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Design and Simulation Low-Cost EEG Brain Attention-Level Recognition System for Students

Khaled A. Alzahrani
Electrical and Computer Engineering Department, King Abdulaziz University, Saudi Arabia

ABSTRACT
In this paper, a novel approach for measuring mind attention level is proposed. The system is entirely created from analog hardware electronic components, making it independent of computers and large processors. The system operates by detecting alpha (8-12Hz) waves in the Electroencephalogram (EEG) that reflect a general impression of attention level. There is an inverse relationship between the level of alpha waves and the degree of attention or sleepiness, especially in adults. The higher amplitude of the alpha waves indicates the lower level of attention and is nearest to a state of relaxation or drowsiness. The proposed design has four EEG brain waves channels. Each channel includes an amplifier to amplify the week signals, a band-pass filter (BPF) to pass alpha waves, and a peak detector to hold the maximum voltage level of each channel. The maximum levels of all four channels are combined by averaging the circuit and feed to indicator circuit to monitor the attention level. The simulation results were successful and as expected in the design.
Keywords - EEG, Attention-Level, Alpha-Waves, Op-Amp, MF-BPF

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I. INTRODUCTION

Because of the technology revolution, today's life is different than the past. It has become more critical to develop solutions to facilitate daily practices and work. In recent months, the world faced the Covid-19 pandemic, which changed the way of dealing with many areas of life. One of the most affected fields is academia, which utilizes distance education due to the necessity of social distancing to reduce the spread of the disease. There are some advantages and disadvantages of the distance education. One of the most significant drawbacks is that the teacher cannot determine the level of student attentiveness. Hence, this paper came to suggest a method that gives the teacher an impression of the students' attention and interaction level. This approach is based on reading Electroencephalogram (EEG) signals, and through these waves, the teacher could have an impression of his student's attention degree.

An Electroencephalogram is a method to read the electrical activity on the scalp generated by brain structure. To read EEG, we use a metal electrode and a conductive media. Mostly, EEG measures the current flow during synaptic excitations of the neural branches of neurons in the cerebral cortex [1]. The history of EEG signals dates back more than a century. The development of the field passes through three main stages. The first stage was performed in 1875 by an English physician named Richard Caton. Richard conducted studies on monkeys and rabbits and discovered electrical currents in the brain. The second stage occurred in 1924, when Hans Berger, a German neurologist, succeeded in amplifying the electrical activity of the brain using standard radio equipment. He noticed that changes in these waves depending on the brain state, such as anesthesia, sleep, and so on. Berge`s discovery is considered as the base of the current applications of EEG signals. He also gives this phenomenon the name "electroencephalography". The third stage occurred in 1934 when Adrian and Matthews presented a study to validate the notion of "human brain waves". They also identified an "alpha rhythm," which is a consistent rhythm that occurs between 10Hz and 12Hz [1].

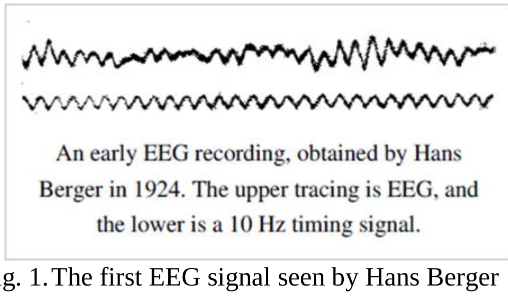

Fig. 1. The first EEG signal seen by Hans Berger [7]

II. LITERATURE REVIEW

Many studies have been conducted to determine the amount of attention in the human mind. One of them utilized NeuroSky's Mind Wave EEG device to collect EEG data from the human brain. The collected data was then compared with video recording images. The research then conducts a correlation procedure between EEG data and recorded video at the same time series [2]. Another research used classification technique to do this task. In this research, the signal was classified using K Nearest Neighbors (KNN), Support Vector Machine (c-SVM), Linear Discriminant Analysis (LDA) and Bayesian classifiers. Record data from 12 subjects in order to achieve a valid dataset. It classified the human attention into two classes: attention and non-attention states. The features were extracted from different frequency bands [3].

This issue is also being discussed in another study to detect the human mind state while driving because the driver's attention is critical when driving in order to avoid vehicle accidents. This objective was accomplished by the use of the deep learning approach in this study. To collect the data, it employed four channels of EEG [4]. Some researchers used time-frequency analysis of the recorded EEG signals. The aim of this research is to see the effect of meditation on the mind signals. They applied the experiment on 10 normal adults and further divided them into two groups: more than 10 years of meditation experience and with no meditation experience. The EEG signals were recorded by using 19 active electrodes with a sampling frequency of 250Hz during meditation. It used Fast-Fourier Transform (FFT) to analyze the recorded data. One of the most important results in this paper is the correlation between *alpha waves* and mind state. It presents that a greater level of an alpha wave is found during a lower level of anxiety. In other words, if the mind is calm the alpha wave amplitude will be higher [5]. Other researchers used mobile brainwave sensors to collect EEG data. The objective of this study is to classify the student into two classes: attentive and inattentive. Common features were extracted from the raw data then it used the Support Vector Machine (SVM) classifier to classify the signal. The classification accuracy achieved up to 76.82% [6].

III. METHODOLOGY

All the presented studies discussed in the literature required a computer to process the EEG signals, and some of them required massive amounts of data to train the system. None of these are needed in our proposed design. The researchers discovered a link between alpha wave amplitude and mind state after conducting many investigations on EEG data and mind state. When the amplitude of the EEG alpha signal increases this indicates a low attention level of the mind. When alpha amplitude decrease (attenuate) this indicates a high attention level of the mind [5][7][8]. Adults have a typical amplitude EEG signal from about 10µV to 100µV when measured from the scalp [7].

The proposed design to detect and monitor the mind's attention level is divided into two main stages: *Initial stage* and *Collection stage*. This design can be integrated with headphone to ease its functionality as shown in figure:2. The details of each stage design are described in the next lines.

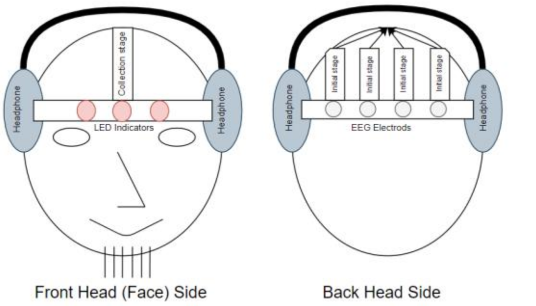

Fig. 2. Initial and Collection stages of the proposed design integrated with a headphone

A. Initial stage:

In this stage, we have a complete chain of analog circuits for each channel and all of them are identical as shown in figure:3.

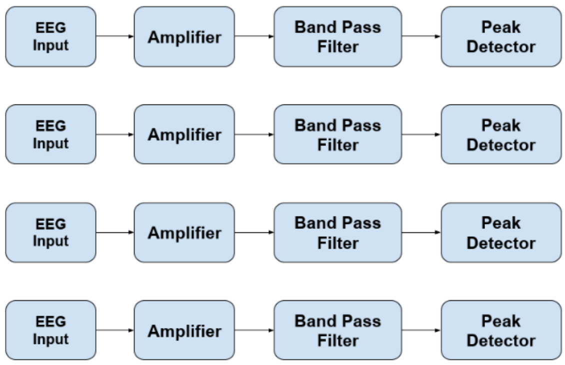

Fig. 3. Initial stage architecture of the attention level recognition system

This stage includes four circuits:

1. EEG input electrode.
2. Amplifier circuit.
3. Band Pass Filter circuit.
4. Peak Detector circuit.

B. Collection stage:

In this stage, the output of all channels will be collected in a single output as an average of all four signals as shown in figure:4.

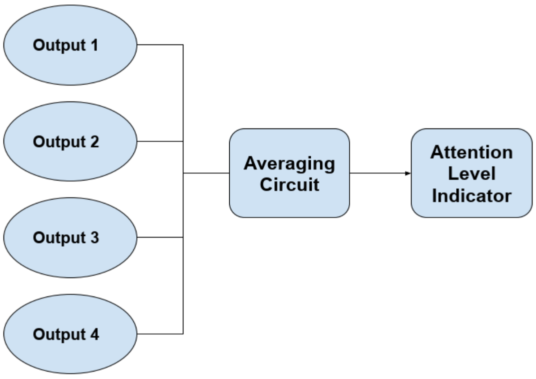

Fig. 4. Collection stage architecture of the attention level recognition system

This stage includes two circuits:

1. Averaging circuit.
2. Attention Level Indicator circuit.

All these circuits will be explained in more details in the following sub-sections.

EEG input: The primary function of this block is to acquire variations in electrical brain activity and feed them to the following amplifier circuit. There are several ways (montage) for connecting the electrodes and feeding them to the next circuit (differential amplifier). One way is to connect the electrode's input to the differential amplifier input, and the second differential amplifier input to a common system reference electrode [7]. This type of connection is known as a single-ended input. This technique of connection will be used in our design and simulation.

Amplifier circuit: The main objective of the amplifier is to enhance the incoming signal from EEG electrodes. The amplification in this circuit should be high enough to reach from micro-volt to milli-volt signal voltage level. The instrumentation amplifier (In-Amp) circuit is commonly used to amplify the weak signals because of its high Common Mode Rejection Ration (CMRR), high input impedance, low noise, and high gain [9]. We ended up with the following design shown in figure:5 after creating the circuit and simulating it multiple times to obtain the desired outcome.

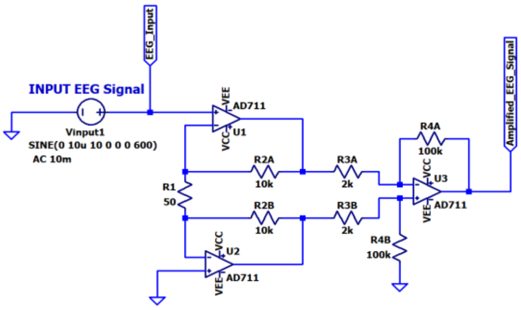

Fig. 5. Instrumentation amplifier circuit design

Band Pass Filter circuit: The major function of this circuit is to filter out any undesired signal and pass only the alpha band signals (range from 8Hz to 12Hz). We implemented this circuit using Multiple Feedback Band Pass Filter (MF-BPF) topology, because it is easy and reliable [10]. The final design of the MF-BPF at 10Hz center frequency is shown in figure:6.

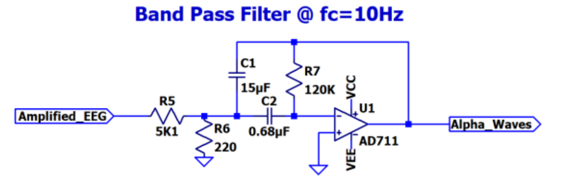

Fig. 6. Multiple feed-back Band Pass Filter circuit design

Peak Detector circuit: The primary purpose of this circuit is to capture positive peaks in the incoming signal and hold them for a defined time period. The obtained signal will be converted from AC to DC after passing through this circuit. The final design of the peak detector circuit is shown in figure:7.

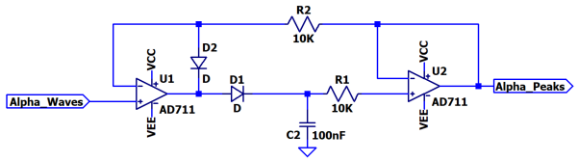

Fig. 7. Active peak detector circuit design

Averaging circuit: The principal role of this circuit is to combine all incoming signals into a single output and produce the average voltage level of them. The circuit is also add a specified gain to raise the average voltage to an appropriate level. The averaging circuit design is shown in figure:8.

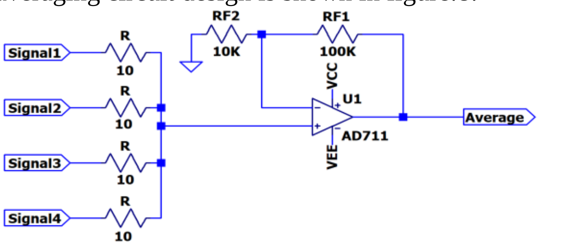

Fig. 8. Averaging circuit design with gain=11

Attention Level Indicator circuit: This is the final circuit of the proposed design. The main function of this circuit is to monitor the attention level by turning the LED indicators ON or OFF. The circuit design is determined by the number of attention levels required. In our case, we designed our circuit to detect and monitor four different levels of attention. We assumed the following attention levels:

- More than 90% (All LEDs are ON).
- Between 70% to 90% (Two LEDs are ON and one LED is OFF).
- Between 50% to 70% (Two LEDs are OFF and one LED is ON).
- Less than 50% (All LEDs are OFF).

Figure:9 shows the indicator circuit with three set-points: A, B and C. When the voltage on the setting point (V_{SET}) is greater than the input average voltage (V_{AVG}) the related LED will be ON.

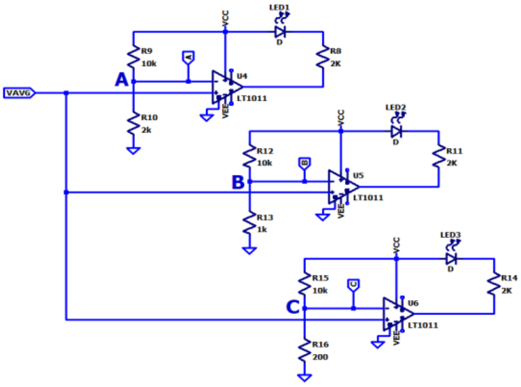

Fig. 9. Attention level indicator circuit design with three set-points

IV. SIMULATION RESULTS

The simulation is carried out using the LTspice simulator tool. LTspice is a free schematic capture and waveform viewer software developed by Analog Devices corporations and it offers high-performance SPICE simulation [11].

As it shown before in figure:9, we have three set-points: A, B and C. The average signal (V_{AVG}) will be compared with these points. These three points will create four attention level zones as illustrated in figure:10. When V_{AVG} exists in Level#1, this indicates a low attention level, and all LEDs current will be OFF. When V_{AVG} exists in level#4, this means a high attention level and all LEDs current will be ON.

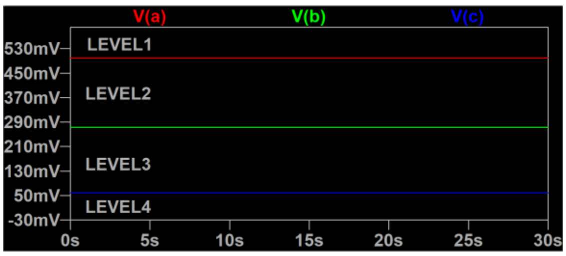

Fig. 10. Three set-points create four attention level zones

The signals in the initial stage are almost similar in all four channels. The only difference is the detailed data, which is derived from different electrodes and head positions. So, we will present the outcome after each circuit of channel#1 and the other channels will have the same behavior. Figure:11 represents the input EEG signal coming from the electrode before amplification. The data was imported to LTspice from external recorded data in form of a text file. This recorded data consists of 55 intervals and each interval last 30 seconds with 500Hz data rate. So, the overall data recording time is 27.5 minutes.

From the recorded data, we chose two different samples with duration of five second at different intervals and using them as input EEG signal to be able to compare the results. We chose five seconds to view the data better and clearer. We took the first sample from the early time of data recording, as we see in the figure:11. After the amplifier circuit, the signal will have an amplitude level in the mV range as it shown in figure:12.

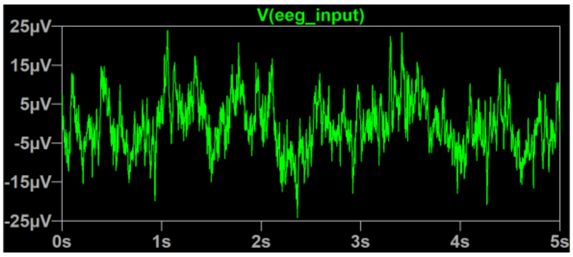

Fig. 11. Input EEG signal to channel 1

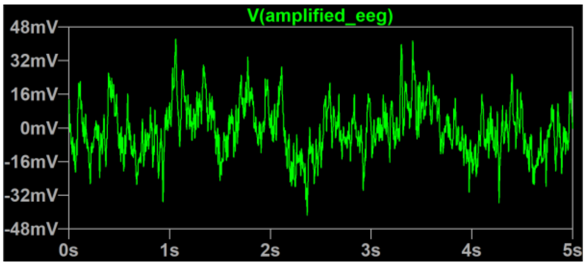

Fig. 12. EEG signal after amplification. The signal level amplified from uV range to mV range

Figure:13 illustrates the output of the BPF. This signal is the alpha wave signal (8Hz to 12Hz) extracted from the input EEG.

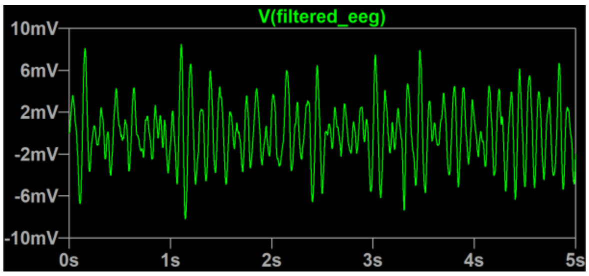

Fig. 13. The output signal of the BPF. It represents the alpha wave

Figure:14 represents the output of the peak detector circuit. As we can see, the circuit captured and held the maximum alpha wave values for a specific time.

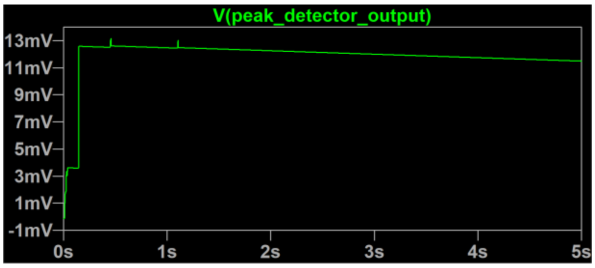

Fig. 14. The output signal of peak detector circuit

Figure:15 depicts the output of the averaging circuit. As we can see, the average signal of all channels output existed in the level#3 zone. This means two LEDs will be ON and one will be OFF as shown in figure:16.

Fig. 15. The output of averaging circuit (green color) exited in level 3 zone

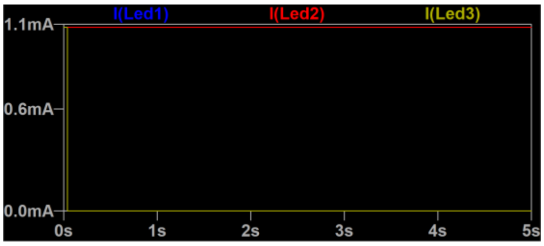

Fig. 16. The state of LED indicators. Tow LEDs are ON (current = 1.1mA) and one LED is OFF (current = zero)

Fig. 17.

The previous results coming from input EEG data picked from early time of data recording. We took another EEG sample from other recording time to compare between the two cases. As you see in figure:17, there are clear difference in the amplitude between two data samples. The green signal represents input EEG signal from data sample#1 and the blue signal represents input EEG signal from data sample#2.

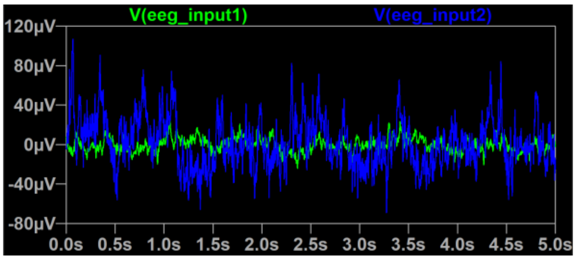

Fig. 18. Input EEG signal samples from two different intervals of the recording data

Figure:18 shows the signals after BPF (alpha waves) for the same different data samples of the previous figure.

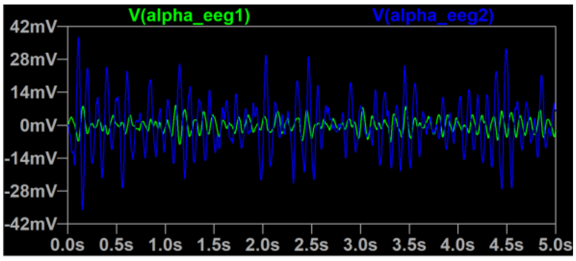

Fig. 19. Alpha waves of sample#1 and sample#2 data

The result of sample#2 is increasing in V_{AVG} level until it reaches to level#2 zone of the attention as shown in the figure:19. Depending on this case, only LED1 will be ON as it shown in figure:20.

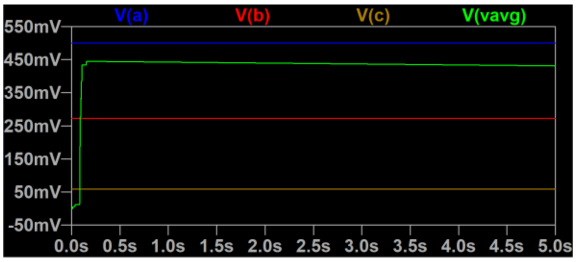

Fig. 20. The output of averaging circuit (green color) exited in level 2 zone when we use sample 2 EEG data

Fig. 21.

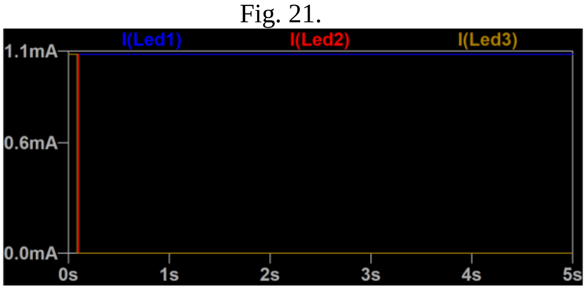

Fig. 22. The state of LED indicators when we use sample 2 EEG data. One LED is ON (current = 1.1mA) and two LEDs are OFF (current = zero)

V. DISCUSSION

The previous section represents the simulation and desired outcomes that were expected in the design section. We utilized from a recorded EEG data for about 27 minutes. During this recorded time, we took two data samples (sample#1 and sample#2) from two different time intervals. The amplitude of sample#2 is higher than sample#1 and this reflected in the attention level indicator circuit as it presented. The interpretation of this result is that: in the first sample, the recording data taken from early recording time and the attention of the person was high, but in the second sample, with the passage of time, the person became tired and his attention decreased. So, as attention decreased the alpha amplitude become higher.

This design can improve the teaching process by helping the teachers to have impressions of their students so they can use different ways to increase the student's attention efficiency. The student attention can be enhanced by using different ways and tools depending on the topic [2]. This technique can also help the institutions in collecting statistical data to evaluate the educational process. The data collection is very important to assess and improve the education process [12]. Some design parameters require further tuning methods, such as collecting data from various adults until we achieve the optimal solution. Moreover, tuning can be done by using a real implemented hardware because the simulation results might be slightly different from the real case. Practically, temperature, humidity, and the precision of electrical components could affect the results. In the future, the proposed design can be manufactured and implemented on a real printed circuit board (PCB) and by using variable resistors we can adjust the set-points to the optimal values. At first, we can use this process for one adult and after that we can test it by feeding data from different adults. Once the output is tested and verified, we can design and manufacture the overall system on an integrated circuit (IC) as a customized design to make it portable and less affected by the environment.

VI. CONCLUSION

In this paper, a new method has been proposed to measure and monitor the attention level. This technique is based on the findings of several studies on the relationship between alpha wave amplitude and mind state. During relaxation, the amplitude of the alpha wave will be greater while during a mental task, the alpha wave amplitude will be attenuated. In this paper, we designed and simulate a pure hardware analog electronic circuits to detect and monitor this phenomenon. This circuit could be used for any application. One of the most important applications that arise in recent years is distance learning. Because of the Covid-19 epidemic, distance learning has grown considerably in the last year. We expect that the distance learning will be main part of the education program around the world. The proposed design can help teachers to have an indication about their student's attention. The simulation results were promising and as expected in the design stage. The proposed design not only focuses on a specified application, but it is a general approach that may be implemented on other concepts rather than a specific application. This work can be developed in the future by testing it on variety of real-world dataset and adjusting the values of the existing components to get the optimal results. It can also be manufactured in small integrated circuits after verifying the values of the final components according to the application intended for it.

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