Portable EEG Signal Acquisition System

Noor Ashraaf Noorazman, Nor Hidayati Aziz

Faculty of Engineering and Technology, Multimedia University, Jalan Ayer Keroh Lama, 75450 Melaka, Malaysia Email: <u>noor.ashraaf@gmail.com</u>, <u>hidayati.aziz@mmu.edu.my</u>

Abstract— The overall objective of this project is to design and implement a single-channel portable EEG amplifier with a bandwidth of 0.05-60Hz for patient monitoring purpose operated by battery. This micro analog biopotential signal will be viewed by an oscilloscope. Successful implementation of the final system would be of benefit to all involved in the use of Electroencephalography for brain computer interface and clinical diagnosis. This project is further divided into three parts which is the acquisition, gain and filtering. For a standard EEG amplifier, it consists of an instrumentation amplifier (IA) followed by a high pass filter, and a right leg drive amplifier. After the first stage gain, the signal will be passed into the second dual operational amplifier for second stage amplification and third stage amplification. Finally the signal will be filtered by a low pass filter to eliminate signal noise. Output signal will be detected by using digital oscilloscope for signal analysis. EEG acquisition is done by placing 2 electrodes at the frontal lobe FP1 and FP2 for Alpha and Beta wave. A successful constructed single-channel portable EEG amplifier is capable of acquiring a satisfactory reading of EEG signal. It can be expanded to be a multi-channel EEG amplifier and convert into digital signal to be viewed in computer for recording and further signal analysis.

Index Terms— Portable EEG Signal Acquisition System, Portable EEG Signal Amplifier, Electro-Encephalogram, Single Channel EEG Amplifier.

I. INTRODUCTION

THE Electroencephalogram (EEG) measures the electrical activity of the brain as seen from electrodes placed on the scalp. The presence of electrical current in the brain was discovered by an English physician, Richard Caton in 1975. The electrical activity is due nerve cell activity and shows a continuous oscillating electrical activity known as rhythm. [1]

The human brain contains approximately 100 billion nerve cells called neurons. Neurons have the amazing ability to gather and transmit electrochemical signals. The Neurons have 3 basic parts, a cell body which has the necessary cells components, Axon which is like a long cable to carry nerve impulse and finally the Dendrites which is the nerve ending branches that connects to other cells to allow electrical transfers between cells.

The generation of EEG potentials requires a neural source close to the inside surface of the skull that is coherent, which means all the neurons must be aligned similarly and act together electrically. Pyramidal cells in the center of the cerebral cortex are the major source of EEG potentials. The dendrites will receive excitatory or inhibitory inputs from surrounding neurons and axons. When the dendrites receive an impulse or input by an ion such as Na+ enters them (become active), current flows into and out of these dendritic processes and the cell body. The cell to dendrite relationship is therefore one of a constantly shifting current dipole, and variations in orientation and strength of the dipole produce wave like fluctuations in a volume conductor. When the sum of electrical activity is negative relative to cell, the cell is depolarized and quite excitable. When it is positive, the cell is hyperpolarized and less excitable.

EEG potentials on the scalp are usually no more than 150uV peak to peak. The brain frequencies depended on the degree of activity of the cerebral cortex. For example, the waves change between states of wakefulness and sleep. Much of the time, the brain waves are irregular and no general pattern can be observed. Yet at other times, distinct patterns do occur. Some of these are characterized to be abnormalities of the brain such as epilepsy. Generally there are four wave groups (alpha, beta, theta, and delta).

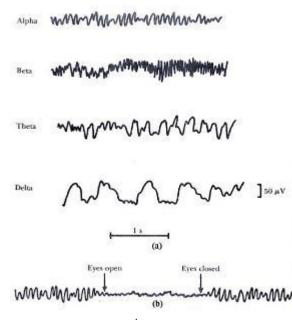
The EEG rhythm and waveforms are varied by the position of electrode placements on certain parts of the brain (fig.1). *Alpha* wave occurs at a frequency between 7.5 and 13Hz. The alpha waves are produced when a person is in a conscious, relaxed state with eyes closed; the activity is suppressed when the eyes are open. The amplitude of the alpha rhythm is largest and intensely occurs in the occipital region and can be best recorded at parietal and frontal regions of the scalp.

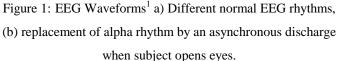
Beta waves normally occur in the frequency range of 14-30Hz and sometimes even as high as 50Hz for intense activity. Beta waves activities are present when people are alert or anxious, with their eyes open.

Theta potentials are large amplitude, low frequency between 3.5 and 7.5Hz waves. Theta is abnormal in alert

College Science in India <u>www.collegescienceinindia.com</u> 3 : 1 February 2009 Portable EEG Signal Acquisition System Noor Ashraaf Noorazman and Nor Hidayati Aziz adults but seen during sleep, and small children. Theta waves occur mainly in the parietal and temporal region.

Delta waves have the largest amplitudes and the lowest frequency in less than 3.5Hz. It is normal rhythm for infants less than one year old and in adults in deep sleep. This wave can thus occur solely within the cortex, independent of the activities in lower regions of the brain. [2]





The system most often used to place electrodes for monitoring the clinical EEG is the International Federation 10-20 system as in figure 2.2. The 10-20 system is not how many electrodes to be put on the scalp but rather a measurement of percentage of 10% or 20% on a certain anatomical landmarks to standardize the placement of electrodes. The positions are defined by certain anatomical reference points as follows: Reference points are nasion, which is the delve at the top of the nose, level with the eyes; and inion, which is the bony lump at the base of the skull on the midline at the back of the head. From these points, the skull perimeters are measured in the transverse and median planes.

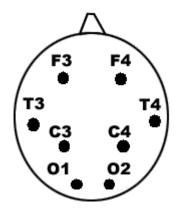


Figure 2: 10-20 Electrode Placement System. The letter above P = parietal, F = frontal, T = temporal, O = occipital as standardized by the American Electroencephalographic Society.

In Clinical EEG measurement, a Neurophysiologist who wish to further localized the sources of EEG activity in the cortex, can place electrodes in such arrays that contain 32, 64, 128, 256 individual electrodes. They are used in medical diagnosis, research in physiological psychology, biofeedback and brain computer interface applications. [3]

In this experiment, 3 electrodes are going to be used, where one of them is a reference electrode. Electrodes are placed at the place of interest e.g. Frontal Cerebrum region for detecting Beta Waves, or at the Occipital region for Alpha Waves. Measurement can be made by a bipolar electrodes which is between each member of a pair electrodes, or mono polar electrodes where one mono polar lead and a distant reference electrode (usually attached to one or both ear lobes), or between one mono polar lead and the average of all.

In the average reference mode, all electrode placement locations are connected to an equal high resistance common point. In the bipolar system, differential measurements are made between successive pairs of electrodes. Theoretically it is an advantage for using differential recording between closely spaced electrodes because it can cancel of the far-field activity common to both electrodes.

II. MATERIALS AND METHOD

A. System Design Concept

In the figure 3 below, shows the overall concept of the system design for the portable EEG signal acquisition system.

¹ EEG States http://neurocog.psy.tufts.edu/images/eeg_states.gif
 College Science in India <u>www.collegescienceinindia.com</u>
 3 : 1 February 2009
 Portable EEG Signal Acquisition System
 Noor Ashraaf Noorazman and Nor Hidayati Aziz

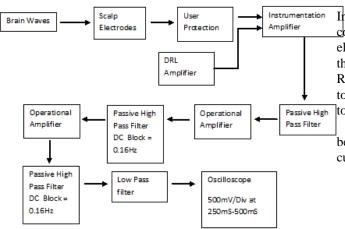


Figure 3: System Design Concept

B. Passive Electrode

Passive electrode is just a piece of metal for conductivity. The type of metal would be gold plated and connected to a single RCA wire for this experiment as in figure 4. Gold are an excellent material for long term stimulation, implantable electrodes, either monophasic or biphasic current pulses. Passive electrodes are taped to the skin using a nonconductive tape along with electrode gel for conductivity. [3]



Figure 4: Small Round Gold Plated Electrode with RCA input

C. Driven Right Leg Amplifier Circuit

A driven right leg (DRL) circuit is used as a connection between the signal source and the amplifier common (0 V, the midpoint between the supply voltages). A DRL circuit reduces the common mode voltage by driving from INA 114 actively to the potential of the amplifier common. A DRL, in addition, protects the user from the consequences of amplifier defects because a series resistor in the circuit limits the maximum current through the ground electrode to a safe level. The common mode suppression of a DRL circuit increases with decreasing frequency. Consequently, the DRL circuit compensates for the decreasing CMRR of the instrumentation amplifier at low frequencies. Conclusively speaking, a DRL should be used in every biomedical recording system for interference suppression and user safety. [3][4][5]

College Science in India <u>www.collegescienceinindia.com</u> 3 : 1 February 2009 Portable EEG Signal Acquisition System Noor Ashraaf Noorazman and Nor Hidayati Aziz The design of the DRL circuit used a TL062 for its High Input Impedance JFET input stage and low power consumption as in figure 5. The construction of the DRL electrode material was the same gold electrode. Capacitor in the feedback loop is chosen to maintain the stability of the Right leg drive loop. It limits the high-frequency gain and help to prevent oscillation. The output of TL062 is then connected to the Right Leg electrode of the user.

If user is not connected to the DRL, VGND electrode must be used instead to avoid INA 114 to have no defined bias current return path and will not work properly.

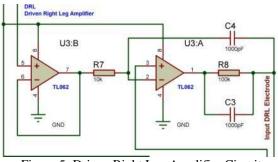


Figure 5: Driven Right Leg Amplifier Circuit

D. Instrumentation Amplifier INA 114

The EEG has a magnitude of about 100uV, so a reasonably high gains, high quality biopotential amplifier is needed.

Instrumentation amplifier is amplifier that amplifies signal difference and rejects input signals common to both input leads. This is very important cause noise is pretty same on both instrumentation amplifier input leads (electrodes and electrode cables are very close so noise influence is same on both of them), so due to its ability to reject input signals common to both input it will reject the noise. Brain potentials are different on each electrode so instrumentation amplifier will amplify brain potentials because it amplifies signals difference.

Instrumentation amplifier INA114 (Figure 6) was used in this project; it is very suitable for medical instrumentation application and uses low power consumption which makes it good for portable design. The general purpose instrumentation amplifier offering excellent accuracy that rejects common signal with 115dB (common mode rejection ration, CMRR = 115dB), has very low offset voltage of 50uV (DC component that amplifier adds to the signal), very low drift voltage of $0.25uV/^{\circ}C$ (another DC component that amplifier adds to the signal that is a function of temperature). The instrumentation amplifier is set to amplify 22 times; it cannot be set to amplify too much because of DC component (power supply is +/- 5V and amplified DC component can't exceed power supply because there will be room for a useful signal as it will affected by noise. [5][6]

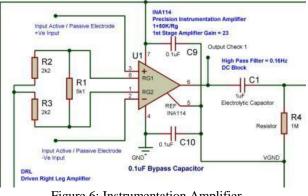


Figure 6: Instrumentation Amplifier

The INA 114 amplification gain (figure 3.13) is around 23, which is set by 3 resistors, 2 x 2.2Kohm and 5.1Kohm resistors.

Calculations:

2.2K in Series = 2200 + 2200 = 4400

4.4K Parallel with 5.1K =

$$G = \frac{50k\Omega}{Rg}$$
$$\frac{1}{4400} + \frac{1}{5100} = \frac{(4400) \times (5100)}{4400 + 5100} = \frac{22440000}{9500} = 2362.1053$$

Using the Gain Formula for INA114,

$$G = 1 + \frac{50k\Omega}{Rg} = 1 + \frac{50000}{2362.1053} = 22.1676 \approx 23$$

To avoid saturation, the gain is set as low as 22. The Reference point Pin 5 is connected to VGND, while Pin 4 is connected to GND. The bypass capacitor at Pin 7 and Pin 4 is used to reduce the amount of ripple (Random electrical noise that causes the voltage to fluctuate) in a circuit. Too much ripple is bad, and can lead to failure of the circuit especially when we are dealing with a microvolt signal.

E. Operational Amplifier TL082

The Operational Amplifier used for 2nd stage is TL082 (figure 7). The 2nd Stage amplifier will amplify the signal to 21 times with high precision, low power non-inverting operational amplifier as in figure 8. [7]

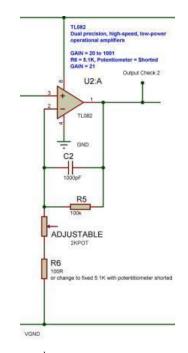


Figure 7: 2nd phase Non- Inverting Amplifier

Gain

$$2^{nd}$$
 Stage *Gain* = 1 + $\frac{R1}{R2}$
With R1 = 100K and R2 = 5.1K,
=1+ $\frac{100K\Omega}{5.1K\Omega}$ = 20.61 ≈ 21

The 3rd Stage amplifier (figure 3.16) is also a non inverting amplifier.

$$3^{rd}$$
 Stage $Gain = 1 + \frac{R1}{R2}$

With R9 and R10 = 2K and R11 and R12 = 100ohm $2K\Omega$ resistors in series = $2K\Omega + 2K\Omega = 4K\Omega$

 100Ω resistors in series = $100\Omega + 100\Omega = 200\Omega$

$$\operatorname{Gain} = 1 + \frac{4K\Omega}{200} = 21$$

Total System Gain = 23 x 21 x 21 = 10143

Output for ECG/EKG test pin Gain = $23 \times 21 = 483$

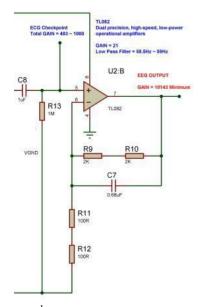


Figure 8: 3rd Phase Non-Inverting Amplifier

F. High Pass Filters

The high pass filters are applied after the Instrumentation Amplifier to remove DC offsets. Its cutoff frequency is 0.16Hz (figure 9). After the first Instrumentation Amplifier, there is a second high pass filter stage, identical to the first filter are applied after the first operational amplifier because amplification brings some new DC component to signal cause of amplifier offset and drift. [7]

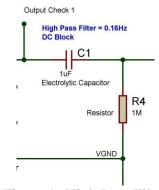


Figure 9: High Pass Filter

Capacitor C1 value = 1u Farad and Resistor R4 value = 1Mohm

Remove DC Offset =

$$\frac{1}{2\Pi RC} = \frac{1}{2\Pi (1M\Omega) \times (1\mu F)} = 0.1592 \approx 0.16 Hz$$

College Science in India <u>www.collegescienceinindia.com</u> 3 : 1 February 2009 Portable EEG Signal Acquisition System Noor Ashraaf Noorazman and Nor Hidayati Aziz

G. Low Pass Filter

A low-pass filter (figure 10) passes low-frequency signals but attenuates frequencies higher than the cutoff frequency. The fixed low pass filter in figure 3.20 will limit the frequency up to 59Hz. Theoretically EEG frequency band is from 0.05 – 100Hz. 59Hz was chosen to filter out the unnecessary signal bigger than 60Hz.It is because Alpha wave is from 7-14Hz, and Beta wave is 15-50Hz. [7]

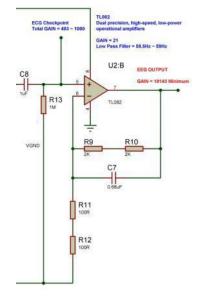


Figure 10: Low Pass Filter

Capacitor C7 value = 0.68u Farad and Resistor R9 and R10 Value of = 4Kohm

Low Pass Filter =

$$\frac{1}{2\Pi RC} = \frac{1}{2\Pi (4K\Omega) \times (0.68\mu F)} = 58.51 Hz \approx 59 Hz$$

H. Power Supply

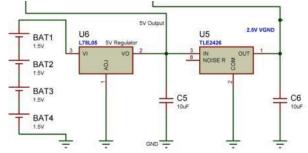


Figure 11: 5V voltage regulator and 2.5V VGND Rail Splitter

Generally a 6V Battery would be enough to power up the entire hardware, but technically speaking, running on 6V battery is likely to damage the ICs. The regulator is able to respond to small fluctuations in the input voltage caused by other loads off the same battery switching on and off. It guarantees a +5v output signal as long as its input is a certain voltage above 5v (called the *drop-out voltage*), and the load on it is not too high. Single chip voltage regulators are available with a range of output current capabilities; from 100mA up to 5A and higher. In this circuit a voltage regulator L078L05 (figure 3.21) regulates 5 Volt from a 6V battery supply to power the whole circuit in order to make it portable

In signal-conditioning applications utilizing a single power source, a reference voltage equal to one-half the supply voltage is required for termination of all analog signal grounds. The 5V regulator is connected to a "rail splitter" TLE2426 in figure 3.21 driving a 2.5V for VGND. A common problem in analog electronics is a requirement for a dualvoltage supply (e.g. +/-5 V) but only having a single supply available, such as a battery. Dual Battery split into two is not a very efficient idea as, sometimes one of the batteries tends to drain faster and this can cause DC offset. [5][8]

The most elegant buffered virtual ground circuit is Texas Instruments' TLE2426. This part is called a "rail splitter": it splits a single supply in two, so you have two "voltage rails" plus ground. It's basically a glorified voltage divider, apply a voltage between its IN and COM pins, and it puts out 1/2 that on the OUT pin. This provides a 2.5V VGND which is half from the 5V Voltage Regulator. Unlike a simple Battery divider, though, it has some buffering circuitry inside so it doesn't become unbalanced. [9]

III. RESULTS AND DISCUSSIONS

The EEG test is performed only when the perfect ECG waveform acquired. This is to make sure that the Instrumentation Amplifiers, Operational Amplifiers and filters are working well and also to ensure all noises and artifacts are at the lowest level as possible. Picture below is when 2 electrodes are position roughly at the fore head of F9 and F10 using the standard 10-20 system, while the DRL electrode placed at the earlobe. It result some muscle artifacts in figure 12.

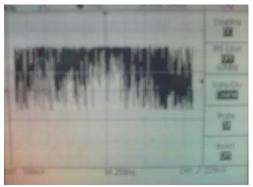


Figure 12: EEG with Muscle Artifacts

College Science in India <u>www.collegescienceinindia.com</u> 3 : 1 February 2009 Portable EEG Signal Acquisition System Noor Ashraaf Noorazman and Nor Hidayati Aziz Acquisition is still continued for 2-3 minutes while the patient is sitting still without any movements. The signal then fluctuates going north (figure 13) and south (figure 14) randomly at a smaller frequency and amplitude. Note that there is some noise interference caused by nearby electrical equipments. After 3-5 minutes of recording signal, the signal stabilizes (figure 15) and 5-10 minutes afterwards, the EEG signal achieved (figure 16). In order to verify this is an EEG signal, Eye blinking test and tooth grinding test are done in figure17.

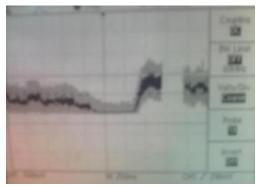


Figure 13: EEG Waveform fluctuate with noise

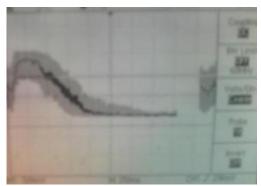


Figure 14: EEG waveform fluctuates with noise 2

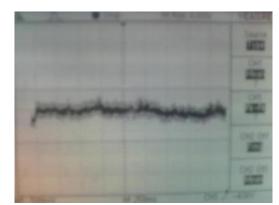


Figure 15: EEG Signal after 3-5Minutes of just looking at the oscilloscope

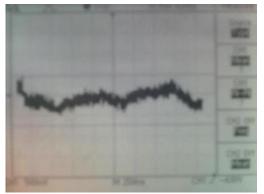


Figure 16: EEG Signal after 5-10 Minutes of acquisition.

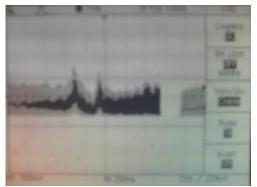


Figure 17: 2 eye blinks test

In the figure 17 above, there are two peaks showing 2 eye blinks which is similar to the figure 4.19 below and followed by signal saturations.

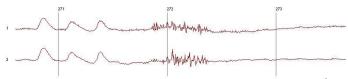


Figure 18: EEG 3 Eye Blinks followed by tooth grinding.²

The figure 18 above was an EEG acquisition using ModEEG V1.0 from Open EEG community. It shows 3 eye blinks and some tooth grinding. This proves that the EEG amplifier was working very well except for the signal saturations and noises that occurred.

Figure 19: EEG Offset

In the figure 19, the EEG rhythm seems to be having a DC offset. This is before the 2^{nd} stage high pass filter for blocking DC component at 0.16Hz after the 2^{nd} amplification done by TL082 dual amplifier. Notice the difference of the signal offset between EEG wave detected on figure 16 and figure 19, in figure 16 the signal does not start and stayed below zero compared to signal in figure 19.

IV. CONCLUSIONS

A single channel EEG amplifier with 2 input active electrodes and DRL amplifier has been designed and implemented into PCB to be in a proper box for the electrode cables to be interfaced to. The portable EEG amplifier managed to capture some brainwave activity, react to eye blinks and tooth grinding despite the noises and artifacts available using oscilloscope. Beside EEG waveform, this hardware also can detect ECG waveform (PQRST) by reducing its Gain to 1,000 from 10,000 initially. Although the system design has been completed and tested, it is not fully accurate and needed more improvements.

REFERENCES

[1] Ranggayan, Rangaraj M. (2002). Biomedical Signal Analysis. IEEE Press. John Wiley & Sons, Inc. pp. 28-31

[2] Reddy DC. (2005). Biomedical Signal Processing: Principles and Techniques. Mc Graw Hill pp. 128-135

[3]Northrop, Robert B. (2001). Noninvasive Instrumentation and Measurement in Medical Diagnosis. CRC Pr I Llc. pp. 92-128

[4]Neuman, Michael R. (1998). Medical Instrumentation Application and Design. John Wiley & Sons, Inc pp.183-233

[5] A.C. Metting VanRijn, A. Peper, C.A. Grimbergen. Instrumentation Amplifier for bioelectric events: a design with minimal number of parts. Retrieved July, 21, 2008 from http://www.biosemi.com/publications/artikel7.htm

[6] Overton A.(2005) Dual Purpose EEG/EKG Instrumentation Amplifier Retrieved August, 21, 2008, from

Portable EEG Signal Acquisition System Noor Ashraaf Noorazman and Nor Hidayati Aziz

² http://www.dcc.uchile.cl/~peortega/ae/images/brainwave-thumb-2.png College Science in India <u>www.collegescienceinindia.com</u> 3 : 1 February 2009

 $http://calarts.edu/~aoverton/Resources/EEG_EKG/schematics.\\ php$

[7] Neuman, Michael R. (1998). Medical Instrumentation Application and Design. John Wiley & Sons, Inc pp.233-287

[8]Tangentsoft. Virtual Ground Circuits. Retrieved June, 28, 2008, from http://www.tangentsoft.net/elec/vgrounds.html

[9]Hills P. (2004). Power Supply Circuits, Retrieved June,28, 2008 from

http://homepages.which.net/~paul.hills/Circuits/PowerSupplies /PowerSupplies.html