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DESIGN OF A DIGITAL MEDICAL DEVICE FOR THE DIAGNOSIS OF PSYCHOSOMATIC DISORDERS

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Abstract- The purpose of this paper is to present a medical device for the reliable diagnosis of psychosomatic illnesses, such as depression, by using the electroencephalographic signal. The presented device allows to detect any asymmetries between the signals from the frontal cortex in both hemispheres. The device is designed to be small in size and easy to use so that it can also be used in medical studies of general practitioners.

Keywords- Medical device, psychosomatic disorders, depression, brain waves detection

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Introduction

Depression is a common term used to describe a wide range of symptoms such as sadness, anxiety, insomnia, lethargy, pains and, in extreme cases, suicide. The main problem in treating depression is to be able to identify a reliable diagnosis. The current method is based on the administration of various tests which are subject to reliability problems. The WHO (World Health Organization) says that depression will strike more than any other disease in next twenty years and represents the pain with the heaviest burden from both an economic (100 billion dollars spent in the U.S. in 2006 [1] and 15 in Italy) and sociological point of view.

The aim of this paper is to design a device based on the ElectroEncefaloGraphic (EEG) signal detection to ensure greater reliability in the diagnosis of the depression in order to reduce costs for both the diagnosis and the treatment of this disease.

The EEG is a measure of extracellular current flow that is generated by the sum of the electrical activity of large numbers of neurons. The measure of such signal consists in detecting the electrical potential difference between an active electrode, placed over the site where neural activity is taking place, and a reference electrode. Both the intensity and the progress of this electrical activity are determined by the excitation of the brain [3]. Changes in electrical potentials recorded are called *electrical brain waves*. The frequency range of these electrical brain waves extends from 0.5 Hz to 100 Hz with an amplitude varying between 20 and 200 microvolts. Depending on the frequency, brain waves are classified into four groups: Alpha (8-13 Hz), Beta (13-50 Hz), Theta (4-7 Hz) and Delta (0.5-4 Hz) [3].

Alpha waves are characterized by a frequency ranging from 9 to 11 Hz for most adults and have an average amplitude of 40-50 microvolts. Alpha waves will be further discussed in this paper since many studies ([3] and [4]) show a relationship between these waves and the presence of the depression.

In fact, Davidson [3] and Niemiec & Lithgow [4] observed that people suffering from depression showed an asymmetric activation of the left frontal cortex than the right, detectable through the study of Alpha waves.

Device Design

The device able to perform the diagnosis of depression disease has to detect the presence of an emphasized and persistent difference between the amplitudes of the Alpha signal from the two lobes of the brain. This difference allows the correct diagnosis of the depression if is greater than a certain threshold determined on the basis of medical data relevant to the correlation between depression and brain waves.

In fact, the average amplitude of alpha waves is between 40 and 50 microvolts and a persistent difference in amplitude of 50% for the dominant hemisphere compared with the non-dominant hemisphere can be considered physiological. Instead, a difference signal between 50-70% is identified as a situation of uncertain diagnosis that should be better investigated. Finally, a difference of more than 70% is regarded as a symptom of a disease.

Therefore the device has an hardware part that can amplify only the difference between the two signals detected on the scalp and a software part that detects the passing of a threshold value.

Design Specifications

The device technical specifications according to the previously described behaviour are as follows:

- A bandwidth ranging from 8 to 13 Hz in order to eliminate dc output, to increase the SNR and to eliminate the problem of aliasing during sampling;

- The CMRR should be high and exceeding 100 dB in order to be able to amplify only the useful differential signal;
- The amplification gain must allow the signal from the electrode to fall within the dynamic input of the analog to digital converter (ADC). Thus, in a difference of between 10 to 100 microvolts and a dynamic of 5V, we get a K gain ranging from 50000 to 500000.

With this specifications we can determine the diagnostic thresholds to ensure the diagnosis of the depression, as summarized in [Table -1].

Table 1- Diagnostic Thresholds

Difference between signals (%)	Difference between signals (µV)	Amplified difference signal (V)
50	16.7	0.835
70	20.6	1.03

The flow diagram to be implemented in the software part of the device is drawn in [Fig-1] where X denotes the signal from the dominant hemisphere and Y the signal from the non-dominant hemisphere.

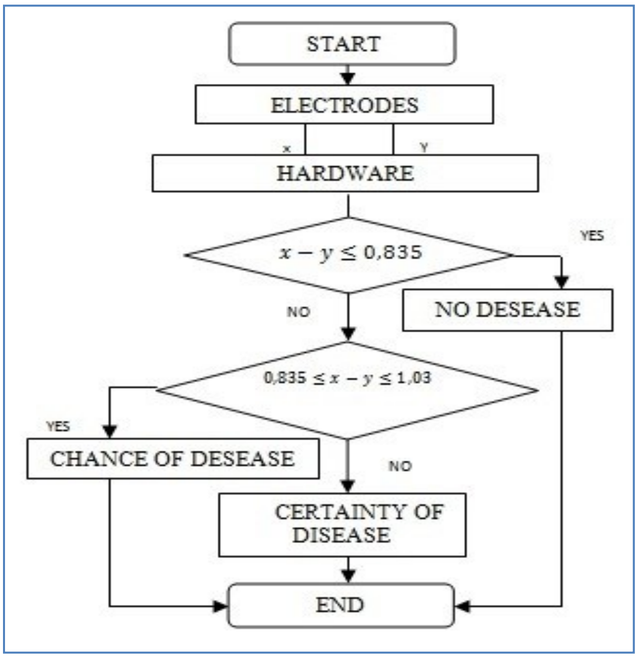


Fig. 1- Flow diagram of the software part of the device

The block diagram of the hardware part of the device is shown in [Fig-2].

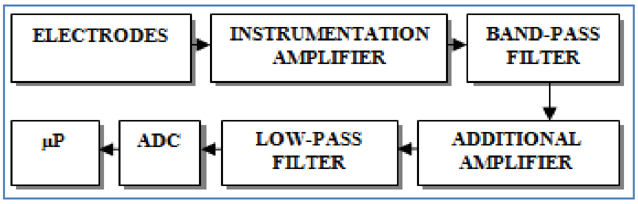


Fig. 2- Block diagram of the hardware section of the device

The signal from the two hemispheres will be collected from two surface electrodes Fp1 and Fp2 position (International 10-20 System) referred to a third electrode placed on the earlobe. Assuming surface Ag/AgCl spot electrodes being used on the scalp, the offset introduced, due to the potential of half-cell, will be equal to 300 mV peak to peak.

The IA should amplify only the difference between the two input signals and it is an essential part of the device. The non-inverting input will be connected to the electrode placed on non-dominant brain hemisphere and the inverting input connected to the dominant hemisphere. The setup used in this project involves the presence of a 3-IA OpAmp. The two OpAmp input system provides a very high input resistance to avoid partition of the input signal on the generator internal resistance and low output impedance. The circuit diagram of used AI is shown in [Fig-3].

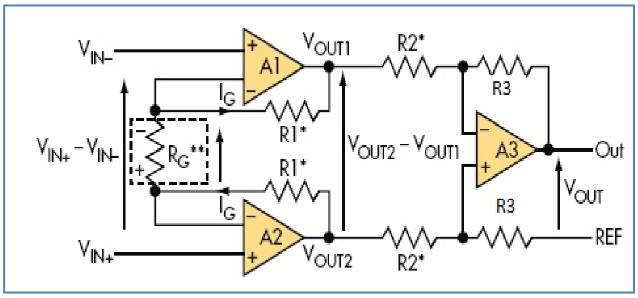


Fig. 3- Circuit diagram IA a 3 OpAmp

The transfer function of this circuit is:

$$V_{out} = (V_{IN}^{+} - V_{IN}^{-})\left(\frac{2R_1}{R_G} + 1\right)\left(\frac{R_3}{R_2}\right) \tag{1}$$

The term $\left(\frac{2R_1}{R_G} + 1\right)\left(\frac{R_3}{R_2}\right)$ represents the amplifier gain and it can be adjusted by changing the R_G resistance, external to the device. The device used in this project is the AD522 from Analog Devices, which provides a high CMRR value of more than 110 dB, amplification up to a factor of 1000 and a maximum noise of 1.5 microvolts peak to peak at 0.1 - 100 Hz. The additional amplification stages can be implemented by the same device by placing the inverting input to ground and setting the resistance R_G so that the gain of the system meets the required specifications.

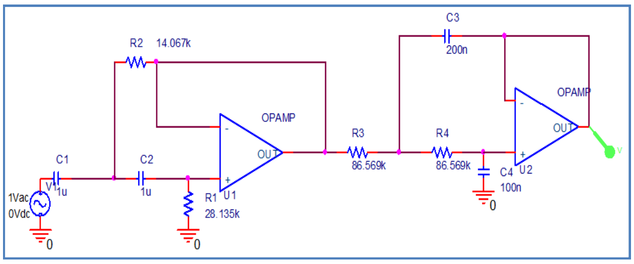


Fig.4- Circuit diagram of BPF

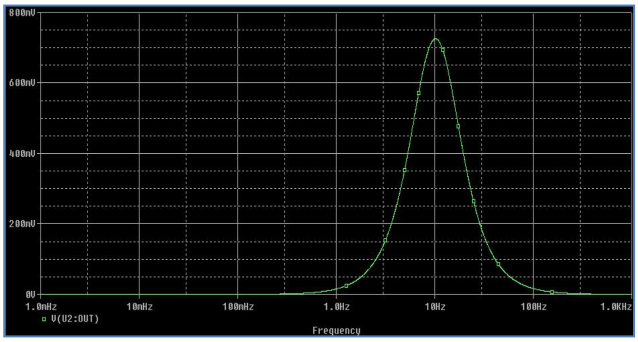


Fig. 5- Frequency response of BPF

The band-pass filter must eliminate all components of the EEG signals that are not useful for the diagnosis of the disease. It is necessary to have a very selective filter to remove the brain waves outside the band of alpha waves (8-13 Hz). This filter is designed as the cascade of a low-pass filter and a high-pass Sallen-Key type and the circuit diagram is shown in [Fig-4], with relative frequency response [Fig-5].

The low-pass filter is always present in a block of sensing circuit. It increases the SNR (Signal to Noise Ratio) attenuating the undesirable signal components present at high frequency such as noise and harmonic components. It eliminates the aliasing problem by avoiding the reply's overlap. You chose a very selective filter of fifth order formed by the cascade of two filters of the second order Sallen-Key and one of the first (RC). The overall transfer function will have the following form:

$$H_{LPF} = \frac{\omega_t^2}{s^2 + sA_1\omega_t + \omega_t^2}\,\frac{\omega_t^2}{s^2 + sA_1\omega_t + \omega_t^2}\,\frac{\omega_t}{\omega_t + s} \qquad (2)$$

where ω_t is the pulse filter cutoff and A_1 and A_2 are the coefficients which determine the trend in frequency of the filter. The main feature required for this filter is the pass band gain of 1. For this reason, an approximation of the Butterworth filter is used where A_1 = 0.618 and A_2 = 1.618. The circuit configuration of the entire filter is shown in [Fig-6] by imposing a cutoff frequency of 18 Hz. [Fig-7] shows the filter frequency response:

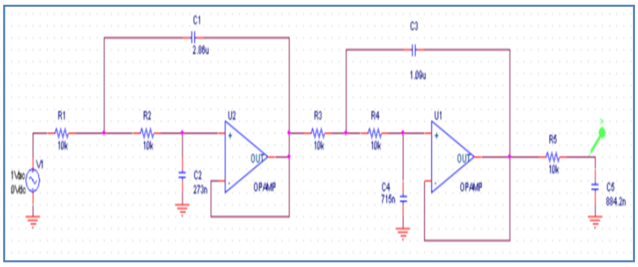


Fig. 6- Circuit diagram of LPF

The first step is the design of the first order filter and relations, below, the transfer function of the one-port RC:

$$H_{LPF} = \frac{1}{sR_5C_5 + 1} \qquad (3)$$

By requiring $R_5C_5 = \frac{1}{\omega_t} = \frac{1}{2\pi.18}$ that equals the second term of (1), we get:

$$C_5 = \frac{1}{\omega_t R_5} = \frac{1}{2\pi.18.10^4} = 884{,}2\ nF \qquad (4)$$

Choosing a resistance value of 10 kW, the capacitance value that meets the previous relation:

$$H_{SK} = \frac{\frac{1}{R_1R_2C_1C_2}}{s^2 + s(\frac{1}{R_1C_1} + \frac{1}{R_2C_1}) + \frac{1}{R_1R_2C_1C_2}}$$

According to the theory of networks, the transfer function of a second-order low-pass Sallen-Key unitary -gain filter is as follows:

$$H_{SK} = \frac{\frac{1}{R^2C_1C_2}}{s^2 + s(\frac{2}{RC_1}) + \frac{1}{R^2C_1C_2}} \qquad (5)$$

To facilitate the sizing it will require that the resistance has the same value. The [Eq-4] becomes:

$$H_{SK}' = \frac{\frac{1}{C_1'C_2'}}{s^2 + s(\frac{2}{C_1'}) + \frac{1}{C_1'C_2'}} = \frac{1}{s^2 + 0{,}618s + 1} \qquad (6)$$

A simple sizing technique is to require that the initial cut-off pulse rate is equal to 1 rad/s and assume a resistance value of 1 Ω. Then we perform a scaling in frequency so that the cutoff frequency becomes 18 Hz. We will have, therefore, for the first of second order filter:

$$H_{SK}' = \frac{\frac{1}{C_3'C_4'}}{s^2 + s(\frac{2}{C_3'}) + \frac{1}{C_3'C_4'}} = \frac{1}{s^2 + 0{,}618s + 1} \qquad (7)$$

then:

C_1'= 3.236 F, C_2'= 0.309 F

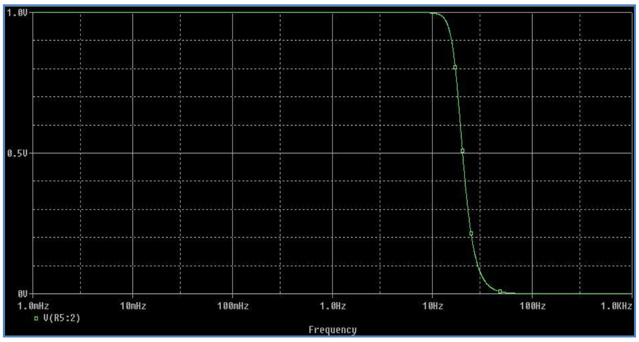
And for the second of second order filter:

$$C_1' = \frac{C_1'}{10000 \cdot 2 \cdot \pi \cdot 18} = 2{,}86\mu F$$
$$C_2' = \frac{C_2'}{10000 \cdot 2 \cdot \pi \cdot 18} = 273nF$$
$$C_3' = \frac{C_3'}{10000 \cdot 2 \cdot \pi \cdot 18} = 1{,}09\mu F \qquad (8)$$
$$C_4' = \frac{C_4'}{10000 \cdot 2 \cdot \pi \cdot 18} = 715nF$$

then:

C_3'= 1.236 F, C_4'= 0.809 F

The resistance values are to bring to those that you usually use for a scalar amplitude of 10000. In this way all the elements take the value of 10 kW. With regard to capacity, they will suffer the effects of scaling in both amplitude and frequency of the transfer of cutting to the desired one. The resulting values are:



[Fig-7] shows the filter frequency response:

Fig. 7- Frequency response of LPF

Analog to Digital Converter (ADC)

An analog to digital converter (ADC) can convert a time-continuous analog signal into a digital discrete-time. With this step, a continuous range of values it is associated with a finite set, whose number depends on the bits that make up the output data. The converter used in this project is the ADS1298 that is used in all medical applications at Texas Instruments. The decision to use this type of converter is not random and is based on the absolute reliability of this device also according to those who have specific requirements. In particular the device has a typical CMRR of 115 dB, a minimum of 105 dB and a typical SNR of 112 dB.

μP and Monitor

The final section of the device comprises two elements necessary for processing and viewing the digitized signal. In particular, the microprocessor will be able to analyze the output signals from the drive and determine if there is an excessive and persistent difference between them. The results of EEG and the test will then be visible on a monitor of a PC connected to the device or through a display located directly on it.

Conclusions

The main object of this paper has been to design a medical device that, according to the clinical observation about the correlation between the depression and the electrical activity of the brain, could be useful to make a sure diagnosis of the depression. The signal is EEG-like and is detected from the prefrontal cortex. In fact, the possibility of identifying, with a low probability of error, the onset of depressive disorders by a detailed study on the non-symmetry, exists between the signals from the prefrontal cortex in both hemispheres. The final consideration, then, comes from this kind of approach to a problem that now is becoming a huge economic and sociological interest: the road taken until now is a good starting point to explore and develop in a broader way a topic of such entity for which is so difficult to find a reliable diagnostic method.

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