less than 0.5V, the average amplitude reading for the entire sample will be greater than or equal to the REM sleep voltage threshold.

Limitations and Advantages:

This at home REM sleep indication system gives patients the opportunity to learn more about their sleep patterns and monitor their quality of sleep throughout the night. The use of an EOG to accomplish this given a more accurate advantage to characterize when a patient is truly in REM sleep. When using just an EEG, the difference in brain waves when in non-REM and REM sleep is difficult to differentiate because the noticeable change is non-uniform frequency rather than amplitude. However, using an EOG allows for easy identification of non-REM versus REM sleep based on an increase in amplitude. Since REM sleep is a movement of the eyes, using EOG gives a more direct reading of the eyes.

One of the greatest limitations of our project is that REM is the only cycle that can be fully analyzed during sleep using an EOG. If the user wanted to track other parts of their sleep as well (analysis of NREM, sleep interruptions, heart rate, etc.), then a more advanced technology would have to be used. A consideration would be combining the usage of an EOG and EEG so that the user's sleep can be more thoroughly analyzed; however, this would increase the amount of electrodes needed to capture data and therefore would minimize the comfort of the user's sleep that our current design allows. Another limitation is that eye movement during REM is very small (~1°), so the signal must be amplified in order to be properly read. There can also be a lot of noise since the peaks from eye movements are small.

Future steps:

Although the focus for this specific project is on a home health monitoring system, this same design can be used to study other sleep phenomenons and illnesses. One possible direction this design can be used for is studying the effects of different mental illnesses, such as depression and PTSD. Sleep disturbances, such as insomnia, influences the trajectory of depression, increasing episode severity and duration as well as relapse rates (10). With over two-thirds of patients that undergo major depressive disorders also experience insomnia, using REM sleep data for patients with depression can give doctors a better direction to help treat them. Another future direction this device can be used for is studying and improving treatment for people diagnosed with REM sleep behavior disorders. This disorder causes the paralysis that usually happens during REM sleep to be absent causing dreams to be vivid and possibly violent.

There is a large variety of other sleep, and specifically REM sleep, disorders that greatly affect people's lives. The complete functions of the brain is still unknown and sleep studies are a constant study for scientists and engineers. This EOG design can be used as a great stepping stone to learn more about how the body functions in a state of deep sleep.

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Appendix

Equations

$$f_c = \frac{1}{(2\pi)(R)(C)} \tag{1}$$

$$R_G = \frac{50.5\ k\Omega}{G - 1} \tag{2}$$

$$G = 1 + \frac{R_3}{R_4} \tag{3}$$