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**Design and Simulation of a device for
measuring the Galvanic Skin Response**

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بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

In the name of ALLAH

the most Gracious the most Merciful

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Dedication

I dedicate this work..

To my dearest parents..

To my brothers and sister..

To my lovely nephews..

To a special person in my life..

Mg.

Table of Contents:

Acknowledgment.....	i
Dedication	ii
Table of Contents:	iii
List of Figures:	vii
Abstract:	ix
General Introduction:	2

Chapter 1: The Basics of Electrodermal Phenomena

1.1. Introduction:	4
1.2. Emotions:.....	4
1.3. Neurophysiology of Emotions:	4
1.3.1. The Limbic System:	4
1.3.2. The Nervous System:	5
1.3.2.1. The Central Nervous System:	6
1.3.2.2. The Peripheral Nervous System:	7
1.3.2.2.1. The Somatic Nervous System:	7
1.3.2.2.2. Autonomic Nervous system (ANS):.....	7
1.3.2.2.2.1. Parasympathetic Nervous System:	8
1.3.2.2.2.2. Sympathetic Nervous System:	8
1.4. Anatomy and physiology	9
1.4.1. The skin:	9
1.4.1.1. The epidermis:.....	9
1.4.1.2. The dermis:	9
1.4.1.3. The subcutaneous fat layer (Hypodermis):	9
1.4.2. Sweat glands:.....	10
1.4.2.1. Types of Sweat Glands:	11
1.4.2.1.1. Eccrine glands:	11
1.4.2.1.2. Apocrine glands:	11
1.4.2.1.3. Apoeccrine glands:	11

1.4.2.2. Innervation of Sweat Glands:	12
1.4.2.3. Thermal vs. Emotional (stress) related sweating:.....	13
1.4.2.4. Control of Sweating:.....	13
1.5. Electrodermal Activity:.....	14
1.5.1. Definition:.....	14
1.5.2. The discovery of electrodermal activity [16]:.....	14
1.5.3. Physiology of the Electrodermal System [6]:	14
1.5.4. Mechanisms of the Electrodermal Electrophysiological Response:.....	16
1.5.5. Recording of electrodermal activity:.....	17
1.5.5.1. Measurement of electrodermal activity:	17
1.5.5.1.1. Endosomatic measurement:.....	17
1.5.5.1.2. Exosomatic measurements:	17
1.5.5.2. Quantification of electrodermal activity:	17
1.5.5.2.1. The Phasic EDA:	18
1.5.5.2.2. The Tonic EDA:	19
1.5.6. Terminology for Electrodermal Phenomena:	20
1.5.7. The bandwidth of the galvanic response of the skin:	21
1.6. Conclusion:.....	21

Chapter 2: Methods of Electrodermal Recording

2.1. Introduction:	23
2.1.1. General:	23
2.2. EDA Recording Models:	23
2.2.1. The Keeler Polygraph:	23
2.2.2. Use of direct current:.....	24
2.2.3. A Stress Sensor Based on GSR Controlled by ZigBee:	25
2.2.4. Local GSR prototypes:	26
2.3. EDA Recording Techniques:	28
2.3.1. Endosomatic vs. Exosomatic Recording:.....	29
2.3.2. The Use of Direct vs. Alternating Current:.....	30
2.3.3. Constant Current vs. Constant Voltage Recording.....	30

2.3.4. Resistance vs. Conductance Units:	31
2.4. Recording Sites:	33
2.4.1. Choice of Sites:	33
2.4.2. Pretreatment of Sites:	34
2.5. The Electrodes:	35
2.5.1. The importance of electrodes:	35
2.5.2. Forms of Electrodes and Their Attachment:	36
2.5.3. Choice of Electrodes:	36
2.5.4. Electrodes Cleaning and Storage:	37
2.5.5. Conclusion on the choice of our electrodes:	37
2.6. Use of the gel:	37
2.7. Sources of noise:.....	37
2.8. Filters:.....	38
2.8.1. Type of filters:	38
2.8.2. Filter response characteristics:.....	38
2.8.2.1. The Butterworth Characteristic:	39
2.8.2.2. The Chebyshev Characteristic:.....	39
2.8.2.3. The Bessel Characteristic:	39
2.8.3. Active and passive filters:.....	40
2.8.3.1. Active filter:.....	40
2.8.3.2. Passive filter:	40
2.9. Conclusion:.....	41

Chapter 3: Circuit Development and Simulation

3.1. Introduction:	43
3.2. System Design:	43
3.2.1. The Electrodes (GSR Sensor):	44
3.2.2. The Detection Stage:	45
3.2.2.1. Detection Stage Detection Stage simulation:	46
3.2.3. Pre-amplification Stage:	47
3.2.3.1. AD620 Gain Selection:.....	48

3.2.3.2. Pre-amplification stage simulation:	49
3.2.4. Filter Stage:	50
3.2.4.1. Filter stage simulation:	51
3.2.4.1.1. Case of GSR signal information with 2Hz frequency:.....	51
3.2.4.1.2. Case of noise with 300mHz frequency:	52
3.2.4.1.3. Case of noise with 50Hz frequency:	53
3.2.5. Amplification Stage:	54
3.2.5.1. Amplification stage simulation:	55
3.2.6. Offset Stage:	56
3.2.6.1. Offset stage simulation:	57
3.2.7. Power supply:	57
3.2.7.1. General effects of electric current:.....	58
3.3. Acquisition System:	58
3.3.1. The Arduino Board description:	59
3.3.2. Interest of the Arduino:.....	59
3.3.3. Arduino UNO:.....	60
3.3.3.1. Hardware:	61
3.3.3.2. Software:	62
3.3.3.3. Programming:	63
3.3.3.4. Serial Communication:.....	64
3.3.4. Arduino use in our work:	64
3.4. The Simulation Environment:	64
3.4.1. Proteus:	65
3.4.2. General presentation of Proteus:.....	66
3.4.3. Features:	67
3.5. Final Realization:.....	68
3.6. GSR Interface:	70
3.7. Conclusion:.....	71
General Conclusion.....	73
References:.....	75
Annexes:	79

List of Figures:

Chapter I

FIGURE I.1: THE LIMBIC SYSTEM.....	5
FIGURE I.2: THE NERVOUS SYSTEM.....	6
FIGURE I.3: THE AUTONOMIC NERVOUS SYSTEM	8
FIGURE I.4: ANATOMY OF THE SKIN	10
FIGURE I.5: SWEAT GLANDS	12
FIGURE I.6: CENTRAL NERVOUS SYSTEM ELICITATION OF EDA IN HUMANS	15
FIGURE I.7: ELECTRICAL EQUIVALENT CIRCUIT FOR THE SKIN	16
FIGURE I.8 : GRAPHICAL REPRESENTATION OF PRINCIPAL EDA.....	18
FIGURE I.9 : DIAGRAM OF AN ELECTRODERMAL RESPONSE, REPRESENTATION OF THE PARAMETERS CALCULATED FROM THE CHARACTERISTICS OF THE RESPONSE SIGNAL.	18
FIGURE I.10 : OHMIC DISTURBANCE DURATION	19
FIGURE I.11 : METHODS OF ELECTRODERMAL RECORDING, UNITS OF MEASUREMENT, AND ABBREVIATIONS IN THE CORRESPONDING CLASSES OF UNITS.	20

Chapter II

FIGURE II.1: KEELER POLYGRAPH MODEL 6338.....	24
FIGURE II.2: ELECTRIC DIAGRAM OF THE DIRECT CURRENT BASED GSR	25
FIGURE II.3: THE GSR CONTROLLED BY ZIGBEE DEVICE PROTOTYPE.....	26
FIGURE II.4: ACQUISITION DIAGRAM.....	26
FIGURE II.5: BLOCK DIAGRAM OF THE 1 ST GSR DEVICE	27
FIGURE II.6: BLOCK DIAGRAM OF THE 2 ND GSR DEVICE	27
FIGURE II.7: BLOCK DIAGRAM OF THE 3 RD GSR DEVICE	28
FIGURE II.8: MODELING OF THE CONDUCTIVITY OF THE EXCRETORY DUCTS OF THE SWEAT GLANDS BY A SET OF VARIABLE RESISTORS CONNECTED IN PARALLEL	32
FIGURE II.9: MEASUREMENT SITES	34
FIGURE II.10: FINGERS ELECTRODES	35
FIGURE II.11: BECKMAN BIOPOTENTIAL SKIN ELECTRODES	35
FIGURE II.12: CROSS-SECTION OF AN Ag/AgCl ELECTRODE.....	36
FIGURE II.13: FILTERS TYPES	38
FIGURE II.14: COMPARATIVE PLOTS OF THREE TYPES OF FILTER RESPONSE CHARACTERISTICS.....	40

Chapter III

FIGURE III-1: THE PROPOSED BLOCK DIAGRAM OF THE GSR CIRCUIT	43
FIGURE III-2: THE ELECTRODES.....	44
FIGURE III-3: THE DETECTION STAGE	45
FIGURE III-4: THE DETECTION STAGE SIMULATION	46
FIGURE III-5: THE PRE-AMPLIFICATION STAGE.....	47
FIGURE III-6: THE PRE-AMPLIFICATION STAGE SIMULATION.....	49
FIGURE III-7: THE FILTER STAGE.....	50
FIGURE III-8: FILTER RESPONSE TO A 2HZ FREQUENCY INFORMATION.....	51
FIGURE III-9: FILTER RESPONSE TO A 300MHZ FREQUENCY NOISE.....	52
FIGURE III-10: FILTER RESPONSE TO A 50HZ FREQUENCY NOISE.....	53
FIGURE III-11: THE AMPLIFICATION STAGE.....	54
FIGURE III-12: AMPLIFICATION STAGE SIMULATION	55
FIGURE III-13: THE OFFSET CIRCUIT	56
FIGURE III-14: OFFSET STAGE SIMULATION	57
FIGURE III-15: BLOCK DIAGRAM OF THE GSR SIGNAL ACQUISITION.....	58
FIGURE III-16: ARDUINO BOARDS TYPES	59
FIGURE III-17: ARDUINO UNO BOARD	60
FIGURE III-18: ARDUINO UNO BOARD CONFIGURATION	61
FIGURE III-19: ARDUINO IDE PROGRAM “SKETCH”	63
FIGURE III-20: PROTEUS SOFTWARE.....	65
FIGURE III-21: ISIS SOFTWARE	66
FIGURE III-22: ARES SOFTWARE	67
FIGURE III-23: PCB LAYOUT ARTWORK	68
FIGURE III-24: ELECTRICAL DIAGRAM OF THE GSR CIRCUIT	68
FIGURE III-26: PCB BACK VIEW	69
FIGURE III-25: 3D MODEL PCB FRONT VIEW	69
FIGURE III-27: GSR INTERFACE WITH AN ECG SIGNAL PLOTTING.....	70

List of Tables:

Chapter III

TABLE III-1: REQUIRED VALUES OF GAIN RESISTORS	48
TABLE III-2: THE EFFECTS OF ELECTRIC CURRENT UPON THE HUMAN BODY	58

Abstract:

The galvanic skin response (GSR) or the Electrodermal Activity (EDA) reflects the activity of the Autonomous Nervous System. It opens the door to several applications such as the detection of the stress level, the recognition of emotions and lie detection. It is an interesting tool in exploring the physiological activity of a person, as it is an easy measure to be implemented and inexpensive compared to other existing techniques.

Our project was initially concerned by the realization of device for measuring and analyzing the galvanic skin response. However, because of the COVID-19 Pandemic, and the closure of the universities and consequently the laboratories from March up today (end of September), the project was limited to simulating the different electronic circuits and acquisitions environment...

The proposed design of the device consists of two main parts respectively hardware and software parts. The hardware part is concerned with all electronic circuits necessary to detect the GSR signal starting from the transducer, passing by shaping circuits up to the acquisition. The proposed transducer are two electrodes placed on the phalanges of the fingers of the hand, the shaping circuits are the Wheatstone bridge, amplifiers and filters, the acquisition is achieved by an Arduino Board. The software part consists on developing programs for the acquisition and visualization of the GSR signal on a PC Monitor. The proposed circuits have been tested by simulating their functions using Proteus. The obtained results are satisfactory.

Key Words:

Galvanic Skin Response – Electrodermal Activity – Skin Resistance– Autonomic Nervous System – Sweat Glands – Sensor – CAD

ملخص:

تتبع استجابة الجلد الجلفانية نشاط الجهاز العصبي الذاتي الذي يفتح الباب لعدة تطبيقات، كمعرفة مستوى التوتر ودراسة العواطف وكاشف الكذب. حيث تعتبر أداة مثيرة للاهتمام في استكشاف النشاط الفسيولوجي للشخص، حيث أنها مقياس سهل التنفيذ وغير مكلفة مقارنة بالتقنيات الأخرى الموجودة.

تعلق مشروعنا في البداية بتصميم جهاز لقياس وتحليل استجابة الجلد الجلفانية. ولكن بسبب جائحة كوفيد-19، وإغلاق الجامعات وبالتالي إغلاق المختبرات (من شهر مارس إلى يومنا هذا)، اقتصر المشروع على محاكاة الدوائر الإلكترونية المختلفة.

يتكون التصميم المقترح للجهاز من جزأين رئيسيين، المعاد والبرمجيات. يتعلق جزء المعاد بجميع الدوائر الإلكترونية اللازمة للكشف عن إشارة استجابة الجلد الجلفانية بدءاً من المستشعر، مروراً بتشكيل الدوائر الإلكترونية. إلى غاية نقل الإشارة إلى جهاز الكمبيوتر، المستشعر المقترح عبارة عن قطبين كهربائيين يوضعان على أصابع اليد، ودوائر هيكلة الإشارة هي جسر ويتستون، مضخمات الإشارة والمرشحات، ويتم نقل الإشارة بواسطة لوح Arduino. يتعلق جزء البرمجيات من تطوير برامج لنقل وعرض إشارة استجابة الجلد الجلفانية على شاشة الكمبيوتر. تمت محاكاة الدوائر الإلكترونية المقترحة باستخدام Proteus. حيث تعتبر النتائج المتحصل عليها مرضية.

كلمات مفتاحية:

إستجابة الجلد الجلفانية - الجهاز العصبي الخضري - الغدد العرقية - مستشعر - نظام التصميم بمساعدة الكمبيوتر

Résumé:

La réponse galvanique de la peau (GSR) ou l'activité électrodermale (EDA) reflète l'activité du système nerveux autonome. Elle ouvre la porte à plusieurs applications telles que la détection du niveau de stress, la reconnaissance des émotions et la détection du mensonge. C'est un outil intéressant pour explorer l'activité physiologique d'une personne, car c'est une mesure facile à mettre en œuvre et peu coûteuse par rapport à d'autres techniques existantes.

Notre projet a été initialement concerné par la réalisation d'un dispositif de mesure et d'analyse de la réponse galvanique de la peau. Toutefois, en raison de la pandémie de COVID-19 et de la fermeture des universités et, par conséquent les laboratoires à partir de mars jusqu'à aujourd'hui (fin septembre), le projet s'est limité à simuler les différents circuits électroniques et l'environnement d'acquisition...

La conception proposée du dispositif se compose de deux parties principales respectivement matérielles et logicielles. La partie matérielle concerne tous les circuits électroniques nécessaires pour détecter le signal GSR à partir du transducteur, en passant par les circuits de mise en forme jusqu'à l'acquisition. Le transducteur proposé sont deux électrodes placées sur les phalanges des doigts de la main, les circuits de mise en forme sont le pont Wheatstone, amplificateurs et filtres, l'acquisition est réalisée par une carte Arduino. La partie logicielle consiste à développer des programmes pour l'acquisition et la visualisation du signal GSR sur un moniteur PC. Les circuits proposés ont été testés en simulant leurs fonctions à l'aide de Proteus. Les résultats obtenus sont satisfaisants.

Mots Clés:

La Réponse Galvanique de la Peau -L'Activité Electrodermale - Résistance de la Peau - Système Nerveux Autonome - Glands Sudoripare - Capteur - CAO

General Introduction

General Introduction:

The electrical conductance of the skin can be used to measure the Electrodermal activity as a factor of emotional responses such as the stress. It varies depending on the amount of moisture induced by sweat on the skin. Sweat is controlled by the sympathetic nervous system, so the conductance of the skin is used as an indication of psychological or physiological arousal. If the sympathetic branch of the autonomic nervous system is strongly awake, the activity of the sweat glands also increases, which increases the conductance of the skin.

Our work then consists initially in the study and the realization of a device allowing to analyses this electrodermal activity. This activity will be extracted through suitably arranged electrodes and electronic circuits for detecting and shaping the resulting signal known by GSR (Galvanic Skin Response). However, because of the COVID-19 pandemic, and the closure of the universities and the labs, the project has been reoriented to simulating the different electronic circuits of the proposed device.

To describe our achievement, the thesis is structured in three chapters:

In Chapter 1, a presentation of the different basic notions on emotions, the nervous system and the skin is made. Also, we define the electrodermal activity phenomena. Then a simplified study of the galvanic response as a signal and its interpretation is also presented through its shape and its characteristics.

In Chapter 2, a relatively detailed description will be presented of some circuits in the literature that can be used to detect GSR. A detailed description of the Electrodermal recording techniques such as the choice of electrodes and measurement methods is presented and discussed in order to select suitable circuits for our proposed design.

Chapter 3 is devoted to the description of our proposed design. This description is carried out from the electrodes, passing through the shaping circuit to the PCB Artwork layout. Moreover, a presentation of different stages simulation results such as testing the detection circuit, amplification, filtering and the offset circuit will be implemented using a simulated GSR signal. Finally, a graphical interface for presenting the GSR signal will be described.

The document is finalized with a general conclusion.

Chapter 1

The Basics of Electrodermal Phenomena

1.1. Introduction:

The galvanic skin response (GSR) or the Electrodermal Activity (EDA) is known to be one of the most sensitive indicators of actions of purely psychic stimulants. It is very often measured in emotional studies as an index of emotion presence, and studies concerning the detection of lies and stress.

In this chapter, we propose by first describing the emotions and their relationship to the EDA. This description is carried out through the presentation of the functioning of the nervous system to show how the electrodermal activity is influenced by emotional activities. Then a simplified study of the galvanic response as a signal and its interpretation is also presented.

1.2. Emotions:

James-Lange or "peripheralist" theory, defined emotions as the perception of physiological changes. Since then, many emotional theories have emerged, leading to different definitions (Sander & Scherer, 2009). However, there is a consensus which defines emotions as the synchronization of three components: the cognitive component or subjective feeling, the behavioral component or motor expression, which corresponds to all the external manifestations linked to this emotion, and finally, the psychophysiological component (Gil, 2009). Neuropsychologists are particularly interested in this last component, which allows them to analyze the impact of an event on a patient. Different measurement techniques provide information on the physiological changes occurring in an individual, such as the measurement of cardiovascular activity, respiratory activity or even Electrodermal Activity (Aue, 2009). The latter is based on variations in cutaneous conductance, that is to say the endocrine activity of the eccrine sweat glands located mainly on the palmar and plantar surfaces (Dawson et al., 2007), These glands secrete sweat which then leads to a variation in skin conductance (Sequeira et al., 2009). [1]

1.3. Neurophysiology of Emotions:

1.3.1. The Limbic System:

It is a region of the brain which is formed by the convolution of the corpus callosum, i.e. the Broca convolution associated with that of the hippocampus. It is made up of a set of very deep nerve centers abundantly linked together. But also, with the associative cortical areas, the thalamus, hypothalamus and the prefrontal areas (physio, 2004). (see **Fig I.1**)

The role of the limbic system is particularly important since it regulates the functioning of certain viscera with regard to the metabolism of emotional life (physio, 2004). Thus, it is responsible for the organization of fundamental instinctive behaviors and the expression of emotions and motivations.[1]

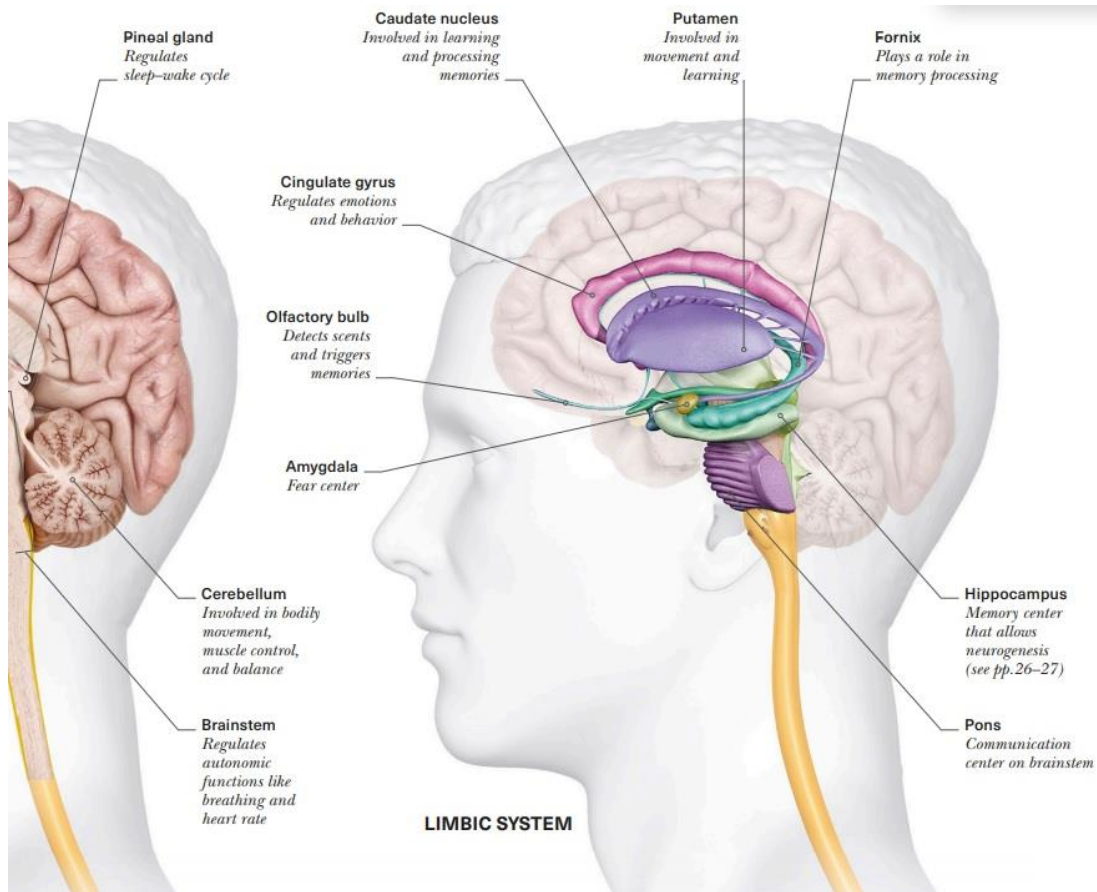


Figure 1.1: The Limbic System [2]

In humans, the high-level controls of physiological activation are based on a network involving the prefrontal and parietal cortices, as well as limbic structures (amygdala and hippocampus), with right lateralization (Critchley, 2002). [2]

1.3.2. The Nervous System:

The nervous system is a complex network that allows an organism to communicate with its environment. The network includes sensory components, which detect changes in environmental stimuli, and motor components, which generate movement, contraction of cardiac and smooth muscle, and glandular secretions. Integrative components of the nervous system receive, store, and process sensory information and then orchestrate the appropriate motor responses.

The nervous system is composed of two divisions: the central nervous system (CNS), which includes the brain and the spinal cord, and the peripheral nervous system (PNS), which includes sensory receptors, sensory nerves, and ganglia outside the CNS. The CNS and PNS communicate extensively with each other. [3]

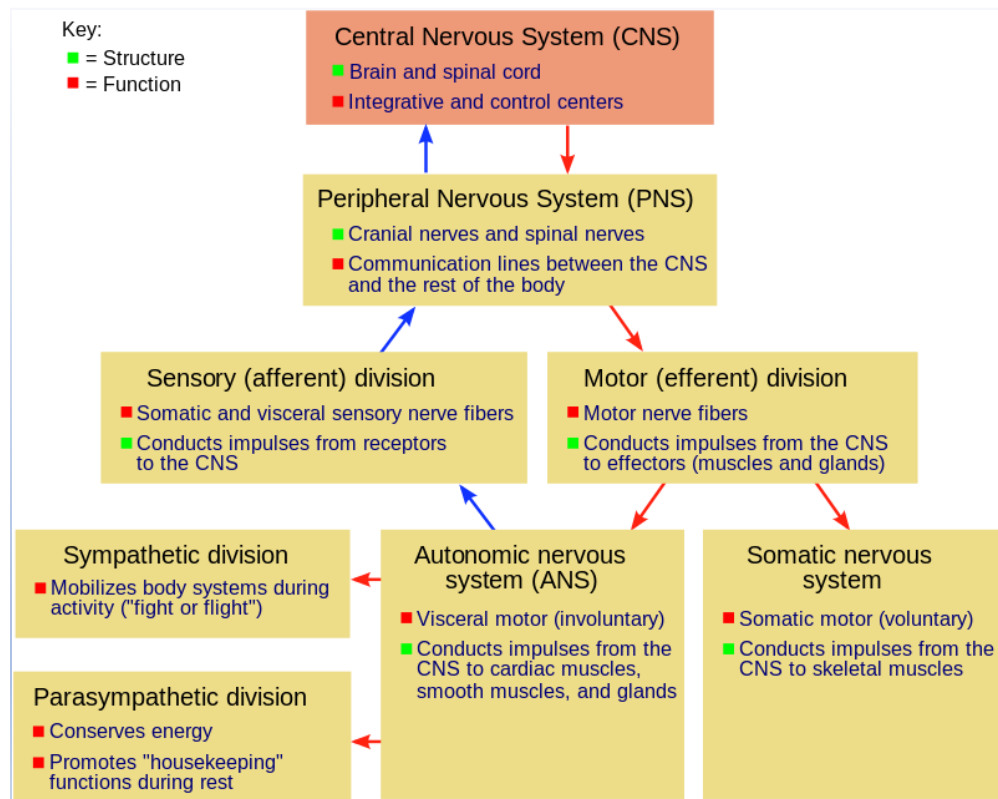


Figure 1.2: The Nervous System

1.3.2.1. The Central Nervous System:

The central nervous system (CNS) is comprised of the brain and spinal cord. The CNS receives sensory information from the nervous system and controls the body's responses. The CNS is differentiated from the peripheral nervous system, which involves all of the nerves outside of the brain and spinal cord that carry messages to the CNS.

The central nervous system plays a primary role in receiving information from various areas of the body and then coordinating this activity to produce the body's responses.[4]

The central nervous system has been thoroughly studied by anatomists and physiologists, but it still holds many secrets; it controls our thoughts, movements, emotions, and desires. It also controls our breathing, heart rate, the release of some hormones, body temperature, and much more.

1.3.2.2. The Peripheral Nervous System:

The peripheral nervous system (PNS) is the division of the nervous system containing all the nerves that lie outside of the central nervous system (CNS). The primary role of the PNS is to connect the CNS to the organs, limbs, and skin. These nerves extend from the central nervous system to the outermost areas of the body.

The peripheral system allows the brain and spinal cord to receive and send information to other areas of the body, which allows us to react to stimuli in our environment.

The peripheral nervous system itself is divided into two parts: the somatic nervous system and the autonomic nervous system, each of these components plays a critical role in how the peripheral nervous system operates. [5]

1.3.2.2.1. The Somatic Nervous System:

The somatic system is the part of the peripheral nervous system responsible for carrying sensory and motor information to and from the central nervous system. The somatic nervous system derives its name from the Greek word soma, which means "body."

The somatic system is responsible for transmitting sensory information as well as for voluntary movement. This system contains two major types of neurons:

Motor neurons: Also called efferent neurons, motor neurons carry information from the brain and spinal cord to muscle fibers throughout the body. These motor neurons allow us to take physical action in response to stimuli in the environment.

Sensory neurons: Also called afferent neurons, sensory neurons carry information from the nerves to the central nervous system. It is these sensory neurons that allow us to take in sensory information and send it to the brain and spinal cord. [5]

1.3.2.2.2. Autonomic Nervous system (ANS):

ANS is a control system in charge of the regulation of peripheral functions such as heart rate, digestion, respiratory rate, pupillary response, urination, and sexual arousal. In other words, it is the autonomic nervous system that controls aspects of the body that are usually not under voluntary control. This system allows these functions to take place without needing to consciously think about them happening, this system comprises two components: the sympathetic and parasympathetic nervous systems. Due to its specific nature, the ANS is not involved only in emotion regulation, but includes a wide variety of other functions related to stress. As a matter of fact, several physiological ANS signs (e.g. HRV, respiration activity, EDA, pupil size and eye movement variation) correlate with subject behavior or emotional status. The most commonly used indexes of activation of the ANS are based on EDA (i.e., sweat glands)

or cardiovascular dynamics. EDA is typically quantified in terms of skin conductance and primarily reflects sympathetic activity. [6]

1.3.2.2.2.1. Parasympathetic Nervous System:

The PSNS is known as “rest and digest” or the “relaxation response” because it creates a restful state of optimal function [7]. This helps maintain normal body functions and conserve physical resources. Once a threat has passed, this system will slow the heart rate, slow breathing, reduce blood flow to muscles, and constrict the pupils. This allows us to return our bodies to a normal resting state.

1.3.2.2.2.2. Sympathetic Nervous System:

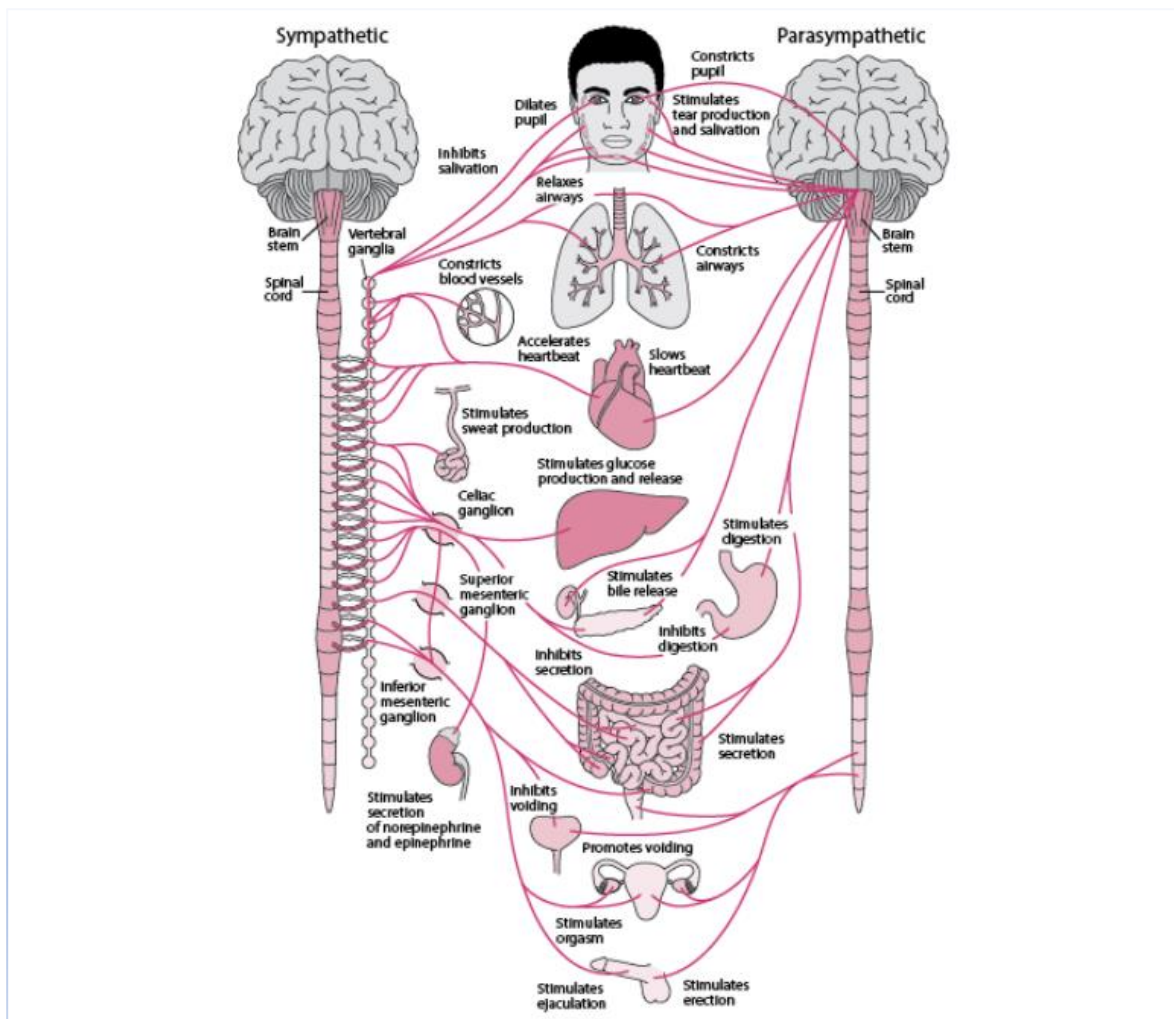


Figure I.3: The Autonomic Nervous System [8]

The SNS is known as “fight or flight” or the “stress response” because it helps you deal with stressful situations [7], By regulating the flight-or-fights response, the sympathetic system prepares the body to

expend energy to respond to environmental threats. When action is needed, the sympathetic system triggers a response by accelerating heart rate, increasing breathing rate, boosting blood flow to muscles, activating sweat secretion, and dilating the pupils. [5]

1.4. Anatomy and physiology

1.4.1. The skin:

The skin is the body's largest organ. It covers the entire body, accounting for about 15% of the total adult body weight. It performs many vital functions, it serves as a protective shield against heat, light, injury, and infection including protection against external physical, chemical, and biologic assailants, as well as prevention of excess water loss from the body and a role in regulate body temperature through sweating glands. it also helps in gathering sensory information from the environment, stores water, fat and vitamin D, and plays a role in the immune system protecting us from disease. The skin is continuous, with the mucous membranes lining the body's surface. [8]

Total skin thickness varies depending on where it is found on the body. The thickest skin is found on the back, the palms of the hands, and the bottoms of the feet, where it can be up to 3 millimeters (mm) thick [9]. The thinnest skin is found on the eyelid, where the epidermis measures just 0.05 mm with very little dermis and subcutaneous fat [10], skin has three layers (see Figure I.4): The epidermis, the dermis and the hypodermis.

1.4.1.1. The epidermis:

The outermost layer of skin, the layer which is visible, a tough protective layer that provides a waterproof barrier and creates our skin tone, it consists of 3 types of cells:

Squamous cells: The outermost layer is continuously shed is called the stratum corneum.

Basal cells: Basal cells are found just under the squamous cells, at the base of the epidermis.

Melanocytes: special cells that create our skin's color, which produce the pigment melanin.

1.4.1.2. The dermis:

It is the middle layer of the skin. it's held together by a protein called collagen. This layer gives skin flexibility and strength. it contains, Blood vessels, Lymph vessels, Hair follicles, sweat glands, Collagen bundles, Fibroblasts, Nerves endings and Sebaceous glands, the dermis also contains pain and touch receptors.

1.4.1.3. The subcutaneous fat layer (Hypodermis):

This is the deepest layer of skin. This layer is primarily made up of fatty tissue called adipose tissue. This is where the body reserves its fat stores. It helps conserve the body's heat and protects the body from injury by acting as a shock absorber.

The subcutaneous layer is also made up of loose connective tissue, larger blood vessels, and nerves. This layer helps connect the upper skin to the musculature below.

This layer varies in thickness depending on where it's found on the body (it's thickest on the buttocks, palms, and feet) as well as age, sex, and health of an individual.

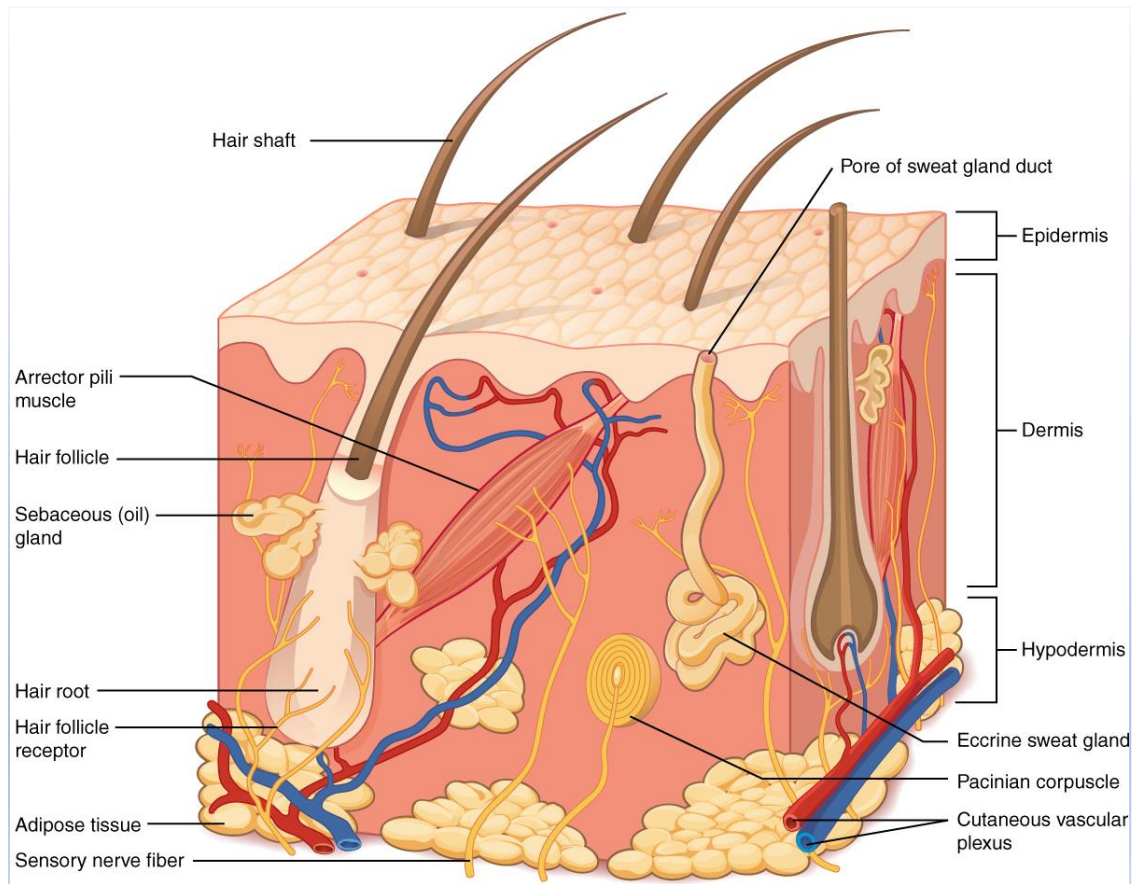


Figure I.4: Anatomy of the Skin [11]

1.4.2. Sweat glands:

Sweat glands are coiled tubular structures vital for regulating human body temperature, these glands are located in the epidermis and produce moisture (sweat) that is secreted through tiny ducts onto the surface of the skin, sweat glands are sometimes referred to as sudoriferous or sudoriparous glands. These names are derived from the Latin word 'sudor' which means 'sweat'.

In humans, roughly 1.6 to 5 million sweat glands are found in the skin, and the amount varies between individuals as well as anatomic sites with an average density of 200 sweat glands/cm² ranging from 64 sweat glands/cm² on the back to 600-700 sweat glands/cm² on the palms and soles of the feet. The primary function of sweat glands is to keep the core body temperature at approximately 37 °C by releasing sweat in a hot environment or during physical activity.

Sweat glands are innervated by neurons, so the process of sweating is controlled by the central nervous system. Thermosensitive neurons in the brain can detect the internal body temperature and external skin temperature, instructing sweat glands to respond accordingly to maintain a constant core body temperature. When an increase in temperature is detected, sweat is induced to cool the skin, and internal body temperature decreases when the sweat evaporates from the surface of the skin. Therefore, sweat glands are essential in keeping the body temperature constant.

1.4.2.1. Types of Sweat Glands:

Humans have three different types of sweat glands: eccrine, apocrine, and apoeccrine.

1.4.2.1.1. Eccrine glands:

The major sweat glands of the human body. They are abundantly distributed all over the skin and mainly secrete a clear, odourless substance, comprised mostly of sodium chloride and water through the surface of the skin. which is involved in thermoregulation.

1.4.2.1.2. Apocrine glands:

The larger sweat glands, located in the axillary and genital regions, they secrete oily substances containing lipids, proteins, and steroids through hair canals and are found only in skin containing hair (restricted to the armpits, mammary, anal, and genital areas), Rather than responding to temperature, apocrine glands often respond to emotional stimuli including anxiety, fear, stress and sexual stimulation. Under these circumstances, sweating is often observed in the armpits, palms, and soles of the feet, these apocrine glandular products can be broken down by cutaneous microbes, producing body odour.

1.4.2.1.3. Apoeccrine glands:

For decades it was believed that these are the only two types of sweat glands. In 1987, however, apoeccrine glands were identified in areas of apocrine glands but secreted watery fluids similar to eccrine glands. [11]

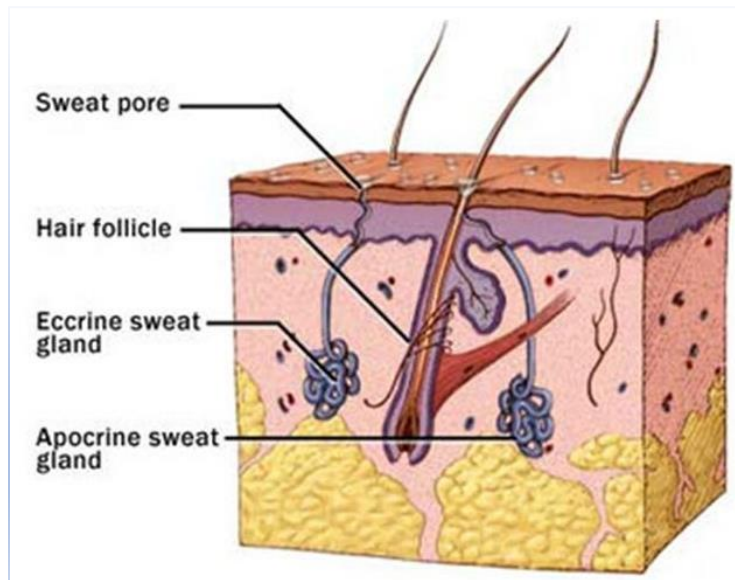


Figure 1.5: Sweat Glands

As a matter of fact, although sweating occurs in response to extremely different stimuli, (i.e., thermoregulation, emotional response (sudomotor nerve activity), or the perspiration insensibilis, (necessary to body water balance), the different behavior of sweat glands is not related to structural and anatomical differences of the gland itself, but only to the region where it is located. The eccrine glands are classified into three groups according to the different behaviors corresponding to the anatomical regions where they belong (of note, this distinction is not, of course, absolute, as in most of biological phenomena):

- The eccrine glands on palms and soles respond almost exclusively to emotional stimuli, such as pain, fear and anxiety, mediated directly by the brain structures involved in emotion; or they respond to particular physiological stimuli, such as movement and deep breathing.
- The eccrine glands of face, arms and forearms occupy an intermediate position between the thermo-regulatory and emotional sweating, responding moderately to psychic and thermal stimuli.
- The eccrine glands of the other areas of the body are almost exclusively involved in the temperature control function.[6]

1.4.2.2. Innervation of Sweat Glands:

“Eccrine glands are innervated by the sympathetic nervous system (SNS), primarily by cholinergic fibers whose discharge is altered primarily by changes in deep body temperature (core temperature), but by adrenergic fibers as well. The glands on palms and soles do not respond to temperature but secrete at times of emotional stress.”

Because they are innervated by the SNS, they are part of the fight or flight response system. “Their innervation consists of two parts, a preganglionic and postganglionic neuron. The preganglionic neuron

is short, originates from the thoracolumbar region of the spinal cord, uses acetylcholine as its neurotransmitter, and synapses with the postganglionic neuron via a nicotinic acetylcholine. The postganglionic neuron for sweat gland innervation differs from other sympathetic postganglionic neurons in that it releases acetylcholine to act on muscarinic receptors; all other sympathetic postganglionic neurons, with the exception of the adrenal medulla, use norepinephrine.” [12]

1.4.2.3. Thermal vs. Emotional (stress) related sweating:

“Sweating on the face, chest, and back is generally due to heat stimuli, while sweating of the palms and soles is due to emotional stress. The axillae have eccrine, apocrine, and apoecrine glands.

Thermal sweating can occur throughout the day, but emotional sweating (palms, soles, and to some degree axillae) stops while sleeping.

Eccrine glands are innervated by the SNS but utilize acetylcholine as the primary neurotransmitter. Thermal sweating and emotional sweating are controlled by different regions of the brain. Thermal sweating is controlled by the hypothalamus via the thermosensitive preoptic sweat center, while emotional sweating is regulated by the cerebral cortex.

A sympathetic signal is carried to endocrine glands via cholinergic autonomic neurons. In patients with primary focal hyperhidrosis, the sweat glands are usually histologically and functionally normal. Rather, the cause of hyperhidrosis appears to be an abnormal or exaggerated central response to normal emotional stress.” [13]

Generalized hyperhidrosis may be due to systemic diseases or medications. “Unlike primary focal hyperhidrosis, patients with generalized, secondary hyperhidrosis usually present as adults and report sweating that occurs both while awake and sleeping.” [14]

1.4.2.4. Control of Sweating:

Neural control of sweating, primarily regulated by the integration of internal and skin temperatures, is paramount for temperature regulation. However, a variety of other non-thermal factors, such as factors associated with exercise and fluid status, modify the sweating response. Further studies are necessary to identify the precise mechanisms by which these non-thermal factors serve to accentuate or attenuate sweating in the resting and exercising human.

1.5. Electrodermal Activity:

1.5.1. Definition:

Electrodermal activity (EDA), also known as the galvanic skin response (GSR), is the general term used to define autonomic changes in the electrical properties of the skin. One of the most frequently used measures of EDA is skin conductance (SC). This can be quantified by applying an electrical potential between two points of skin contact, usually the medial or distal phalanges of the non-dominant hand, and measuring the resulting electric current between them. Electrodermal signals are a manifestation of the activity in eccrine sweat glands that are innervated by the sympathetic branch of the autonomic nervous system (ANS), mainly by the sudomotor nerves [15]. Indeed, when the sudomotor nerves stimulate the production of sweat, the conductivity measured on the skin surface changes as a result of sweat secretion and variations in ionic permeability of sweat gland membranes [16]–[18].

1.5.2. The discovery of electrodermal activity [16]:

The empirical study of the electrical changes in human skin began over 100 years ago in the laboratory of Jean Charcot, the French neurologist famous for his work on hysteria and hypnosis. Vigouroux (1879, 1888), a collaborator of Charcot, measured tonic skin resistance levels from various patient groups as a clinical diagnostic sign. In the same laboratory, Féré (1888) found that, by passing a small electrical current across two electrodes placed on the surface of the skin, one could measure momentary decreases in skin resistance in response to a variety of stimuli (visual, auditory, gustatory, olfactory, etc.). The basic phenomenon discovered by Féré is that the skin momentarily becomes a better conductor of electricity when external stimuli are presented. Shortly thereafter, a Russian physiologist named Tarchanoff (1890) reported that one could measure changes in electrical potential between two electrodes placed on the skin without applying an external current. Hence, Féré and Tarchanoff are said to have discovered the two basic methods of recording electrodermal activity in use today: the exosomatic method and the endosomatic method. The exosomatic method refers to the method of recording the skin response (or its reciprocal, skin conductance) by passing an external current across the skin, whereas recording the skin potential response without involving an external current is referred to as the endosomatic method (Dawson et al., 2007).

1.5.3. Physiology of the Electrodermal System [6]:

Although the local processes underlying the EDA in the skin are well known, the central origins of EDA are still under study. EDA is the result of the interaction between local processes in the skin and sympathetic nervous system activity. At least two different CNS sources have been identified as areas controlling the sudomotor activity that leads to the electrodermal changes (see **Figure I.6**). However, they use the same peripheral sudomotor efferents to the sweat glands as a common final pathway. Specific central sudomotor pathways are not well established, and even with the aid of brain imaging, no final breakthrough has been reached in clarifying the central elicitation or inhibition of electrodermal phenomena.[19]

The hypothalamus is the area of the brain that directly regulates the secretion of sweat; it is the main center of thermoregulation, then it is supposed to play an important role in the origin of the EDA signal. The hypothalamus functions are influenced by different brain structures, which are part of the limbic system.

Moreover, also the cortical area interacts with the limbic system, which can also affect the hypothalamus activity and, consequently, the EDA. As a matter of fact, previous studies [20], [21] have shown a decrease or the disappearance of the skin conductance response to an emotional stimulus in subjects with lateral-frontal lesions, comparing with other cortical areas lesions. Therefore, the sudomotor reflex seems to be under the complete control of the limbic system and brain structures associated with it. Specifically, the amygdala and the hippocampus are the limbic structures mostly involved in the control of the hypothalamic functions related to the sudomotor nerve activity. The amygdala should play an excitatory function, whereas the hippocampus plays an inhibitory function. Specifically, the amygdala plays a key role in sweating control as response to emotional stimuli. This because of the involvement in the behavioral pattern memory (emotions behavior, social behavior, endocrine and autonomous functions).

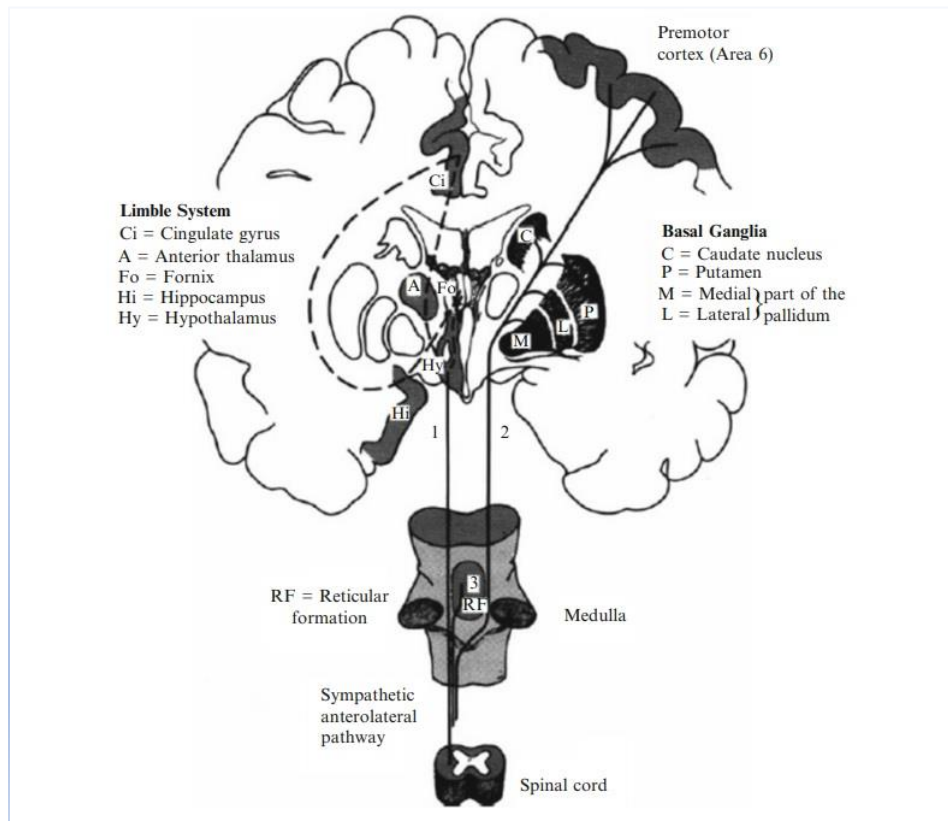


Figure 1.6: Central nervous system elicitation of EDA in humans

There are lots of empirical evidences that electrodermal activities are generated by sweat glands in conjunction with epidermal membrane processes. Sweat secretion leads to two phenomena: the filling of sweat ducts and the moistening of the relatively dry upper epidermal layer, the stratum corneum. When

the ducts are filled, the skin conductance increases due to shunts through the epidermal barrier that connect the surface of the skin with the highly conductive dermal tissue. On the other side, the moistening of the corneum increases skin conductance thanks to salty sweat. [6]

1.5.4. Mechanisms of the Electrodermal Electrophysiological Response:

By applying a potential difference between two sites of the skin, it is possible to observe a flow of current through it. This is due to the movement of free ions present in the skin structures. Blood, sweat ducts and interstitial fluid have a different conductivity because of their different ionic concentration, The dermis and the subcutaneous layer act as good conductors because of the bloodstream, the lymphatic system, and the interstitial fluid. On the other hand, the corneum shows relative impermeability to water and acts as a barrier for the diffusion of the ions. This barrier, however, is traversed by the ducts of sweat glands, which allow the diffusion of both sweat and ions. The slow changes in the EDA due to this mechanism have been postulated as the cause of the tonic component. In addition to the resistive properties, the skin has capacitive properties. They derive from the cell membranes, which may show similar characteristics to the capacitors, In conclusion, the skin can be interpreted as an electrical network formed by RC circuits in series and parallel. We can assume that the capacitive elements can be loaded very quickly, but once that they are fully charged, they cannot scroll other current and therefore they cannot further influence the EDA. [6]

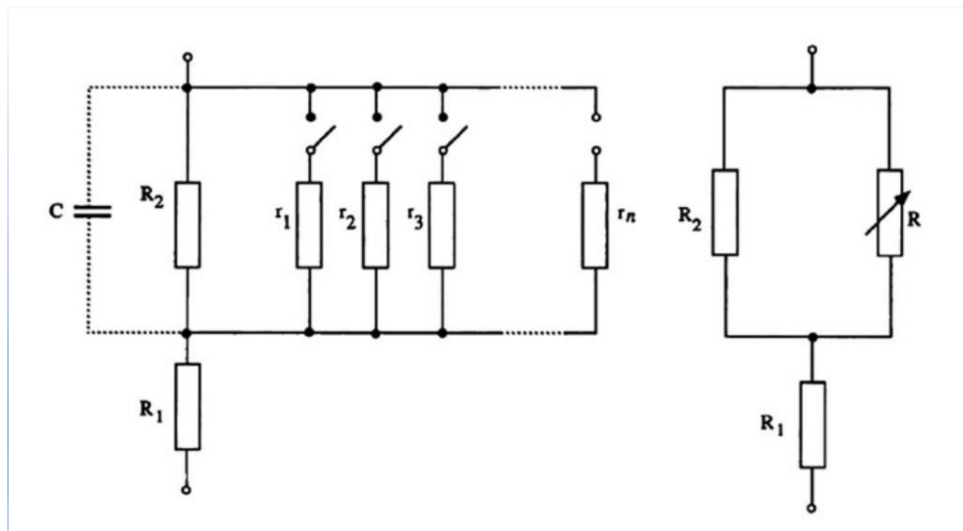


Figure 1.7: Electrical equivalent circuit for the skin

Left-hand panel: according to Montagu and Coles [22]. R_1 : resistance of the dermis and the body core. R_2 : resistance of the stratum corneum. r_1, \dots, r_n : connectable resistances of the sweat gland ducts. C : capacitive element. **Right-hand panel:** Simplified Montagu-Coles model. R : variable resistance resulting from sweat gland ducts. [6]

1.5.5. Recording of electrodermal activity:

1.5.5.1. Measurement of electrodermal activity:

There are three different methods of measuring EDA: (a) without the application of an external current, which is therefore called the endosomatic method, and (b) two exosomatic methods which either apply direct current (DC) via electrodes on the skin or apply alternating current (AC) instead.

1.5.5.1.1. Endosomatic measurement:

This type of measurement does not require the application of an external voltage or current source, because the electrical potential of the skin is taken directly. However, the measurement of the cutaneous potential is very delicate because of its very low amplitude and of its sensitive to external disturbances.

1.5.5.1.2. Exosomatic measurements:

Exosomatic measurements must apply a stimulus (voltage or current) in order to acquire the skin resistance signal. The type of stimulus can be in DC or AC (current or voltage), but measurements in DC have been more widely used thanks to its ease of implementation.

In DC measurement, if voltage is kept constant, EDA is recorded directly in skin conductance (SC) units, while skin resistance (SR) units are obtained when current is kept constant. Accordingly, if the effective voltage is kept constant in AC measurement, EDA is recorded directly as skin admittance (SY), while the appliance of constant effective current results in skin impedance (SZ) recordings. [16]

Likewise, accurate measurement of skin conductance requires special attention to the type and location of the electrodes, the electrolytes used, and the characteristics of the measurement instrumentation.

1.5.5.2. Quantification of electrodermal activity:

The most frequently used measure of EDA is the SC. The SC signal can be decomposed in two components, tonic and phasic, which have different time scales and relationships to exogeneous stimuli: The tonic electrodermal component represents the baseline level of the signal whereas the phasic component indicates a direct response to a specific stimulus.

The notation used here reflects the parameters for an expression of electrodermal activity in conductance. It is possible to transform this notation for an expression in resistance (SCR becomes SRR for skin resistance response, and SCL becomes SRL for skin resistance level). We can also use the more generic notation EDR for electrodermal response and EDL for electrodermal level.

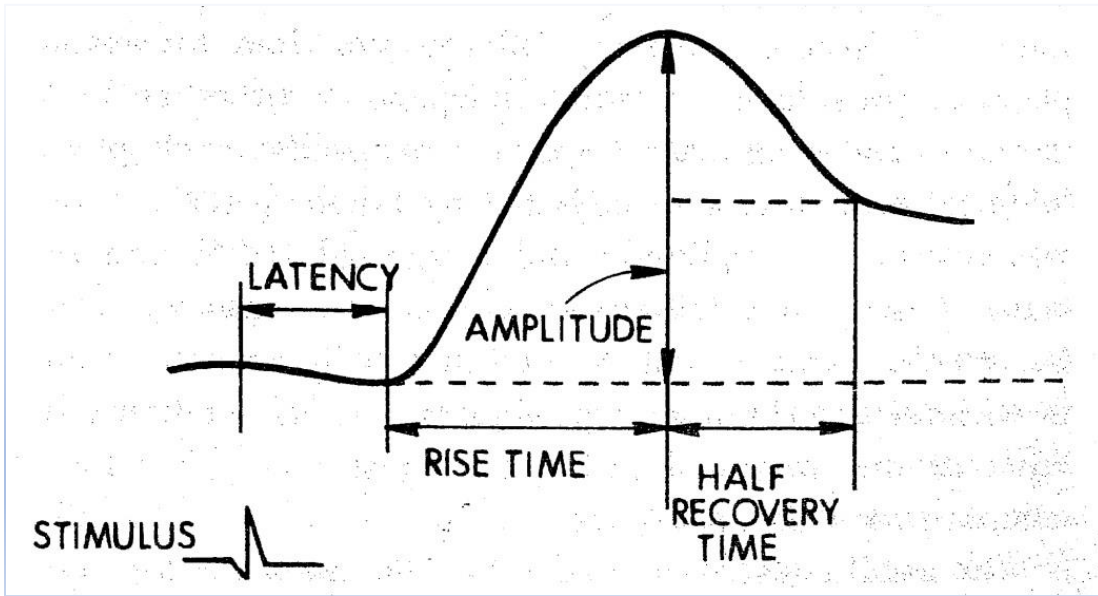


Figure I.8: Graphical representation of principal EDA

1.5.5.2.1. The Phasic EDA:

It is represented by a fast-changing component, called skin conductance response (SCR), reflecting the evoked response of the eccrine sweat glands to an external stimulus. The SCR is defined as the SC transient arising within a predefined window (1–5s) after the stimulus onset and satisfying a minimum amplitude criterion (0.05S). It's calculated from the characteristics of the signal during an electrodermal response.

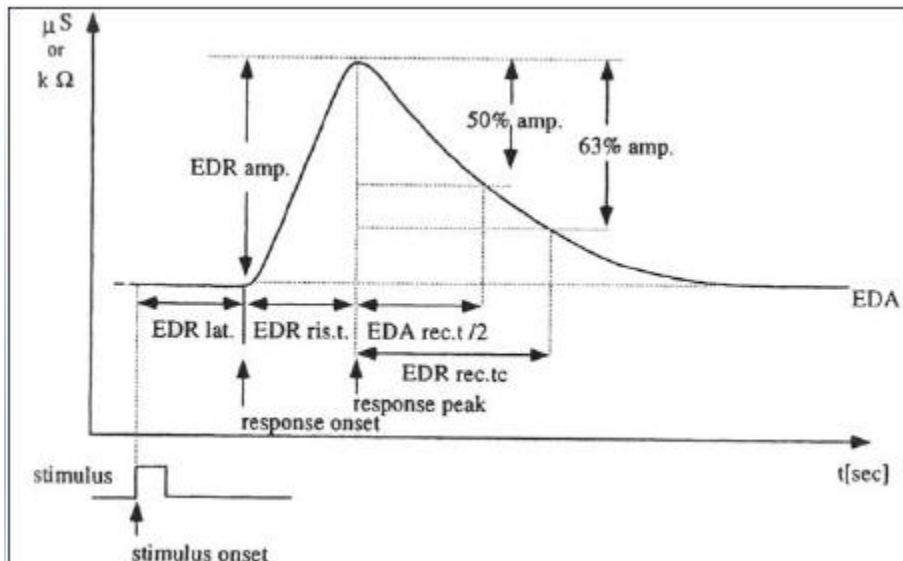


Figure I.9: Diagram of an electrodermal response, representation of the parameters calculated from the characteristics of the response signal.

- There are often phasic parts of EDA which cannot be related to any specific stimulus, and hence, they are called spontaneous or nonspecific SCRs. [19]

The answer is quantifiable in two ways:

by its amplitude: it is the difference between its starting value and its extremum (in $k\Omega$ or in μS); a distinction will be made between the amplitude measurement of the response, the amplitude at 50% and the amplitude at 63%.

by its duration: known as Ohmic Disturbance Duration: it is the time that elapses between the first inflection of the resistance and its return to a non-disturbed base level (in s): we will distinguish the response time, the rise time, return time to 50% amplitude and return time to 63% amplitude. Generally, the amplitude and the duration of ohmic disturbance increase with the felt impact of the stimulus by the subject (see Figure I.10 below).

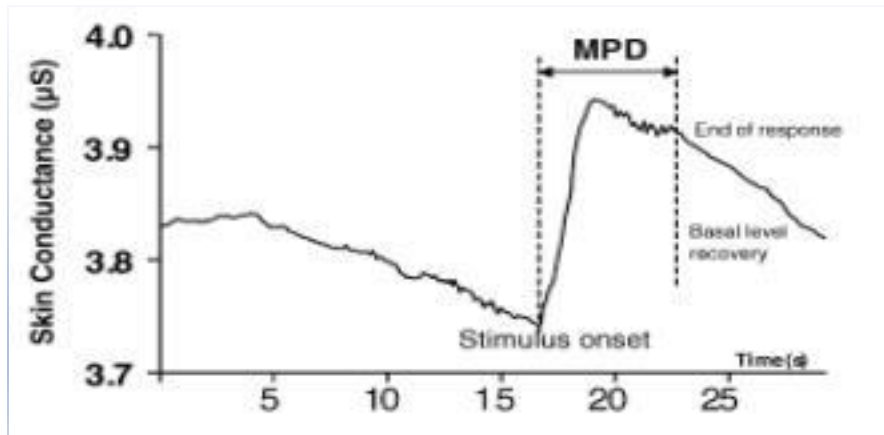


Figure I.10: Ohmic disturbance duration

1.5.5.2.2. The Tonic EDA:

It is represented by the slow-varying baseline level of the SC, called the skin conductance level (SCL). Variations in the SCL are thought to reflect slow changes in the ANS dynamics. These are determined over longer signal periods (preferably without the presence of stimulation), Its variation is much slower than the phasic response.

1.5.6. Terminology for Electrodermal Phenomena:

Methods of recording	endo-somatic	exosomatic			
Applied current		direct current		alternating current	
Units	skin potential	skin resistance	skin conductance	skin impedance	skin admittance
Abbreviations:					
in general	SP	SR	SC	SZ	SY
tonic (level)	SPL	SRL	SCL	SZL	SYL
phasic (response)	SPR	SRR	SCR	SZR	SYR
Supplementary abbreviations:					
nonspecific reaction	NS.SPR	NS.SRR	NS.SCR	NS.SZR	NS.SYR
frequency	SPR freq.	SRR freq.	SCR freq.	SZR freq.	SYR freq.
amplitude	SPR amp.	SRR amp.	SCR amp.	SZR amp.	SYR amp.
latency	SPR lat.	SRR lat.	SCR lat.	SZR lat.	SYR lat.
rise time	SPR ris.t.	SRR ris.t.	SCR ris.t.	SZR ris.t.	SYR ris.t.
recovery time: 63 % recovery	SPR rec.tc	SRR rec.tc	SCR rec.tc	SZR rec.tc	SYR rec.tc
50 % recovery	SPR rec.t/2	SRR rec.t/2	SCR rec.t/2	SZR rec.t/2	SYR rec.t/2

Figure I.11: Methods of electrodermal recording, units of measurement, and abbreviations in the corresponding classes of units.

In addition, various suffixes are added to the abbreviations of EDRs as shown in the lower part of Figure I.11, indicating the parameter which is obtained from the phasic component:

SCR lat. (skin conductance response latency): during a response caused by the subject's exposure to a deliberate stimulus, the response is qualified as an oriented response. This parameter represents the delay between the stimulus and the establishment of the electrodermal response (this parameter only applies in the case of a directed response).

SCR amp. (skin conductance response amplitude): amplitude of the variation in conductance measured between the value at the establishment of the response and the value reached at the maximum of the response (called "peak" of the response).

SCR ris. t. (skin conductance response rise time): rise time of the response measured between the instant of establishment of the response and the instant of the peak of the response.

SCR rec._{1/2} and SCR rec._{tc} (recovery time of skin conductance response): the time that is needed to recover either 50% (i.e., SCR rec._{t/2}) or 63% (i.e., SCR rec._{tc}) of the amplitude.

SCL (skin conductance level): average value of the conductance signal, generally measured over periods without phase responses.

NS.SCR freq. (frequency of non-specific skin conductance responses): frequency of appearance of non-oriented phasic responses (i.e. not deliberately provoked), usually expressed in number of responses per minute. Although this parameter is based on the detection of phasic responses, it is nevertheless considered as a tonic parameter of the electrodermal activity.

NS.SCR amp. Sum (sum of nonspecific skin conductance responses amplitudes): sum of the amplitudes of non-oriented phasic responses, calculated over a given period. [23]

1.5.7. The bandwidth of the galvanic response of the skin:

A bandwidth ranging from 0 to 5 Hz allow the faithful reproduction of the resistance or conductivity levels of skin and their changes. If only the changes are of interest, a bandwidth ranging from 0.5 to 5 Hz is satisfactory. [24]

1.6. Conclusion:

Through this chapter a description of the electrodermal activity has been made. Thus, through a description of the Anatomy and physiology of the nervous system, skin and sweat glands, with respect to their contributions to electrodermal phenomena. In addition to the mechanism of the EDA phenomena, this response was defined and described through its representation as a signal and the way in which it can be recorded. For the time being, these descriptions are incomplete, since the central origin of sweat gland activity is not fully understood in detail, However, most findings are taken from animal preparations and so generalization to humans may not be conclusive.

Chapter 2

Methods of Electrodermal Recording

2.1. Introduction:

The quantification of the activity of the Autonomous nervous system opens the door to several applications such as the detection of the stress level, the recognition of emotions and lie detection, which can be studied through the Electrodermal activity expressed through the galvanic skin response (GSR). As described in the previous chapter, the GSR signal results from the electrodermal activity of the skin. It can be detected through suitably arranged electrodes and through an adequate configuration.

the aim of this chapter is to present the different GSR recordings methods and models, to describe and study the different configurations that are used to correctly detect this signal. This signal subsequently be acquired through a PC for a further processing and analysis of those characteristics correlated with the physiological and / or emotional state of a subject.

2.1.1. General:

The observation of electrodermal phenomena requires only relatively basic equipment. As a consequence, a variety of recording methods have been proposed.

If you have a multimeter on hand, then you can measure the resistance between two fingers by pressing one probe against each finger. The range for the resistance of skin is typically 50k to 10M Ohm (per Sean Montgomery). Skin conductance is the reciprocal of that resistance. Thus 50k Ohm is 20 uS (micro Siemens) and 10M Ohm is 0.1 uS. To summarize, skin conductance is inversely proportional to skin resistance.

However, if one just looks at their skin resistance on a DMM, then it will be very difficult to determine when their skin is responding to emotional changes. Thus, a circuit is required which produces an output voltage proportional to the change in skin resistance. The circuit needs to filter out noise and amplify the GSR signal, This output voltage can then be digitized and acquired on a PC for subsequent digital processing and analysis of its variability.[25]

2.2. EDA Recording Models:

2.2.1. The Keeler Polygraph:

In 1921, John A. Larson, a Canadian psychologist developed what many consider to be the original *lie detector* when he added the item of respiration rate to that of blood pressure. He named his instrument the “*polygraph*”, a Greek word which means *many writings*, since it could read several physiological responses at the same time and document these responses on a revolving drum of smoked paper.

In 1938, Leonarde Keeler further refined the polygraph when he added a third physiological measuring component which measure changes in a subject's galvanic skin resistance during questioning, he called it “the *psychogalvanometer*”.

In 1939, Leonarde Keeler patented what is now understood as the prototype of the modern polygraph “*The Keeler Polygraph*”. Today, Leonarde Keeler is known as the *father of polygraph* (*Brief History of the Polygraph*).

the “*The Keeler Polygraph*” Model 6338 depicted on Figure II.1 below was the first “Plethysmic Polygraph” manufactured by 'Associated Research' of Chicago, Illinois in the early 1950's. The Model 6338 was introduced as a four-channel instrument, which recorded simultaneously changes in relative blood pressure, heart rate, pulse wave amplitude, blood volume, oxygenation of the blood, respiration and electrical skin resistance. The G.S.R. component consisted of a pair of finger electrodes, or a hand electrode connected to a input circuit of a direct couple solid-state amplifier with a balanced differential output, feeding the pens. These reading are obtained by utilizing electronic and pneumatic monitoring.

The 6338 required a 115-volt AC current. It weighs 10 Kg and is 45 x 28 x 15 cm, the 6338 incorporated newly designed printed circuits, and a new inking system where the pens are fed from removable, individually capped ink bottles with colored ink available. The newly designed vent valves have a positive lock to prevent leaks. (*Leonarde Keeler and His Instruments*)



Figure II.1: Keeler Polygraph model 6338

2.2.2. Use of direct current:

The potential difference resulting from the injection of a constant current is measured between two electrodes, thus the measured voltage is an image of the resistance of the skin under Ohm's law.

According to Edelberg, an injected current of maximum $10 \mu\text{A}\cdot\text{cm}^{-2}$ is advised [Edelberg, 1967]. A current source is produced according to the description given by Dave Van Ess from a unit gain differential amplifier (DIFFAMP), whose analog reference V_{ref} is fixed at $AGND = V_{pp}/2$.

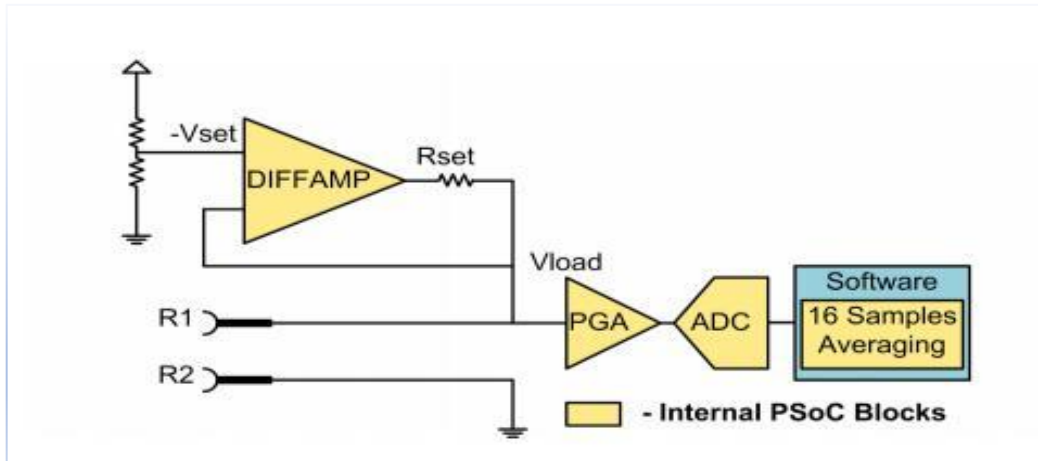


Figure II.2: Electric diagram of the direct current based GSR

[Van Ess, 2002]. In this way, the voltage drop across the terminals of the adjustment resistor R_{set} is constant, thus fixing the current passing through it. Assuming the ideal operational amplifiers, ie an infinite input impedance and a zero-output impedance, the current passing through R_{set} is strictly equal to that passing through the resistance of the skin.

With $V_{set} = -0.917$ V, $V_{ref} = 1.650$ V and $R_{set} = 330$ k Ω , we obtain $I_{set} = 2.13$ μ A. The electrodes used for the measurement of the skin's electrical resistance are Ag / AgCl disks 8 mm in diameter (ie an area of 0.5 cm²) leading to a current density of 4.24 μ A.cm⁻², value in accordance with the limit given by Edelberg [23].

2.2.3. A Stress Sensor Based on GSR Controlled by ZigBee:

a stress sensor based on Galvanic Skin Response (GSR), and controlled by ZigBee, a technology that makes it possible to obtain wireless links at a very low cost and with very low energy consumption. there are two parts: the hardware design of the GSR and the algorithm which detects the emotional state of the user.

This device is designed in order to detect the different conductance of the skin when a person is under stress or when not. It uses just two electrodes which are placed on the fingers and act as if they were the two terminals of one resistance

The output voltage of the designed circuit is connected to the ADC of a ZigBee board. There are two ZigBee boards: one for acquiring the data, and a second one to send it to the computer. This second board (the coordinator) also receives information about other devices and functions of the domotic application.

The user can use the stress sensor anywhere in his home provided he is at a distance of less than 10 meters, By using a wireless communication system, the user is provided with a certain degree of freedom when using the device, which allows him to master different emotional situations that can lead the sufferer into dangerous situations. The GSR device detects whether there has been an effort or a different situation from being relaxed, but the main problem is that, at the moment, the first algorithm does not distinguish between being stressed or making an effort. [28]

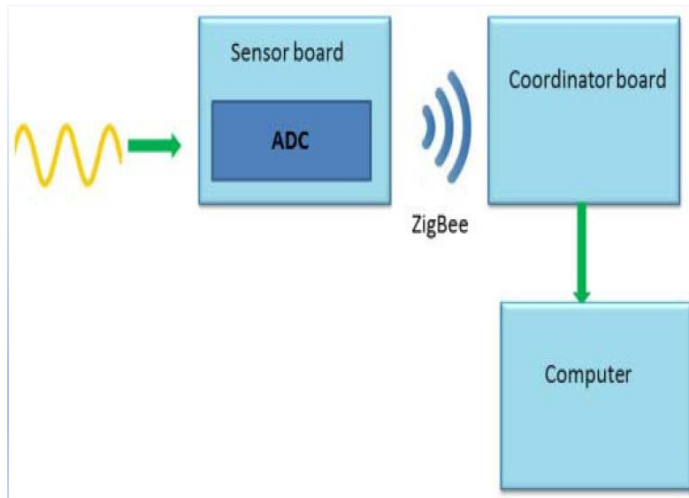


Figure II.4: Acquisition Diagram

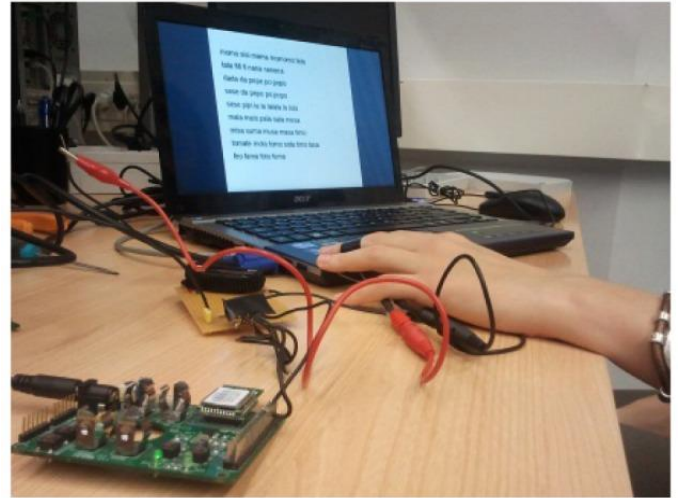


Figure II.3: The GSR Controlled by ZigBee device prototype

2.2.4. Local GSR prototypes:

- a. In 2009, a work that consists of realizing a device that measures the galvanic response of the skin. The idea was based on the direct detection of the resistance of the skin by the exosomatic method (requires the application of an external stimulus: current or voltage AC / DC) followed by a card which contains the shaping circuit, acquisition interface circuit (a 16F88 microcontroller), and for digital processing and monitoring using the PC (with C ++). For detection they used unpolarizable electrodes, the detected signal requires an electronic circuit for its shaping which consists of a constant voltage source 0.5V DC, an isolated power supply circuit, component elimination circuit continuous DC offset, pre-amplification and isolation circuit, 50Hz rejection circuit, amplification and filtering circuit. The proposed device it is made up of two parts, a hardware part (hardware: a microcontroller with acquisition through the serial port of the PC) and a software part (software: based on a C ++ BUILDER algorithm) And finally the PC, which will process and record the GSR signal. [24]

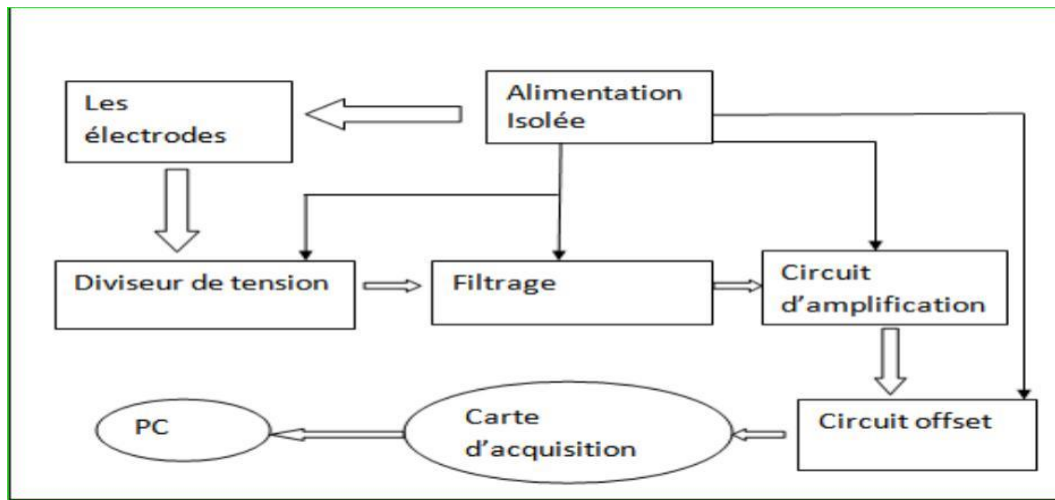


Figure II.5: Block diagram of the 1st GSR Device

- b. In 2013, in the same context another proposal for the study and realization of a device that measures and analyzes the GSR signal. The designer used the same principle but with a different block diagram. The main difference is in the hardware where an Arduino acquisition board was used and the digital processing of the GSR signal was achieved by a program developed in MATLAB. [29].

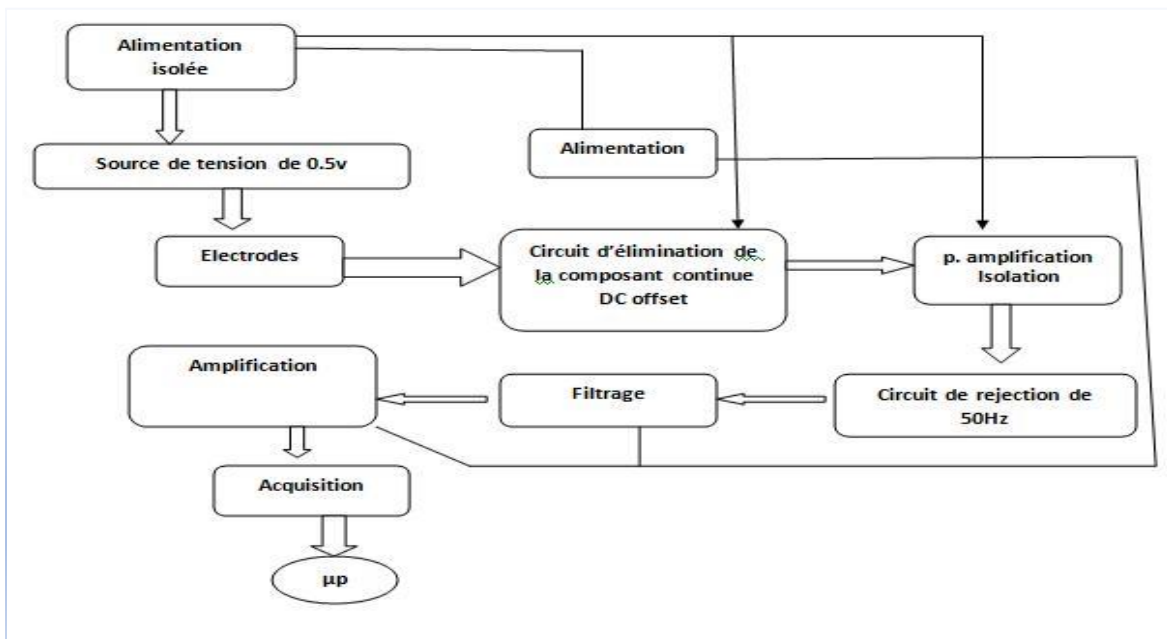


Figure II.6: Block diagram of the 2nd GSR Device

- c. In 2019, another GSR project was developed. The proposed device consists on the realization of a lie detector prototype based on the measure of the electrodermal activity (galvanic skin response). The designer used the same design of the 2013 project [29] with a slight difference in the hardware. They used a Wheatstone bridge as the GSR detection stage and they add a pre-amplification stage. [30]

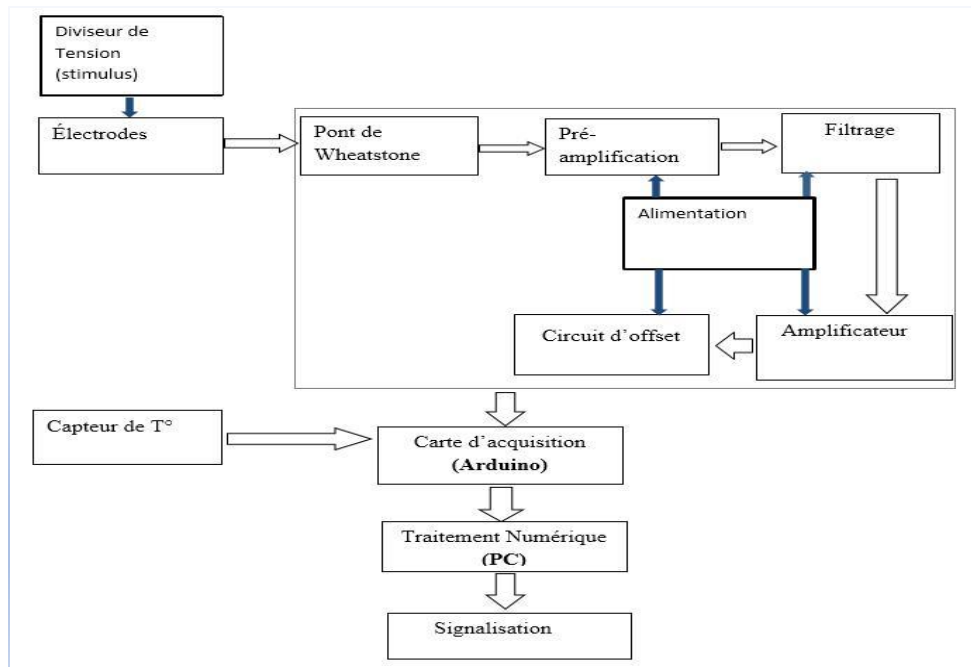


Figure II.7: Block diagram of the 3rd GSR Device

2.3. EDA Recording Techniques:

During the 1970s and 1980s, there have been several attempts to standardize techniques of electrodermal recording (e.g., Fowles et al., 1981; Lykken & Venables, 1971). However, because their basis was not always empirically wide-ranging, these recommendations do not provide sufficient information on what will result as a consequence of their violation. Therefore, the methodology proposed by Venables and Christie (1980) and recommendations by a commission of the Society for Psychophysiological Research (Fowles et al., 1981), will be used. Although the use of constant voltage methodology for exosomatic EDA recording was generally preferred by the authors of the two decisive publications from the 1980s, not all researchers adhered to that particular recommendation. This is not unjustified, since the general preference for CV can be questioned, because both the constant voltage and constant current methods have advantages and disadvantages. As far as exosomatic EDA measurement is concerned, the constant current recording will be included as a standard methodology as well. [16]

2.3.1. Endosomatic vs. Exosomatic Recording:

Although advantages and disadvantages of using an external current in electrodermal recording had been thoroughly discussed in the literature (e.g., Grings, 1974, p. 277), the majority of EDA studies have been performed with exosomatic methods. Therefore, Fowles et al. (1981) took up the recommendation already made by Lykken and Venables (1971) that skin conductance should be preferred over skin potential recording, unless researchers have a definite interest in comparing their work with the relevant literature on SP. Nevertheless, either techniques has its own advantages and disadvantages as summarized below.

Exosomatic EDA recording has the following technical advantages over endosomatic recording (Edelberg, 1967):

1. Exosomatic measures are always unidirectional and therefore easier to analyze. This is particularly not the case for biphasic or triphasic SPRs which are inseparably composed of negative and positive waves.
2. Exosomatic recording is less affected by electrode artifacts such as bias potentials or drift
3. When constant current is used in exosomatic recording, considerably less amplifier gain is required as compared to endosomatic recording.
4. No inactive reference electrode is required at an abraded site. Abrasion may cause pain and bear the danger of infections.
5. Fowles et al. (1981) mentioned that the sensitivity of SPL to hydration effects is probably greater than that of SCL.

By contrast, according to Edelberg (1967), endosomatic methods have the following advantages over exosomatic ones:

1. Endosomatic recording is regarded as being more “physiological,” since the skin system is not influenced by an application of an external current. This is especially an advantage in long-term recordings.
2. Electrode polarization is prevented since no external current is applied.
3. No special circuits are needed, as endosomatic EDA measurement can be performed with sufficiently sensitive high-ohmic amplifiers.

Fowles et al. (1981) added two further advantages of endosomatic methods:

4. The simple counting of NS.EDRs without regard to amplitude may be more sensitive in SP measurement than in SC measurement, according to a personal note of Edelberg to Fowles et al. (1981).
5. Endosomatic recordings will not be affected by variations in contact area, as long as skin areas with different potentials are not connected with each other.[16]

*The recommendation had been made that with constant current recordings the current density should be limited to 10 mA/cm² and electrodes with the greatest possible area should be used [16].

However, Forbes and Bolles (1936), as well as Edelberg (1967) suggested that the positive and negative potential waves may have independent behavioral significance. Furthermore, testing physiological models of the skin requires potential recording as well.

From the present author's point of view, endosomatic recording should be revitalized, not for general application but in basic research, as an aid to gaining a better theoretical understanding of electrodermal phenomena. [31].

2.3.2. The Use of Direct vs. Alternating Current:

EDA recordings are mainly performed using direct current. Even the elementary use of the alternating current recording method has only been realized in a small number of studies to date. Boucsein reports that impedance measurements were primarily performed in the field of dermatology, particularly for monitoring the healing of skin wounds [Salter, 1979], Both advantages and disadvantages exist in using either method.

With AC recording, electrode polarization and error potentials are ruled out. These may play a role despite using to a high degree nonpolarizable electrode being nowadays available.

Difficulties may arise in AC recording from amplification and filtering, if the EDA signal itself contains higher frequency AC components, the elimination of possible noise during recording and amplification is more complicated than in DC recording, since the noise may be within the same frequency range as the to-be-recorded signal. [16]

In general, AC measurement is more complicated in both recording and evaluation but can provide more information about the electrodermal system (the access to the capacitive quantities of the skin) than DC recording, However, current instrumentation does not allow AC measurement in ambulatory conditions and the production of such instrumentation still requires significant developments. [23]

2.3.3. Constant Current vs. Constant Voltage Recording

Another issue that had been regarded is whether to use constant current or constant voltage in exosomatic recording. However, the discussion on this topic suffered from not clearly separating recording methods and measurement units.

As a simple matter of fact, the use of constant current will result in resistance values, while recording with constant voltage gives conductance values. Reporting the latter ones is in accordance with the SPR commission's recommendations. [32]

The following comparison of both recording methods has been given by Edelberg (1967). Constant current techniques have the following advantages:

1. They need less amplification than constant voltage techniques, by about a factor of 10. This is especially useful in field recordings.
2. The density of the current flow through the electrodes is limited and therefore the danger of electrode polarization is reduced.
3. An unknown series resistance (e.g., a dry corneum) has a less serious effect in a constant current as compared to constant voltage system.

By contrast, constant voltage methods have the following advantages:

1. Results are immediately expressed in conductance units and do not have to be transformed if one prefers reporting conductance values.
2. In a certain sense, the system is self-correcting with respect to the peripheral influence of the EDL upon the EDR amplitude.
3. The reference resistance, over which the amplifier measures the voltage, is low and constant, which leads to a good, constant relationship of the electrodermal system's impedance and the input impedance of the amplifier.
4. High voltages over single sweat glands resulting from current concentration on a few ducts are avoided, thus eliminating the danger of sweat gland damage.
5. The currents flowing through both electrodes are independent from each other.
6. When electrodes of different sizes are used (which is not usual), no matching of the current density to the electrode area must be made. [16]

From the present author's point of view, there is no need in general to switch from constant current to constant voltage recording. Both recording methods have certain advantages and disadvantages, and it is therefore recommended simply using the technique available. However, at least in EDA research, the constant voltage method is to be preferred in behalf of standardization. [31]

2.3.4. Resistance vs. Conductance Units:

The controversy on an adequate unit of measurement for exosomatic EDA dates back to the 1950s and is still not settled. According to Grings (1974), the question of the unit of measurement should be focused on for mainly three reasons:

1. An attempt on theoretical considerations to find the most appropriate electrical unit, especially with taking concepts of the electrical model of the skin into regard.
2. The statistically founded choice of units with respect to desirable distributional characteristics for further treatment of the data, e.g., normal distribution, and independence of means and variances from each other.

3. The search for relatively baseline-independent EDR units, i.e., such units where the EDR (as a measure of change) is not dependent upon the directly preceding EDL

As a general result from the 1984 reanalysis of the Boucsein and Hoffmann (1979) study, values obtained from either constant current or constant voltage recordings that were transformed into the other unit were equivalent to those obtained with the method providing the appropriate values directly.[31]

Lykken and Venables (1971) argued strongly for the direct measurement of skin conductance with a constant voltage system. This argument was based in part on the fact that skin conductance had been shown to be more linearly related to the number of active sweat glands and their rate of secretion. Indeed, according to the model proposed by Edelberg, where we can see the overall resistance as being composed of small resistances in parallel (Figure **Error! No text of specified style in document.**1), a variation of one of these resistances results in a linear variation of the conductance, which is a linear combination of all the conductances that model the excretory channels:

$$G_{tot} = G_1 + G_2 + \dots + G_n$$

Conversely, a variation of one of these resistances results in a nonlinear variation of the overall resistance, due to the inverse transformation of the conductance into resistance:

$$R_{tot} = \frac{1}{1/R_1 + 1/R_2 + \dots + 1/R_n}$$

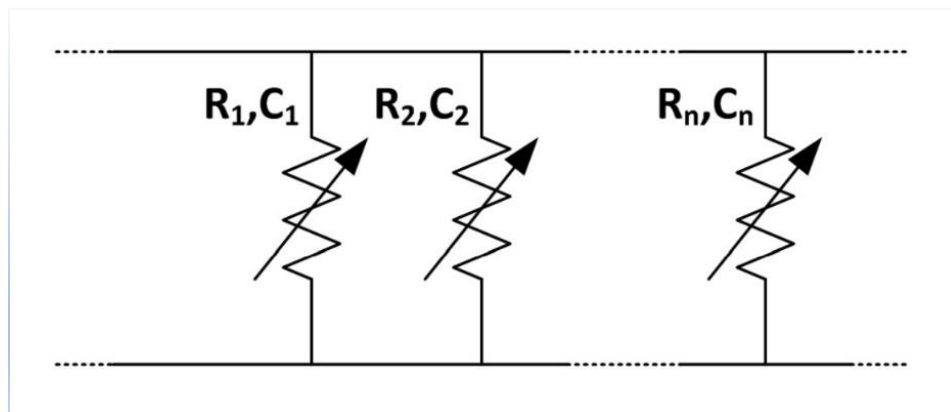


Figure II.8: Modeling of the conductivity of the excretory ducts of the sweat glands by a set of variable resistors connected in parallel

Thus, in the case of conductance, a measured variation in the amplitude of the signal is proportional to the variation of the sweat level in the excretory channels, directly dependent on the activity of the sympathetic nervous system. In the case of resistance, this amplitude also takes into account the value of all other resistors, and therefore requires correction to allow the comparison of variations of amplitudes having different base values. [23]

Thus, unlike the relationship of SRR and SRL, the SCR is potentially independent of SCL, since a given increment in the number of active sweat glands will produce the same increment in the total conductance of the pathway regardless of the level of basal activity. Boucsein (1992, pp. 208-16) stated that the discussion of this issue often confounds the choice of method of measurement with the choice of units of measurement. He raised thoughtful questions about the bioelectrical assumptions underlying the parallel conduction model. Nevertheless, Boucsein agreed on pragmatic grounds with the recommendation to use constant-voltage methods and skin conductance units (for the sake of standardization in the field). [33]

The general conclusion here is that the unit of measurement is more important for results than the recording method with which results are obtained.

2.4. Recording Sites:

Electrodermal recording is usually performed with two electrodes. exosomatic techniques use two active sites, while endosomatic recording requires an active and an inactive site. Several proposals have been made concerning the choice and a possible pretreatment of EDA recording sites. However, attempts for standardization have not yet been fully successful.

2.4.1. Choice of Sites:

Most researchers make use of the palms or the volar surfaces of the fingers as active sites for electrodermal recording. The following reasons for this are given by Venables and Christie (1980):

1. Electrodes can be fixed easily, and those sites are not susceptible to disturbance by movement.
2. The size of available area is sufficient.
3. Those sites are relatively free from scarring.
4. Palmar sites show distinguished electrodermal activity

For Exosomatic Measurement:

The high density of sweat glands presents on the palms of the hands and soles of the feet make them preferred measuring sites. If the subject does not need both hands for experimentation, the non-dominant hand is usually chosen. On the hand, Following Edelberg (1967), Venables and Christie (1980) recommended the medial phalanges of the index and middle fingers for bipolar recordings (sites A and B in Figure II.9).

In case of difficulties to appear with fixing the electrodes to the fingers (e.g., if fingers are too slim or electrodes with a large surface are used), bipolar recordings from thenar and hypothenar eminences (sites C and D in Figure II.9) is a solution which became very common. [16]

For Endosomatic Measurement:

The inactive electrode being necessary for endosomatic recording should be placed on a site that has the smallest potential difference between the skin surface and the body core and being essentially inactive in terms of SPRs.

For palmar SP recordings, Venables and Christie (1980) recommended fixing the inactive electrode to a slightly abraded site on the volar surface of the forearm (site E in Figure II.9). [16]

The objective of a good electrode fixation is to avoid any variation of the contact surface during the experiment. Electrodes should be held so that they do not fall out after a few minutes, due to hand movements or excessive sweating. [23]

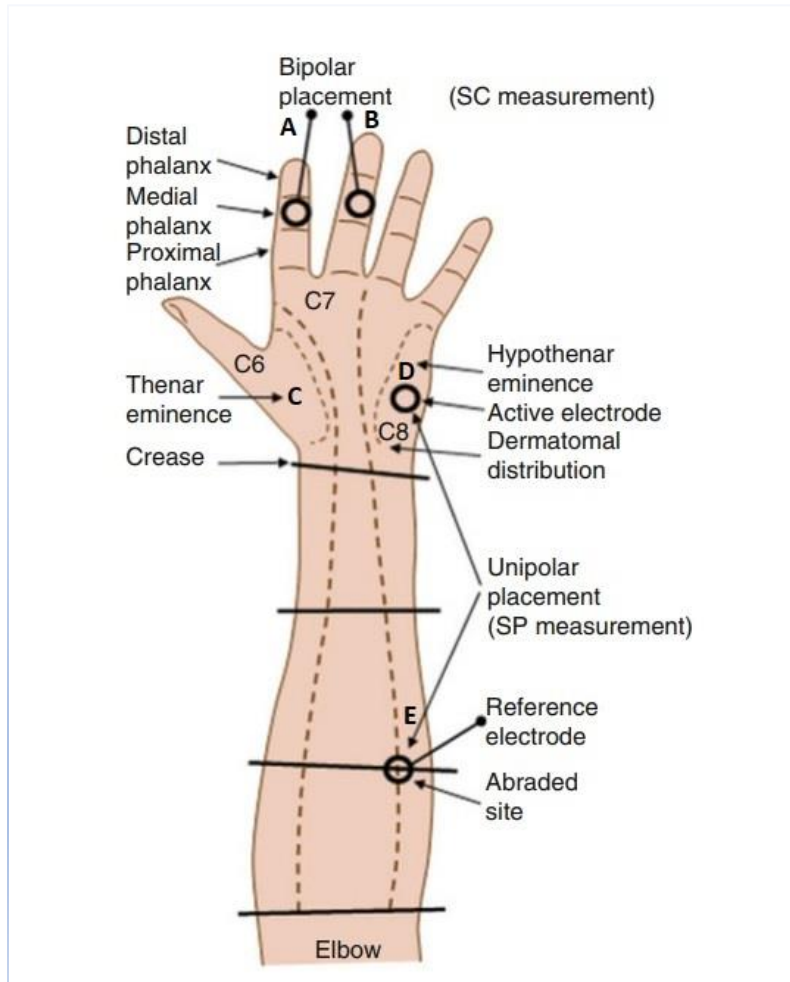


Figure II.9: Measurement Sites

2.4.2. Pretreatment of Sites:

According to the present author's experience, there is normally no need for a pretreatment of sites used for exosomatic recording. In cases of extremely oily skin, cleaning of skin surface with alcohol may be advisable in order to enable fixation of the adhesive tape to keep the electrodes in position.

By contrast, the site used for the inactive electrode in endosomatic recording must be pretreated. The stratum corneum has to be removed to diminish the potential difference between the site and the body core underneath the electrode. This can be done by light rubbing with fine sandpaper. [19]

2.5. The Electrodes:

2.5.1. The importance of electrodes:

For a good detection of the EDA Signal, it is important that the sensor (the electrodes in our case) is correctly chosen and placed. (See Figure II.10) which illustrates the arrangement of the electrodes in this application.



Figure II.10: Fingers Electrodes

Sensors are one of the most important parts in the signal acquisition chain. The sensors transform a physical quantity into an observable quantity such as for example a voltage or an electric current.

In the design of systems, the part concerning the sensors is often neglected and dealt with at the end of the study, Unfortunately, if the choice of sensors is not made up correctly, the signals acquired by the system will be unusable in most cases.

For example: BECKMAN BIOPOTENTIAL SKIN ELECTRODES (See Figure II.11), fixed to the skin using an adhesive disc, ensure a particularly stable contact. [34]

The choice of electrodes is a key issue for measuring electrodermal activity.



*Figure II.11: BECKMAN
BIOPOTENTIAL SKIN
ELECTRODES*

2.5.2. Forms of Electrodes and Their Attachment:

The EDA electrodes predominantly used today are disc electrodes having the electrode surface on the bottom of a cylindrical plastic chamber. The space between the electrode surface and the bottom of the ring is filled with the electrode cream containing the electrolyte (Figure II.12).

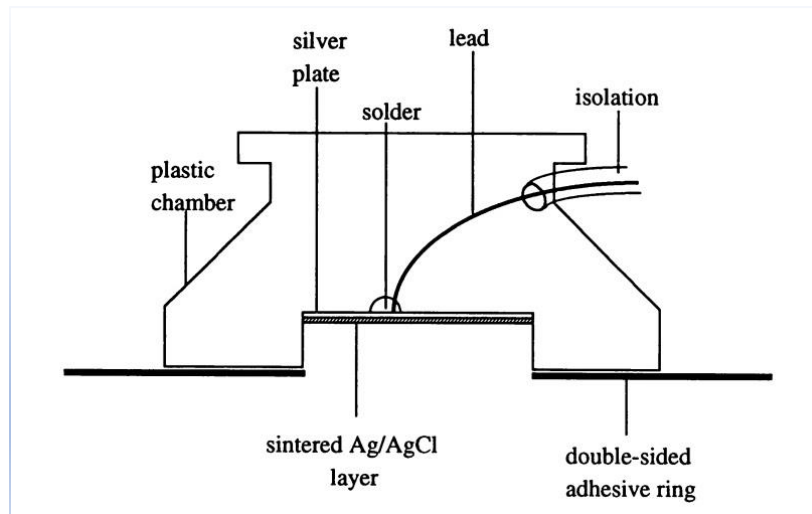


Figure II.12: Cross-section of an Ag/AgCl electrode

The electrode surface consists of a silver plate which is covered by a sintered Ag/AgCl layer. It is soldered to an insulated lead and enclosed by a cylindrical plastic chamber which is attached to the skin with a double-sided adhesive collar. [16]

2.5.3. Choice of Electrodes:

Electrodes used to measure electrodermal activity must meet two constraints [McAdams, 2006]:

- They must have a low degree of polarization at the passage of a current; i.e. a low resistance at the electrode-electrolyte interface.
- They must have a low offset voltage, i.e. identical potentials at the point of operation.

Today sintered silver/silver chloride (Ag/AgCl) electrodes are practically the only standard EDA electrodes in use. These are so-called reversible electrodes which are made from a metal in contact with a solution of its own ions (Fowles et al., 1981). Such electrodes display the smallest possible bias potentials and are nonpolarizable to a high degree According to Edelberg (1967) recommendations [16], They are commonly used with a disc-shaped contact surface. There are different recommendations as to the size of this surface. The choice is far from obvious, because Venables and Christie emphasize "[...] a non-monotone relationship between the tonic or phasic level of electrodermal activity and the contact surface of the electrodes" [Venables and Christie, 1980, p. 33], but they did not find significant variations for electrodes with diameters greater than 10 mm, Mitchell and Venables (1980) recommended that for finger recording the electrode area should be around 8 mm in diameter (approximately 0.503 cm^2) . [23]

2.5.4. Electrodes Cleaning and Storage:

For cleaning and preserving the electrodes, it is important to pay attention to the surface of the electrodes. In particular, it is not advisable to clean them with a cloth, it is preferable to rinse them immediately after use under water (distilled water if possible) to avoid deposits of limestone. After rinsing, they should be stored in dry conditions. [19]

2.5.5. Conclusion on the choice of our electrodes:

The electrodes used for measuring the electrodermal activity are generally metallic "reversible" electrodes made of Silver / Silver-Chloride (Ag/AgCl) with 8 mm in diameter according to the recommendations of Fowles et al [Fowles et al. 1981]

2.6. Use of the gel:

Unlike measurements such as ECG, EEG or EMG, which use hypertonic electrolytes to obtain a very high conductivity, measurement of the electrodermal activity needs a gel that minimizes the interactions between the skin and the electrolyte. For this, gels must be isotonic, that is to say, they must have an ionic concentration closest to that of the skin. The use of gels for ECG, EEG or EMG is not compatible with measurement of electrodermal activity as they may change the resistance of the skin. [19]

2.7. Sources of noise:

As long as the signal of the electrodermal activity has a low amplitude and a low frequency (5Hz), it can be superimposed with several noise sources:

- Mains noise of 50 Hz.
- The noise of electromagnetic fields due near transmitter such as the sector, cell phones, power sources....
- In a hospital environment, high frequency generators in radiology can be sources of such disturbances just like simple fluorescent tube lighting, capacitive decoupling...
- The subject's movement. Can change the amount of contact between the finger and the electrode, thus changing the resistance of the junction which will influence the size of EDA. This type of noise can be minimized by asking the subject to remain stable during the measurement.

2.8. Filters:

A filter is a circuit capable of passing (or amplifying) certain frequencies while attenuating other frequencies. Thus, a filter can extract important frequencies from signals that also contain undesirable or irrelevant frequencies. This function is essential in order to avoid aliasing in the useful spectrum of undesirable frequencies when the signals have to be sampled or converted to another form (digital, for example).

2.8.1. Type of filters:

The four primary types of filters include the low-pass filter, the high-pass filter, the band-pass filter, and the notch filter (or the band-reject or band-stop filter), however, that the terms "low" and "high" do not refer to any absolute values of frequency, but rather they are relative values with respect to the cutoff frequency.

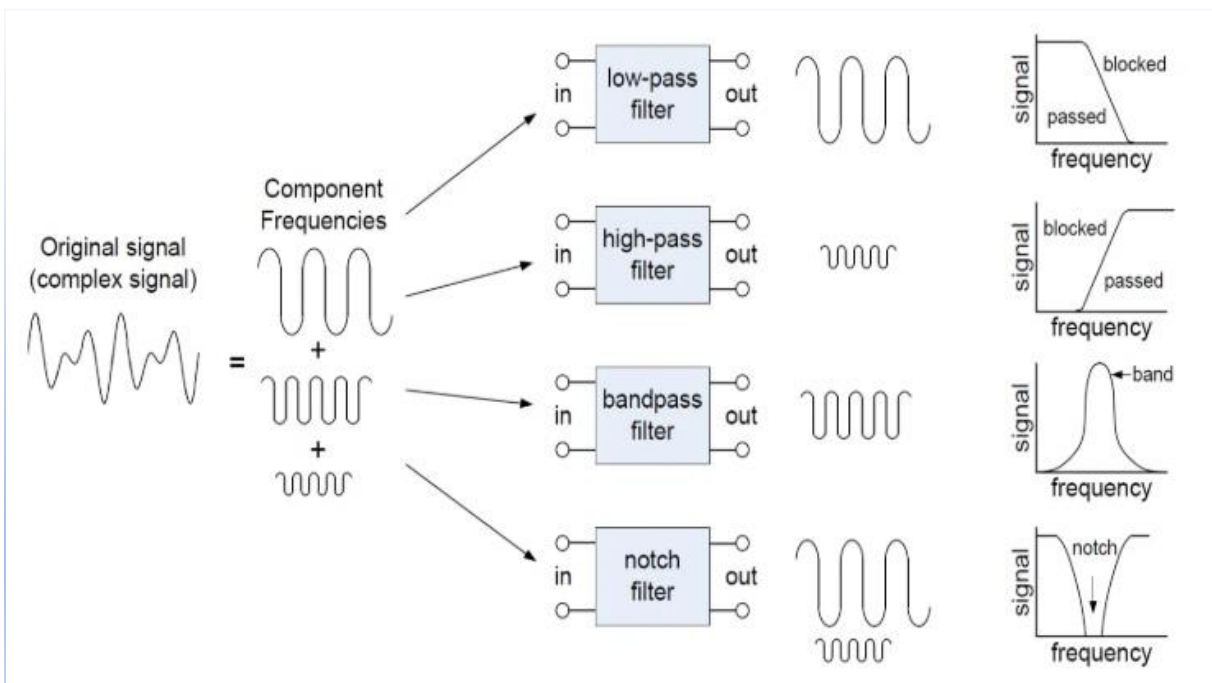


Figure II.13: Filters Types

2.8.2. Filter response characteristics:

Each type of filter response (low-pass, high-pass, band-pass, or band-stop) can be tailored by circuit component values to have either a Butterworth, Chebyshev, or Bessel characteristic. Each of these characteristics is identified by the shape of the response curve, and each has an advantage in certain applications.

2.8.2.1. The Butterworth Characteristic:

The Butterworth characteristic provides a very flat amplitude response in the passband and a roll-off rate of -20 dB/decade/pole.

The phase response is not linear, however, and the phase shift (thus, time delay) of signals passing through the filter varies nonlinearly with frequency. Therefore, a pulse applied to a filter with a Butterworth response will cause overshoots on the output because each frequency component of the pulse's rising and falling edges experiences a different time delay. Filters with the Butterworth response are normally used when all frequencies in the passband must have the same gain. The Butterworth response is often referred to as a maximally flat response.

2.8.2.2. The Chebyshev Characteristic:

Filters with the Chebyshev response characteristic are useful when a rapid roll-off is required because it provides a roll-off rate greater than -20 dB/decade/pole. This is a greater rate than that of the Butterworth, so filters can be implemented with the Chebyshev response with fewer poles and less complex circuitry for a given roll-off rate. This type of filter response is characterized by overshoot or ripples in the passband (depending on the number of poles) and an even less linear phase response than the Butterworth.

2.8.2.3. The Bessel Characteristic:

The Bessel response exhibits a linear phase characteristic, meaning that the phase shift increases linearly with frequency. The result is almost no overshoot on the output with a pulse input. For this reason, filters with the Bessel response are used for filtering pulse waveforms without distorting the shape of the waveform. [35]

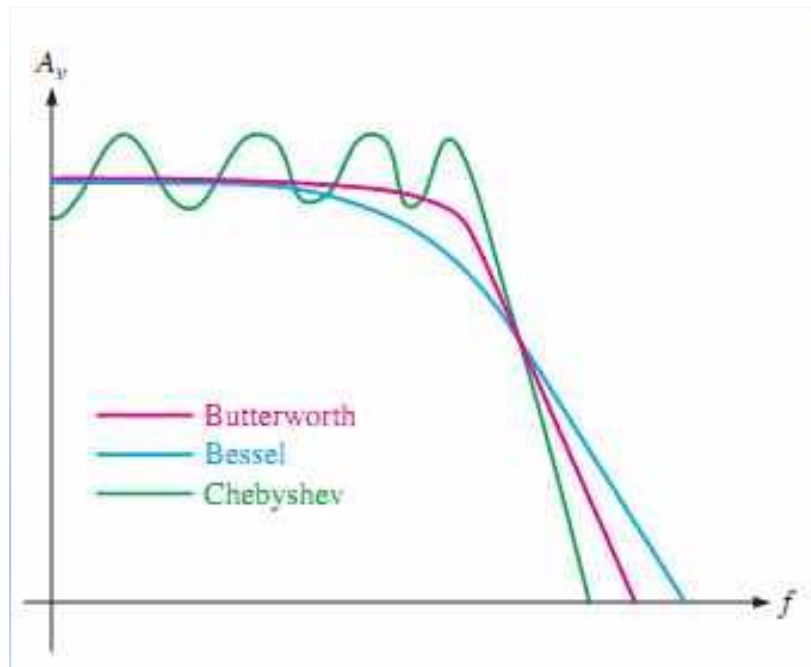


Figure II.14: Comparative plots of three types of filter response characteristics.

2.8.3. Active and passive filters:

2.8.3.1. Active filter:

Active filters are implemented using a combination of passive and active (amplifying) components, such as op-amps, in addition to resistors and capacitors, but not inductors. They require an outside power source. Operational amplifiers are frequently used in active filter designs. These can have high Q factor, and can achieve resonance without the use of inductors. However, their upper frequency limit is limited by the bandwidth of the amplifiers.

Active filters are capable of dealing with very low frequencies (approaching 0 Hz), and they can provide voltage gain (passive filters cannot). Active filters can be used to design high-order filters without the use of inductors; this is important because inductors are problematic in the context of integrated-circuit manufacturing techniques. However, active filters are less suitable for very-high-frequency applications because of amplifier bandwidth limitations. Radio-frequency circuits must often utilize passive filters. [36]

2.8.3.2. Passive filter:

Passive filters are based on combinations of only passive components resistors (R), inductors (L) and capacitors (C). These types are collectively known as passive filters, because they do not depend upon an external power supply and they do not contain active components such as transistors.

Passive filters are most responsive to a frequency range from roughly 100 Hz to 300 MHz. The limitation on the lower end is a result of the fact that at low frequencies the inductance or capacitance would have to be quite large. The upper-frequency limit is due to the effect of parasitic capacitances and inductances. Careful design practices can extend the use of passive circuits well into the gigahertz range. [36]

2.9. Conclusion:

Through this chapter, a description of some EDA recording device models has been made, a detailed description and comparison of EDA recordings techniques , the electrodes and their importance for optimal detection of the signal, in addition to the measurement sites on the subject for optimal detection of galvanic skin response, The chapter was concluded with a description of filters and source of noise that can affect the measurement of GSR,

Chapter 3

Circuit Design and Simulation

3.1. Introduction:

In this chapter, we discuss the proposed GSR circuit design. This study is carried out from the sensor, passing through the shaping circuit to the PCB Artwork layout. Since the labs in this period of COVID-19 were closed (from march up today end of the end of September), our work was based only on simulation.

3.2. System Design:

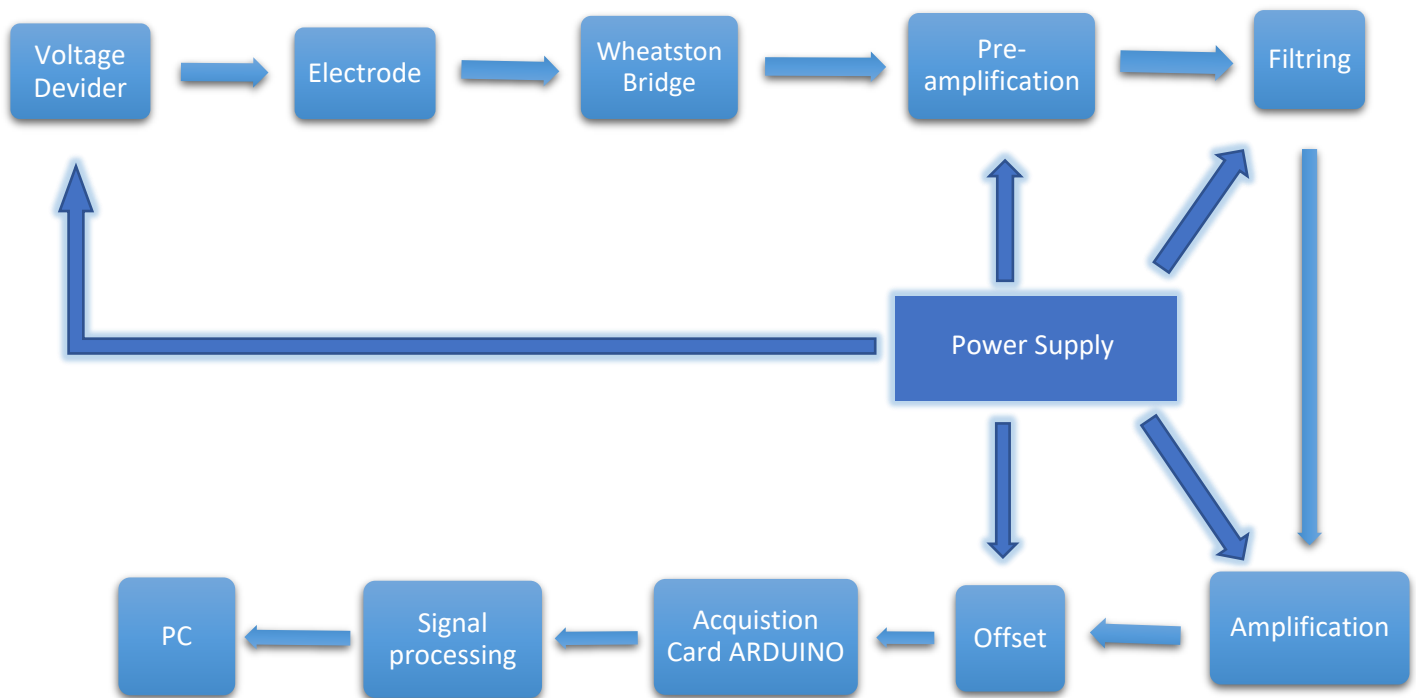


Figure III-1: The proposed Block diagram of the GSR circuit

The proposed device design is according to the block diagram given in Figure III-1, It brings together the different parts listed below:

- ✓ DC voltage source of 0.5V.
- ✓ The sensors (electrodes).
- ✓ Detection circuit (Wheatstone bridge).
- ✓ Pre amplification stage.
- ✓ Filter circuits (band pass filter)
- ✓ Amplification circuit.
- ✓ Offset circuit.
- ✓ Acquisition card (ARDUINO UNO).
- ✓ Monitor + PC.

3.2.1. The Electrodes (GSR Sensor):

As described in the previous chapter, the choice of the electrodes is very important to guarantee a good detection of the Galvanic skin response.

The electrodes used for measuring the electrodermal activity are a metallic “reversible” and “non-polarizable” electrode made of Silver / Silver-Chloride (Ag/AgCl) with 8 mm in diameter according to the recommendations of Fowles et al. [Fowles et al. 1981]. They are simply attached on the fingertips of the hand (distal or medial) location using a scratch closure tape, to ensure good fixation and therefore avoid the appearance of artifacts in the signal. A photo of such electrodes is given in Figure III-2 below.



Figure III-2: The Electrodes

3.2.2. The Detection Stage:

To detect our GSR signal, we used a Wheatstone bridge with a sensitive element (the electrodes) which provides a linearity of response. The bridge is supplied by 0.5V fixed by a voltage divider (see Figure III-3), since the skin conductivity values are linear only when the applied voltages are below 0.5 V. The voltage across the bridge (V1, V2) can be used to extrapolate the conductivity of the skin by linking the two ends of the bridge to a pre amplifier. There is no need to use the voltage followers for impedance matching since the instrumentation amplifier AD620 used in our design has a high input impedance of approximately $10\text{G}\Omega$ ($10^9 \Omega$) and 2pF (10^{-9}F) (see data sheet on the annexes).

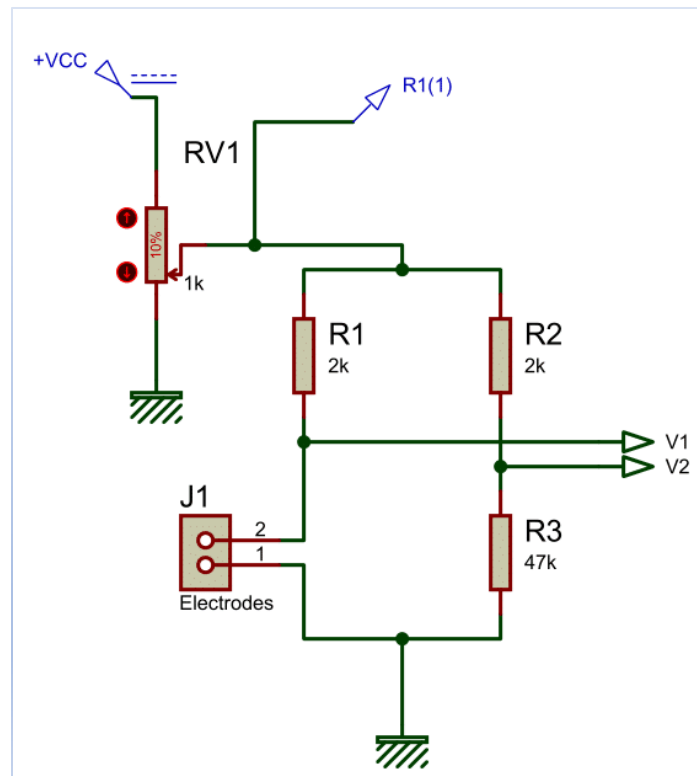


Figure III-3: The Detection Stage

3.2.2.1. Detection Stage Detection Stage simulation:

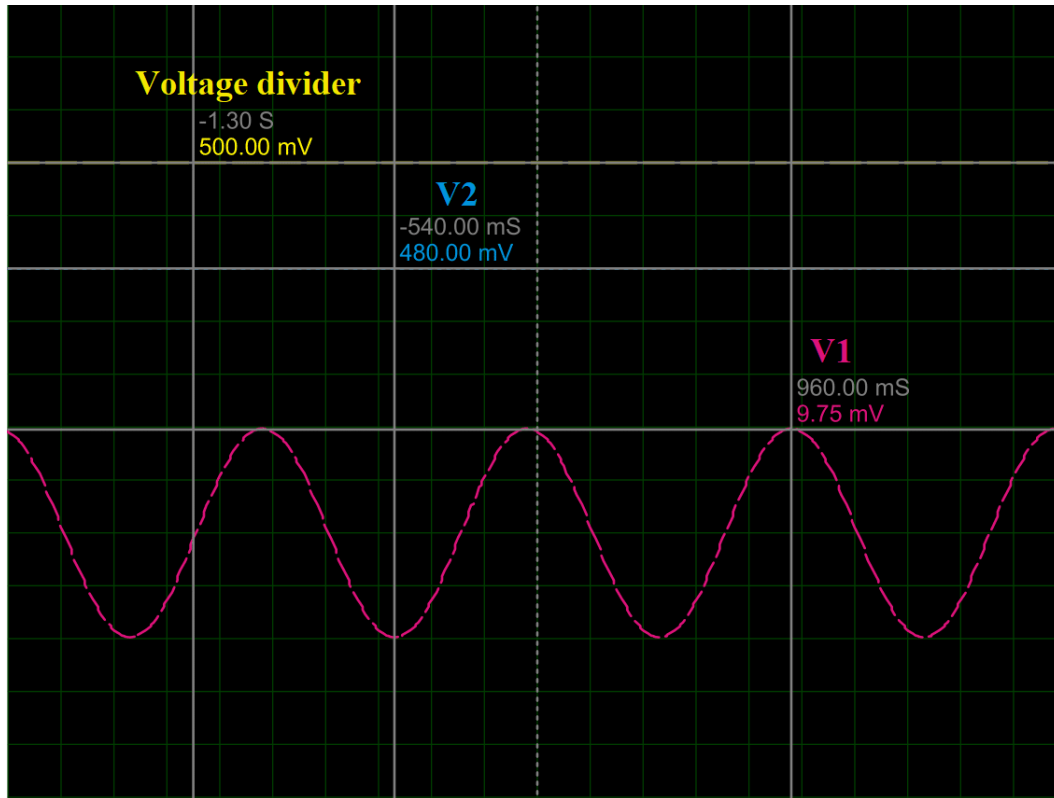


Figure III-4: The Detection Stage Simulation

The Figure III-4 above illustrate the detection stage simulation, the bridge is supplied by 500mV DC, V1 represents the first end voltage of the Wheatstone bridge which is connected to the electrodes. It corresponds to the simulated GSR signal. This is generated using a sinewave with 10mV amplitude and 2Hz frequency, while V2 represents the second end voltage of the Wheatstone bridge.

3.2.3. Pre-amplification Stage:

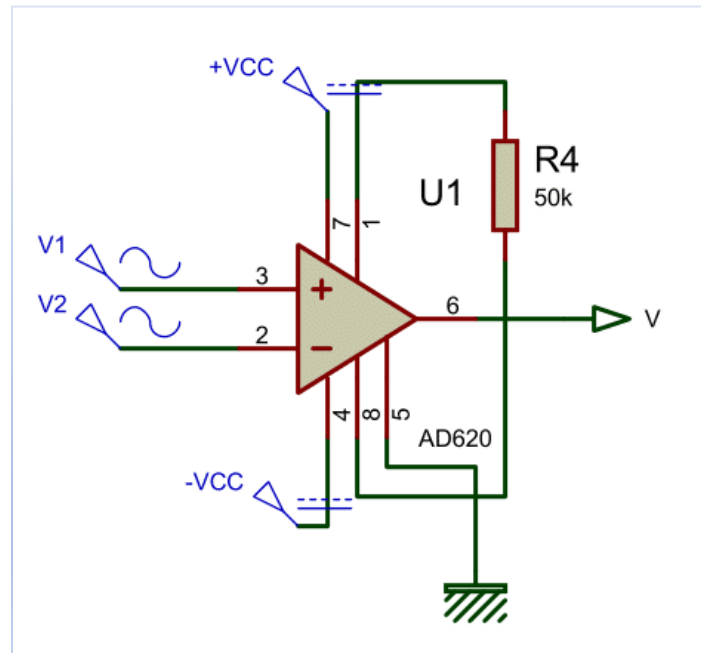


Figure III-5: The Pre-amplification Stage

As specified above, in order to amplify the detected voltage across bridge we chose an AD620 instrumentation amplifier (see Figure III-5). Some of its main characteristics are given below (for more details see the data sheet provided in the annexes):

- ✓ Gain set with one external resistor (Gain range 1 to 10,000)
- ✓ Wide power supply range (± 2.3 V to ± 18 V)
- ✓ Higher performance than 3 op amp IA designs
- ✓ Low power, 1.3 mA max supply current
- ✓ Excellent dc performance (B grade)
- ✓ 50 μ V max, input offset voltage
- ✓ 0.6 μ V/ $^{\circ}$ C max, input offset drift
- ✓ 100 dB min common-mode rejection ratio ($G = 10$)
- ✓ Low noise
- ✓ 120 kHz bandwidth ($G = 100$)
- ✓ High input impedance ($10G\Omega/2pF$) [37]
- ✓ Low output impedance (few $m\Omega$ s)[37]

3.2.3.1. AD620 Gain Selection:

The AD620 gain is resistor-programmed by R_G (R_4 in our design), or more precisely, by whatever impedance appears between Pins 1 and 8. The AD620 is designed to offer accurate gains using 0.1% to 1% resistors. (Table III-1) shows required values of R_G for various gains. Note that for $G = 1$, the R_G pins are unconnected ($R_G = \infty$).

For any arbitrary gain, R_G can be calculated by using the formula:

$$G = \frac{49.4K\Omega}{R_g} + 1$$

In our case, R_4 value is $50K\Omega$, so the selected gain is: $G = 2$

Required Values of Gain Resistors are shown in the table below:

1% Std Table Value of $R_G(\Omega)$	Calculated Gain	0.1% Std Table Value of $R_G(\Omega)$	Calculated Gain
49.9 k	1.990	49.3 k	2.002
12.4 k	4.984	12.4 k	4.984
5.49 k	9.998	5.49 k	9.998
2.61 k	19.93	2.61 k	19.93
1.00 k	50.40	1.01 k	49.91
499	100.0	499	100.0
249	199.4	249	199.4
100	495.0	98.8	501.0
49.9	991.0	49.3	1,003.0

Table III-1: Required Values of Gain Resistors

3.2.3.2. Pre-amplification stage simulation:

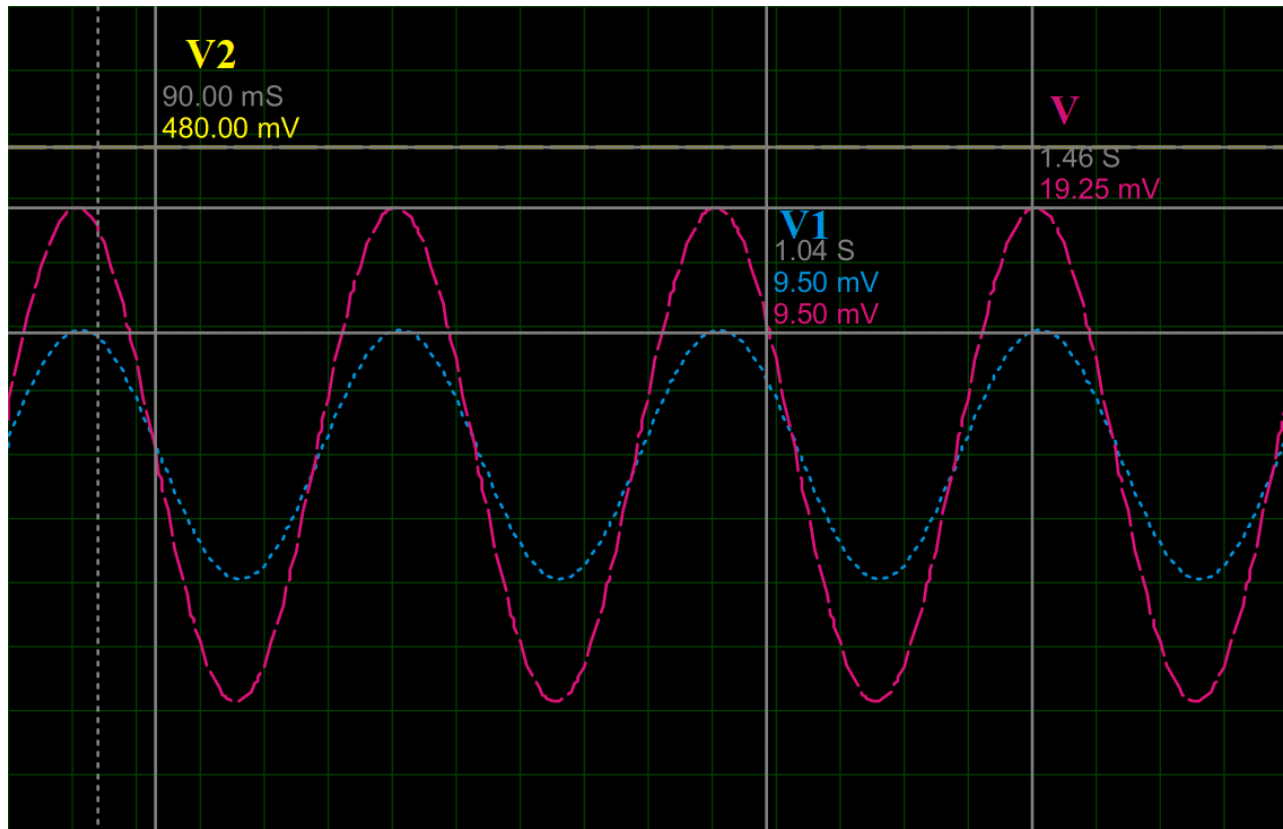


Figure III-6: The Pre-amplification Stage Simulation

The Figure III-6 above illustrate the Pre-amplification stage simulation, 'V1' and 'V2' (see Figure III-5) represent the Wheatstone bridge ends voltage which they are applied to the AD620 inputs, 'V' represent the AD620 amplified output voltage.

3.2.4. Filter Stage:

The GSR signal, thus amplified, can be embedded in different noise sources, so filtering is necessary. In most cases, active filters are chosen because of their advantages compared to passive filters specifically the gain and the selection of respectively the pass band and the cutoff responses.

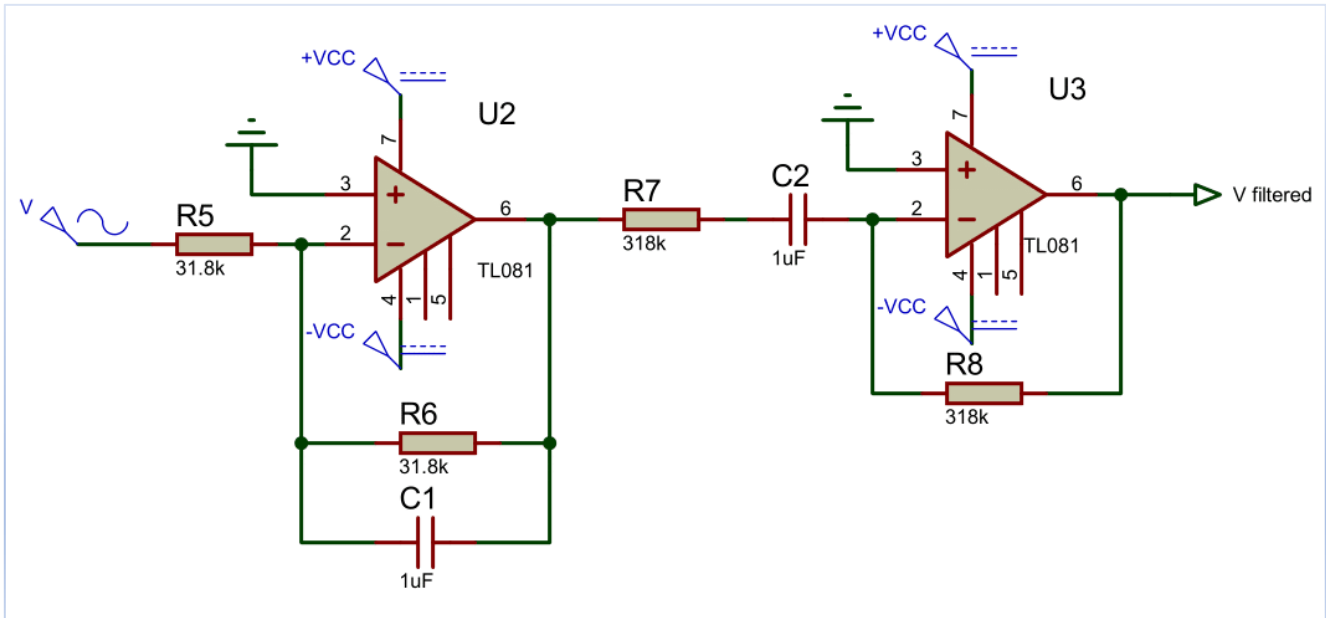


Figure III-7: The Filter Stage

In our implementation, we opted for an active band pass filter (see Figure III-7), it is designed by cascading a low pass filter with cutoff frequency $F_{c1}=5\text{Hz}$ (see equation 1 below) and a high pass filter with a cutoff frequency $F_{c2} = 0.5\text{Hz}$ (see equation 2 below). Both are designed using the TL081 operational amplifier because of its low noise, less input offset error, its low cost and availability compared to other general-purpose op-amplifiers such as UA741, TI071, ...etc. (for more characteristics see the data sheet provided in the annexes)

$$F_{c1} = 1 / 2\pi * R6 * C1 = 5\text{Hz} \dots\dots\dots (1)$$

$$F_{c2} = 1 / 2\pi * R8 * C2 = 0.5\text{Hz} \dots\dots\dots (2)$$

3.2.4.1. Filter stage simulation:

In this section, different cases of filtering simulation using generated sinewaves with different frequencies are illustrated in Figure III-8, figure III-9 and figure III-10 below.

3.2.4.1.1. Case of GSR signal information with 2Hz frequency:

the Figure III-8 below illustrate a simulated GSR signal information with a frequency of 2Hz, the input and the output signals are superimposed, which means that the information is preserved.

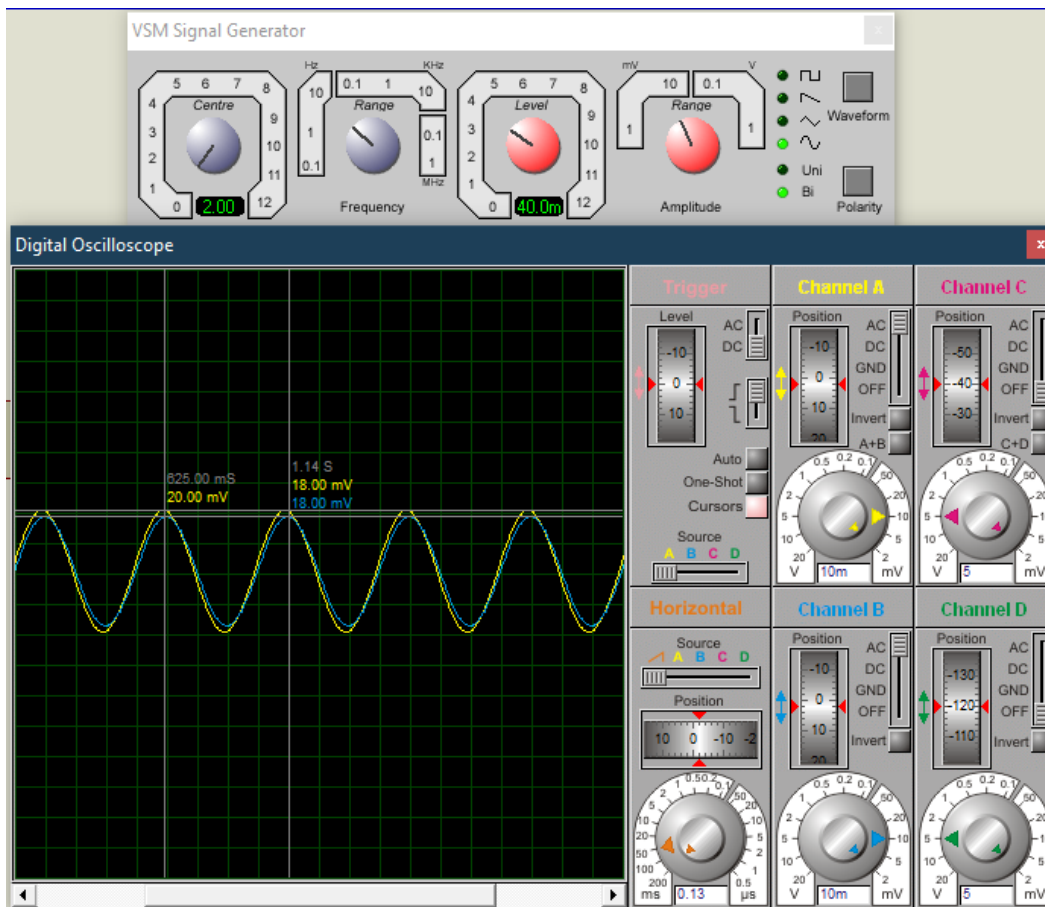


Figure III-8: Filter Response to a 2Hz frequency information

3.2.4.1.2. Case of noise with 300mHz frequency:

The Figure III-9 below illustrate a simulated noise signal with a frequency of 300mHz, the high pass filter cutoff frequency is set to 0.5Hz in which the output signal amplitude is reduced compared to the input signal.

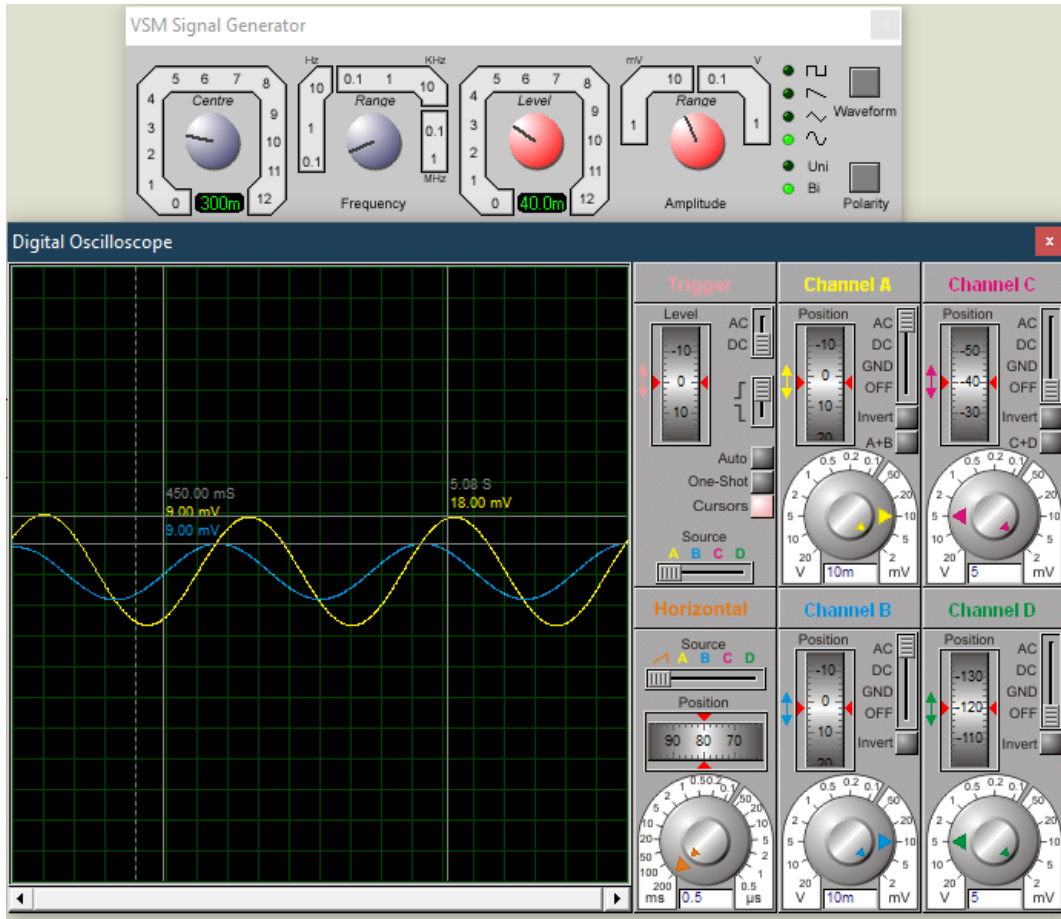


Figure III-9: Filter Response to a 300mHz frequency noise

3.2.4.1.3. Case of noise with 50Hz frequency:

The Figure III-10 below illustrate a simulated noise signal with a frequency of 50Hz, the low pass filter cutoff frequency is set to 5Hz, so the noise signal amplitude is reduced from 20 mV to 2mV.

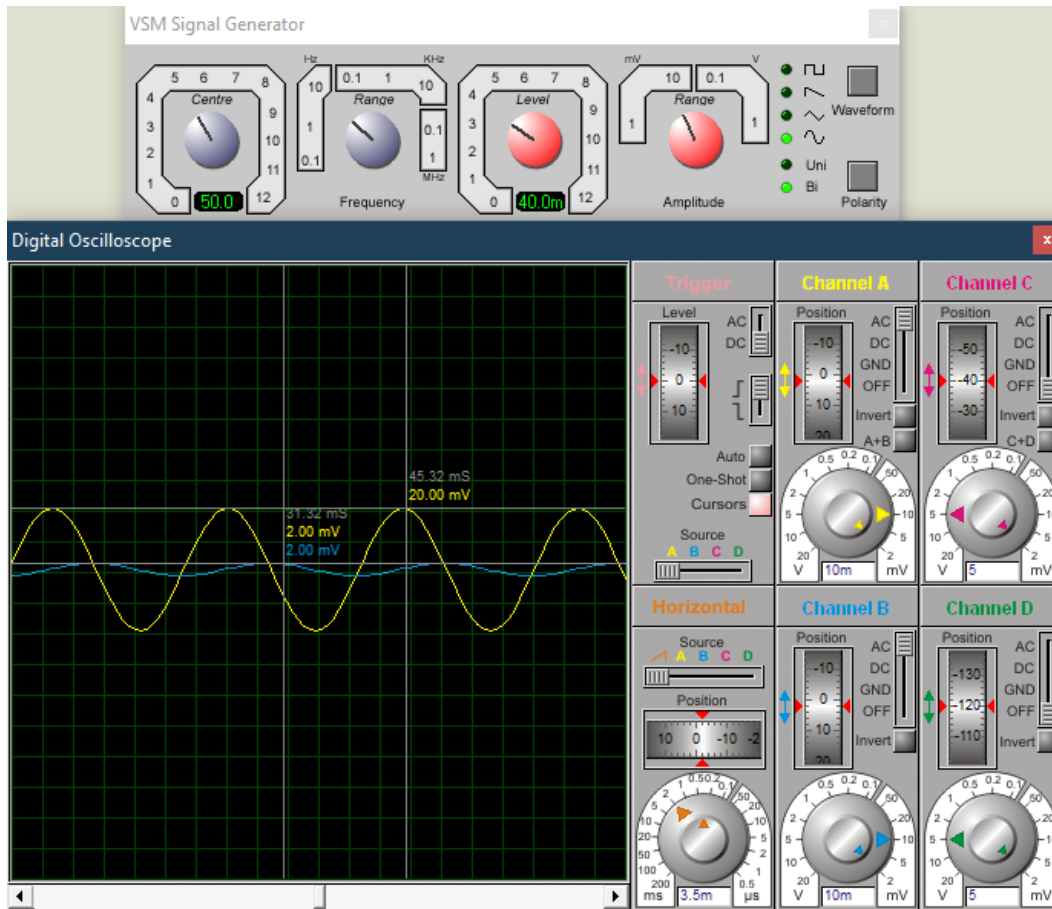


Figure III-10: Filter Response to a 50Hz frequency noise

3.2.5. Amplification Stage:

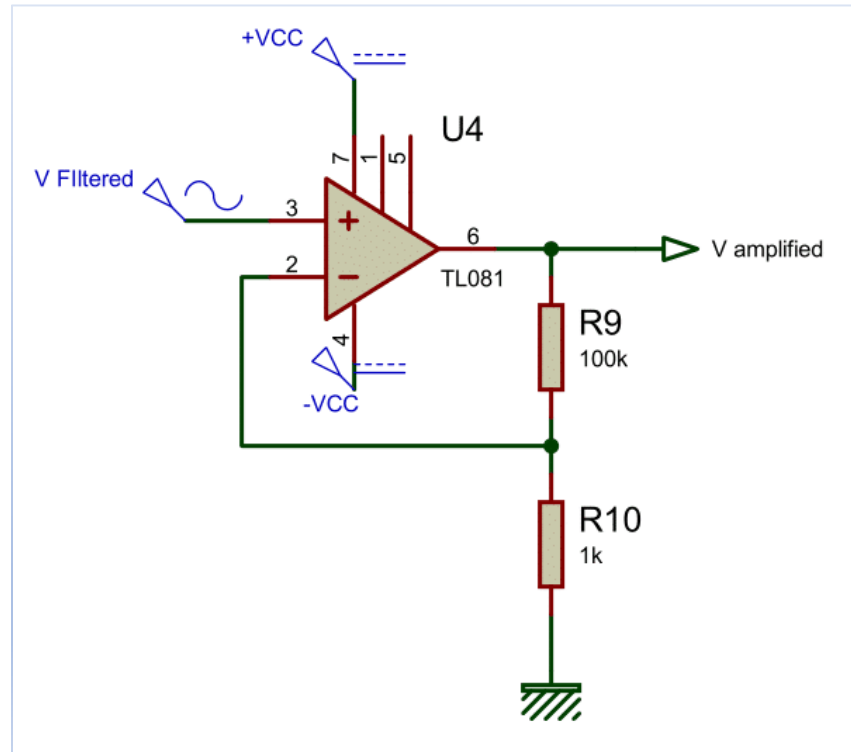


Figure III-11: The Amplification Stage

Considering that The GSR signal at the output of the pre-amplification remains relatively low (some mVs) to be used by the acquisition board, another stage of amplification is required, we used a non-inverting amplifier TL081 (see Figure III-11) with the following gain formula:

$$G = 1 + \frac{R1}{R2}$$

$$G = 1 + \frac{100}{1} = 101$$

$$G = 100$$

This gain is chosen such that the GSR signal must not exceed 5 V maximum (corresponding to the maximum voltage of the Arduino board input) under any physiological conditions.

3.2.5.1. Amplification stage simulation:

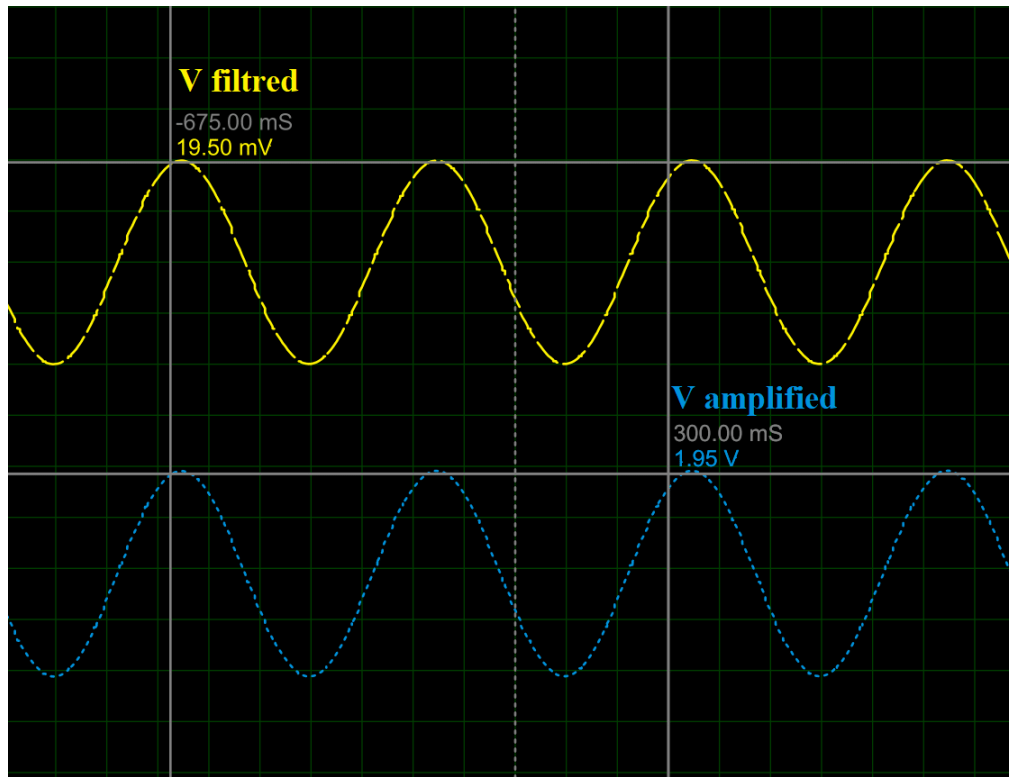


Figure III-12: Amplification Stage Simulation

The Figure III-12 above represents the Amplification stage simulation, the filtered signal issued from the filter stage (see Figure III-11) is applied to the non-inverting input of the amplifier where the gain is set to 100.

3.2.6. Offset Stage:

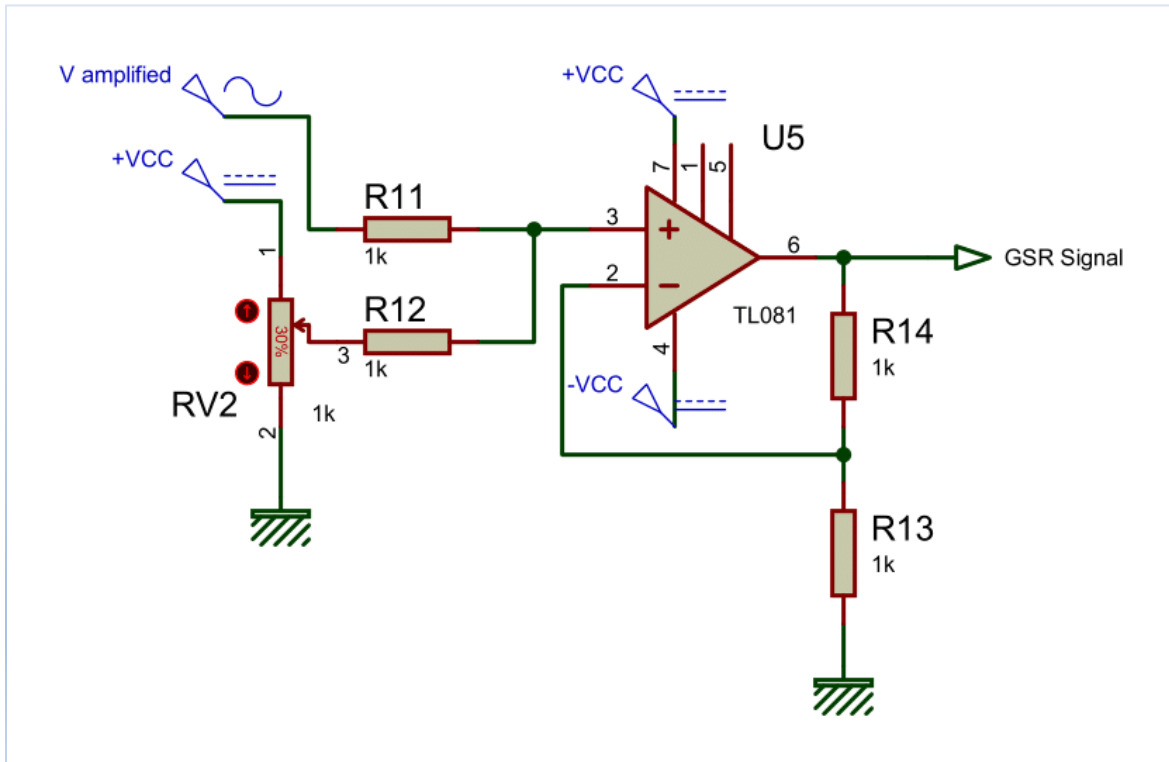


Figure III-13: The Offset Circuit

After amplification, The GSR signal is bipolar, however and because the analog input of the Arduino acquisition board is unipolar (must vary between 0 and 5V maximum) an offset circuit is then needed. This circuit (see Figure III-13) makes it possible to add a DC component to the GSR signal to shift it towards the positive part, it is an operational amplifier configured as an adder (with a gain of 1). The DC component is generated from the voltage (+ Vcc) and the potentiometer RV2. This voltage as well as the GSR voltage are applied to the input (+) respectively through R12 and R11 with the same values of 1K Ω .

3.2.6.1. Offset stage simulation:

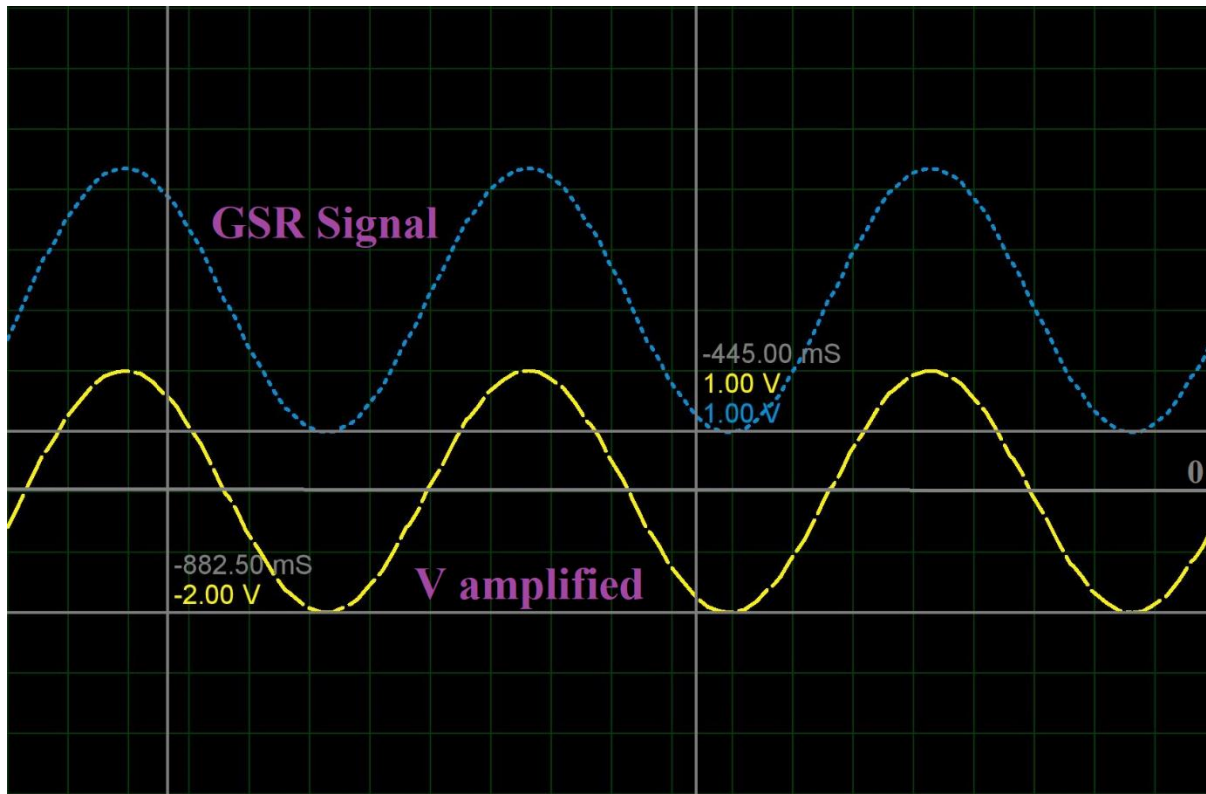


Figure III-14: Offset Stage Simulation

The Figure III-14 above represents the Offset stage simulation, using the RV2 potentiometer (see Figure III-13) we add a DC component to our amplified bipolar signal, in step to use it in the Arduino acquisition board unipolar input.

3.2.7. Power supply:

We should know that the supply voltage of our circuit will be injected directly into the human body through the electrodes placed on the fingers, so we must take in consideration the medical safety standards. Indeed, an electric current generated from a power supply can cause irreversible physiological effects. These effects depend on different parameters such as:

- Contact voltage
- The condition of the skin (dry or wet)
- Contact time
- Contact surface
- Frequency (DC, HF, LF)
- The general condition of the patient (sex, weight, illness, etc.)

3.2.7.1. General effects of electric current:

The general effects of electric current differ for man, woman and child. For the same amount of current, women generally have worse symptoms than men. In the case of child or babies normally there is a distinct dark mark, similar to a burn on the lips, once that in the first years of life babies use the mouth to discover the world around them.[38]

Electric current (contact for 1s)	Effect
Below 1 mA	Not perceptible
1 mA	Threshold of feeling, tingling
5 mA	Slight shock. Not painful. Average individual can let go. Involuntary reaction can lead to indirect injuries
6-25 mA (women)	Painful shocks. Loss of muscle control
9 to 30 mA (men)	Freezing current, "can't let go". The person may be thrown away from the power source. Individual cannot let go. Strong involuntary reaction can lead to involuntary injuries
50 to 150 mA	Extreme pain. Respiratory arrest. Muscles reactions. Possible Death.
1 to 4.3 A	Fibrillation of the heart. Muscular contraction and nerve damage occur. Likely death.
10 A	Cardiac arrest, severe burns. Death is probable

Table III-2: the effects of electric current upon the human Body [38]

3.3. Acquisition System:

In view of a digital processing of the GSR signal and its visualization on a PC, an acquisition board must be developed or eventually used and configured. In our project, we use an ARDUINO Uno Board since it is available in the market with a low cost and offers several possibilities for the digitalization and the acquisition of signals and programming, Figure III-15 below illustrate the block diagram of the GSR signal acquisition.



Figure III-15: Block diagram of the GSR signal acquisition.

3.3.1. The Arduino Board description:

Arduino is an open-source platform used for building electronics projects. Arduino consists of both a physical programmable circuit board (often referred to as a microcontroller) and a piece of software, or IDE (Integrated Development Environment) that runs on your computer, It can be programmed using C and C++ language to write and upload computer code to the physical board.[39]

The Arduino is able to interact with anything that is controlled by electricity in any way such as LEDs, motors and displays, In short, we can say that Arduino is the brain of thousands of projects and has become a very popular choice because of its flexibility and low cost.[40]

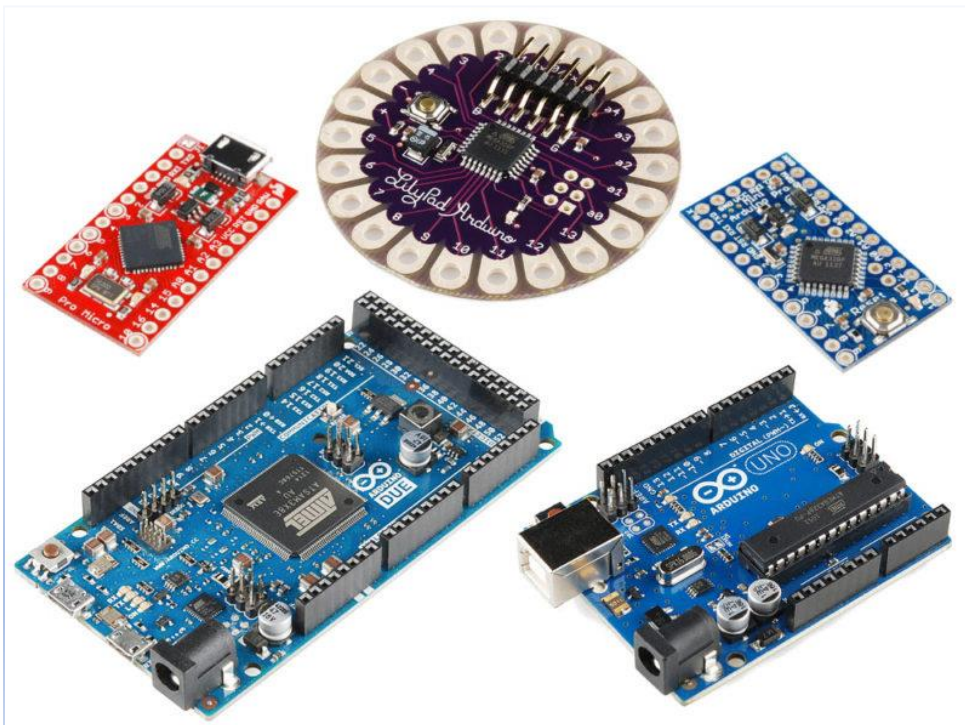


Figure III-16: Arduino boards Types

3.3.2. Interest of the Arduino:

- **Inexpensive:** Arduino boards are relatively inexpensive compared to other microcontroller platforms. The least expensive version of the Arduino module can be assembled by hand, and even the pre-assembled Arduino modules cost less than \$50.
- **Cross-platform:** The Arduino Software (IDE) runs on Windows, Macintosh OSX, and Linux operating systems. When most microcontroller systems are limited to Windows.
- **Simple, clear programming environment:** The Arduino Software (IDE) is easy-to-use for beginners, yet flexible enough for advanced users to take advantage of as well. For teachers, it's

conveniently based on the Processing programming environment, so students learning to program in that environment will be familiar with how the Arduino IDE works.

- **Open source and extensible software:** The Arduino software is published as open source tools, available for extension by experienced programmers. The language can be expanded through C++ libraries.
- **Open source and extensible hardware:** The plans of the Arduino boards are published under a Creative Commons license, so experienced circuit designers can make their own version of the module, extending it and improving it. Even relatively inexperienced users can build the breadboard version of the module in order to understand how it works and save money.

3.3.3. Arduino UNO:

Arduino Uno is a microcontroller board developed by Arduino.cc which is an open-source electronics platform mainly based upon the 8-bit AVR microcontroller Atmega328, the board is equipped with sets of digital and analog input/output (I/O) pins that may be interfaced to various expansion boards (shields) and other circuits.

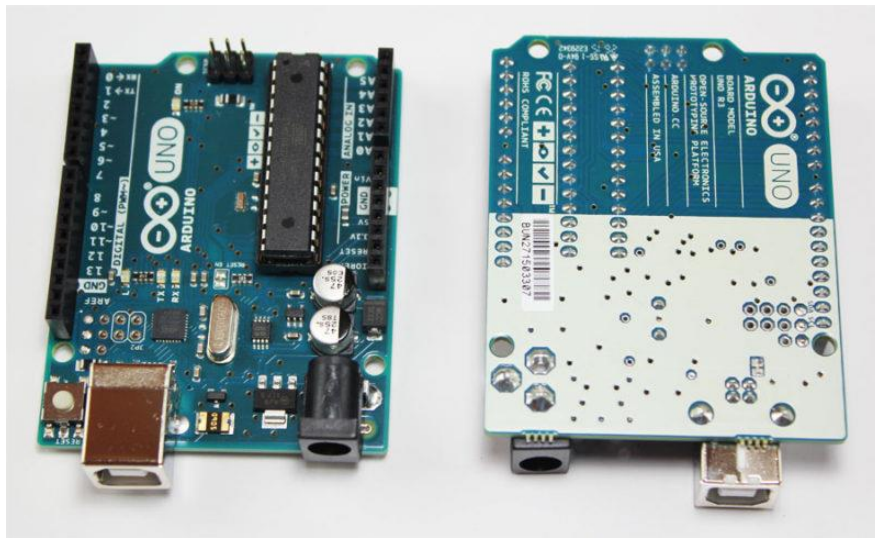


Figure III-17: Arduino UNO board

“Uno” means one in Italian and was chosen to mark the release of Arduino Software (IDE) 1.0. The Uno board and version 1.0 of Arduino Software (IDE) were the reference versions of Arduino.

3.3.3.1. Hardware:

The Arduino board is a small microcontroller board, which is a small circuit (the board) that contains a whole computer on a small chip (the microcontroller), An Arduino's microcontroller is also pre-programmed with a boot loader that simplifies uploading of programs to the on-chip flash memory, which allows us to transfer the new program into the microcontroller without having to use external hardware programmer. Currently, optiboot bootloader is the default bootloader installed on Arduino UNO.

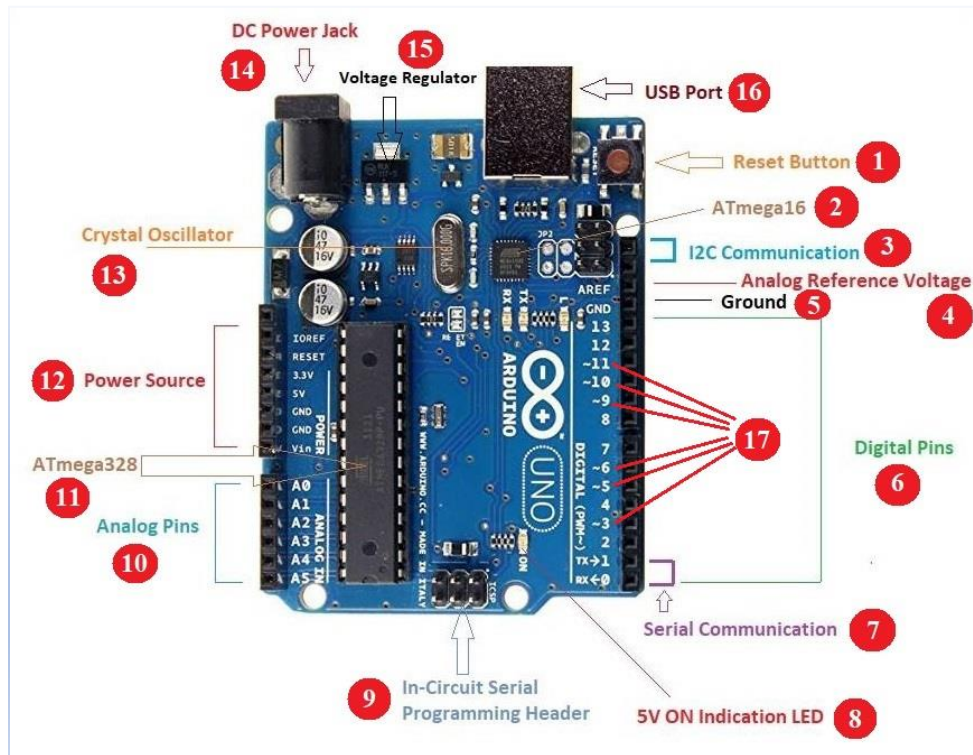


Figure III-18: Arduino UNO board configuration

Here are the components that make up an Arduino board and their functions:

1. **Reset Button** – This will restart any code that is loaded to the Arduino board.
2. **ATmega16** – Serial communication pathway using USB com driver.
3. **I2C Communication** – Master Reader/Slave protocol between two Arduino boards
4. **AREF** – Stands for “Analog Reference” and is used to set an external reference voltage.
5. **Ground Pin** – There are a few ground pins on the Arduino and they all work the same.
6. **Digital Input/Output** – Pins 0-13 can be used for digital input or output.
7. **Serial Communication (TX/RX)** – Transmit and receive data indication LEDs.
8. **Power LED Indicator** – This LED lights up anytime the board is plugged in a power source.
9. **ICSP** – enable the user to program the Arduino board’s firmware.
10. **Analog Pins** – These pins can read the signal from an analog sensor and convert it to digital.
11. **ATmega328** – This is the brains and is where the programs are stored.

12. Power Sources

- a. **3.3V Pin** – This pin supplies 3.3 volts of power to your projects.
- b. **5V Pin** – This pin supplies 5 volts of power to your projects.
- c. **Ground Pins** – There are a few ground pins on the Arduino and they all work the same.
- d. **IOREF** - The input/output reference. It provides the voltage reference with which the microcontroller operates.

13. **Crystal Oscillator** – a quartz with clock speed of 16MHz.

14. **DC Power Jack** – This is used for powering your Arduino with a power supply

15. **Voltage Regulator** – This controls the amount of voltage going into the Arduino board.

16. **USB Port** – Used for powering up your Arduino and uploading sketches.

17. **PWM** – The pins marked with the (~) symbol can simulate analog output.[40]

3.3.3.2. Software:

The Arduino project provides the Arduino integrated development environment (IDE), which is a cross-platform application written in Java. It originated from the IDE for the Processing programming language project and the Wiring project. It is designed to introduce programming to artists and other newcomers unfamiliar with software development. It includes a code editor with features such as syntax highlighting, brace matching, and automatic indentation, and provides simple one-click mechanism for compiling and loading programs to an Arduino board. A program written with the IDE for Arduino is called a "sketch".

3.3.3.3. Programming:

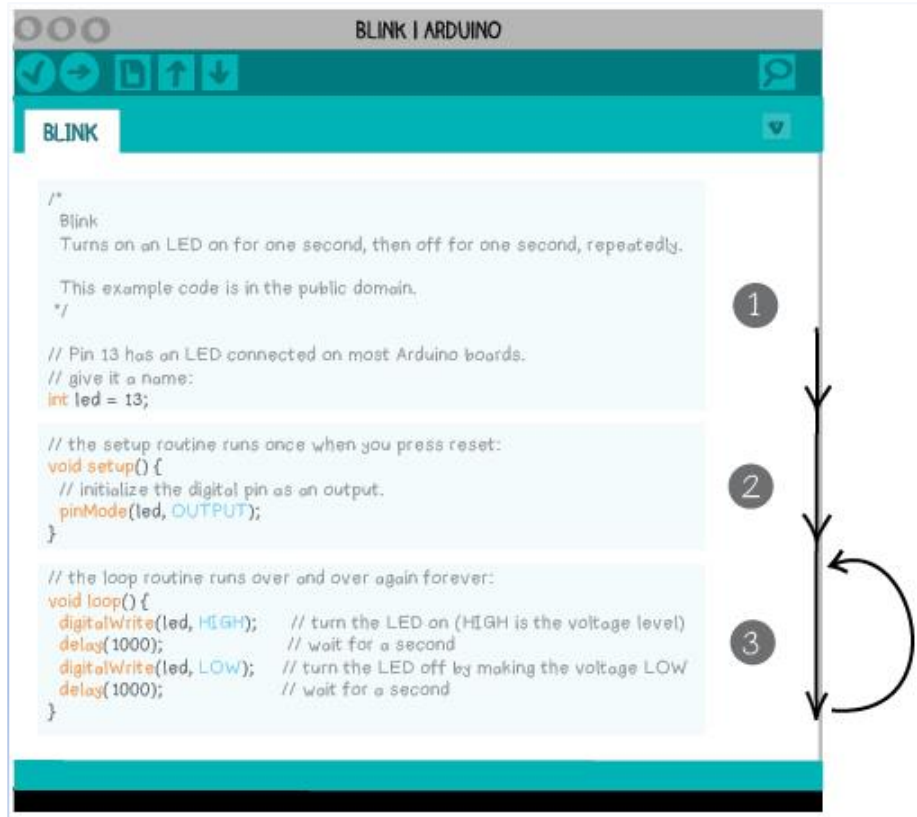


Figure III-19: Arduino IDE program “Sketch”

The Arduino IDE supports the C and C++ programming languages using special rules of code organization. The Arduino IDE supplies a software library called "Wiring" from the Wiring project, which provides many common input and output procedures. A typical Each Arduino program has three main parts:

a. Variable declaration section:

All of the variables that you are using in your code should be listed here, before the setup and loop sections.

b. Setup Section:

It runs once when the program begins, Statements that lay the foundation for actions that happen later on in the program are put in here.

c. Loop Section:

After the setup section runs, the loop section runs over and over until the board is turned off or reprogrammed—hence the word loop. The statements that carry out the main action of your program are in this section.[41]

3.3.3.4. Serial Communication:

Arduino Uno comes with an ability of interfacing with other Arduino boards, microcontrollers and computer. The Atmega328 placed on the board provides serial communication using pins like Rx and Tx. The Atmega16 incorporated on the board provides a pathway for serial communication using USB com drivers. Serial monitor is provided on the IDE software which is used to send or receive text data from the board. [42]

After compilation and linking with the GNU toolchain, also included with the IDE distribution, the Arduino IDE employs the program “avrdude” to convert the executable code into a text file in hexadecimal coding that is loaded into the Arduino board by a loader program in the board's firmware.[43]

3.3.4. Arduino use in our work:

The GSR signals measured by the circuit described above have the property of being continuous to pass from analog to digital. There is a need to carry out an analog to digital conversion. To do this, an integrated circuit called an analog-digital converter (ADC) is used. The voltages to be converted are applied to the input of the circuit; it compares them with the reference voltage (V_{ref}) and delivers on its outputs in the form of a digital code proportional to the values of these voltages. Whatever the type of acquisition carried out; the resolution criterion must be taken into account in estimating the precision of the measurement. When the acquisition takes place over time, the second important criterion will be the interval of time that we will allow to elapse between the taking of two successive samples. This entry is generally made at regular time intervals, we then speak of sampling period (T_e) or e sampling frequency (F_e). These operations are all available on the Arduino board, we just have to set the suitable parameters for our signal in the program to inject into Arduino. The GSR signal is applied to the board via the analog input A1 of the ARDUINO Board. Since the GSR signal frequency varies to up to 5Hz depending on the physiological state of the person, the sampling frequency must be greater than 10Hz according to Shannon theorem. In our design, we use a baud rate of 9600.

3.4. The Simulation Environment:

In any electronic project, and before proceeding to the practical work, it is preferable to simulate your work in somehow, to avoid problems and to facilitate the understanding of the project. There is different software computer aided design of electronic circuits available in the market such as NI Multisim, KiCad and Proteus. To design and simulate our project we used Proteus because it is easily available and offers most of the components required for our simulation in its library.

3.4.1. Proteus:

Proteus Professional is a software package for computer-aided design of electronic circuits. Developed by the company Labcenter Electronics, the software is used mainly by electronic design engineers and technicians to create schematics and electronic prints for manufacturing printed circuit boards, it was initially developed in Yorkshire, England by Labcenter Electronics Ltd and is available in English, French, Spanish and Chinese languages. The Figure III-20 below illustrate Proteus software interface.

Proteus is a simulation software for various designs with microcontroller. It is mainly popular because of availability of almost all microcontrollers in it.

After Simulating your circuit, you can directly make PCB design with it so it could be an all in one package for students and engineers.

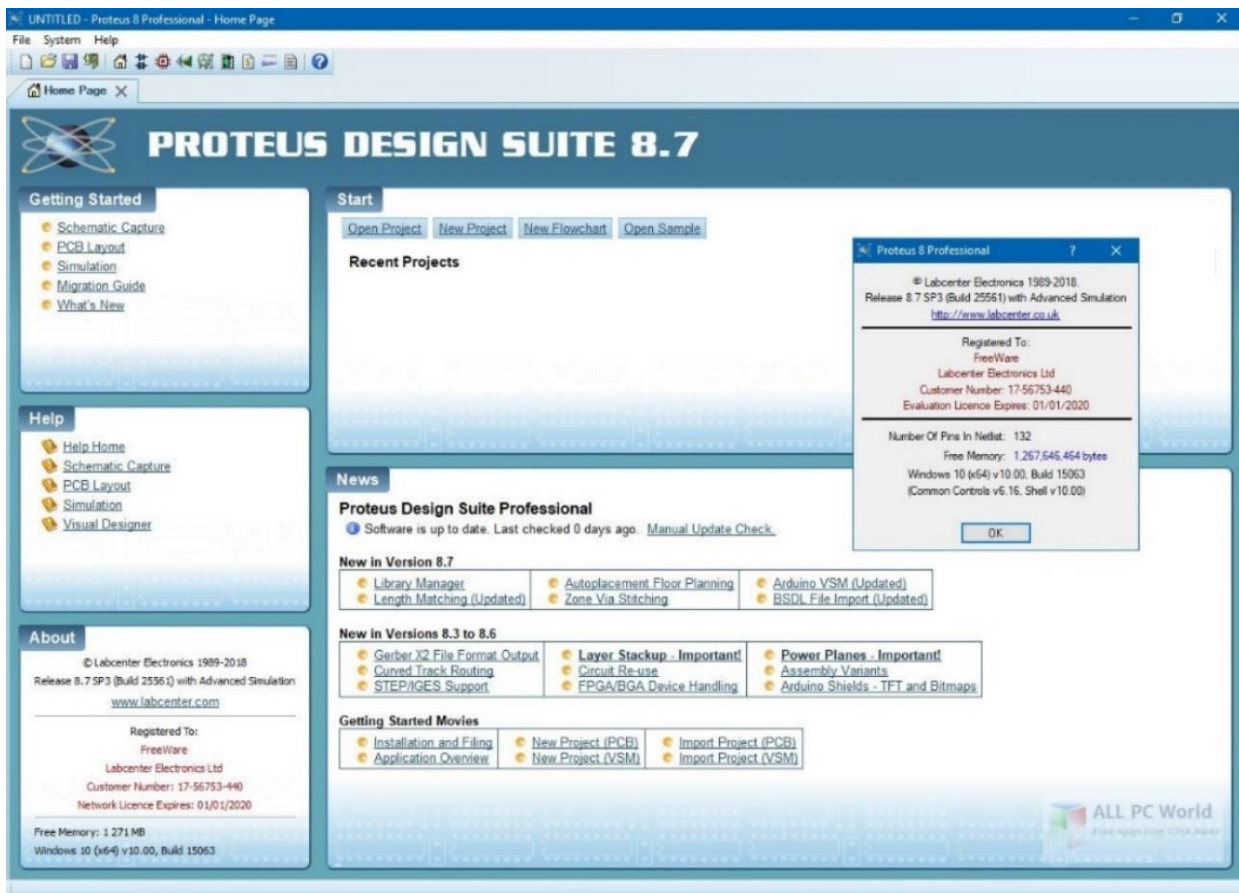


Figure III-20: Proteus Software

3.4.2. General presentation of Proteus:

The Proteus Design Suite is a Windows application for schematic capture, simulation, and PCB (Printed Circuit Board) layout design, the two main software that interests us are:

The "ISIS" software, mainly known for editing electrical diagrams. In addition, this software also makes it possible to simulate these diagrams which allows us to detect certain errors from the design stage. Indirectly, the circuits designed using this software can be used in documentation because it allows controlling the majority of the graphic aspect of the circuits. The Figure III-21 below illustrates the electrical diagram of the proposed GSR device design.

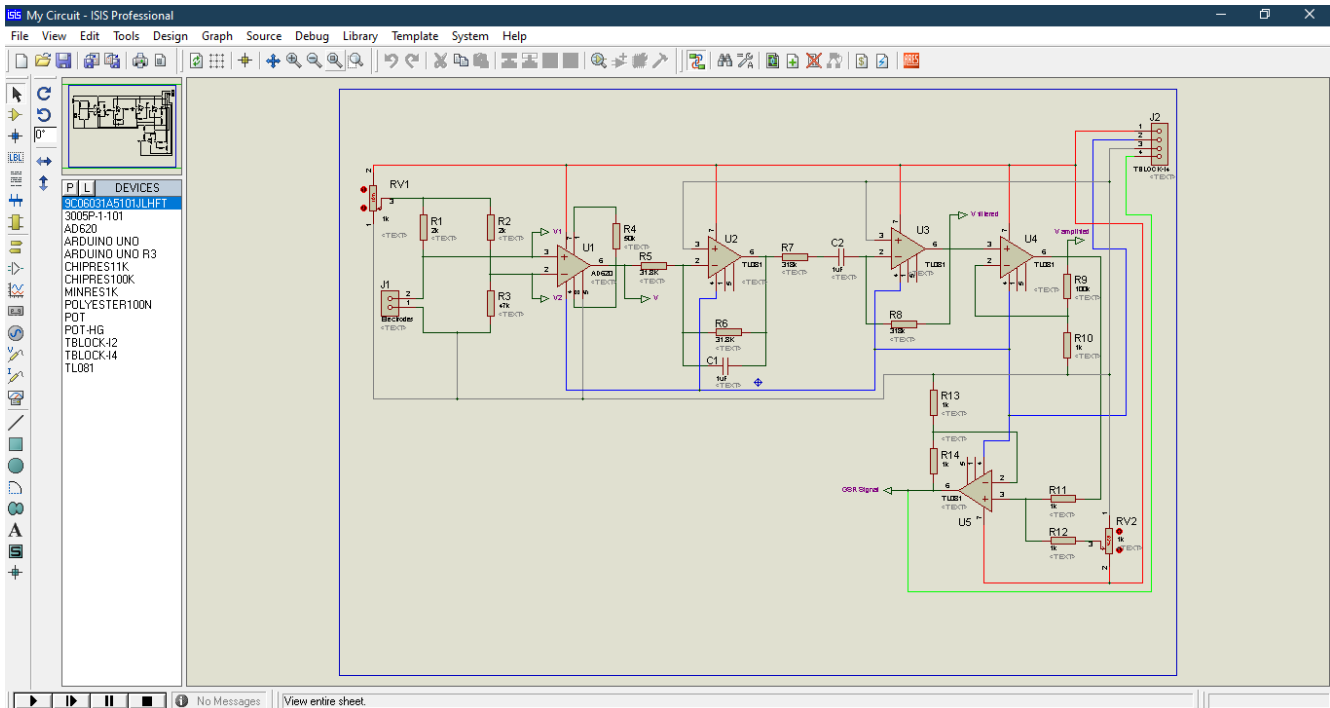


Figure III-21: ISIS Software

The "ARES" software is an editing and routing tool which, from the circuit simulated on "ISIS", allows you to place the components and perform the routing automatically. This printed circuit is more efficient if it is produced by selecting manual mode in the "Ares" tool. This part of the work is the most important because it requires concentration and a know-how which is obtained with time and especially with practice. The Figure III-22 below illustrates the PCB board layout of the simulated proposed GSR device design.

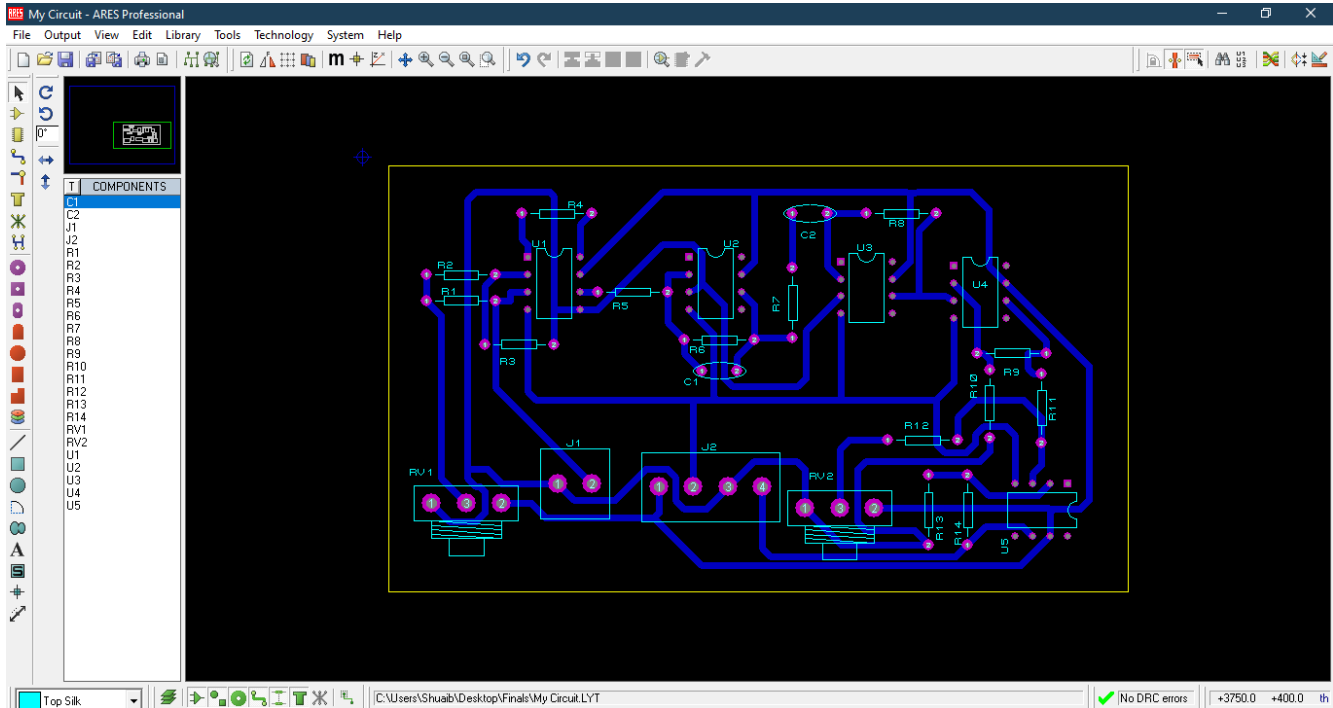


Figure III-22: ARES Software

3.4.3. Features:

ISIS has wide range of components in its library. It has sources, signal generators, measurement and analysis tools like oscilloscope, voltmeter, ammeter etc., probes for real time monitoring of the parameters of the circuit, switches, displays, loads like motors and lamps, discrete components like resistors, capacitors, inductors, transformers, digital and analog Integrated circuits, semi-conductor switches, relays, microcontrollers, processors, sensors etc.

ARES offers PCB designing up to 14 inner layers, with surface mount and through hole packages. It is embedded with the foot prints of different category of components like ICs, transistors, headers, connectors and other discrete components. It offers Auto routing and manual routing options to the PCB Designer. The schematic drawn in the ISIS can be directly transferred ARES. [44]

3.5. Final Realization:

The General electrical diagram of the Galvanic skin response (GSR) circuit and the PCB layout are given on the figures below:

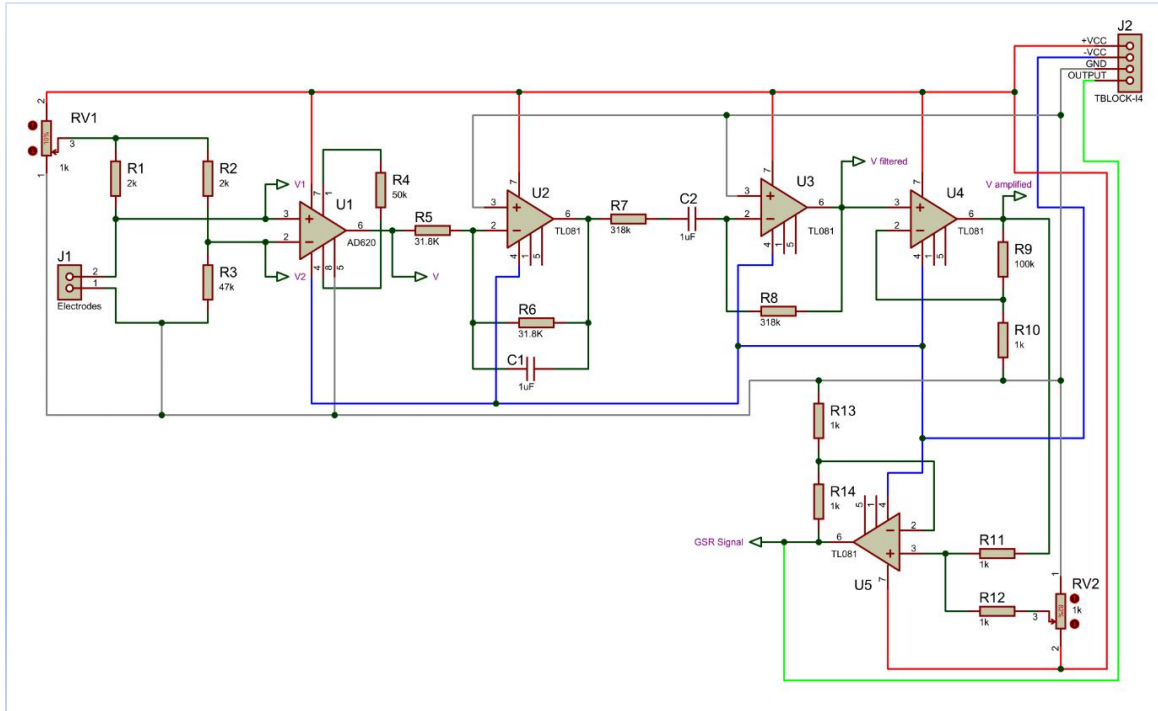


Figure III-24: Electrical diagram of the GSR circuit

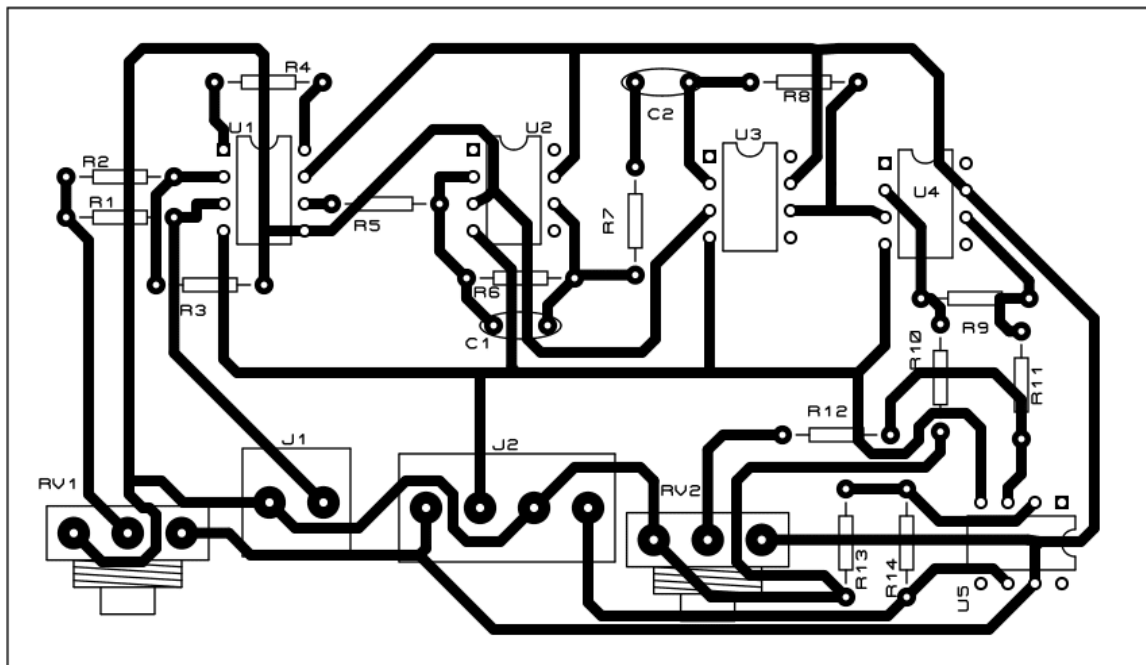


Figure III-23: PCB Layout Artwork

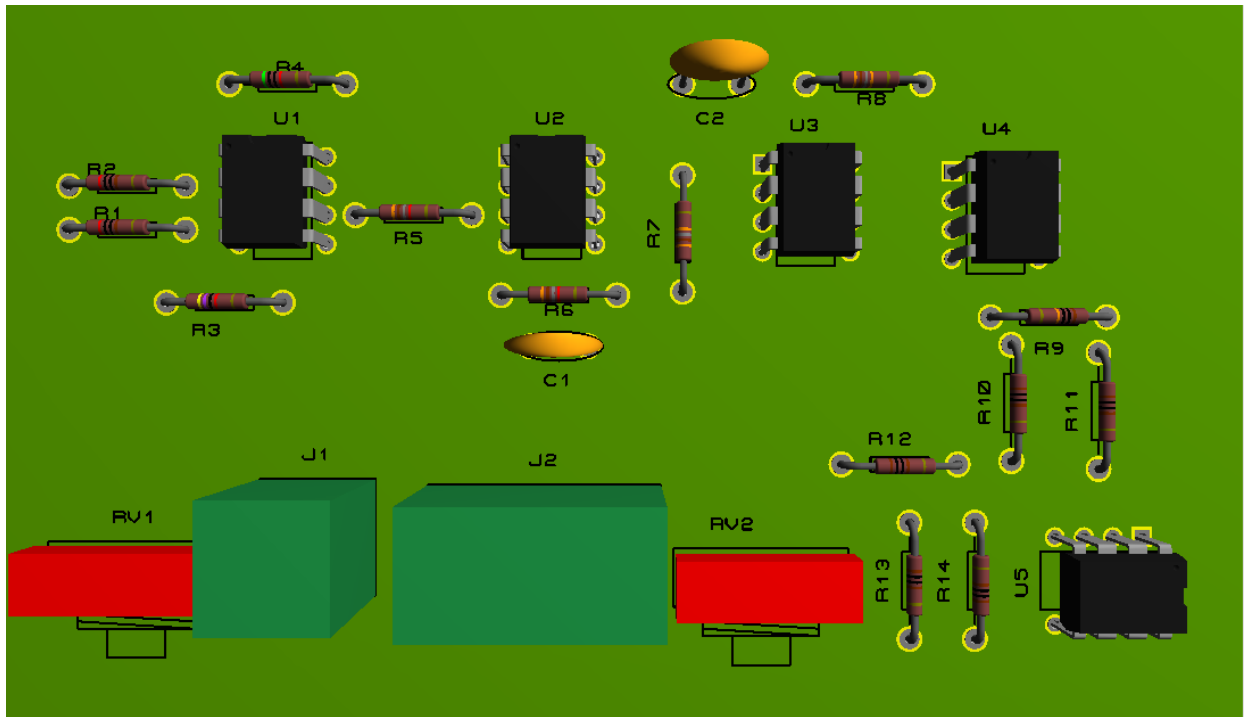


Figure III-25: 3D Model PCB Front View

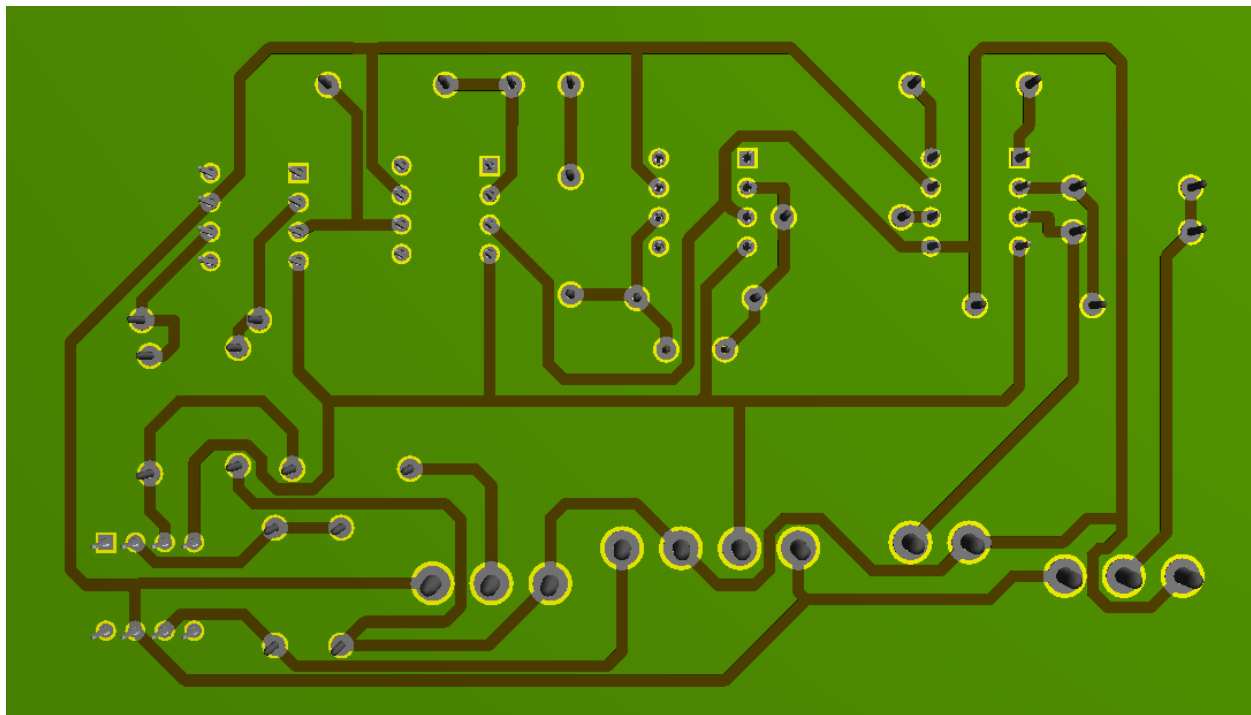


Figure III-26: PCB Back View

3.6. GSR Interface:

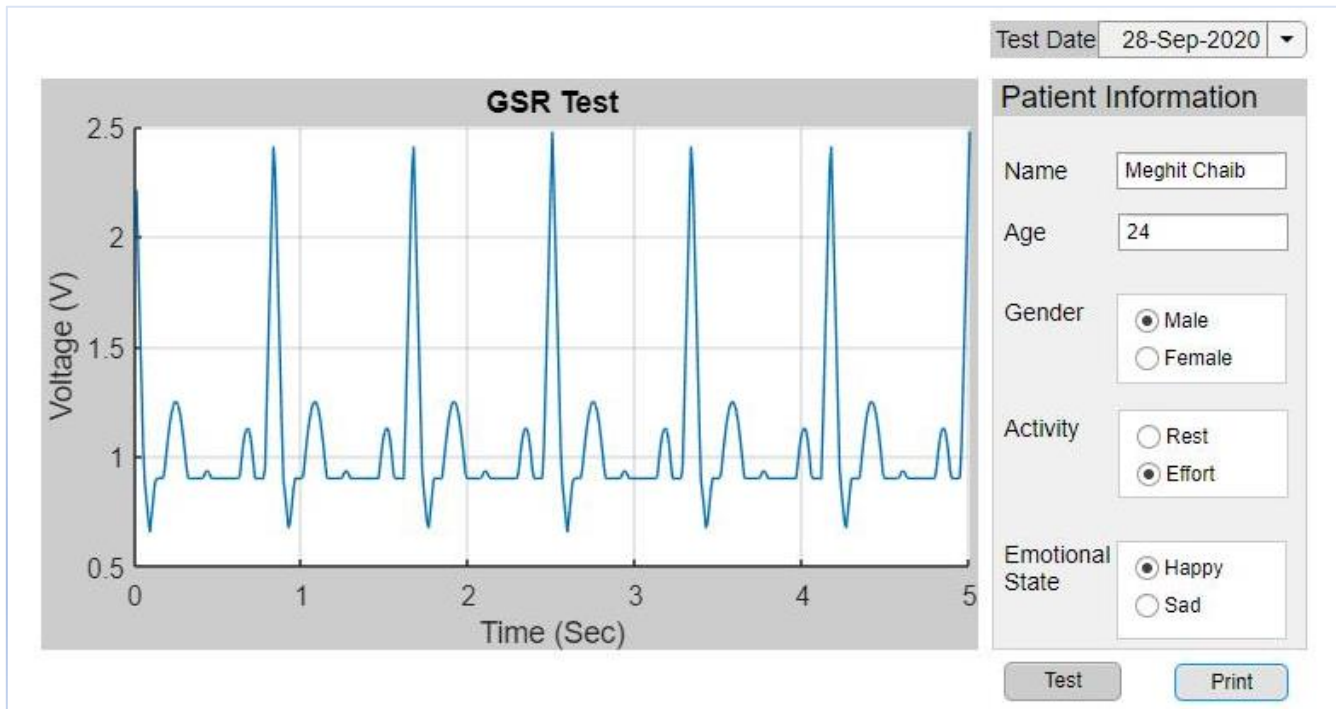


Figure III-27: GSR interface with an ECG signal plotting

The Figure III-27 above illustrate the GSR signal presentation interface, it is an application that we developed using MATLAB App Designer, it's an alternative to the GUI (Graphical User Interface) which is an interactive visual component for computer software system. A GUI displays objects that convey information, and represent actions that can be taken by the user. The objects change color, size, or visibility when the user interacts with them.

GUI objects include icons, cursors, and buttons. These graphical elements are sometimes enhanced with sounds, or visual effects like transparency and drop shadows.[45]

App Designer integrates the two primary tasks of app building – laying out the visual components of a graphical user interface (GUI) and programming app behavior. It is the recommended environment for building apps in MATLAB, to design a User Interface,

drag and drop visual components to the design canvas and use alignment hints to get a precise layout.

App Designer automatically generates the object-oriented code that specifies the app's layout and design.

To define the app behavior, you can use the integrated version of the MATLAB Editor to define your app's behavior. App Designer can automatically check for coding problems using the Code Analyzer. You can view warning and error messages about your code as you're writing it, and modify your app based on the messages. [46]

Since the GSR signal is a random signal and doesn't have a known shape, we generate an ECG signal then we plot it on the interface that we designed (for the program of the graphical interface buttons, see the annexes).

3.7. Conclusion:

In this chapter, a detailed description of the different stages constituting our circuit was described and simulated. First, the GSR signal detection circuit was presented and discussed. This was followed by the description of the shaping circuits mainly filters and amplification. Then, the software computer aided design Proteus used to simulate the proposed design was presented before some results of simulation of the proposed GSR designed circuit were illustrated and discussed followed by modeling a PCB Layout, Then the acquisition board ARDUINO Uno used for the digitalization and the acquisition of the GSR signal was described. Finally, an application was developed using MATLAB App Designer to present the GSR signal.

General Conclusion

General Conclusion

In this thesis, we are interested in the study and simulation of an integrated device, of reasonable size, placed on an ergonomically acceptable zone (the fingers), which makes it possible to monitor the galvanic skin response "GSR". It can possibly be used for the quantification of the ANS activity and thus allow to treat the psych-physiological changes by measuring the psycho galvanic reflex.

The approach we adopted to conduct this study is the one that any engineer wishing to develop a system must adopt. Thus, a theoretical study of the Electrodermal phenomena was carried out in the first place, followed by a detailed description of the various proposals of measurement techniques that can be implemented to correctly detect this quantity and finally the simulation.

In fact, in the theoretical study that we carried out on this electrical quantity, different aspects of the electrodermal phenomena or the galvanic skin response has been described. this response was defined anatomically and physiologically, then described through its representation as a signal and the way it can be recorded.

After this study, a description of some EDA recording device models has been made followed by a detailed description of recordings techniques. Thus, the electrodes and their importance for optimal detection of the signal has been presented.

After underlining the measurement method to use in our work, we proposed our design. It consists of the GSR signal detection and shaping. This study was first conducted through a description of the detection stage, this was followed by such a detailed description of shaping circuits that could be used to ensure good acquisition and therefore measurement of the GSR signal.

The next step was devoted to the simulation of our proposed design, the software computer aided design Proteus was used to simulate the different circuits and illustrate some simulation results, then to model a PCB layout, followed by a detailed description of Arduino acquisition board.

The last stage of this work was to develop a graphical interface to present the GSR signal. This interface was made using MATLAB App Designer.

As perspectives, first we have to realize and tests practically the device. Then, for a better quantification of the ANS activity, it is to establish a deeper computer data processing on this GSR signal, and to couple this technique (GSR) with other techniques such as the detection of the heart rate, respiratory rate in the same device.

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Annexes

Annexes



TL081, TL081A, TL081B, TL082, TL082A
TL082B, TL084, TL084A, TL084B

SLOS081I – FEBRUARY 1977 – REVISED MAY 2015

TL08xx JFET-Input Operational Amplifiers

1 Features

- Low Power Consumption: 1.4 mA/ch Typical
- Wide Common-Mode and Differential Voltage Ranges
- Low Input Bias Current: 30 pA Typical
- Low Input Offset Current: 5 pA Typical
- Output Short-Circuit Protection
- Low Total Harmonic Distortion: 0.003% Typical
- High Input Impedance: JFET Input Stage
- Latch-Up-Free Operation
- High Slew Rate: 13 V/ μ s Typical
- Common-Mode Input Voltage Range Includes V_{CC+}

2 Applications

- Tablets
- White goods
- Personal electronics
- Computers

3 Description

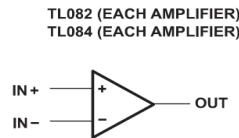
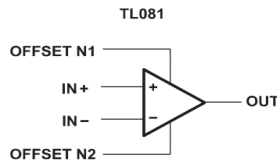
The TL08xx JFET-input operational amplifier family is designed to offer a wider selection than any previously developed operational amplifier family. Each of these JFET-input operational amplifiers incorporates well-matched, high-voltage JFET and bipolar transistors in a monolithic integrated circuit. The devices feature high slew rates, low input bias and offset currents, and low offset-voltage temperature coefficient.

Device Information⁽¹⁾

PART NUMBER	PACKAGE	BODY SIZE (NOM)
TL084xD	SOIC (14)	8.65 mm × 3.91 mm
TL08xxFK	LCCC (20)	8.89 mm × 8.89 mm
TL084xJ	CDIP (14)	19.56 mm × 6.92 mm
TL084xN	PDIP (14)	19.3 mm × 6.35 mm
TL084xNS	SO (14)	10.3 mm × 5.3 mm
TL084xPW	TSSOP (14)	5.0 mm × 4.4 mm

(1) For all available packages, see the orderable addendum at the end of the data sheet.

Schematic Symbol



An IMPORTANT NOTICE at the end of this data sheet addresses availability, warranty, changes, use in safety-critical applications, intellectual property matters and other important disclaimers. PRODUCTION DATA.

Annexes

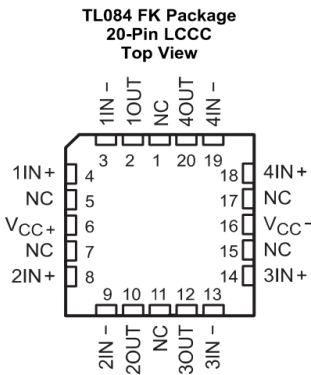
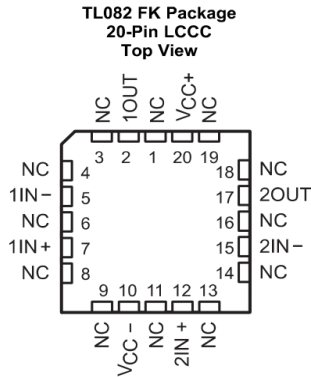


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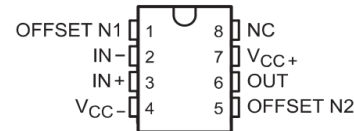
TL081, TL081A, TL081B, TL082, TL082A
TL082B, TL084, TL084A, TL084B

SLOS081I—FEBRUARY 1977—REVISED MAY 2015

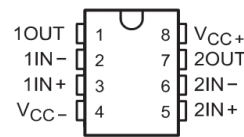
5 Pin Configuration and Functions



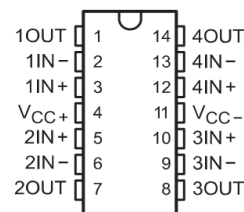
**TL081 and TL081x D, P, and PS Package
8-Pin SOIC, PDIP, and SO
Top View**



**TL082 and TL082x D, JG, P, PS and PW Package
8-Pin SOIC, CDIP, PDIP, SO, and TSSOP
Top View**



**TL084 and TL084x D, J, N, NS and PW Package
14-Pin SOIC, CDIP, PDIP, SO, and TSSOP
Top View**



Pin Functions

NAME	PIN					I/O	DESCRIPTION
	TL081	TL082		TL084			
	SOIC, PDIP, SO	SOIC, CDIP, PDIP, SO, TSSOP	LCCC	SOIC, CDIP, PDIP, SO, TSSOP	LCCC		
1IN-	—	2	5	2	3	I	Negative input
1IN+	—	3	7	3	4	I	Positive input
1OUT	—	1	2	1	2	O	Output
2IN-	—	6	15	6	9	I	Negative input
2IN+	—	5	12	5	8	I	Positive input
2OUT	—	7	17	7	10	O	Output
3IN-	—	—	—	9	13	I	Negative input
3IN+	—	—	—	10	14	I	Positive input
3OUT	—	—	—	8	12	O	Output
4IN-	—	—	—	13	19	I	Negative input
4IN+	—	—	—	12	18	I	Positive input
4OUT	—	—	—	14	20	O	Output

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3

Product Folder Links: [TL081](#) [TL081A](#) [TL081B](#) [TL082](#) [TL082A](#) [TL082B](#) [TL084](#) [TL084A](#) [TL084B](#)



Low Cost Low Power Instrumentation Amplifier

AD620

FEATURES

Easy to use

- Gain set with one external resistor
(Gain range 1 to 10,000)
- Wide power supply range (± 2.3 V to ± 18 V)
- Higher performance than 3 op amp IA designs
- Available in 8-lead DIP and SOIC packaging
- Low power, 1.3 mA max supply current

Excellent dc performance (B grade)

- 50 μ V max, input offset voltage
- 0.6 μ V/ $^{\circ}$ C max, input offset drift
- 1.0 nA max, input bias current
- 100 dB min common-mode rejection ratio (G = 10)

Low noise

- 9 nV/ $\sqrt{\text{Hz}}$ @ 1 kHz, input voltage noise
- 0.28 μ V p-p noise (0.1 Hz to 10 Hz)

Excellent ac specifications

- 120 kHz bandwidth (G = 100)
- 15 μ s settling time to 0.01%

APPLICATIONS

- Weigh scales
- ECG and medical instrumentation
- Transducer interface
- Data acquisition systems
- Industrial process controls
- Battery-powered and portable equipment

Table 1. Next Generation Upgrades for AD620

Part	Comment
AD8221	Better specs at lower price
AD8222	Dual channel or differential out
AD8226	Low power, wide input range
AD8220	JFET input
AD8228	Best gain accuracy
AD8295	+2 precision op amps or differential out
AD8429	Ultra low noise

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CONNECTION DIAGRAM

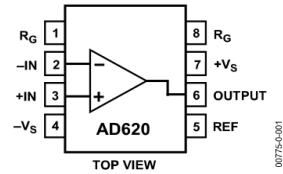


Figure 1. 8-Lead PDIP (N), CERDIP (Q), and SOIC (R) Packages

PRODUCT DESCRIPTION

The AD620 is a low cost, high accuracy instrumentation amplifier that requires only one external resistor to set gains of 1 to 10,000. Furthermore, the AD620 features 8-lead SOIC and DIP packaging that is smaller than discrete designs and offers lower power (only 1.3 mA max supply current), making it a good fit for battery-powered, portable (or remote) applications.

The AD620, with its high accuracy of 40 ppm maximum nonlinearity, low offset voltage of 50 μ V max, and offset drift of 0.6 μ V/ $^{\circ}$ C max, is ideal for use in precision data acquisition systems, such as weigh scales and transducer interfaces.

Furthermore, the low noise, low input bias current, and low power of the AD620 make it well suited for medical applications, such as ECG and noninvasive blood pressure monitors.

The low input bias current of 1.0 nA max is made possible with the use of Superbeta processing in the input stage. The AD620 works well as a preamplifier due to its low input voltage noise of 9 nV/ $\sqrt{\text{Hz}}$ at 1 kHz, 0.28 μ V p-p in the 0.1 Hz to 10 Hz band, and 0.1 pA/ $\sqrt{\text{Hz}}$ input current noise. Also, the AD620 is well suited for multiplexed applications with its settling time of 15 μ s to 0.01%, and its cost is low enough to enable designs with one in-amp per channel.

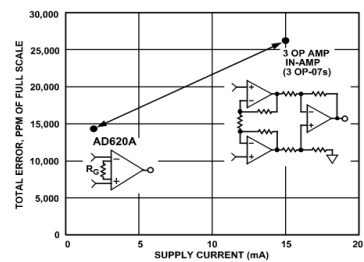


Figure 2. Three Op Amp IA Designs vs. AD620

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Annexes

AD620

SPECIFICATIONS

Typical @ 25°C, $V_S = \pm 15\text{ V}$, and $R_L = 2\text{ k}\Omega$, unless otherwise noted.

Table 2.

Parameter	Conditions	AD620A			AD620B			AD620S ¹			Unit
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
GAIN	$G = 1 + (49.4\text{ k}\Omega/R_G)$										
Gain Range		1		10,000	1		10,000	1		10,000	
Gain Error ²	$V_{OUT} = \pm 10\text{ V}$										
G = 1			0.03	0.10		0.01	0.02		0.03	0.10	%
G = 10			0.15	0.30		0.10	0.15		0.15	0.30	%
G = 100			0.15	0.30		0.10	0.15		0.15	0.30	%
G = 1000			0.40	0.70		0.35	0.50		0.40	0.70	%
Nonlinearity	$V_{OUT} = -10\text{ V}$ to $+10\text{ V}$										
G = 1–1000	$R_L = 10\text{ k}\Omega$		10	40		10	40		10	40	ppm
G = 1–100	$R_L = 2\text{ k}\Omega$		10	95		10	95		10	95	ppm
Gain vs. Temperature											
G = 1				10			10			10	ppm/°C
Gain > 1 ²				–50			–50			–50	ppm/°C
VOLTAGE OFFSET	(Total RTI Error = $V_{OSI} + V_{OSO}/G$)										
Input Offset, V_{OSI}	$V_S = \pm 5\text{ V}$ to $\pm 15\text{ V}$		30	125		15	50		30	125	μV
Overtemperature	$V_S = \pm 5\text{ V}$ to $\pm 15\text{ V}$			185			85			225	μV
Average TC	$V_S = \pm 5\text{ V}$ to $\pm 15\text{ V}$		0.3	1.0		0.1	0.6		0.3	1.0	$\mu\text{V}/^\circ\text{C}$
Output Offset, V_{OSO}	$V_S = \pm 15\text{ V}$		400	1000		200	500		400	1000	μV
Overtemperature	$V_S = \pm 5\text{ V}$			1500			750			1500	μV
Average TC	$V_S = \pm 5\text{ V}$ to $\pm 15\text{ V}$		5.0	15		2.5	7.0		5.0	15	$\mu\text{V}/^\circ\text{C}$
Offset Referred to the Input vs. Supply (PSR)	$V_S = \pm 2.3\text{ V}$ to $\pm 18\text{ V}$										
G = 1		80	100		80	100		80	100		dB
G = 10		95	120		100	120		95	120		dB
G = 100		110	140		120	140		110	140		dB
G = 1000		110	140		120	140		110	140		dB
INPUT CURRENT											
Input Bias Current			0.5	2.0		0.5	1.0		0.5	2	nA
Overtemperature				2.5			1.5			4	nA
Average TC			3.0			3.0			8.0		$\text{pA}/^\circ\text{C}$
Input Offset Current			0.3	1.0		0.3	0.5		0.3	1.0	nA
Overtemperature				1.5			0.75			2.0	nA
Average TC			1.5			1.5			8.0		$\text{pA}/^\circ\text{C}$
INPUT											
Input Impedance											
Differential			10 2			10 2			10 2		$\text{G}\Omega_{\text{pF}}$
Common-Mode			10 2			10 2			10 2		$\text{G}\Omega_{\text{pF}}$
Input Voltage Range ³	$V_S = \pm 2.3\text{ V}$ to $\pm 5\text{ V}$	$-V_S + 1.9$		$+V_S - 1.2$	$-V_S + 1.9$		$+V_S - 1.2$	$-V_S + 1.9$		$+V_S - 1.2$	V
Overtemperature		$-V_S + 2.1$		$+V_S - 1.3$	$-V_S + 2.1$		$+V_S - 1.3$	$-V_S + 2.1$		$+V_S - 1.3$	V
Overtemperature	$V_S = \pm 5\text{ V}$ to $\pm 18\text{ V}$	$-V_S + 1.9$		$+V_S - 1.4$	$-V_S + 1.9$		$+V_S - 1.4$	$-V_S + 1.9$		$+V_S - 1.4$	V
Overtemperature		$-V_S + 2.1$		$+V_S - 1.4$	$-V_S + 2.1$		$+V_S + 2.1$	$-V_S + 2.3$		$+V_S - 1.4$	V

ABSOLUTE MAXIMUM RATINGS

Table 3.

Parameter	Rating
Supply Voltage	±18 V
Internal Power Dissipation ¹	650 mW
Input Voltage (Common-Mode)	±V _S
Differential Input Voltage	25 V
Output Short-Circuit Duration	Indefinite
Storage Temperature Range (Q)	−65°C to +150°C
Storage Temperature Range (N, R)	−65°C to +125°C
Operating Temperature Range	
AD620 (A, B)	−40°C to +85°C
AD620 (S)	−55°C to +125°C
Lead Temperature Range (Soldering 10 seconds)	300°C

¹ Specification is for device in free air:
 8-Lead Plastic Package: $\theta_{JA} = 95^{\circ}\text{C}$
 8-Lead CERDIP Package: $\theta_{JA} = 110^{\circ}\text{C}$
 8-Lead SOIC Package: $\theta_{JA} = 155^{\circ}\text{C}$

Stresses above those listed under Absolute Maximum Ratings may cause permanent damage to the device. This is a stress rating only; functional operation of the device at these or any other conditions above those indicated in the operational section of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

ESD CAUTION



ESD (electrostatic discharge) sensitive device. Charged devices and circuit boards can discharge without detection. Although this product features patented or proprietary protection circuitry, damage may occur on devices subjected to high energy ESD. Therefore, proper ESD precautions should be taken to avoid performance degradation or loss of functionality.

Annexes

Arduino Sketch for real time AnalogRead and serial monitoring:

```
int mg
float GSR
void setup() {
  Serial.begin(9600); // initialize serial communication at 9600 bits per second:
}
void loop() {
  mg = analogRead(A1); // read the input on analog pin 1:
  GSR = mg * (5.0 / 1023.0); // Convert the analog reading (which goes from 0 - 1023) to a voltage (0 - 5V):
  Serial.println(GSR); // print out the value you read:
  delay(2); //wait 2 milliseconds before the next loop for the analog-to-digital converter to settle after the last reading:
}
```


Annexes

MATLAB program for real time AnalogRead and plot:

```
clear
clc

%User Defined Properties

a = arduino('Com7')           % define the Arduino Communication port
arduino = serial('Com7', 'BaudRate',9600)
plotTitle = 'GSR';           % plot title
xlabel = 'Time (sec)';       % x-axis label
ylabel = 'Voltage (mS)';    % y-axis label
plotGrid = 'on';           % 'off' to turn off grid
min = 0;                    % set y-min
max = 5;                    % set y-max
delay = 0.001;             % make sure sample faster than
resolution

%Define Function Variables
time = 0;
GSR = 0;
count = 0;
%Set up Plot
plotGraph = plot(time,GSR, '-r' )
hold on
axis([yMin yMax min max]);
grid(plotGrid);
tic
while ishandle(plotGraph) %Loop when Plot is Active will run until
plot is closed
    mg = readVoltage(a, 'A1')*1 ; %Data from the arduino
    count = count + 1;
    time(count) = toc;
    GSR(count) = mg(1);
    set(plotGraph, 'XData', time, 'YData', GSR);
    axis([0 time(count) min max]);
    pause(delay); %Update the graph
end
delete(a);
```

GSR interface using MATLAB App Designer:

1. Test Button Program:

```
function TestButtonPushed(app, event)
    x=0.01:0.01:5;
    default=1;
if(default==1);
    li=30/72;

    a_pwav=0.25;
    d_pwav=0.09;
    t_pwav=0.16;

    a_qwav=0.025;
    d_qwav=0.066;
    t_qwav=0.166;

    a_qrswav=1.6;
    d_qrswav=0.11;

    a_swav=0.25;
    d_swav=0.066;
    t_swav=0.09;

    a_twav=0.35;
    d_twav=0.142;
    t_twav=0.2;

    a_uwav=0.035;
    d_uwav=0.0476;
    t_uwav=0.433;
else
    rate=input('\n\nenter the heart beat rate :');
    li=30/rate;
    %p wave specifications
    fprintf('\n\np wave specifications\n');
    d=input('Enter 1 for default specification else press 2: \n');
    if(d==1)
        a_pwav=0.25;
        d_pwav=0.09;
```

Annexes

```
        t_pwav=0.16;
else
    a_pwav=input('amplitude = ');
    d_pwav=input('duration = ');
    t_pwav=input('p-r interval = ');
    d=0;
end
%q wave specifications
fprintf('\n\nq wave specifications\n');
d=input('Enter 1 for default specification else press 2: \n');
if(d==1)
    a_qwav=0.025;
    d_qwav=0.066;
    t_qwav=0.166;
else
    a_qwav=input('amplitude = ');
    d_qwav=input('duration = ');
    t_qwav=0.166;
    d=0;
end
%qrs wave specifications
fprintf('\n\nqrs wave specifications\n');
d=input('Enter 1 for default specification else press 2: \n');
if(d==1)
    a_qrswav=1.6;
    d_qrswav=0.11;
else
    a_qrswav=input('amplitude = ');
    d_qrswav=input('duration = ');
    d=0;
end
%s wave specifications
fprintf('\n\ns wave specifications\n');
d=input('Enter 1 for default specification else press 2: \n');
if(d==1)
    a_swav=0.25;
    d_swav=0.066;
    t_swav=0.09;
else
    a_swav=input('amplitude = ');
    d_swav=input('duration = ');
```

Annexes

```
t_swav=0.09;
d=0;
end
%t wave specifications
fprintf('\n\n\t wave specifications\n');
d=input('Enter 1 for default specification else press 2: \n');
if(d==1)
    a_twav=0.35;
    d_twav=0.142;
    t_twav=0.2;
else
    a_twav=input('amplitude = ');
    d_twav=input('duration = ');
    t_twav=input('s-t interval = ');
    d=0;
end
%u wave specifications
fprintf('\n\n\tu wave specifications\n');
d=input('Enter 1 for default specification else press 2: \n');
if(d==1)
    a_uwav=0.035;
    d_uwav=0.0476;
    t_uwav=0.433;
else
    a_uwav=input('amplitude = ');
    d_uwav=input('duration = ');
    t_uwav=0.433;
    d=0;
end
end
pwav=p_wav(x,a_pwav,d_pwav,t_pwav,li);
%qwav output
qwav=q_wav(x,a_qwav,d_qwav,t_qwav,li);
%qrswav output
qrswav=qrs_wav(x,a_qrswav,d_qrswav,li);
%swav output
swav=s_wav(x,a_swav,d_swav,t_swav,li);
%twav output
twav=t_wav(x,a_twav,d_twav,t_twav,li);
%uwav output
uwav=u_wav(x,a_uwav,d_uwav,t_uwav,li);
```

Annexes

```
%ecg output
ecg=pwav+qrswav+twav+swav+qwav+uwav;
plot(app.UIAxes,x,ecg);
drawnow;
end
```

2. Print Button Program:

```
function PrintButtonPushed(app, event)
robot = java.awt.Robot();
temp = app.UIFigure.Position; % returns position as [left bottom width
height]
allMonPos = get(0, 'MonitorPositions');
curMon = find(temp(1)<(allMonPos(:,1)+allMonPos(:,3)),1, 'first');
curMonHeight = allMonPos(curMon,4)+1;
pos = [temp(1) curMonHeight-(temp(2)+temp(4)) temp(3)-1 temp(4)]; % [left
top width height].... UL X, UL Y, width, height
rect = java.awt.Rectangle(pos(1),pos(2),pos(3),pos(4));
cap = robot.createScreenCapture(rect);
    % Convert to an RGB image
rgb=
typecast(cap.getRGB(0,0,cap.getWidth,cap.getHeight,[],0,cap.getWidth), 'uint
8');
imgData = zeros(cap.getHeight,cap.getWidth,3, 'uint8');
imgData(:,:,1) = reshape(rgb(3:4:end),cap.getWidth,[]);
imgData(:,:,2) = reshape(rgb(2:4:end),cap.getWidth,[]);
imgData(:,:,3) = reshape(rgb(1:4:end),cap.getWidth,[]);
imshow(imgData);
```