# EEG Anesthesia Monitor

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***Abstract*—Anesthesia is a medication administered during medical procedures. It is a common practice in the United States despite the risk of complications and the long-term effects being unknown, especially in a developing brain. Currently, general anesthesia, which causes full unconsciousness in the patient, is monitored through vital sign tracking, including pulse oximetry, electrocardiogram, blood pressure, and heart rate. The purpose of this paper is to create an electroencephalogram (EEG) circuitry for anesthesia monitoring and research that is easy to implement, accurate, and noninvasive. An EEG, which measures brain signals, can provide better and more accurate monitoring of the effect that anesthesia has on neurons and brain activity to provide more personalized patient care with less risk of complications associated with over or under-sedation. This was accomplished through the use of dry electrodes, an instrumental amplifier, and cascading filters to capture the signal and process it so that it is amplified and free from noise. Due to the ways that anesthesia affects EEG signals, it is important that beta, gamma, alpha, theta, and delta waves are kept in the signal to monitor the level of sedation. The EEG constructed was successful in providing good-quality data for anesthetic research and analysis.**

## I. Introduction

### A. Background

Anesthetics refer to the medications used under anesthesia, which all work the same way by temporarily blocking pain sensory signals from the nerves to the sensory centers in the brain. There are many types of anesthesia, which are used depending on the type of medical procedure and have varying degrees of pain blockage, including local anesthesia, sedation, regional anesthesia, and general anesthesia. Local anesthesia requires the least amount of medication as it provides numbness to small sections of the body and is used during minimally invasive procedures so the patient is still conscious. Regional anesthesia provides numbness to a larger portion of the body, but similar to local anesthesia, the patient is still conscious. Sedation brings patients to a state of semi-consciousness. Finally, general anesthesia blocks pain in the entire body by making the patient unconscious and insensitive to pain for invasive procedures. For the purposes of this study, EEG signals under general anesthesia where the patient loses consciousness will be of interest. General anesthesia can entail many different types of medications, but a commonly used medication is propofol (1). Currently, anesthesia is monitored through vital sign tracking, including pulse oximetry, electrocardiogram, blood pressure, and heart rate (2).

Electroencephalography, or EEG, is a biomedical tool that measures the electrical activity of synchronously firing populations of neurons (3). The electrical signal is obtained through electrodes placed on the scalp. This method for brain activity analysis is cheap and noninvasive and can provide insight into neural processes. Within an EEG signal, different frequencies of signals are associated with different levels of cognitive function(3). Delta waves range between 0.5 to 4 Hz and are associated with deep sleep(1). Theta waves range between 4 to 8 Hz and are associated with brain activity within the transition between awake and asleep. Alpha waves range between 8 to 12 Hz and are associated with a relaxed, but awake brain state. Beta waves range between 12 to 30 Hz and are associated with the brain activity involved in concentration and active thinking. Finally, gamma waves range between 30 to 100 Hz and are associated with the highest level of cognitive function, alertness, and concentration (1).

As for the effects of anesthesia on EEG, the medication causes the brain circuits to change oscillation patterns by slowing them down(1). This shift in brain communication and signal pathways prevents the neurons in different regions of the brain from communicating and causes the patient to lose consciousness. This loss of consciousness associated with anesthetics is comparable to a coma rather than a deep sleep(4). At proper levels of administered propofol anesthetic, EEG patterns include organized beta-gamma oscillations that transition to slow-delta oscillation (1). Under anesthesia, the amplitude of these waves is lower than in a normal awake state. Alpha waves become coherent and slow after a prolonged state or maintained state of unconsciousness. Under too much sedation, burst suppression can occur, which is periods of inactivity and excitement or peaks in voltage. When reawakening after sedation, the slow alpha oscillations turn to beta and gamma oscillations, and the amplitude of the waves decreases as the person wakes up (1). These characteristics of EEG signals are crucial in the design of the circuit to obtain signals to monitor the level of medication administered.

### B. Motivation

Anesthesia is a very common medical practice, with nearly 40 million anesthetics administered annually in the United States (5). While it is extremely common, there are associated risks. Over-sedation is linked with hemodynamic instability, respiratory depression, and prolonged recovery times (2). Under sedation, there are risks of intraoperative awareness

and a stress response during the procedure (2). In third-world countries such as Ethiopia, anesthesia is also commonly used. However, only about 58% of hospitals meet the minimum WHO anesthesia safety requirements and only about 69% of hospitals meet the patient monitoring requirements (6) Furthermore, the long-term effects of anesthesia are still unknown, especially regarding anesthetics in children and their developing brains (7). There is a need for more accurate anesthesia monitoring to provide better patient care and for further research on the long-term affects of anesthesia on neural pathways.

### C. Goal

The goal of this paper is to create a circuit that accurately captures and processes the neural activity of a patient undergoing general anesthesia. The purpose of the EEG is to be monitored by an anesthesiologist or other trained medical professional so that proper dosage is given dependent on the individual and their response to the medication. The effect of anesthetics on a patient depends on the type and dosage of the medication as well as the age of the patient, and therefore, traditional monitoring practices are less effective and safe for the patient. The circuit we are creating is designed to accurately measure signals so that more personalized patient care with minimized complications can be achieved.

## II. Methods

### A. Block Diagram

Below is a block diagram of the circuit used as a road map for the analysis of EEG signals. In the following sections, each circuit component and its purpose will be discussed in detail.

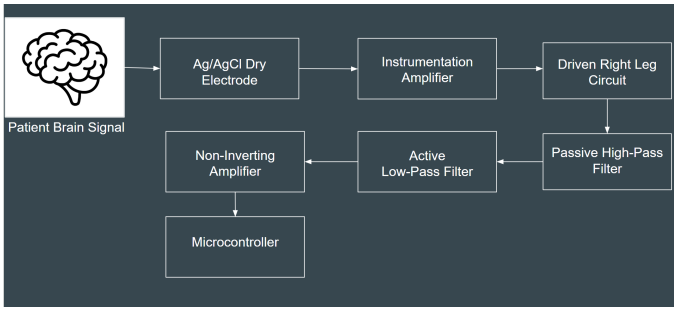


Fig. 1. The block diagram of the circuit schematic

### B. Circuit Components

*1) Ag/AgCl Electrodes:* Dry Ag/AgCl electrodes measure voltage, or changes in electrical potential, on the scalp. Dry electrodes were chosen because they are useful for long-term monitoring and provide accurate data even with slight movement, which is expected under general anesthesia. Additionally, these electrodes have low impedance, no need for skin preparation, and a good signal-to-noise ratio.

*2) Instrumental Amplifier:* The EEG signal, initially between 10-100 $\mu$V, is amplified by an instrumentation amplifier, specifically the AD624. This amplifier is chosen for its high precision, low noise, and exceptional common-mode rejection ratio (CMRR), crucial for enhancing the EEG's minute fluctuations by filtering out the significant DC component from the electrode interface.

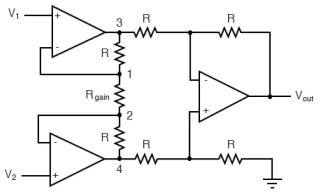


Fig. 2. Instrumental Amplifier

$$Gain_{IA} = 1 + 2R/R_{gain} \tag{1}$$

*3) Driven Right Leg:* The Driven Right Leg (DRL) circuit, integral to the EEG setup, functions to mitigate common-mode interference, particularly the 60 Hz noise from power lines, while enhancing safety. It operates by actively cancelling electromagnetic interference that the body, acting as an antenna, may pick up. This circuit is crucial in biological signal amplification systems where it ensures the minute biological signals are not masked by external noise. Thus, the DRL circuit is a key component in preserving the clarity and accuracy of the measured signals.

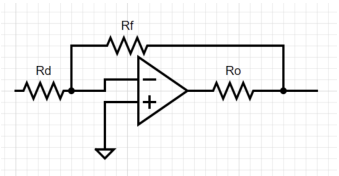


Fig. 3. DRL Circuit

$$Gain_{DRL} = -R_f/R_d \tag{2}$$

*4) Cascading Filters:* After amplification, the signal is filtered via 5 different pipelines to obtain the desired EEG signal waves: gamma, beta, alpha, theta, and delta. This is achieved by cascading a passive high-pass filter to remove low-frequency noise with an active low-pass filter to attenuate high-frequency interference and amplify the desired signal.

$$f_C = 1/2\pi RC \tag{3}$$

The following equation gives the gain of the Active Low-Pass Filter.

$$Gain_{LP} = -R_2/R_1 \tag{4}$$

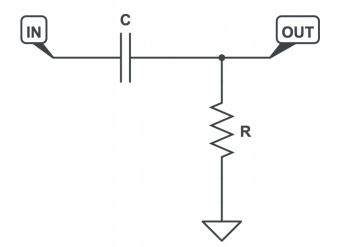


Fig. 4. Passive High-Pass Filter

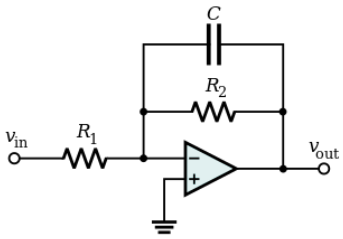


Fig. 5. Active Low-Pass Filter

*5) Buffer:* The buffer, utilizing an operational amplifier, effectively isolates each filter stage, preventing interaction and ensuring that the input and output impedance across filters remain unaffected. Thus, the filter is indispensable for maintaining the fidelity of the filtered signals through the cascade, ensuring optimal performance and signal quality.

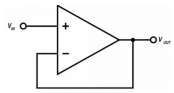

Fig. 6. Buffer Circuit

*6) Non-Inverting Op Amp:* The final component in our EEG circuit is a non-inverting operational amplifier (op-amp), which applies additional gain to the filtered signals to achieve an overall gain of approximately 10,000. This final amplification step is critical as it elevates the EEG signals from their original range (10-100 $\mu$V) to a level (around 1 V) suitable for analog-to-digital conversion by the ADC within the micro-controller. This ensures the signals are within an optimal range for precise digital processing and analysis.

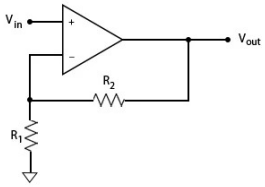


Fig. 7. Non-Inverting Op Amp

$$Gain_{OA} = 1 + R_2/R_1 \quad (5)$$

### C. Circuit Schematic

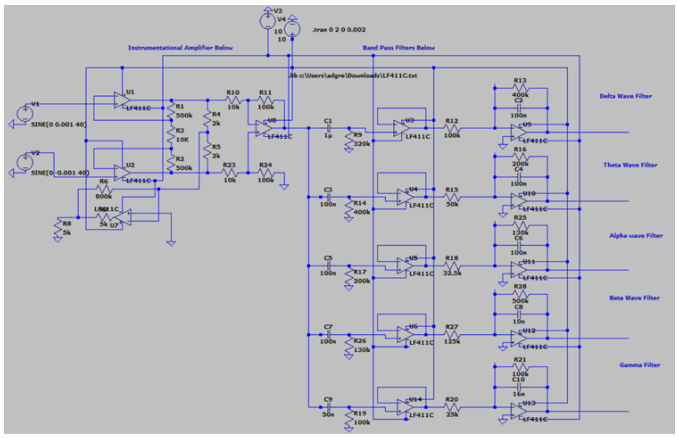

Fig. 8. Schematic of the Entire Circuit

### D. Circuit Simulations

Time domain analysis of the circuit shows that the instrumentation amplifier can amplify the signal significantly, making it easier to visualize the EEG signals after being passed through the cascading filters and ADC. The output of the instrumentation amplifier can be seen in figure 9. The green line represents the input wave from the electrodes, a 0.001V amplitude sine wave with a frequency of 1Hz and the blue wave is the output from the instrumentation amplifier, a 2V amplitude sine wave with a 1Hz frequency.

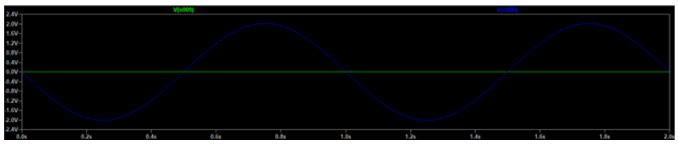

Fig. 9. The Input and Output Sine Waves of the Instrumentation Amplifier

The 0.5Hz to 4Hz delta wave filter works well, in figure 10 below, it can be seen that the input wave is filtered very well, the blue line represents the output wave of the delta filter and it can be seen that it has a significantly larger amplitude than the output of the other filters and the input wave. The green line represents the input to the filters from the IA, the red line is the output of the theta filter, the turquoise line is the output of the alpha filter, the magenta line is the output of the beta filter and the grey line is the output of the gamma filter. This is consistent across all of the below figures.

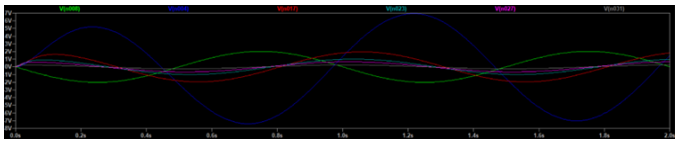

Fig. 10. The 1Hz Frequency Input to the Filters and the Output from them

The other filters, however, show less reliable filtering. This is because the order of the filters is not very high leading

to a slower roll-off which allows signals outside the desired frequency range into the specified range.

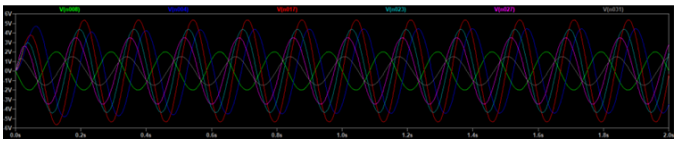

Fig. 11. The 6Hz Frequency Input to the Filters and the Output from them

With the 6Hz input frequency, seen in figure 11, the amplitude from the theta filter still has a higher frequency than the other frequencies. However, the outputs from the delta, alpha, and theta filters are still high due to the slow roll-off of the filters.

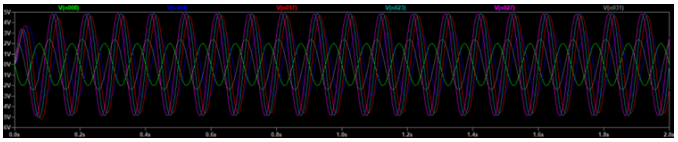

Fig. 12. The 10Hz Frequency Input to the Filters and the Output from them

With the 10Hz input frequency, seen in figure 12, the amplitude from the outputs of the theta, alpha, and beta filters appear to be equal due to the slow roll-off of the filters.

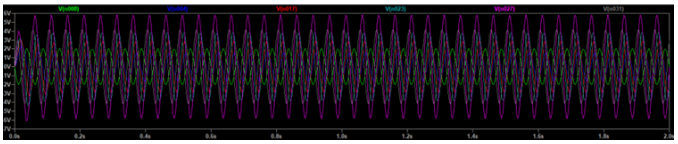

Fig. 13. The 20Hz Frequency Input to the Filters and the Output from them

With the 20Hz input frequency, seen in figure 13, the amplitude of the beta filter has a noticeably higher amplitude, than the outputs from the other filters. This implies that the other filters are attenuating the signal, however, the roll-off is so slow that a significant amount of the signal is still being allowed to pass through.

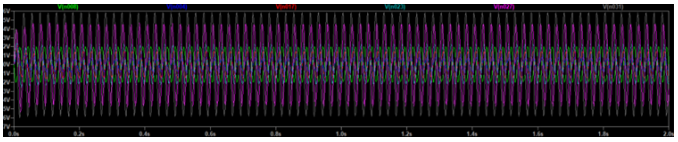

Fig. 14. The 40Hz Frequency Input to the Filters and the Output from them

With the 40Hz input frequency, the amplitude of the gamma frequency filter is the largest as expected, and the amplitude from the beta filter is the next largest. The output amplitudes from the delta and theta filters are significantly smaller than the input from the IA, and the amplitude output from the alpha filter appears equal to the input amplitude from the IA. The output amplitude from the beta filter still has a large output amplitude of 4.5V compared to the gamma filter's output voltage of 6V.

## III. Discussion

### A. Advantages

The advantages of EEG anesthesia monitoring is that it is cheap and easy to implement, it is a non-invasive procedure, and allows for personalized patient care instead of population-based dosing guidelines, which can sometimes lead to anesthetic overdosing or under dosing. (8) Inadequate sedation levels can lead to risks associated with excessive sedation including hemodynamic instability, respiratory depression, and prolonged recovery times, or conversely intraoperative awareness and stress response. One advantage of our design is that it significantly amplifies the EEG signal and filters the noise out and outputs only the five different frequencies of our interest.

### B. Limitations and Future Improvements

The main limitation of the circuit is that the roll-off is too slow. This limits the attenuation meaning that frequencies that should only appear at the output of one filter can be seen in the output of multiple filters which affects the ability to draw high-quality insights that could be used to draw conclusions on the patient's current state. This could be improved by replacing the passive high pass filter and active low pass filters, with two active filters such as higher-order Sallen-Key or Multiple Feedback filters as the roll-off from these filters will be higher than the roll-off of the current filters being used.

The next steps for our device is to incorporate spectral analysis from the raw EEG, which is used to visualize small changes in the frequency structure, and a digital output of the spectrogram easily accessible to the anesthesiologist.

### C. Significance

The significance of leveraging EEG for anesthesia monitoring extends far beyond its cost-effectiveness and ease of implementation. This approach represents a paradigm shift towards more personalized and adaptive anesthesia management, offering a tailored sedation plan that respects the unique physiological responses of each patient. By mitigating the risks associated with both under and over-sedation, EEG monitoring enhances patient safety and outcomes.

This project contributes to the scientific foundation of biomedical engineering and neurophysiology, offering a framework for future research endeavors aimed at the enhancement of medical monitoring devices. The envisioned enhancements to EEG monitoring technology, particularly in facilitating real-time, data-driven anesthetic adjustments, hold the potential to revolutionize anesthetic management practices. The significance of this project lies not only in its immediate application to improving anesthetic care through personalized monitoring but also in its broader implications for medical device innovation, patient safety, and the advancement of personalized medicine. This work represents a critical step forward in the optimization of surgical outcomes and the enhancement of patient experiences, underscoring the pivotal role of technological innovation in the evolution of healthcare practices.

## IV. Acknowledgments

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