DESIGN AND CONSTRUCTION OF THE AUTOMATED EXTERNAL DEFIBRILLATOR

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ABSTRACT

In the advanced medicinal profession, the accessibility to the medical service with a responsible device becomes an indispensable culmination. With the expeditious progress toward the patient, the survival percentage is increasing significantly. According to the mortality rate encounter, the survivability of the mortal tolerates from the congenital disease, and the fortuitous circumstance. To be specific, In the urgent resuscitation mission that effectively harms the vitality and unable to transport the victim under the medical progress. To heighten the survival proportion, we prioritized that the crucial device in urgent missions should be portable. The Automated External Defibrillator or AED is a powerful device that corresponds to the according to circumstance. The Automated External Defibrillator is the portable life-rescue instrument with the ability in the analytical and remediating of the heart situation by the electrical utilization. The convenient accessibility for the crucial device increases the success standard on the urgent mission and in the accidental coincidence.

In this project, we emphasize the essential factor and the utilization of the Automated External Defibrillator. The related function approaching the fundamental purpose of the AED constructs for the basic observation of the utilization. The charging and discharging characteristic of the capacitance implementing the energy accumulation for the electrical deliverance towards the victim. The commanding framework with the associated microcontroller and circuit condition establishes the

suitable pathway for the utilization procedure. These functional designs and applicability with conventional purpose afford a more comprehensive performance within the relevant transaction. Individually, the invention is the basis of the recognition of the requisite performance as the life-saving units.

ACKNOWLEDGEMENTS

The accomplishment of this design and construction of the Automated External Defibrillator progresses with both direct and indirect compensation support in the knowledge and facilities. The achievement of the project is unable to perform placidly without these people following.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS/ABBREVIATIONS

Symbols/Abbreviations	Terms
AED	Automated External Defibrillator
WHO	World Health Organization
NCDs	Non-Communicable diseases
ECG / EKG	Electrocardiogram (Electrokardiogram)
SA Node	Sino atrial Node
AV Node	Atrioventricular Node
HCM	Hypertrophic Cardiomyopathy
BPM	Beat per Minutes (Heart rate unit)
HCM	Hypertrophic Cardiomyopathy
EMF	Electromotive force
SPST	Single pole, single throw relay type
SPDT	Single pole, double throw relay type
DPST	Double pole, single throw relay type
DPDT	Double pole, double throw relay type
NC	Normal Close
NO	Normal Open
AVR	Advanced Virtual RISC
RISC	Reduced-instruction-set Computing
IDE	Integrated Development Environment
I/O	Input and Output
USB	Universal Serial Bus
AC	Alternating Current
DC	Direct Current
DFU	Device Firmware Upgrade
ZVS	Zero Voltage Switching
MOSFET	Metal-Oxide-Semiconductor Field-Effect Transistor.

CHAPTER 1
INTRODUCTION

1.1 Background and Significance of the study

Referring to the WHO, it describes trends and probabilities of mortality. Also, the relevant condition and threats affect the extent of humanity. In particular, the observation of the non-communicable disease in Thailand describes the tendency of the risk factor and mortality of the people in society. The conclusion in graphical data investigation and diagram illustrate the account of the significant disease and sickness approaching Thai healthcare attention. The percentage distribution representing each non-communicable disease is evenly scattering. Therefore, the majority of the disease threatening the survivability of people within Thailand represents the Cardiovascular disease and the other NCDs. As mentioned above, Cardiovascular disease conduct a life-threatening state to each people silently. To overcome this situation, the enhancement of individual health and involving technology advancement is essential and necessary to our being. In the vision upon the personal health perspective, the progression and sustaining of the healthful condition are exercises and sportive activities. The exercise activities that accompany a group of the athlete and exerciser consider as the sustaining activities to the wellness aspect. Conversely, the individual arrangement of the movement can categorize as personal enhancement exceedingly. The objective of these relevant movements is the advancement of physical capabilities in strength and firmness individually.

Among the current inclination of wellness activities and progression, the alternative of the action and motivation influence the health awareness of the people within the society. The sports campaign conduces to raise as a choice to those who seek for healthiness. Therefore, the excessive amount of training and strain methods harm wellness rather than enhancement. The damaging consequences and the strain in the body cause a terrible effect on training efficiency. In the worst cause, the excessive burden toward the internal organ and muscles in critical states conducts a dangerous symptom of illness toward the victim. The popularity of the sports activities of the running and marathon increasing distinctively from the decade. The participation with well-trained physical abilities conquers their achievement through various training. Even with the great asset, the sudden illness approached in random and unexpectable. In the past few years, the report announcing the death from the sport strained increased relate to the sudden cardiac death. The frequent symptom and issues discovered within the incident are acute heart failure and cardiac arrhythmia. These relevant matters happen with many factor-related such as the disproportionate size of myocardial, frequently or harsh chest impact, myocardial inflammation from the viral infection, acute coronary syndrome, valvular heart disorder, heart stroke, arrhythmia, a misconducting electrical signal in heart function. All the mentioned symptoms and expressions throughout the cardiac and vascular issues suffer in acute heart failure and critical arrhythmia condition.

Within the instantaneous rescue process within the accident, the scheme relies on the skill of the residential staff and medical field abilities in that particular situation. With the aid of the appropriate equipment and device, it harnesses the possibilities of conducting appropriate treatment for the most beneficial response in each condition that transpired. AED or the automated external defibrillator consider as one of the life-saving equipment. Therefore, the accessibility of this device is undervaluing than the expectation organizes for the rescue standard. The most observation problem is the deficient distribution of the device with either a considerable or crowded area, and unable to exert the AED in emergency cases. Most of the AED spreading in society currently imports from other nations as the majority. This project expects the manageable circuit and fundamental assessment of the AED manipulation to alleviate the obstacle in the rescue process and providing additional life securing in significant condition.

1.2 Project objective

The composition of the simple automated external defibrillator circuit considers enabling the fundamental abilities within the standard. For instance, charge-shock algorithm, voice support, and electrocardiogram manipulation recognize as the essential abilities of the AED. Additionally, expectations desire in the possibility to comprise with standard properties of the AED.

1.3 The result expectation of the project

The composition of the simple AED circuit can compete with all aspects of the necessary potential and avoiding the tolerance of the result. Moreover, the consideration of the AED meeting the approximation of the standard requirement as the appropriate device.

1.4 Project report outline

Studying the essential and necessary components of the AED together with operative options that attainable in AED. The circuit and function blueprint distinguish the AED as the simple circuit construction which resembling the standard AED circuit construction panel in each function. Experimenting and observing the abilities and the capacities of the built circuit with the analyzation of the collecting data with the model requirement and improving the construction of the project. The content within this report is organized as follows:

Chapter 2 reviews content over the essential statement and information related to the AED construction.

Chapter 3 describes the design and implementation of method that conduct to achieve the data and result for the experimenting discussion

Chapter 4 demonstrates of the following data from the practical methodology set for the experimenting process

Chapter 5 as the final session within this report, reviewing the task achievement and summarizing the conclusions about main purpose of the project. Finally, future work is discussed with particular focus the discussion according to the experimental result.

CHAPTER 2
Literature Review

2.1 Heart

A heart describes as a hollow organ with specific muscle characteristics with a proportion in extent comparable to the fist located beneath the cheat area slightly left within the breastbone between two lungs. The heart contributes itself as the circulatory system's essential organ that circulates the blood and the necessary nutrition all over the whole system within the biological structure. Therefore, the extraction of the waste and unnecessary element occurs within the vascular system cooperate with the functional abilities of the other relative operation. According to these systematic routines, sufficient blood flow to the cooperate system and biological arrangement demonstrate through the whole process of the cardiovascular system.

The direction of the blood and essential component within the cardiovascular circulation relates to the heart and the vessel's cooperation. Initially, it attains the blood with deoxygenated properties via specific blood vessels. It delivers from all over the body and transfers into the first section of the blood maneuver. The flow of blood transfusion receives specific prevention of the reverse flow with the ability of the heart valve on each side. Then, the deoxygenated blood transfer to the lungs for blood purification refers to the action that extracts waste and consumption out simultaneously with replenishes the necessary nutrient and components instead. The oxygenated blood transfuses back into the heart domain in the right section of the essential organ and reserving oxygenated blood, and essential nutrients deliver accompanying blood through the particular vessels distributing in the whole body.

According to the heart properties from the beginning, the heart attains the significant type of muscle with the potentiality to conduct the electrical activities and implies the system routine responding to their principal function. This relevant electrical signal emitting correspond to the particular node within the heart resides within the Sinus node. The frequency of the node action toward the heart cycle approximates around 60 to 120 beats per minute. The conducting of the electrical signal provides guidance and assisting the heart contraction in pulse to deliver blood out of the heart to the body. Moreover, the function of the heart affects a variety of factors within the biological system, such as hormones. The electrical conductivity and signal initiation relate to the entire heart muscular capabilities and function. With the collapse of either electrical proficiency or cardiac muscle strength, these symptoms can influence heart failure occurrence.

2.1.1 Heart’s chamber

The heart composition within the cardiovascular system divides into four distinct sections as a chamber for the internal cavity as shown in the Fig.2.1. There are a significant capability and residing function in each chamber's part. The distinguish heart can separate into two categories refer to the upper-lower section of the heart and the containing blood inside the heart. The heart divides into the left and right sections. The left heart's chamber cooperates with the manipulation of the deoxygenated blood that requires the essential component transferring in the lungs further. Therefore, the right portion of the heart engaged with refining blood manipulation via the lungs corresponding vessels. Moreover, the organ division in the upper-lower part demonstrates the atrium and ventricle section from the entire organ. According to all heart division, the gesture describes as there following.

2.1.1.1 Left atrium: This chamber locates at the top left of the heart portion and receiving blood from the upper deoxygenated blood vessels transporting from the body above the section and the lower deoxygenated blood vessels with the blood from beneath the segment. The circulation will continue to the left ventricle through the tricuspid valves in the middle of the portion.

2.1.1.2 Left ventricle: This chamber locates the frontmost section of the heart. Receiving the blood transfer from the left atrium section through the tricuspid valve and preserve to send to the lungs for nutrition replenishment and gas exchange through the pulmonary valve.

2.1.1.3 Right atrium: This chamber locates underneath, and the backmost with relatively miniature in size. The blood that passes through the gas exchanging process within the lungs entering this section before transfer to the right ventricle throughout the mitral valve.

2.1.1.4 Right ventricle: This chamber is the last portion before the blood is transferring to the whole body through the aorta. The circulation of the blood receives from the left atrium through the mitral valve. The thickness of this chamber is significantly thicker than the rest according to the pumping function to sustain enough proficiency for the heart contraction.

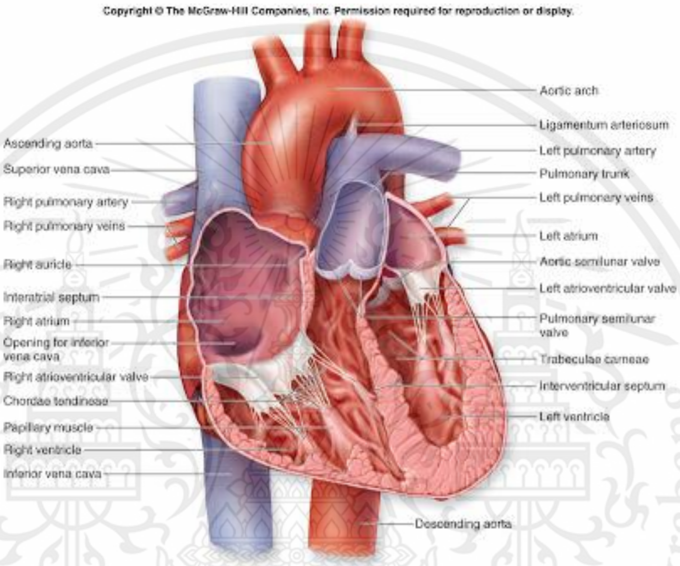


Fig 2.1 The anatomy of heart with illustration and chamber and related vessels
(Source: http://daisypuri.blogspot.com/2011/01/internal-structure-of-heart.html)

2.1.2 Relative heart component

2.1.2.1 Heart layer: The main structure of the heart distributes into three different layers shown in Fig 2.2 with the detail as follows.

1) Epicardium, the outermost layer consists of the pericardium with the serous fluid protecting and preserving the organ from the impact while the heart's function is undergoing.

2) Myocardium, the intermediate layer that contains most of the cardiac muscle conducting particular contraction for the circulation system and preserving the electrical activity within the heart.

3) Endocardium, the innermost layer consists of the endothelium cell and the heart valve.

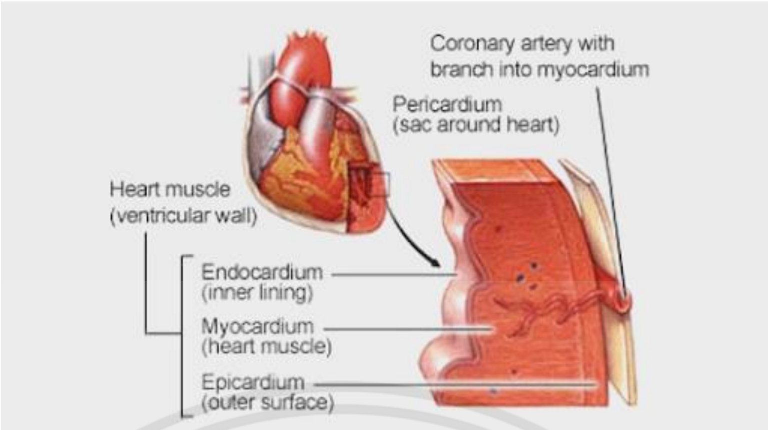


Fig 2.2 The heart layer distribution
(Source: http://www.vascularinnovations.com/heart-basics.html)

2.1.2.2 The cardiac septum: Inside the heart chamber comprise the specific internal cardiac septum, including the atrioventricular septum and Atrioventricular valve that distribute the upper and lower portions, interatrial septum that isolates the left and right atrium, and interventricular septum that separate the left and right ventricle section.

2.1.2.3 Heart valve: The component of the heart that restrain the circulating direction in the appropriate order and preventing the reverse flow that can cause the disordered circulation within the heart chamber as shown in Fig.2.3.

1) Tricuspid: The valve finds inside the left side of the heat between the upper and lower part of an organ.

2) Bicuspid: located between the right atrium and right ventricle.

3) Pulmonary: dwelling at the terminate pulmonary artery preventing reverse flow for the blood streaming to the gas exchanging process.

4) aortic valve: locate at the aorta near the bottom left area provides restriction towards reverse flow for the blood streaming distribute to the body.

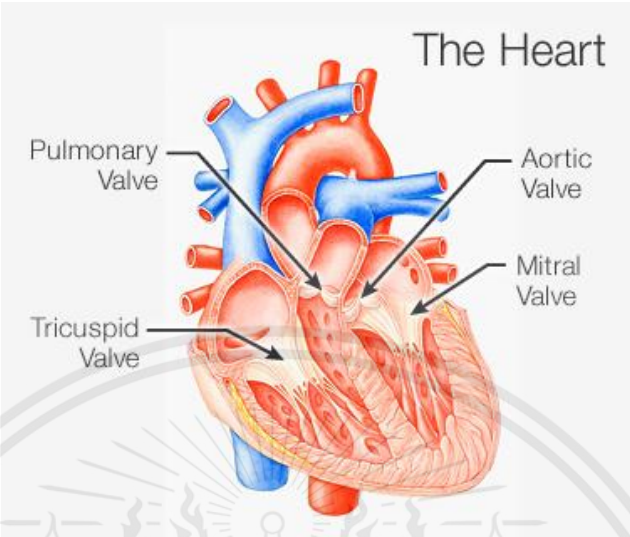


Fig 2.3 The location of the heart valve

(Source: https://www.webmd.com/heart-disease/guide/heart-valve-disease#1)

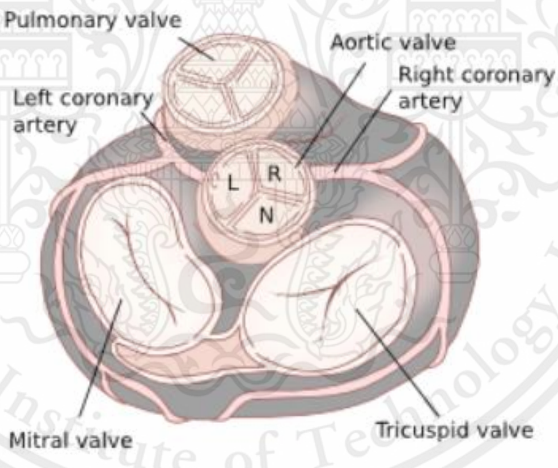


Fig 2.4 The cross-section image of the heart valve

(Source: http://echocardiografie.nl/valves/aortic-valve/)

2.2 The cardiac cycle

It is the synchronicity phenomenon of the cardiac movement causes the pressure fluctuation within the heart chamber. The consequence of the pressure change within the cardiovascular environment is the blood streaming flow through different heart portion in the manner of conventional cardiovascular current.

Moreover, a heart behavior inside the cardiac cycle as shown in Fig.2.5 corresponds with the biological factor and the electrochemical activities residing in the functional aspect of the system. The cardiac cycle analysis assists the medical personnel information basis for vital to the clinical understanding of cardiac auscultation, pathology, and interventions.

2.2.1 Systole: the activity refers to the interactivity of the heart in the contraction and the ejection of the blood. Systole causes the chamber of the heart vacant from the blood filling and prepares for a subsequent load of the blood entering. Systole both have in the atrium and ventricular sections. The systole will conduct during the atrium chamber, both left and right received blood from the particular organ from biological function. The relevant pressure and flow cause the atrium section to depolarize and contract the muscle to eject the blood out of the chamber according to responsibility assigning this relative movement as the Atrium systole. Additionally, the corresponding action in the ventricular section causing the depolarization and eject the blood out of the chamber with particular contraction referring to the Ventricular systole. The ventricular systole divides into two phases. First, the stages that the blood pressure in the ventricular chamber increase and conduct to the isovolumic contraction. Then, the ejection phase contribution causes a contraction of the cardiac muscle expatriates all blood away from the ventricular sections.

2.2.2 Diastole: the interaction of the heart according to the ventricular filling. The relaxation of the cardiac muscle resolve in the process of the preparation of the systole stage that blood transfusion to an accompanying chamber and relative organ. The relaxing period of the ventricular prioritizes on the preparation for subsequence contraction of the ventricular cardiac muscle. Moreover, this interaction corresponds in both the atrium and ventricular in the cardiac cycle within the cardiovascular function.

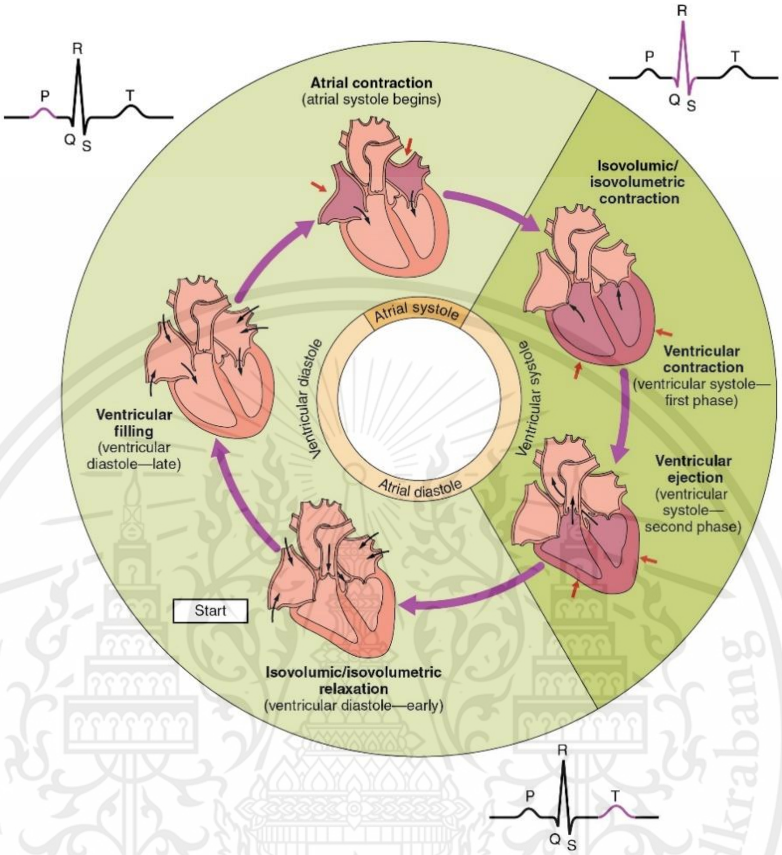


Fig 2.5 The cardiac cycle explanation with corresponding ECG waveform

(Source: https://opentextbc.ca/anatomyandphysiology/chapter/19-3-cardiac-cycle/)

2.2.3 Cardiac output and stroke volume

The cardiac output refers to the relativity between the amount of blood ejecting from the heart in a specific period as shown in Fig.2.6. Typically, the periodic upon observing the cardiac output applies in a second span. Four factors are affecting cardiac output include heart rate, preload, afterload, and contractility. These associated factors are necessary for the application and analyzing the cardiac output. The stroking capacity considers the volume of blood transferring escaping from a heart in each beating or single cycle of the cardiovascular function. In the calculation method, the stroke volume is a particular value considering the product of the cardiac output. According to those relative values, the cardiac output value is the outcome of the multiplication between the stroke volume and the heart rate. For instance, if the stroke volume in a single cycle is 80 milliliters and the heart rate in a person is 74 beats per minute. The results for the cardiac output are 74 multiply by 80, which is 5,920 milliliters per minute or almost 6 liters in one minute's capabilities of the blood pumping. In conclusion, any effect that can tolerate or stimulate the heart rate value or the stroke volume can alter the amount of the cardiac output proportionally.

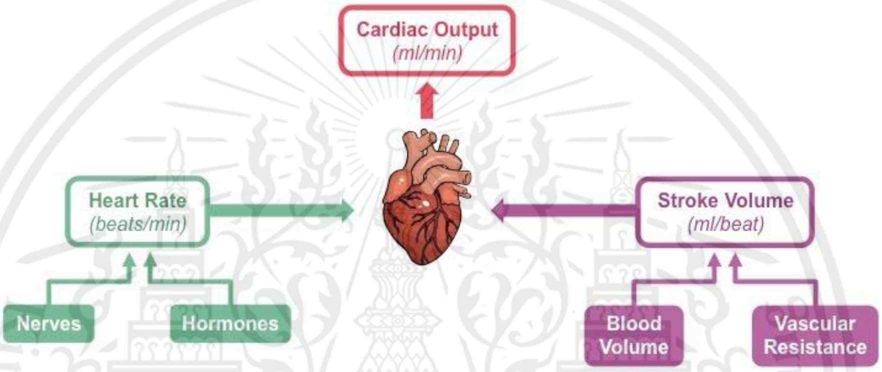


Fig 2.6 The cardiac output and relative factor that can influence the result (Source: https://ib.bioninja.com.au/options/option-d-human-physiology/d4-the-heart/cardiac-output.html)

2.2.4 Electrocardiogram

The measurement and the observation of the electrical activities of the muscular function within the cardiovascular system. The relationship between cardiac muscle and conduction of the electrical behavior interpretation of heart from the specific node inducing the particular signal for the cardiac cycle. This related note refers to the SA Node producing the signal and approaching the AV Node. The signal emitting from the atrioventricular node spread through the bundle branches and cover all relative cardiac muscle extent with the Purkinje fiber. These correlations of the cardiovascular manner as a cardiac excitation implement with the graph can describe under the complex of the electrocardiogram graph distribution.

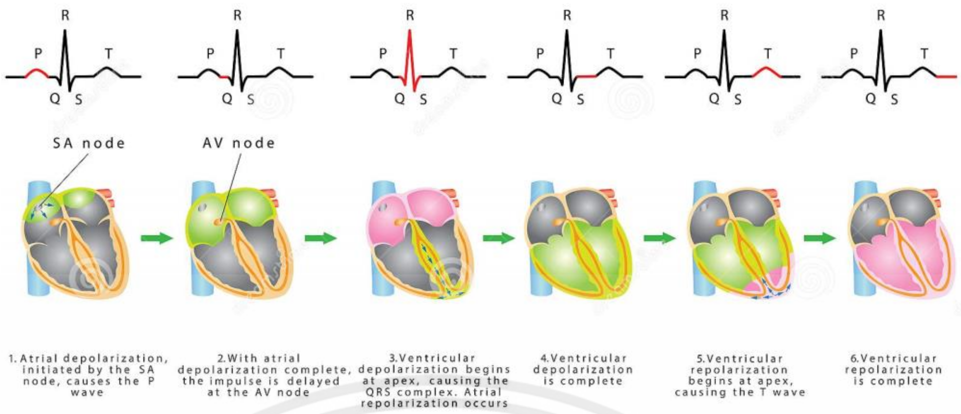


Fig 2.7 The heart excitation mechanism compare with the electrocardiogram
(Source: https://www.dreamstime.com/cardiac-cycle-sequence-heart-excitation-associated-deviation-ecg-waves-tracing-diagram-phases-image193685458)

2.2.4.1 The segmentation of the electrocardiogram: the structure of the electrocardiogram can divide into a particular section as shown in Fig.2.8 correspond with the cardiac excitation stage. The electrocardiogram can distribute into a specific complex according to the Fig.2.9 demonstrating the mechanism detail.

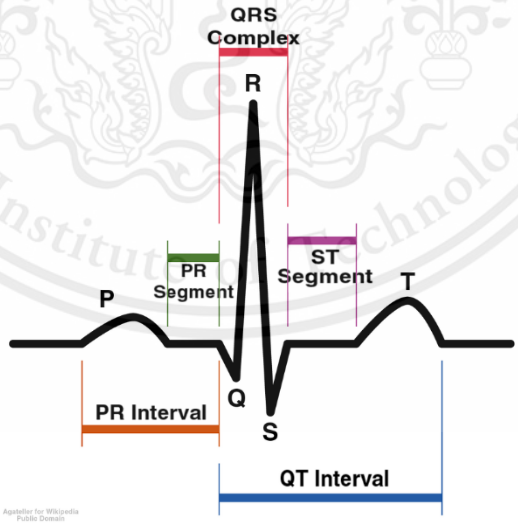


Fig 2.8 The segmentation of the electrocardiogram
(Source: https://www.researchgate.net/figure/Illustration-of-the-Electrocardiogram-a-The-heart-cycle-b-A-normal-ECG_fig1_220861943)

1) P wave: the wave generated from the interaction of the Sinoatrial node emitting signal to the left atrium and right atrium as a depolarization. Then, the related heart chamber contract and pressure the blood within the chamber subsequent chambers.

2) PR interval: The section the range of P and R waves distribute the signal via the SA Node to the corresponding AV Node. Then, the relative signal spread in the ventricular chamber through the His bundles, coordinated left and right bundle branches, and the Purkinje fiber.

3) PR segment: this segment positions between the P wave and QRS complex. For the PR segment, it distributes the time delay of atrial and ventricular activation.

4) QRS complex: The summation of the electrochemical activity in the cardiovascular measurement of the overall formation from the depolarization state. This particular depolarization value gains from the left and right ventricles before the consolidation in the ventricular chamber occurs.

5) T wave: the summarization of the electrochemical activity of the repolarization along the process within every single cardiac cycle from the ventricular chambers. The repolarization from the atrium is insignificant because the calculation of the repolarization summary detail obstructs by an action of the depolarization of the ventricle oblique.

6) ST segment: The specific interval that initiation the ventricular repolarization state from the point that terminates of the QRS complex. The interconnection within this segment refers to the J point that indicates the initiation point of the T wave location.

7) QT interval: The segment that demonstrates the summarization of the depolarization and repolarization activities of the heart. This segment locates and measures from the Q wave in the QRS complex to the T wave.

8) U wave: indicate as a tiny wave band after the curve of the T wave. U wave doesn't show up any significant measurement and transmit in the same direction with T wave.

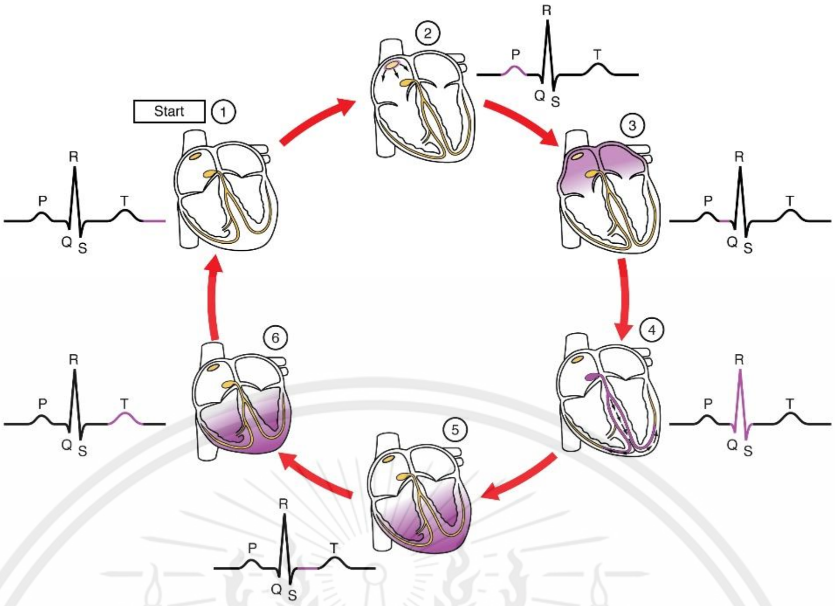


Fig 2.9 The correlation in the heart and electrocardiogram demonstration

(Source: https://commons.wikimedia.org/wiki/File:2023_ECG_Tracing_with_Heart_ContractionN.jpg)

2.2.4.2 The electrocardiogram measurement: The measurement of the electrocardiogram assessment requires a sensor for the signal evaluation as an electrode. The electrode of the at the lead position. The lead location implies to the point on the body that specific in the electrocardiogram evaluation. The electrode attached properties contain positive and negative charges separately different due to the positioning.

1) standard twelves lead measurement.

This measurement refers to the Bipolar lead or standard limb lead. The difference in the voltage measurement places the lead electrode between the point at the arms and legs. The theory of Einthoven's Triangle that is the triangular positioning of the electrode and state a heart at the triangle center. The lead state at the triangular angle in this reference triangle theory. For instance, both left arm and leg with a right arm present the electrode position corresponding in the electrocardiogram measurement. With the evaluation, if the voltage difference with a particular lead will appraise the remainder simultaneously. These corresponding leads consist of

- lead I: the voltage difference demonstrates by the left and right arm electrode position.
- lead II: the voltage difference demonstrates by left leg and right arm electrode position.
- lead III: the voltage difference demonstrates by left leg and arm electrode position.

According to all of this connection, the Einthoven triangle constructs between the formation linkage between attaching lead I, II, and III in the limbic system shown in Fig.2.10. The zero points appear in the Einthoven triangle feature as all lead angle measurements approximate in the value around 60 degrees and state and the triaxial reference system.

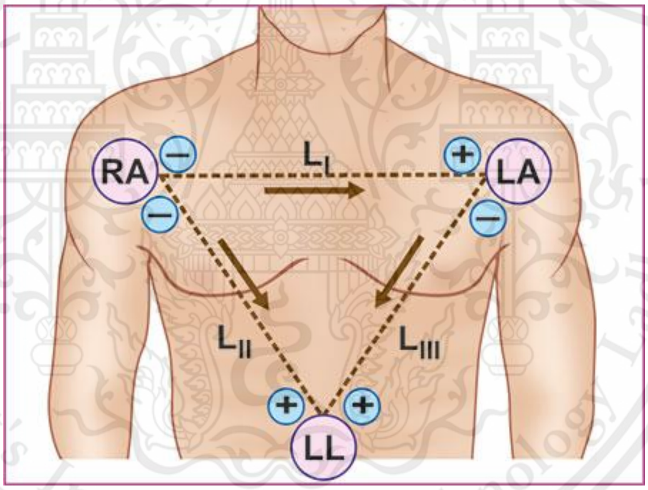


Fig 2.10 Bipolar limb lead for Lead I, II, and III measurement
(Source: https://www.jaypeedigital.com/book/9789350255919/chapter/ch2)

Unipolar limb lead: the corresponding of the lead voltage in the limbic measurement considers with the reference point consisting of the zero voltage as properties. The reference refers to the central terminal of the heart recording through the unipolar range. Therefore, the result demonstrates the as expressly low voltage output requiring the augmentation application as shown in Fig.2.11. The augmented measurement of this section refers to the augmented limb leads consist of three points of the attachment.

- aVL: the difference of voltage in the left arm toward the central terminal with signal augmentation.
- aVR: the difference of voltage in the right arm to the reference point with signal augmentation.
- aVF: the difference of voltage in the left leg to the reference point with signal augmentation.

The "a" in the acronym of the unipolar measurement refers to the augmented. This method increases the precision in the electrocardiogram analysis with the 50 percent to signal for better resolution in the relevant signal commentary.

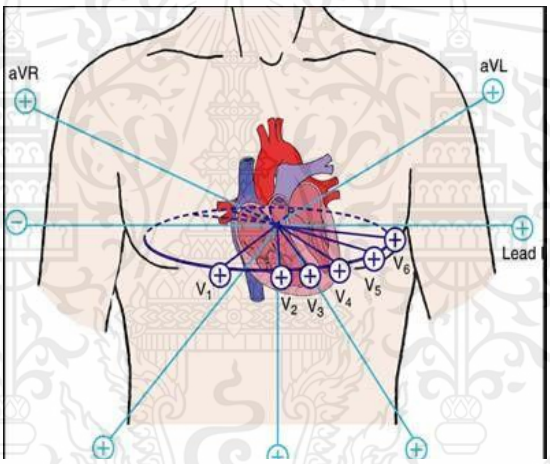


Fig 2.11 The distribution of the augmented leads and chest leads
(Source: https://www.primemedicaltraining.com/12-lead-ecg-placement/)

Chest lead: Unipolar chest lead or the precordial lead is the voltage measurement in the identical polarity within the horizontal plane as shown in Fig2.11. The location of the related electrode connecting places at the precordial area on the chest extent. The voltage difference records from the entire heart electrochemical activity. This lead attachment approves and recommends by the American Heart Association includes this appendage as follows.

- V1: the cavity in the fourth ribs at the boundary right side of the sternum placement.

- V2: the cavity in the fourth ribs at the boundary left side of the sternum placement.
- V3: Placing amidst of the V2 position and V4 position.
- V4: the cavity in the fifth ribs in the middle line of the left clavicle.
- V5: the cavity in the fifth ribs int same V4 attachment plane in front of the anterior axillary line on the left side.
- V6: cavity in the fifth ribs at the same level as V4 in the middle order to Midaxillary line

2.3 The cardiac disease

Cardiac disease is the condition that affects the malfunction of the cardiovascular systems, including the deterioration of the heart content causing the breakdown point for heart failure. Heart failure occurs from a variety of the condition and situation depends on the person and wellness concern. Therefore, heart failure can induce by the defect structure and misconduct of the cardiovascular routine in the body. The effect of the heart failure display in the patient in two types categorizes the severity and hazardous factor toward the victim, including the acute heart failure that manifests the patient as an instantaneous disturbance in heart rhythm, cause the corrupting heat function. Moreover, chronic heart failure experiences in the patient once suffering acute heart failure, and during the therapeutic process consists of the continuously detecting heart failure and the cardiovascular malfunction in a long period.

2.3.1 Hypertrophic cardiomyopathy

This disease is a congenital disease. It expresses as the thickness of the left ventricle becomes excessive in size the general extent. This myocardium enlarging doesn't occur from any effect from another disease influencing. Moreover, hypertrophic cardiomyopathy discovers in the population all over the world. Spreading tendency doesn't depend on genetic similarity, preferentially specific factor as national or gender.

In the patient that suffering HCM, the myocardium within the left ventricle size approximates around 15 centimeters. Whereas, the average measurement notes up to an estimated 25 centimeters, and the size extent can disproportionate up to 30-50 centimeters. Nevertheless, the unnecessary thickness occurrence in the heart doesn't relate to the HCM symptom leading to heart failure all the time. It was possible to correlate the genetic issue for HCM patients to induce heart failure alternatively. This type of disease causes the patient to achieve effortless depletion and fatigue, the pain inside the chest occurs inconsistently, and seldomly the symptom doesn't manifest and develops for wellness observation. The heart failure from this reference disease transpires from the chronic heart failure with lo awareness of the therapeutic and treatment causes the obstruct in the blood circulation for 90 percent. This incident induces the pressure within the left ventricle chamber to the crisis threshold. The heart failure causing by the HCM factor interacts with another disease to cause the failure statement, such as pulmonary hypertension, abnormal relaxation in the myocardium, and the contracting rate become inconsistent proportion to the exercise state and rest state as shown in the Fig.2.12.

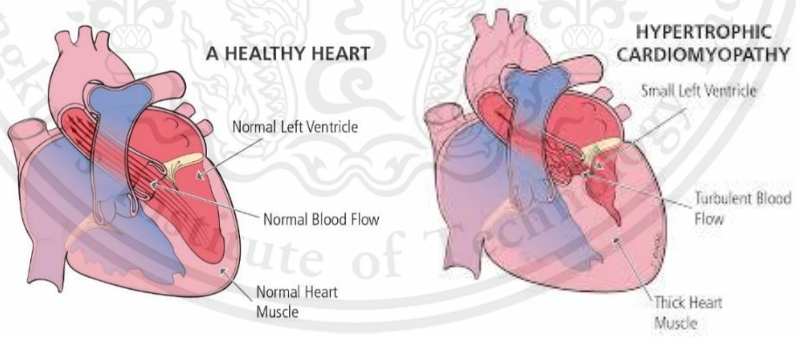


Fig 2.12 The hypertrophic cardiomyopathy and healthy heart comparison
(Source: https://intermountainhealthcare.org/services/heart-care/conditions/hypertrophic-cardiomyopathy/what-is-hypertrophic-

2.3.2 Viral myocarditis

The infection within the myocardium of the heart interacts with an infectious agent and virus shown in the Fig.2.13. Most of these cause from virus induce viral myocarditis, including enterovirus (coxsackievirus, enterovirus, echovirus), and adenovirus that contaminate via the pneumonic system, digestive tract, or the existence of the virus progenitor for the child in a pregnant state. The infection of the particular virus causes the patient to suffer viral myocarditis and cardiac cell necrosis. This symptom affects cardiac muscle proficiency demonstrating in significantly decreasing the work capability. In the initial stage, the patient suffers from readily fatigue and cardiomegaly. At the critical level, the patient can suffer from viral myocarditis cause death. Whereas, the patient that can accommodate the lifestyle with the fixed-condition heart situation consists of the possibility to produce comprehensive treatment over this particular disease. However, if the patient can revise themself to their infirmity without completely restore. It will leave the fibrous structure with the myocardium and induce permanent vulnerability.

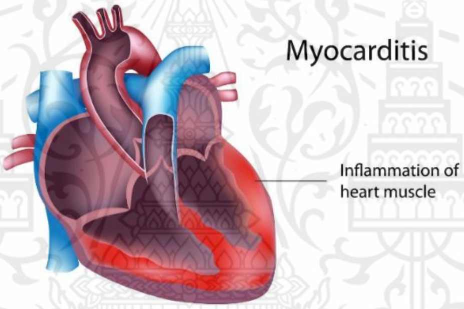


Fig 2.13 The red area correspond to infection zone in viral myocarditis disease
(Source: http://www.secondscount.org/pediatric-center/pediatric-detail?cid=d0c36202-3ca1-4ea3-9d39-1525b56a0a58#.X61dj8gzZPY)

2.3.3 Valvular defection (stenosis and regurgitation)

The disease affects the pathological structure of the heart valve and causes deformity to their activities and responsibility as shown in Fig.2.14. The defect in the heart valve can declare into two significant types, including valvular stenosis and valvular regurgitation. These relevant indications cause heart failure and mortality. This disease can observe in the newborn to the elderly stage. The newborn with the valvular defection effect from the pregnancy and in the elderly age occurs after the infecting of the rheumatic heart disease. According to the condition, the patient suffers from easily fatigued and abnormality in heart rhythm. Moreover, pulmonary hemorrhage, paralysis, and heart failure transpire in critical situations in valvular disease cases.

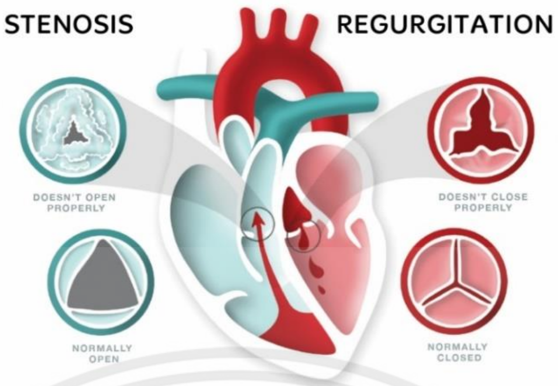


Fig 2.14 The heart valve disease distribution
(Source: https://www.heartfoundation.org.nz/your-heart/heart-conditions/heart-valve-disease)

2.3.4 Heatstroke

Heatstroke is the symptomatic matter when the overall of the body state as the overheating from the exert temperature. Typically, a consequence of prolonged exposure or physical revealing within high temperatures. If the core temperature of the victim emanates to 40 degrees Celsius or higher. The condition from the summer air and the heating domain with relevant state causes heatstroke to the victim undoubtedly. These heat injuries consider as a severe impairment requiring treatment and medical emergency immediately. The heatstroke usually occurs in combination with dehydration that drives to the deterioration in the temperature control system in the body and leads to functional failure, including the cardiovascular system as well. The heatstroke frequently happens as a progression from milder such as heat cramps, fainting, and heat exhaustion. Therefore, heatstroke can suffer in every people. Despite the people without sign or record about the heat injuries can experience heatstroke. The symptom of heatstroke injuries is the observation of the resemble body function, such as lack of sweating, harnessing body heat, nausea, vomiting, fainted, rapid heartbeat, and unconsciousness.

2.3.5 Coronary Artery disease

The ischemic heart condition refers to the circumstance that the coronary artery that nourishing the heart vitality becomes stenosis or obstruct the pathway with the vessel aging shown in Fig 2.15. The corresponding artery vessel wall thickness is increasing with the accumulation of the lipid molecule and the limestones within the vessels. The stiffness of the artery that delivers the nutrient and essential component to heat enhance producing stenosis and obstruct the progress. These symptoms induce the heart function deficit in the supplementary blood and necessary element. In a prolonged situation, the cardiac muscle will undergo necrosis according to the inadequate supplement from the related symptom. Cheat pain occurs as a sign of the relative disease before the critical situation manifests as heart failure.

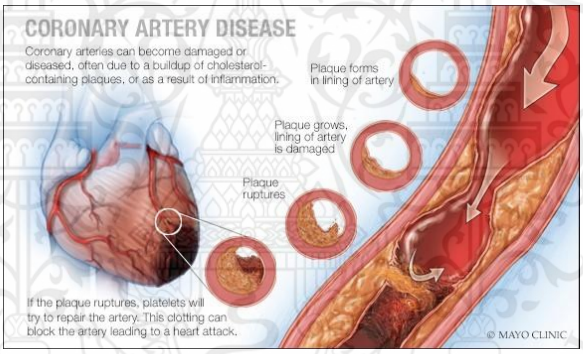


Fig 2.15 The coronary heart disease demonstration
(Source: https://lingardprivate.com.au/specialties/heart-centre/coronary-artery-disease)

All the mentioned diseases in this topic relate to the symptoms corresponding to the interfering heart function or deteriorate cardiovascular function. The similarity in these diseases show as the fatigue and exhaustion to the patient and create the factor leading the patient heart capacity falsifying and failure in ultimately.

2.4 The cardiac arrhythmia

An arrhythmia is a difficulty observing in the heart beating rhythm. The regular rhythm of the heart function becomes the rhythm that changes in the shape of the standard electrical activities displaying configuration. The cardiac arrhythmia differs from the demonstrating of graphical record from a normal heartbeat that defines as leading to a regular resting pulse rate of sixty to a hundred beats a minute. This affliction refers to a bunch of conditions that affect the heart to beat irregular, too slowly, or too quickly. a number of the arrhythmias don't seem to be severe or cause complications. However, the condition of the irregular rhythmic function of the heart will increase the chance for the speed of viscus arrest and stroke.

2.4.1 The type of the arrhythmia

The arrhythmia can distinguish into two significant irregularities of electrical heart signals. The heart rate that increases over the 100 bpm of the resting heart threshold refers to the fast heartbeat or Tachycardia. Nevertheless, the heart rate decreasing rate lower the 60 bpm of the resting heart refers to the slow heartbeat or Bradycardia. According to these conditions, the fast and slow rate can cause different symptoms conceding a location that issue as problematic alignment.

2.4.1.1 The tachycardia at the Atrial heart

1) Atrial fibrillation: it is the symptomatic sign observing the rapid heartbeat as shown in Fig.2.16. It effects by the chaotic atrial impulse. These signals occur in rapid, uncoordinated, and ineffective atrial contraction.

Fig 2.16 The atrial fibrillation signal
(Source: https://aclsmedicaltraining.com/atrial-fibrillation/)

2) Atrial flutter: The similarity of this condition resembles Atrial fibrillation as shown in Fig.2.17. Whereas, the heart rhythm observes as more in the pattern of the arrhythmia of the atrial fibrillation that contains more disorganization of the impulse.

Fig 2.17 The atrial fluttering – the observed as sawtooth pattern
(Source: http://www.cai.md.chula.ac.th/lesson/pairoj2/contents/patient/p5explain.htm)

3). Supraventricular tachycardia: It is the tachycardia version that includes different symptoms from fibrillation and fluttering together. It originates over the ventricles within Av node or the atrial section shown in Fig.2.18.

Fig 2.18 Supraventricular tachycardia signal pattern
(Source: https://www.proacls.com/training/video/supraventricular-tachycardia)

4) Wolff-Parkinson-White syndrome: A supraventricular cardiac arrhythmia sort that further electrical pathway appears between the atria and also the ventricles. This pathway could permit electrical signals to pass between the atria and also the ventricles while not passing through the AV node, resulting in short circuits and rapid heartbeats. This symptom will establish solely in adulthood. However, the explanation for this disorder originates from birth as shown in Fig.2.19.

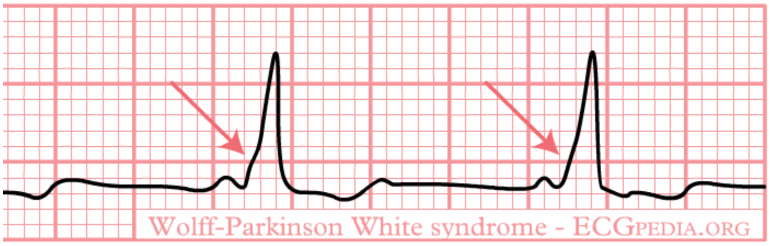


Fig 2.19 Wolff-Parkinson-White syndrome signal pattern
(Source: https://www.lecturio.com/magazine/wolff-parkinson-white-

2.4.1.2 The tachycardia at the ventricular heart

1) Ventricular tachycardia: the fast rate of the heartbeat, irregular heart rate originates from the abnormality in the ventricular contraction. The fast heart rate prohibits the function of the ventricle in replenishing and contracting efficiently to deliver adequate blood to the body as shown in Fig.2.20.

Fig 2.20 Ventricular tachycardia signal pattern
(Source: https://litfl.com/ventricular-tachycardia-monomorphic-ecg-library//)

2) Ventricular fibrillation: It happens with fast and chaotic electrical impulses inflicting within the ventricles shown in Fig.2.21. The signal represents a heart quivering inefficaciously rather than pumping necessary blood to the body. Most people who retrieve from fibrillation have underlying heart disease or have intimated severe trauma.

Fig 2.21 Ventricular fibrillation signal pattern
(Source: https://www.cancertherapyadvisor.com/home/decision-support-in-medicine/hospital-medicine/ventricular-tachycardia/)

3) Long QT syndrome: It is a heart dysfunction that drives to the heightened risk in rapid or chaotic pulsations. The rapid heartbeats may lead to fainting presenting in the abrupt change in the electrical signal. The symptom of this condition mentions being born with a genetic mutation or congenital heart defects that increase the risk of long QT syndrome as shown in Fig.2.22.

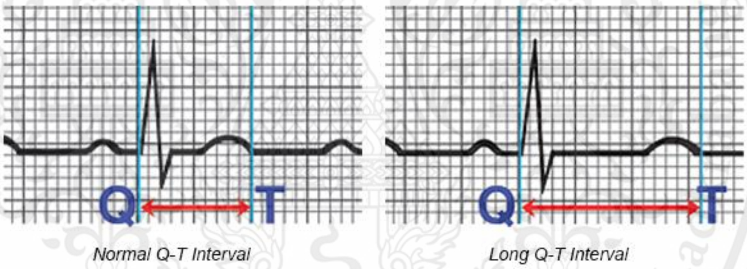


Fig 2.22 Long QT syndrome signal pattern
(Source: https://my.clevelandclinic.org/health/diseases/17183-long-q-t-syndrome-lqts)

2.4.1.3 The bradycardia

1) Sick sinus syndrome: It is the inefficient heart pacing from the sinus node. Due to this condition, the heart is unable to send the impulses properly to the responding node. The pulsation can alternately change between a sluggish rhythm and faster pace. Scarring near can also cause this syndrome. The sinus node becomes slower with related disruption, or impulse obstruction as shown in Fig.2.23.

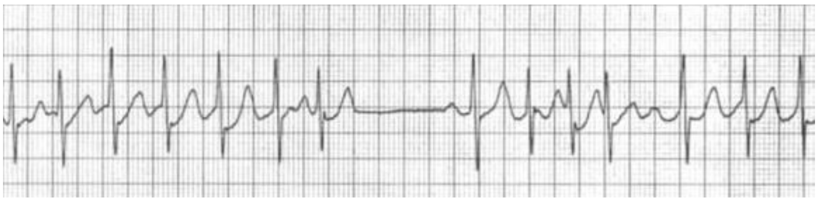


Fig 2.23 Sick sinus syndrome signal pattern
(Source: https://litfl.com/sinus-node-dysfunction-sick-sinus-syndrome/)

2) Conduction block: It is the symptom that the electrical pathway from the SA Node pathway to the AV node. Moreover, an obstructing signal pathway can occur in the ventricular zone as well. The blockade affects the signal pathway as the interrupting impulses generating the slower signal or the severe case to the skipped beat shown in Fig.2.24.

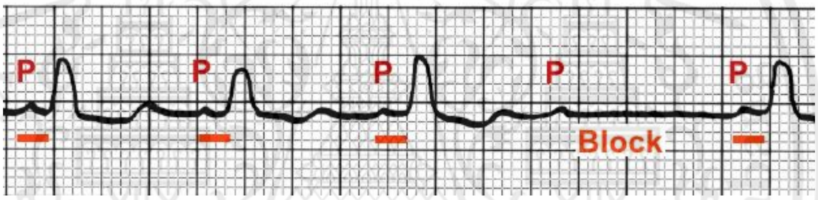


Fig 2.24 ECG conduction block signal pattern
(Source: https://www.slideshare.net/smcmedicinedept/ecg-conduction-block)

2.5 The Automated External Defibrillator

An automated external defibrillator (AED) is a portable rescue device utilizing an associated emergency accident and crucial incident. The required performance of the AED is that the ECG analytical method observant over the actual severe arrhythmia. For example, grievous perceives ventricular fibrillation and chamber cardiac arrhythmia automatically. Therefore, the treatment method needs the corresponding action with the analytical performance of the device for immediate rescue. The center will perform the essential perform of blood pumping solely through the synchronization of the heart muscle fibers is lost. Restoring it's to their traditional synchronal operating is named defibrillation. It consists of delivering a therapeutic dose of electrical energy to the affected heart with a device. This activity toward the patient grants the opportunity of the patient suffering from heart failure. Also, it obtains the normal cardiac cycle and receives proper treatment.

Fig 2.25 The AED example
(Source: https://www.aedsuperstore.com/zoll-aed-plus-package.html)

AED design for utilization in every generation and gender as shown in Fig.2.25. It consists of the information within the device as the voice instructor guidance, and some type contains the screen to visualize the process for a further assistant associate for conventional action in rescue. This device associates with the first response or the CPR unit in the emergency incident with the heart failure or the accident that require heartbeat resynchronization immediately.

This device corresponds with the conventional electrical circuit and takes the practical and fundamental training is adequate for the application of the AED in the actual performance.

2.5.1 The history of the AED

In 1899, two physiologists in Geneva recognized the process and arrangement of defibrillation. They discovered that small electrical discharges cause body cavity flicker. Initially, the defibrillator was used by Claude Beck in academia in 1947. In the 1960s, Gesture was the first to successfully treat a 14-year-old boy who had undergone surgery due to a congenital breast defect. In the 1960s, portable defibrillators were introduced into ambulances. The defibrillator is the only defibrillator discovered for resuscitation of people with abnormal and persistent ventricular fibrillation or ventricular arrhythmia after the rescuer arrived.

Sudden cardiac arrest could be an important public health problem associated affects a calculable 500,000 folks each year. a sudden cardiac arrest will strike anyone, thus it's remarkably very important to be ready to reply quickly to sharp internal organ arrest. Having an accessible AED accustomed to instantly delivering a life-saving shock typically means the distinction between life and death. Once a victim experiences sudden cardiac arrest, with a shockable rhythm, each minute counts; every minute a victim goes while not defibrillation, the possibilities for survival decrease by 7%-10%. However, having associate AED put in at your location will enable on-the-spot trained responders, or close emergency responders, deliver probably life-saving defibrillation medical care quickly and effectively

2.5.3 The AED high-voltage part characteristic

2.5.2.1 Charging

When the capacitor operates the charging, the electrons transmit from one metal plate to another one. Continue this process until the potential difference across the capacitor corresponds to the potential difference across the battery. Since the current changes during the charging process, the charging rate corresponds to the charging rate of the battery. In addition, the current is initially maximum but gradually decreases to zero. The following formula can be used to calculate the charge after a certain charging time to find the charge, voltage, and current as shown in the Fig.2.26:

$$Q = Q_f(1 - e^{\frac{-t}{CR}})$$

$$V = V_f(1 - e^{\frac{-t}{CR}})$$

$$I = I_0 e^{\frac{-t}{CR}}$$

Where: Q / V / I is the charge / voltage / current in time.
t is time constant.
Q_f is the maximum final charge.
V_f is the maximum final voltage.
C / R is the capacitance / resistance.

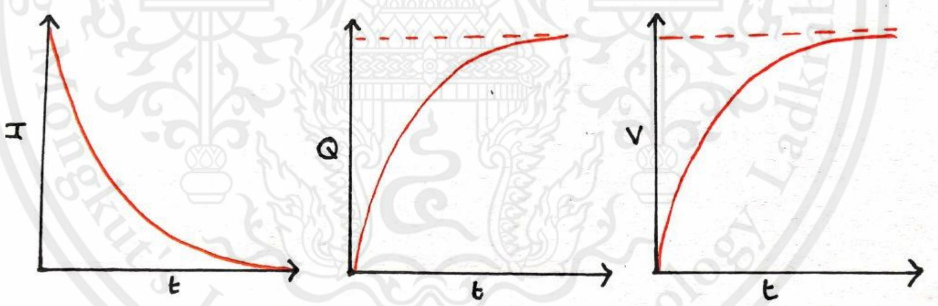


Fig.2.26 Discharging graphs between of a time constant and related variable (Source: https://www.scienceandmathsrevision.co.uk/topic/charging-and-discharging-capacitors/)

2.5.2.2 Discharging

When a capacitor is discharged, the contemporary will be maximum on the start. This will progressively lower till attaining 0 while the contemporary reaches 0, the capacitor is completely discharged as there's no charge saved throughout it. The particular graphical displaying shown in Fig.2.27.

And there's the equation for calculation for locating the charge, voltage, and contemporary in a capacitor discharge observe as:

$$Q = Q_0 e^{\frac{-t}{CR}}$$

$$V = V_0 e^{\frac{-t}{CR}}$$

$$I = I_0 e^{\frac{-t}{CR}}$$

Where: *Q* / *V* / *I* is the charge / voltage / current in time
t is the time constant
Q_f is the maximum final charge
V_f is the maximum final voltage
C / *R* is the capacitance / resistance

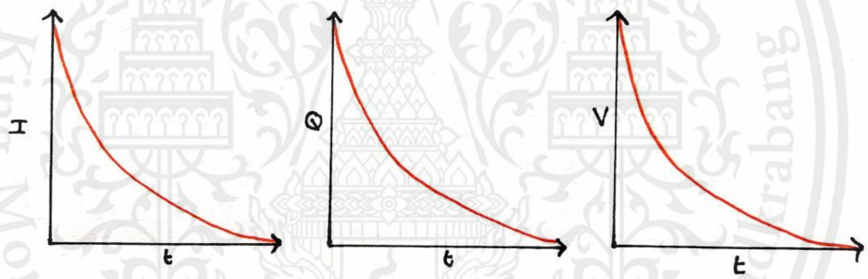


Fig.2.27 Discharging graphs between of a time constant and related variable
(Source: https://www.scienceandmathsrevision.co.uk/topic/charging-and-discharging-capacitors/)

2.5.2.3 Time constant

The time constant is the time required to reduce the capacitor by approximately 37%. Two factors affect the speed at which the load passes: resistance and capacitance. This means that the time constant can be found using the following equation:

$$t = RC$$

Where: *t* is the time constant
C / *R* is the capacitance / resistance

2.6 Electrical components

2.6.1 Capacitor

The invention of the capacitor was invented the project participant about this topic at Leiden University. The first capacitor is a very similar Leiden glass device, which is a simple two-pin device. External and internal sheet metal separated from the glass. The inside of the pot is half-filled with water and metal wire through a stopper and a metal rod used to connect with the spherical wire. This means that when the ball comes into contact with energy, the electricity will be transferred to the sheet metal to store the energy as shown in Fig.2.28.

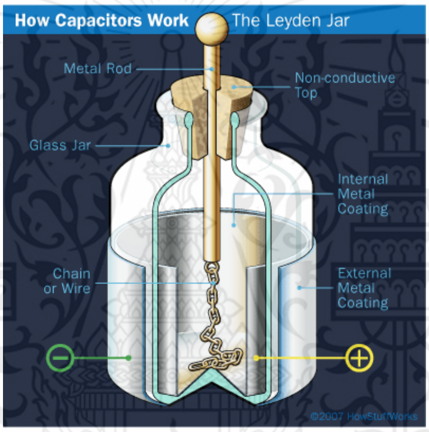


Fig.2.28 A Leyden Jar
(Source: https://electronics.howstuffworks.com/capacitor.htm)

Therefore, the capacitor is the two-terminal, fundamental passive electrical component. Which is similar to a battery, but it only has the function of storing energy. The electrostatic field in the form of an electric field is called charge, and the energy released from the capacitor is called discharge. Each capacitor has a different size and shape. Nonetheless, all capacitor contains two metal plates that are the electrical conductor separated by the non-conduction is called 'dielectric'. Whereas, the material of a dielectric can be considered as paper, glass, rubber, ceramic, plastic, air or anything that can block the current flow. And the metal plate can use the material of aluminum, silver or the thin film of other metal as shown in Fig.2.29.

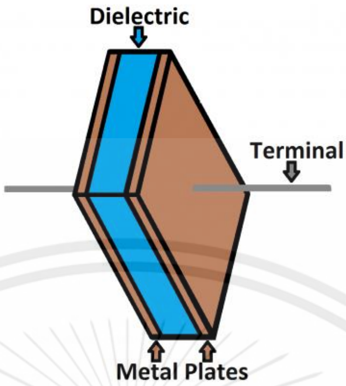


Fig.2.29 The structure of capacitor.
(Source: https://learn.sparkfun.com/tutorials/capacitors/all)

2.6.1.1 The capacitance of a capacitor

Capacitance is a measure of the ability of an actual capacitor in energy supplementary. Capacitance is a characteristic of capacitors and can be described as Farad capacitance, in which a single Coulomb charge is stored at a voltage of 1 volt. A container the size of a cube. If the capacity is larger, more power can be stored. There are three ways to add more capacitance to capacitor A. First, the size of the metal plate should be increased, and secondly, the overlap area of the surface of the metal plate should be increased. Secondly, the dielectric material must be a suitable insulator and the best material. It must be composed of polar molecules: one side has more positive charges, and the other side has more negative charges as shown in Fig.2.30. The capacity can be calculated using the following formula:

$$C = \varepsilon_r \frac{A}{4\pi d}$$

ε_r is the dielectric's relative permittivity (a constant value of dielectric material)

A is the area of the metal plate

d is the distance between the metal plate

The capacitance unit according to the utilization is Farad. This related unit has no negative value presenting in the application. Capacitors are usually used in units of microfarads, nano-farads, and picofarads because farads can be a very large unit of measurement.

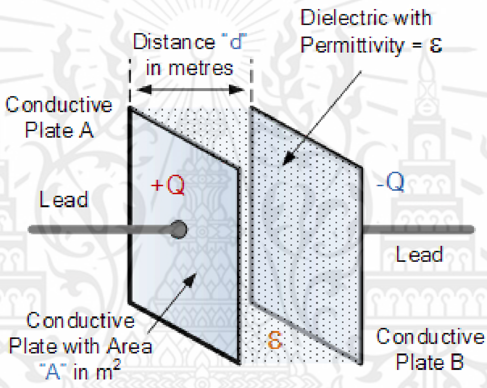


Fig.2.30 The capacitance equation.
(Source: https://www.electronics-tutorials.ws/capacitor/cap_1.html)

2.6.1.2 the principal work of capacitor

A capacitor has two metal plates, and each metal plate has the same number of positive and negative charges, which is called electrical neutrality. When connecting the capacitor to the battery, it is the only metal plate connected to the positive terminal of the battery. The battery loses electrons. The metal plate connected to the other side of the negative electrode of the battery receives electrons from the battery. However, there is a dielectric between the metal plates. This prevents the electrons from moving one metal plate to another metal plate. These charges accumulate on the metal plate. Then, the capacitor is fully charged. The metal plate that attracts the positive electrode of the battery will develop a net positive charge, and the other side that attracts the negative electrode will develop a net negative charge and develop a battery pile. Then, the two metal plates generate an electric field under the action of the attraction force of the two metal plates and maintain the capacitance e of the capacitor. In addition, using a dielectric material with polarity increases the capacitance, which means you have to change the charge on the two metal plates until the molecules align with the correct electric field, because the negative metal plate may be more attractive, so the positive and the attractive force between the negative plates is greater. The metal plate repels more electrons.

2.6.1.3 Types of capacitor

The capacitor can be classified into three groups such as Fixed capacitor, Variable capacitor and Select capacitor.

1.) Fixed Capacitor

Fixed capacitor is a capacitor that can't be changed the capacitance value. There are commonly characterized to be a circle or cylinder. There are many different fixed value capacitors which can be categorized by the material of dielectric as electrolytic, ceramic and silver mica capacitors. All fixed capacitor types are commonly used in the general electric circuit as shown in Fig.2.31:

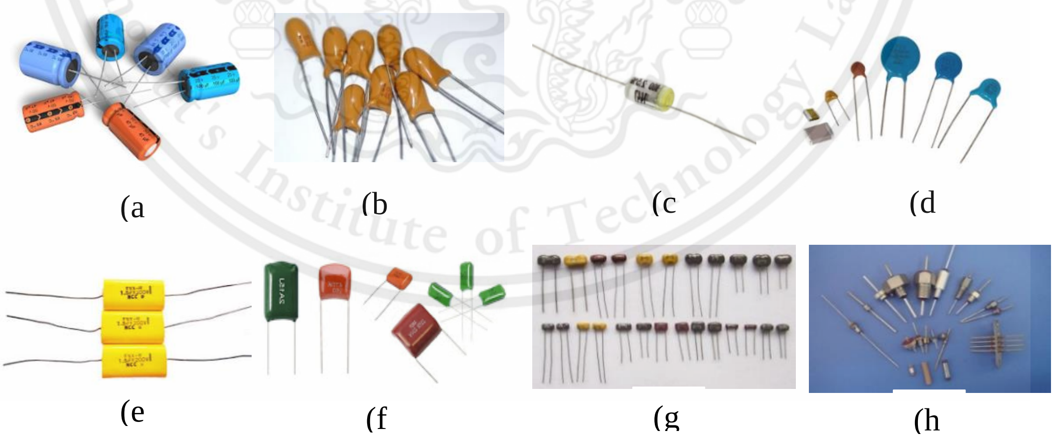


Fig.2.31 The fixed capacitor types consist of (a) Electrolyte capacitor, (b) Tantalum Electrolyte Capacitor, (c) Polystyrene Capacitor, (d) Ceramic Capacitor, (e) Bipolar Capacitor, (f) Mylar Capacitor, (g) Silver Mica Capacitor and (h) Feed-through Capacitor
Source: https://ake-remake.blogspot.com/2018/09/capacitor.html

Generally, the electrolyte one is the most popular leaded type in the electric circuit for providing high capacitance value greater than 1 microfarad. Because the internal structure is similar to the battery which has a positive and negative charge. Moreover, it's appropriate for the work that use the low frequency or direct current. In the contrast, it can cause the electric current leakage and faults. And the other types, there are differences in the internal structures can apply to different conditions.

2.) Variable Capacitor

The value of the capacitance is alternately changed with the spindle. The internal structure containing more than a couple of a metallic plates that placed to close each other. Then, it demonstrates that one plate is stationary and another plate can induce the mobility. There is different type of material of dielectric such as air, mica, ceramic and plastic film. And it is known as the trimmer and padder as shown in in Fig.2.32

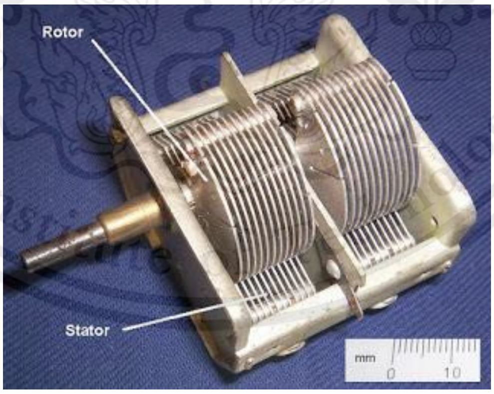


Fig.2.32 Variable Capacitor.
(Source: https://ake-remake.blogspot.com/2018/09/capacitor.html)

3.) Select Capacitor

In a capacitor, there consists of different values to choose for the coordinating purposes with the utilization of the capacitive efficiency. The value that appropriates providing to the related system conduct the suitable and comprehensive with the combination of the electrical compartment shown in Fig.2.33.

Fig.2.33 Select Capacitor.
(Source: https://ake-remake.blogspot.com/2018/09/capacitor.html)

2.6.2 Transformers

Transformers are the passive electrical gadget that transmits electricity crossing the circuit by increasing and decreasing the voltage level, but no power and frequency changed or the process of electromagnetic induction. Transformers change the voltage to increase known as 'Step up transformer' but to reduce the voltage call 'Step down transformer'.

The construction of a transformer consists of three major components, namely a magnetic core, primary and secondary winding (also known as a coil). Furthermore, each component is insulated to prevent the contract between the magnetic core and winding, and the contact of each coil layer in the primary and secondary winding as shown in Fig.2.34. Which the magnetic core (or Iron core) is made up of a thin silicon plate in order to provide a continuous magnetic path that is insulated call laminate iron core, and the material of a coil can be copper or aluminum.

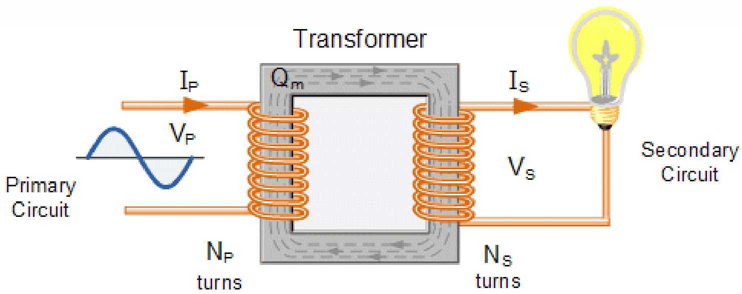


Fig.2.34 A typical voltage transformer
(Source: https://www.electronics-tutorials.ws/transformer/transformer-basics.html)

2.6.2.1 The working principle of the transformer

Transformers apply electromagnetic conduction according to Faraday's law, which refers to the mutual inductance between two or more coils, to achieve the transmission of electrical energy between circuits. The basis of this law is to predict how the magnetic field will interact with the circuit and generate an electromotive force (EMF).

Fundamentally, the primary winding is supplied by an alternative electrical source. The alternative current is charging through the winding produces the magnetic flux and magnetomotive force to surrounds the primary winding and magnetic core as shown in Fig.2.35. While the magnetic flux is continually charging as the amplitude and direction. Meanwhile, some portion of the secondary winding link with this flux. So, there are charging the flux linkage in the secondary winding. Therefore, the alternative flows in the winding which, makes the magnetic poles to be alternated between poles with the velocity equal to the electrical frequency. The magnetic line will intersect with the winding on the magnetic core and producing the voltage induction (Induce EMF) to another circuit or secondary winding. Therefore, the voltage and current will be transmitted with no electrical frequency changed.

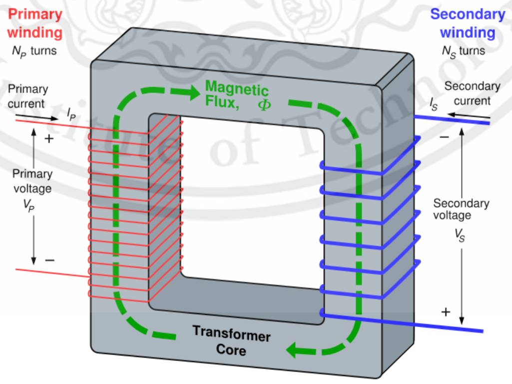


Fig.2.35 The simply operating transformer.
(Sourcehttps://energyeducation.ca/encyclopedia/Transformer)

However, the tune number of the transformer affects the rate of the voltage transforming with the primary and secondary coil. If there are more turns on the primary than the secondary coil is the step-down. In contrast, there are more turns on the secondary coil than the primary coil is the step-up. Which the turn ratio between the primary and secondary coil has the relationship with voltage and current as:

$$\frac{N_p}{N_s} = \frac{V_p}{V_s} = \frac{I_s}{I_p}$$

N_p = Number of turns in the primary coil

N_s = Number of turns in the secondary coil

V_p = Voltage across the primary

V_s = Voltage across the secondary

I_p = Current through the primary

I_s= Current through the secondary

2.6.2.2 The categorization of transformer with the utilizing purposes

A transformer classifies of the type into different application based on purpose, construction, supply, and usability.

1.) Based on the purpose

1.1) Step up transformer

Increasing the voltage level by setting the number of turns of the coil in the secondary more than the primary. Which is the basic form of a step-up transformer.

1.2) Step down transformer

Decreasing the voltage level, which is opposite to the step-up transformer. So, this type is often used in power transmission and distribution network.

2.6.2.3 Voltage regulation, Losses and efficient of transformer

1.) Voltage regulation

Voltage regulation is the parameter that indicates the ratio of voltage changed at the secondary winding. "which can observe from the difference between the load connection and no-load connection transformer. If there is a large difference, it means the transformer is bad.

In contrast, if there is a small difference; means there is good control of the voltage in the transformer. And, Factors influencing the voltage regulation are iron core compression, coiling or good design of core.

2.) Losses

The transformer is the electromechanical device that has the least losses of the power because the transformer cannot move. But it contains only two losses: the loss in magnetic core and the loss in conduction coil.

3.) Efficiency

The transformer efficiency is the operating capability in the transformer which, equally as the ratio of the output and power input. If the power input and output have a large difference, indicates the low-efficiency transformer. In contrast, the value of power input and output are similar, means a high-efficiency transformer. Therefore, the transformer will be high efficiency or low efficiency depended on the losses of the transformer.

2.6.3 Relays

A relay is an electrical device that can convert electrical energy into magnetic energy by applying a minimum current to the coil, thereby changing the open and closed state of the contacts. Therefore, the relay is like an electronic switch, and its main function is to close or open the contacts in a non-contact manner. Human intervention in the switch in the circuit. The relay can work both electrically and mechanically. However, the relay can be amplified to handle higher voltages and currents. Because the voltage applied to the relay coil is too small, it will cause the contacts to switch to a high voltage.

The relay design is mainly divided into four groups. First of all, the contact is the most important relay in the relay, just like a switch, the relay controls the current in another circuit. The choice of contact material depends on the type and size of the interrupted current or the operating frequency and voltage. Then, the bearing can be single-stage or multi-stage, thereby providing high sensitivity and low friction. Instead, Multi-Ball has less friction and greater resistance.The electromechanical design of the relay is one of the most important designs, namely the magnetic circuit design and the mechanical connection of the core, yoke, and armature. Therefore, the electromagnet is composed of soft iron and coils. Responsible for ensuring that the voltage in the circuit controls the establishment of the magnetic field. The contact then changes its status as shown in Fig.2.36.

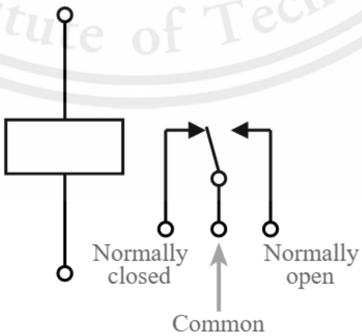


Fig.2.36 A relay circuit symbol.
(Source: https://www.electronics-notes.com/articles/electronic_components/electrical-electronic-relay/what-is-a-relay-basics.php)

2.6.3.1 The concept process of relay

Electromagnetic attraction is the fundamental based mechanism that relay utilizing in an application. When the circuit of the relay senses the fault present day, it energizes the electromagnetic area which produces the brief magnetic area. These magnetic area movements the relay armature for establishing or lasts the connections. The small electricity relay has the simplest one-touch, and the high-electricity relay has contacts for establishing the switch. The internal segment of the relay is proven inside the discerning below. It has an iron center that's wound via way of means of a manipulate coil. The electricity deliver is given to the coil thru the contacts of the burden and the manipulating switch. The present-day flows thru the coil produce the magnetic area around it. Due to this magnetic area, the top arm of the magnet draws the decrease arm. Hence near the circuit, which makes the present-day glide thru the burden. If the touch is already closed, then its movements oppositely and subsequently open the contacts shown in Fig.2.37.

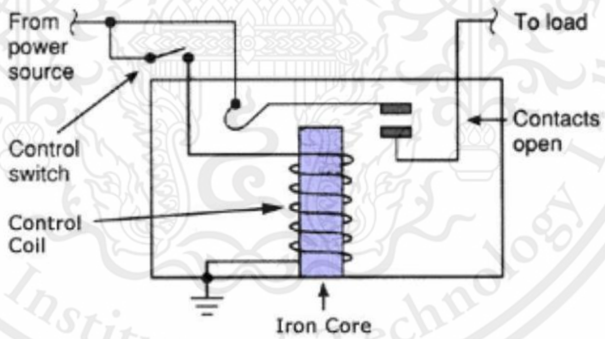


Fig.2.37 The relay function
(Source: https://www.electgo.com/what-is-a-relay/)

2.6.3.2 Types of relay

A relay can be classified into different categories based on the principle of operation and the polarity.

1.) Functional categorization

1.1) Electrothermal relay

An electrothermal relay is a device for preventing the electric machinery and battery from overheating at the time of overloading. So, this type is also in the electrical circuit that monitors temperature. The principal work of this type is; When two different materials are combined, a bimetallic belt is created. When the strip is excited, it tends to bend. The way to take advantage of this feature is that the type of bend creates a connection to the contact.

1.2) Electromechanical relay

Electromechanical relay is used in the low voltage circuit for building the magnetic field after that occur to induced the contacts of a circuit into another circuit. Therefore, this type is the standard relay that can use in the project circuit.

1.3) Solid State relay

A solid-state relay is an electronic relay device, but it does not use mechanical components such as electric heating and electromechanical relays, but uses semiconductor components, so the switching speed of the device can be easier and faster. Compared with other relays, it has a longer service life and faster switching time as shown in Fig.2.38.

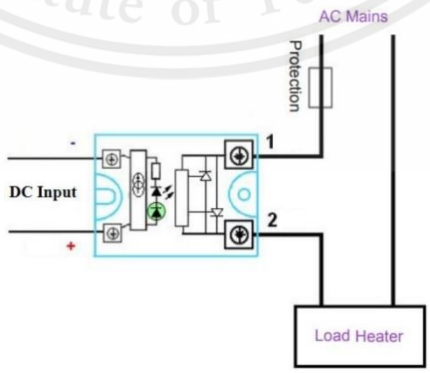


Fig.2.38 The construction of solid-state relay
Source: https://www.primusthai.com/primus/Knowledge/info?ID=122

1.4) Hybrid relay

A hybrid relay is the combination of both particular characteristics and features of electromechanical and solid-state relays.

2.) Polarity categorization

2.1) Polarized relay

They are similar to electromechanical relays but have both permanent magnets and electromagnets. The movement of the armature depends on the polarity of the input signal applied to the coil. Used in Telegram applications.

2.2) Non-polarized relay

This type of relay attains the specific feature in a non-polarity coil application. It operates the function that similar to the polarity one with designated input signal reservation.

2.6.3.3 Pole and throw

Pole and throw current are relay configurations, where poles can be regarded as shown input ports and related moving parts, and junk can be regarded as output ports. It has the following categories:

1.) Single pole, single-throw (SPST)

It contains one circuit with NC and NO contacts. It is similar to the push button shown in Fig.2.39.

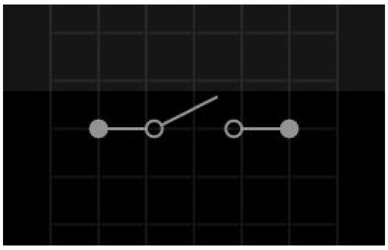


Fig.2.39 The SPST circuit symbol.
(Source: https://circuitdigest.com/article/relay-working-types-operation-applications)

2.) Single pole, double-throw (SPDT)

It contains one circuit before and can changeover contacts. It is considered as the slide switch shown in Fig.2.40.

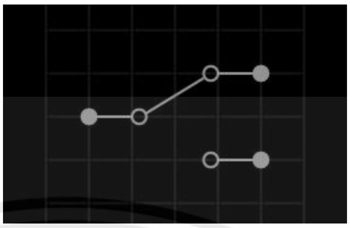


Fig.2.40 The SPDT circuit symbol.
(Source: https://circuitdigest.com/article/relay-working-types-operation-applications)

3.) Double pole, single-throw (DPST)

It contains two circuits with only NC and NO. And the contacts of these either opened and closed are done concurrently as shown in Fig.2.41.

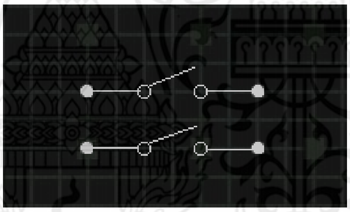


Fig.2.41 The DPST circuit symbol.
(Source: https://circuitdigest.com/article/relay-working-types-operation-applications)

4.) Double pole, double-throw (DPDT)

It is the functional combining of the both type mention earlier and attain the ability to changeover contacts. Also, it has the core function as the characteristic ability of SPDT and DPST as shown in Fig.2.42.

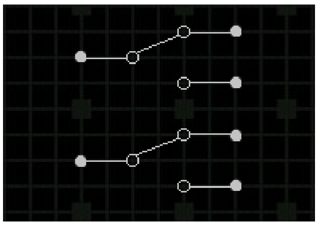


Fig.2.42 The DPDT circuit symbol.
(Source: https://circuitdigest.com/article/relay-working-types-operation-applications)

2.7 Arduino board

Arduino is the AVR microcontroller board. This particular microcontroller elaborates on the complete platform that opens in authorization for the electronic figure. It refers to the characteristics that non-complicated in all the utilization. In the hardware, MCU or microcontroller unit is the incorporation with the other electronics or recognize to Arduino board which many models of Arduino board may be different in the size and specification such as efficient voltage or the number of transceivers channel. And in the software, Arduino developed part of programming that also known as IDE. It allows putting the other command on the different models of Arduino board. Also, it can download another library from the internet for increasing convenience. And the tool for programming with the language Arduino is the C/C++ language. Therefore, the Arduino board is suitable for beginners and still flexible and further develop enough for the advanced user. And over the years, the Arduino is the main of many projects for the student and professional.

Arduino board is simple to connect with accessories, which the users can be using the shield Arduino board or the electric circuit from the outside to correlate into the I/O in the Arduino board and writing the development programs shown in the Fig2.43.

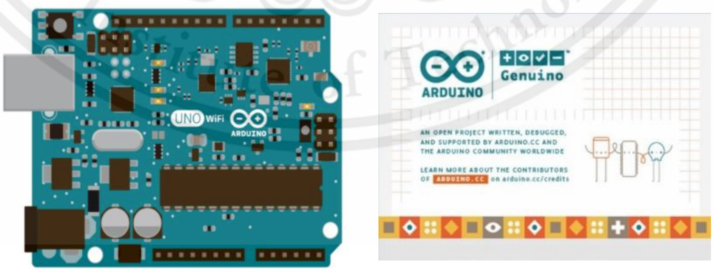


Fig.2.43 Arduino Board (left) and Arduino program (right)
(Source: https://www.arduino-makerzone.com/article/1/arduino-basic-ep0-arduino-คืออะไร-ทำอะไรได้-มีกี่แบบ)

2.7.1 The board of the Arduino Uno type

The Italian word describes the word “Uno” meaning one. It is the first version of Arduino and is the most popular standard board with a size of 68.6x53.4mm. Therefore, this specific type of board refers to the microcontroller application the fundamental capability of the ATmega328P. It consists of 20 as a sum of the output ports for both the analog and digital, the resonating ceramic with 16 Hz properties, the corresponding power jack, and a resetting button. It contains simple usability because it has everything needed to support a microcontroller board such as the simple connection to the computer with the USB or using an adaptor or battery AC-to-DC to start working on Arduino Uno Board. Furthermore, the Arduino Uno Board has been evolving until to be the R2 and R3 versions which these versions have installed the transducer of USB-to-serialRevision 2 on the board and adding the resistor to pull the related pin to the ground; making it easy to insert into DFU Revision 3.

Currently, the Arduino microcontroller in Uno type as shown in the Fig.2.44 is the most recommend. Because of its low price and it contains the libraries support which is mainly referred to as agreement with board function and if some of the compartment function collapses, users are able to replenish the components.

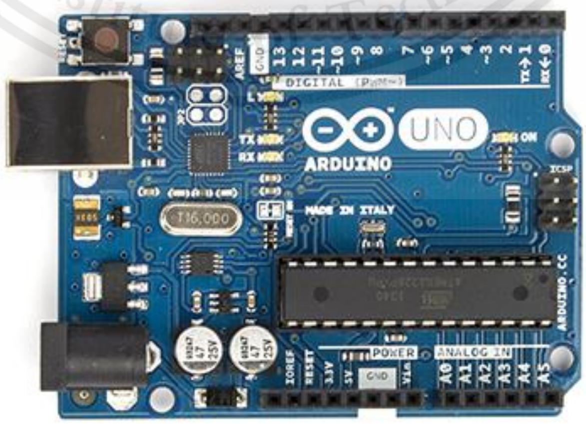


Fig.2.44 Arduino Uno R3 Board
(Source: https://sites.google.com/site/karanwinatktech/unit1)

2.7.2 Programming pattern on the Arduino

1. Coding via the Arduino IDE program. Which can download from Arduino.cc/en/main/software shown in Fig.2.45.

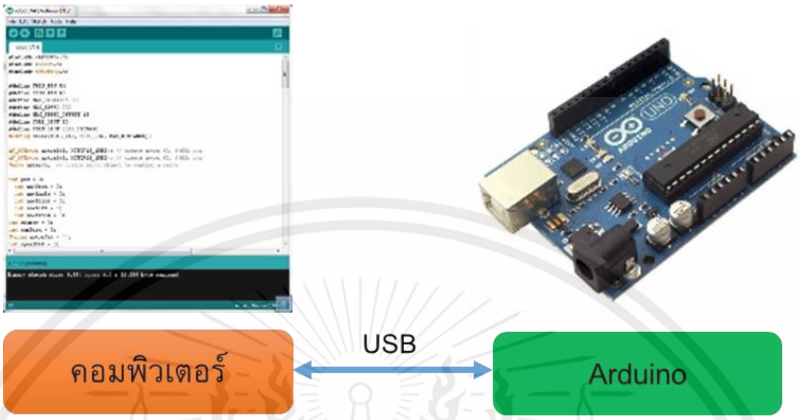


Fig.2.45 the connection between computer and Arduino board
(Source: https://blog.thaieasyelec.com/what-is-arduino-ch1/)

2. After completely coding, users have to select the used board model and Serial port number shown in Fig.2.46 and Fig.2.47.

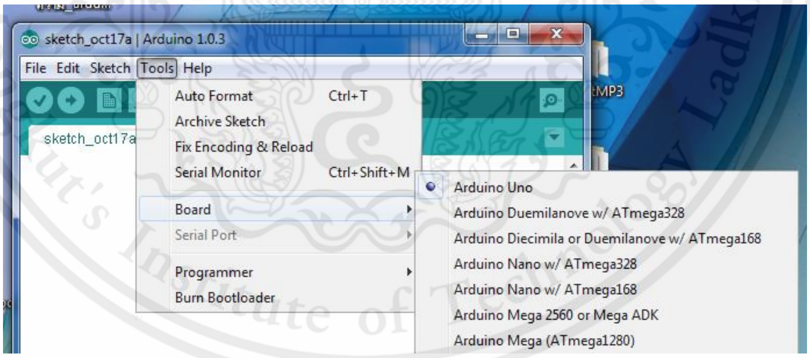


Fig.2.46 selection the board model
(Source: https://blog.thaieasyelec.com/what-is-arduino-ch1/)

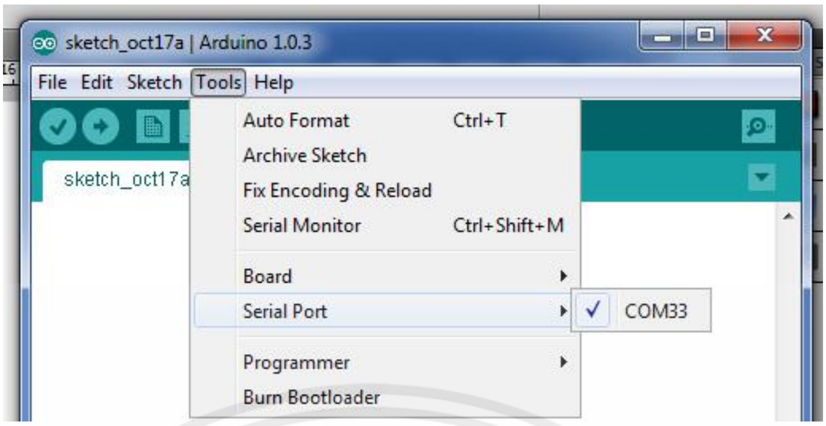


Fig.2.47 selection the Serial port
(Source: https://blog.thaieasyelec.com/what-is-arduino-ch1/)

3. press Verify button to verify and compile the code, then press Upload button to upload the code program to the Arduino board via USB. The board will start working as the code after done uploading as shown in Fig.2.48.

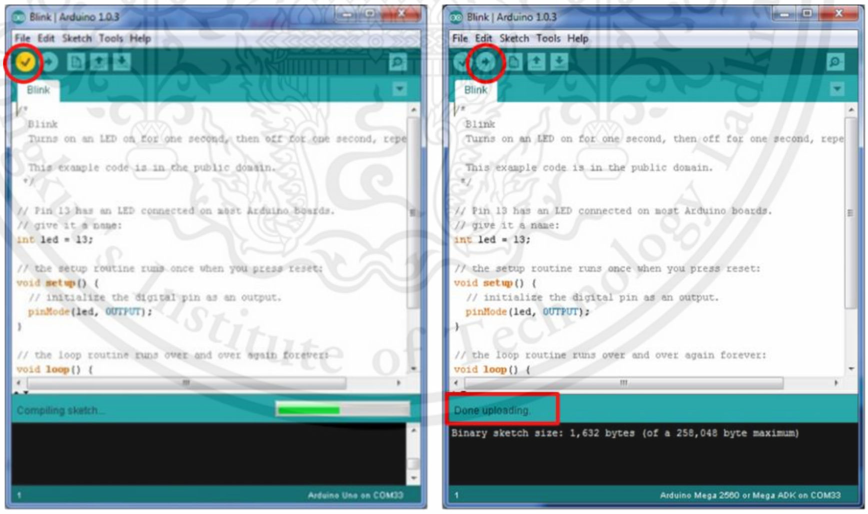


Fig.2.48 Press the verify and upload button
(Source: https://blog.thaieasyelec.com/what-is-arduino-ch1/)

CHAPTER 3
METHODOLOGY

Within this chapter, the analytical process of the design and construction of the Automated External Defibrillator. This chapter distributes the methodology into the process planning, relative component, hardware and software application, and the methodological process.

3.1 Process planning

Table 3.1 Process planning table

Active plan in first semester																
process	August				September				October				November			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Planning Phase																
Specific the capstone project topic	■															
Gathering related information of AED		■	■	■												
Accumulate the data of relevant apparatus			■	■												
Planning the working under the rest of the semester			■													
Distribute the responsibility work for project				■												
Preparation Phase																
Sepecified the component requirement					■											
Processing Phase																
Searching and attaining the components					■	■	■	■								
Test the fundamental and adapt the components function with project							■	■	■	■	■	■	■	■	■	
Gathering the experimental data										■	■	■	■	■	■	
Conduct the project Thesis and presentation (Chapter 1-3)												■	■	■	■	

Active plan in second semester																
process	January				February				March				April			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Preparation Phase																
The study over the ECG detection module	■															
The voice supporting data and component preparation		■														
The electrode probe and consecutive load for the discharging preparation			■	■												
Processing Phase																
The ECG detection with module AD8232 3 leads (limb lead)				■	■	■										
The ECG detection with moodule AD8232 2 leads (lead II)						■	■									
The voice supporting circuit Test							■	■	■							
The coordinating system of the ECG detection and highvoltage test							■	■	■	■	■	■				
Overall circuit combination experiment and check-up										■	■	■	■			
The Statement Conclusion Phase																
Gathering the experimental data and evaluate the result													■			
Discussion over the project point and possibilities														■	■	
Conduct the project Thesis and presentation (Chapter 1-5)																■
Conduct the project Thesis and presentation (Chapter 1-5)																■

According to figure Table 3.1, we establish research planning for our project in the first semester period as showing in the corresponding table. In the first month, we describe it as the pre-phase for the project consisting of the information accumulating and data research about the topic relevant to the project.

Moreover, we distribute the working responsibility toward the research within this period. Then, we order the components and ready ourselves whenever the shipment arrives. The rest of the time in this semester, we prioritize experiment and data collecting in the charge and shock working with one of the corresponding functions within AED capability for this semester. For the second semester period, the project emphasizes the related operation coordinating with the AED necessary performance. The first month in this period highlights the preparation of the required component to conduct the experimenting circuit and gathers the result for the step considerably. The related compartment to this refers to the voice supporting and the ECG detection circuit. The following period focuses on the construction and incorporation of the prototype circuit. Then, the data from this relevant system gather for the experimental conclusion and discussion phase. The final section of the second semester emphasizes the thesis file for the conclusion of the project research.

3.2 The design and construction of Automated External Defibrillator block diagram.

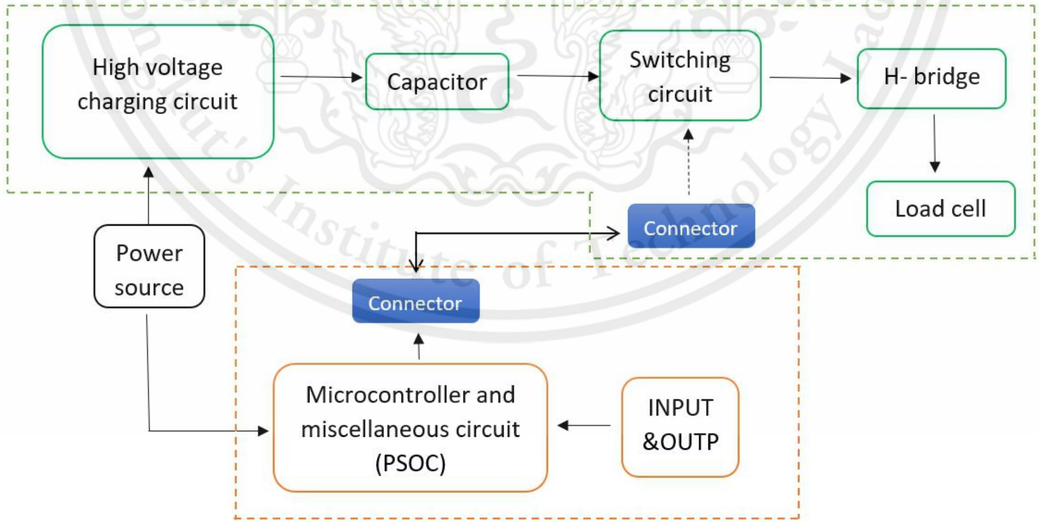


Fig3.1 The researching block diagram for the Automated External Defibrillator in the design and construction process

As the displaying in Fig.3.1, we prioritize the core function of the Automated External Defibrillator regards to the electrical charging and shocking template. We demand to implement the electronic appliance with the capability to elaborate the voltage to meet the standard requirement, storing the electrical charge and distribute it to the associated circuit, and ensuring the voltage and current release within the aspired event.

The diagram consists of two sections with their corresponding subunits. The first section describes the central function of AED that contains (i) a high voltage source that refers to a step-up transformer to increase the voltage demand to our requirement status (ii) capacitor that accumulates charge and releasing it corresponding with their principal activities (iii) switching circuit part operating the circuit alternating with the related function (iv) H-bridge for the current amplification and driving it to the load cell or target. Then, the other section consists of the smart controller section (v) microcontroller with the functional controller for (vi) miscellaneous circuit and relevant controlling action that implies to the relevant demonstration of the working process.

3.2.1 The related hardware

Table 3.2 The table of the related apparatuses

	Equipment	Picture	Function
1	DC-DC high voltage capacitor charging ZVS boost module		Amplifying the voltage from 10-32 Volts to 450-780 Volts as a step-up transformer.
2	Arduino Uno board		Microcontroller for related circuit and component

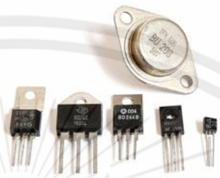
Table (continue)			
3	Capacitor		Storing and distributing of the collecting electrical charge
4	Transistor (MOSFET)		Enable and disable the associated circuit connection
5	Relay		Enable and disable the associated circuit connection and ensuring fundamental safety issue
6	Push button		Activated the component capabilities
7	Cable jumper		Wiring connection
8	Generator		Power source

Table (continue)			
9	Multimeter		Measurement the DC Voltage
10	AD8232		ECG monitoring
11	Lead II detection		ECG monitoring
12	18650 Li-ion battery		Power Source
13	JQ6500		Sound Module

According to Table 3.2 is the list of components used in the project. Several components enable to organize locally. However, some components require the purchasing and shipments from aboard, including high voltage generator and specific module in this table.

3.3 The high-voltage preparation procedure

The equipment in the initial come in the distribution in an isolated component. First, we prioritize to observe the voltage amplifying capabilities of the step-up transformer with the multimeter as shown in the Fig.3.2. Then, the connection wires prepare for the connection with the generator that applies the initial voltage into the transformer and capacitor for the electrical charge accumulation shown in Fig.3.3.

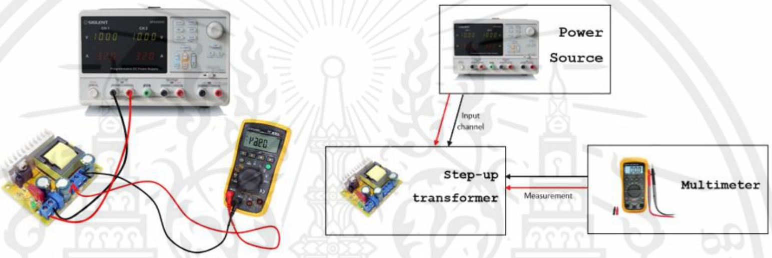


Fig3.2 The voltage amplifying check-up

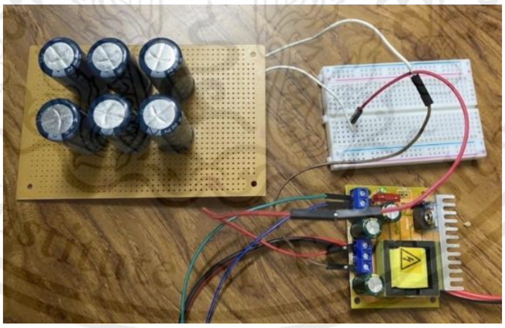


Fig3.3 The connection from the generator to transformer
and capacitors

3.3.1 Selected capacitance and circuit preparation

After the process of the transformer preparation, according to the standard of the Automated External Defibrillator requires the output voltage around 1200 volts and comprises the energy discharging approximately 200 Joules. The multimeter or the electrical measurement unit unable to withstand the immense amount of charge and voltage. We intended to scale the voltage experiment into a different ratio that can correlate with the desire voltages and energy shown in Fig3.4 to Fig.3.6. The capacitor in the preparation stage employs the commercial capacitor instead of the supercapacitor that is extremely limited and difficult to obtain the module for the research.

Fig3.4 The prepared capacitive bank utility instead of the supercapacitor (1st model)

Fig3.5 The prepared capacitive bank utility instead of the supercapacitor (2nd model)

Fig3.6 The prepared capacitive bank utility instead of the supercapacitor (3rd model)

The preparation of the different values of the capacitor can generate an appropriate charge and shock performance in significant construction shown in Fig.3.7. The relay utilizes within this circuit as the current pathway available for the releasing the electrical charge in particular moment. The preaparation of the relay within this circuit as the normal open circuit as shown in the Fig.3.8. The actication of the relay that permit the current from the capacitive bank to transmits to the load cell activate throught the active low- high for the relay.

Initially the relay seperate circuit until the relevant active input allow them to transfer the current. According to this ability, it consider relay as the circuit changing mudule.

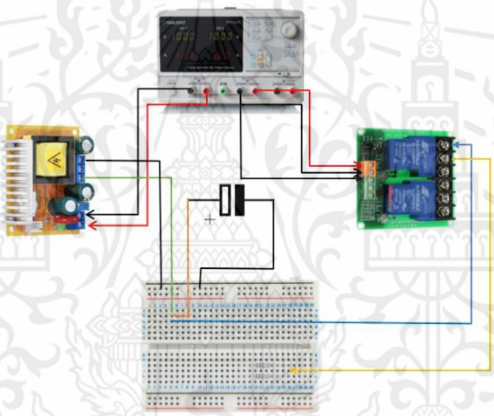


Fig3.7 The relay connection for basis of a circuit observation diagram

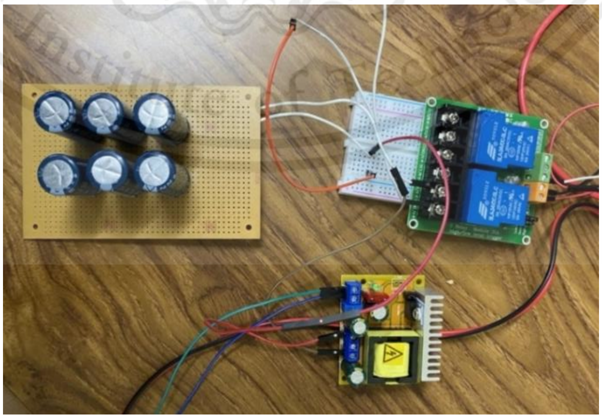


Fig3.8 The relay connection to the cooperated component

The construction of the voltage divider in this circuit is to eveluate the electricla proficiency through the measurement device that can withstand the voltage in low capacity accordong to Fig.3.9. We applied the formalation as the figure below to distribute the voltage of the circuit discharging from the capacitor shown in Fig.3.10.

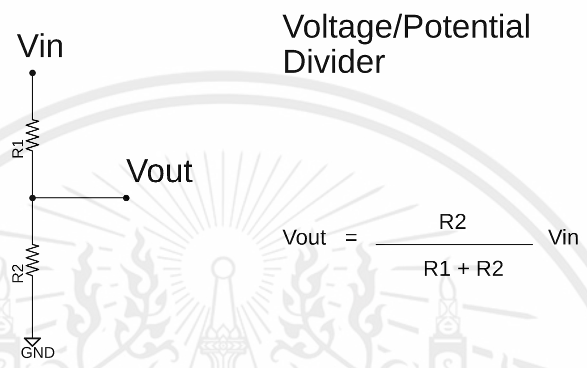


Fig3.9 Voltage divider formula and basic schematic
(Source: https://www.electroniclinic.com/what-is-a-voltage-divider-or-potential-divider-formula-and-practical-uses/)

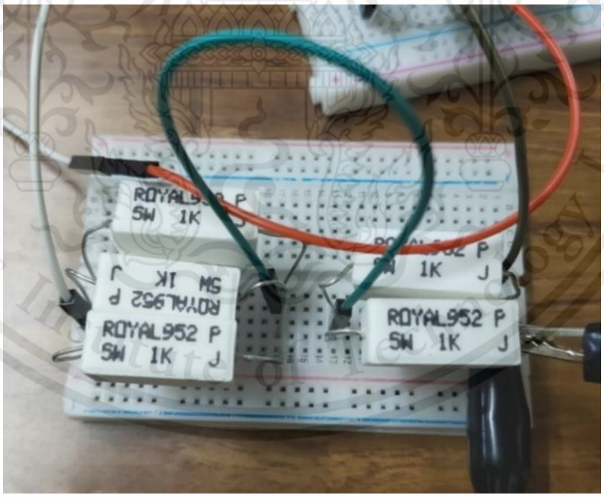


Fig3.10 The voltage divider connection in the prepared circuit

The consequence of the dividing of the relative voltage enables us to recognize the diagram of the voltage activity through the oscilloscope measurement that preserves the observing with individually low voltage application.

3.3.2 Charging progress

For the overall process, the charging activities conduct with the combination of the power supply generating the electrical source delivers to the step-up transformer throughout the connection. The transformer combines with the capacitive bank originating from the series of the capacitor for collecting the electrical charge shown in Fig.3.11.

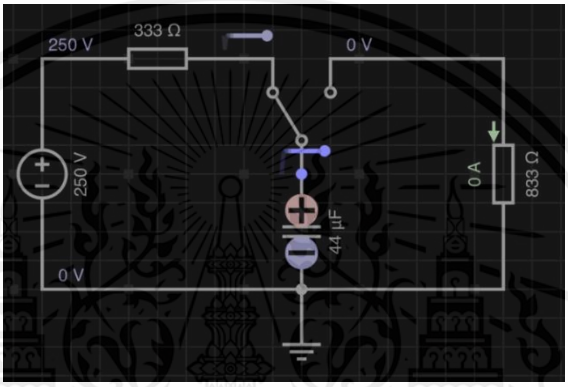


Fig3.11 The electrical charge delivers from the source to the capacitor diagram

3.3.2.1 The comparison with capacitance capabilities

The functional activities of the capacitive bank corresponding to the charging and discharge advocates and compares with the graphical demonstrating phenomenon of capacitance as shown in the Fig.3.12. This figure demonstrates the charging and discharging curve potential of capacitor application. The observation result from the circuit requires to

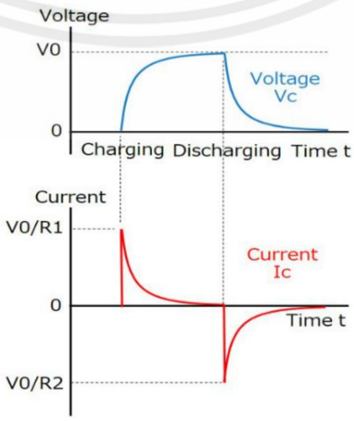


Fig3.12 The diagram demonstrates the capacitance activities in charging and discharging
(Source: https://www.electronics-tutorials.ws/rc/rc_1.html)

compare with this specific graph and a standard of the process in releasing an appropriate charge as the electrical shock function. Moreover, the charging time and the durability of the storing electrical charge requires the concern under the application.

The desire value can calculate through these specific equations and set up the appropriate value with collecting variable with relative output determination. The eqaution for charging the time comstant of the capacitance ability follow as:

$$\tau = RC$$

These calculatoin corresponding to the time factor to the capacitance acitivities where R represents the resistance in the RC circuit and C for the capacitance within the relevant diagram.Which the equation for calculating discharing follow as:

$$v(t) = V_s e^{-\frac{t}{RC}}$$

The equation above demonstrate the voltage output at the capacitance discharging within the corresponding timeconstant and the reletive resistance and capacitance within the ciruit. The Vs represent the input voltage and Vc represents for the capacitive voltage.

For the performance of the voltage capabilities with the corresponding utilization of the capacitance value with specific voltage demand, We apply equation (3.3) to calculate the specification of the capacitance value to adjust with the particular utilization of the circuit of the project.

3.3.3 Discharging progress

The application of the discharging require the connection of the capacitive bank to load cells and disconnection of the the capacitive bank with the generating source respectively. The connection from the capacitive bank to the load cell with the relay as the enable and disable to pathway of the current for the appropriate action of the Automated external Defibrillator. Whereas, the reponsibilty of the relay can replace by the power transistor the connect base to the functional source, the collector to the capacitive bank, and the emiiting to load cell respectively. Moreover, the load cell connects to the voltage divider for the electrical activity observation as shown in Fig.3.13.

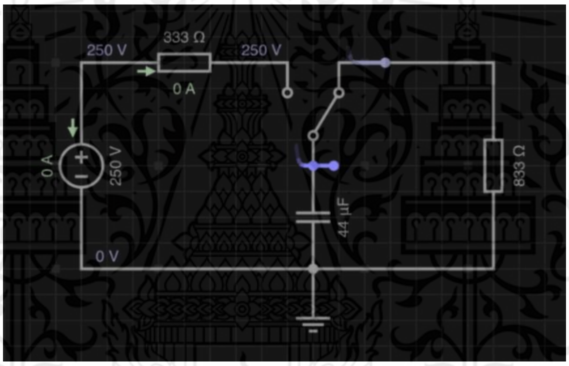


Fig3.13 The circuit switching as the discharge operation diagram with relay

3.3.3.1 The discharging probe design and preparation.

The actual electrode pad designing for AED application purposes is the disposable pads that adhesive to the patient body. Currently, the experiment requires an electrode pad that enables us the multiple measurement purpose as the result collection. The metallic probe considers for this section with the electroconductivity and the heat resistance as the characteristics. Moreover, the property containing the actual impedance that allows the current to flow with less resistance requires. The stainless steel is the decision toward the testing pad for the consecutive operation and the data collection with the following design in Fig.3.14.

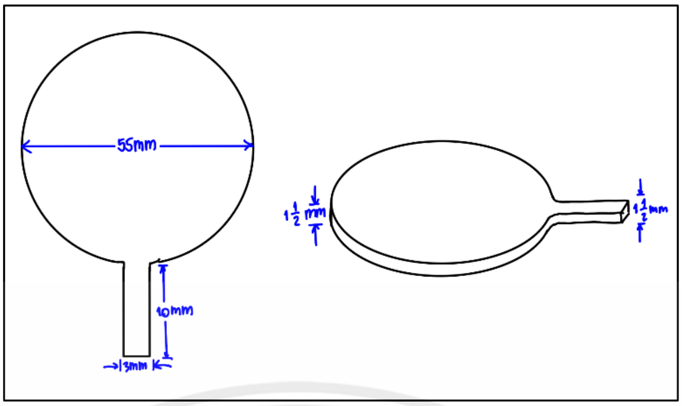


Fig3.14 The testing pad design for the application of multiple measurement

The design of the pad refers to the thin-liked shape using in the actual field. The stainless-steel tip extension purpose is the connection point with the wiring to the high-voltage part for the electrical delivery to the referring pads shown in Fig.3.14. Also, the side attaching to the reference load polishes for the uniform surface reducing uneven distribution of the electrical pathway.

Fig3.15 The testing pad work piece for the application of multiple measurement

3.3.4 The evaluation method

The preparation of the circuit of the high-voltage function for the energy output evaluation requires a specific load for the procedure. For this experiment, the load application refers to the human chest that contains a value of approximately 500 ohms. This value indicates to resembles the other mammal chest impedance as well. So, we conducted the energy output verification both in the physical result and the data accumulation for further analysis.

1) The test with the preparation meat

The preparation of the particular load substitution for the realistic result collecting base on the reference load requires the load that resembles the human chest. According to the human chest, the impedance around 500 determines the average in the animal being flesh resistivity. Therefore, the experiment load is the chicken breast. The breast meat resembles the human chest, not for the similar impedance value but the application used to determine the side effect of the electrical transmission over the flesh. We assume that if the burnt damage presenting on the meat refers to the electrical activities side-effect and heat generation exceeding the safety point. So, the chicken breast utilizing in this operation shows in the Fig.3.16.

Fig3.16 The chicken breast for the reference load in the operation

2) The testing with the calibration unit

The evaluation of the energy characteristics required significant testing calibration to generate the specific value. The standard energy of the AED releasing to the patient is in the range from 120 to 200 joules per shocking. Then, the calibration unit in the figure below is the unit from the faculty facilities and properties. The model of the calibration unit of the Bio-Tek applies in the energy output determination from the high voltage part of the circuit shown in Fig.3.17. Also, it will involve the testing measurement of the final construction of the AED prototype again for the steady value supporting evidence.

Fig3.17 Bio-Tek calibration unit

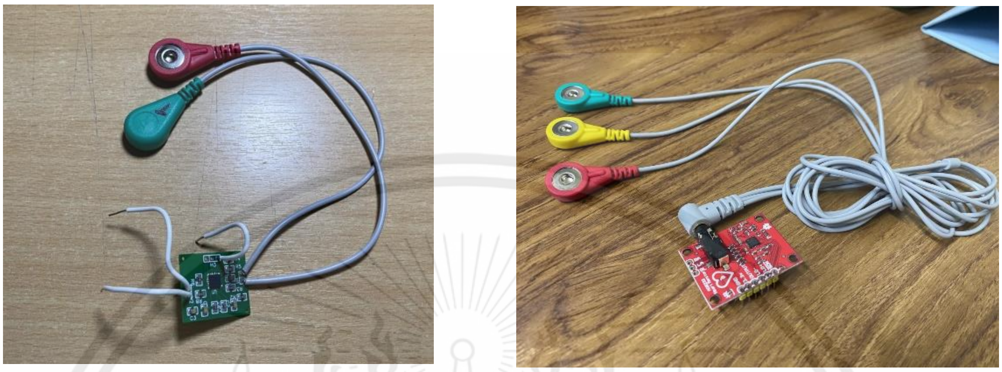
3.4 The ECG detection circuit preparation

For the AED operation, ECG detection is the fundamental assessment of the relation between the irregular heart rhythm adjustment with the corresponding sudden electrical impulses transmission. Initially, we prioritize the coordinating function to demonstrate and set the fundamental condition of the ECG with the essential operation of the AED framework.

3.4.1 The constructing preparation

The construction of the ECG detection consists of the microcontroller board and the detection module shown in Fig.3.18. This experiment applying Arduino for the functional condition set up and operate with the coordinating signal generated from the calibration unit. The module AD8232 with three leads as the lead attachment for the Einthoven's triangle liked observation and repetition of the actual AED pads attachment with AD8232 lead II function.

These modules utilize in this method to verify the ECG pattern generated. The constructed pattern as shown in Fig.3.19 and the practical circuit in Fig.3.20.



(a) (b)

Fig3.18 ECG detection module (a). AD8232 limb lead detection
(b) AD8232 lead II detection module

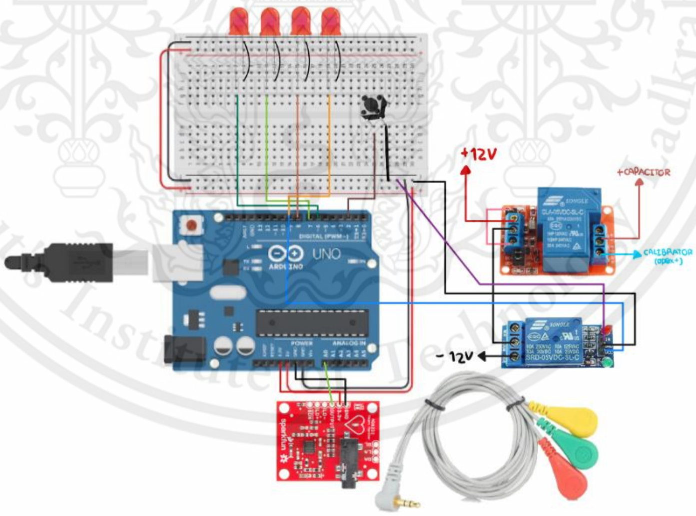


Fig3.19 ECG detection circuit construction design

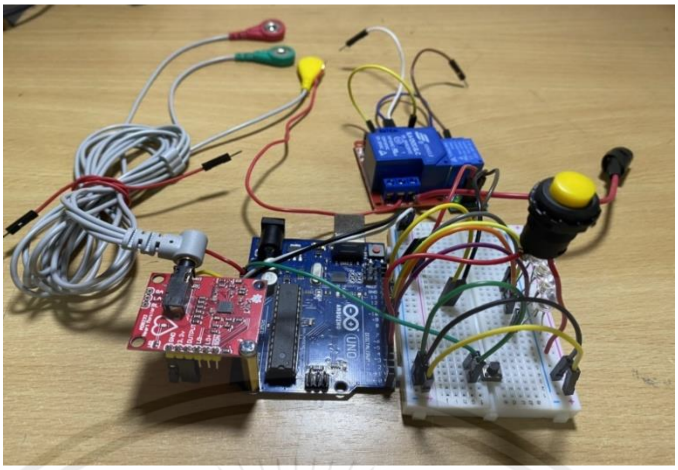


Fig3.20 The appearance of the ECG detection circuit

3.4.2 Output accumulation

The experimental result of the ECG pattern identification related to the R waveform within the generated waveform observes with specific value designated as the setting up among 30, 60, and 120 bpm. The operative data will correlate with code inside the Arduino that sets the observation in the serial monitor and manipulate the R wave average value as the threshold of the detection as the identification factor as the interface shown in Fig.3.21 and application code in Fig.3.22. Also, the module AD8232 lead II attaches on the sternum and apex location signal emitting.

Fig3.21 The calibration unit bpm generated set up interface

3.5 Supporting voice circuit preparation

The application of the voice support system describes as the user assistance in the emergency condition disclaiming. The indication of the current situation and operation of the framework relate with a sound system to announce for the user practical application.

3.5.1 Voice module circuit preparation

The application of the voice support module refers to the JQ6500 module in Fig.3.22 that initiates the record files with input the electricity into the responsible channel. In this part, we launch the recorded file and manipulate it to the AED function with the relay to allow and prohibit the current flow into the module for the sound activation constructed as shown in Fig3.34.

Fig3.22 Voice support module JQ6500

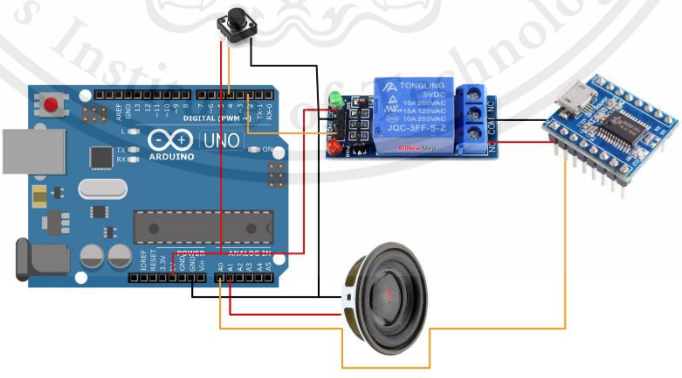


Fig3.23 The design of the sound module JQ6500 manipulation with Arduino

The sound supporting module is the accessory function in the essential part of the AED operating composition. The relay in this according system utilizes the sound announcing operation. The files recording will perform according to the specific condition as follow.

1) The prototype initiation plays "AED operating is ready, place electrodes on the chest and plug into the machine.".

2) The capacitance charging activates plays “Charging in progress, please stand clear of the patient".

3) The ECG analysis and discharging verification plays “ Do not touch the patient, analysis for shocking in progress.”

4) The completion pf process plays “The operation complete”.

3.6 The combination of all relevant framework

The last procedure of the project is combining all of the circuit functions as a single circuit construction as shown in Fig3.26. This part conducts the evaluation of the performance and the results for the experiment of the constructed AED prototype shown in Fig.3.27. The high-voltage circuit coordinates the responsibility with the ECG as the observation over the patient when the sound support announces the status of the process accordingly.

Fig3.24 The design of the combing circuit platform of the AED prototype

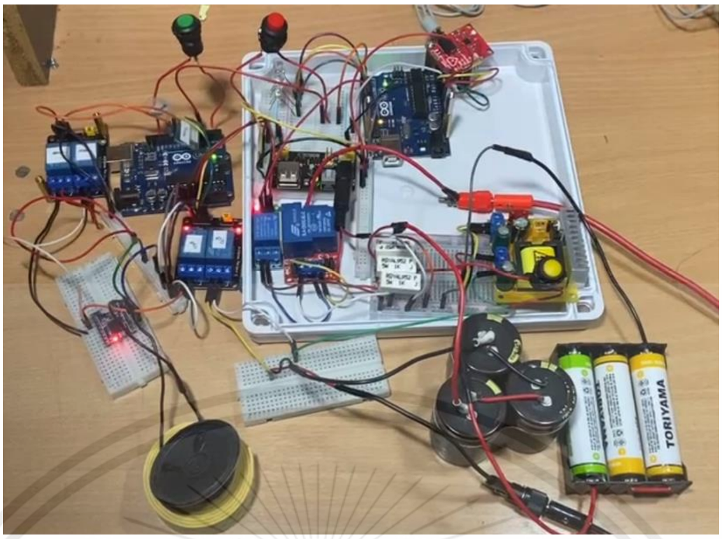


Fig3.25 The overall construction appearance without box

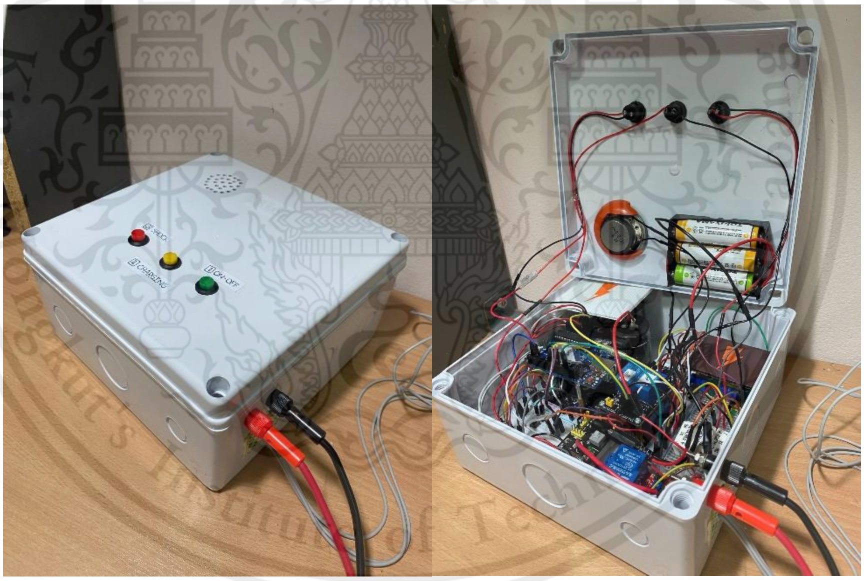


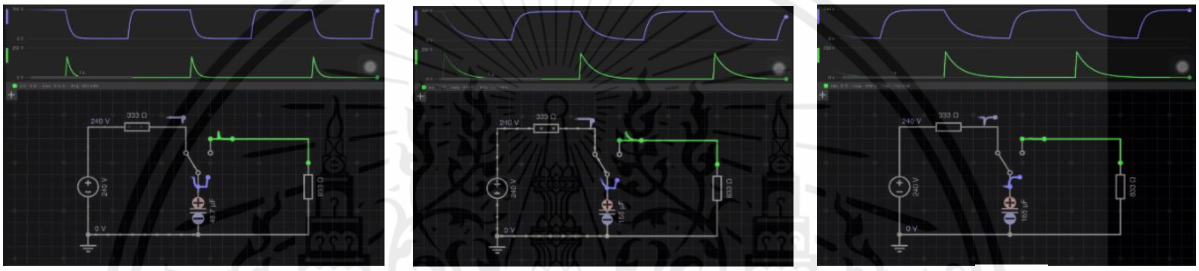
Fig3.26 The overall construction appearance arranging in box

CHAPTER 4
EXPERIMENTAL RESULT

The experimental result section details the following experiment for each of the diagram and circuitry proceeds. The relevant statement distributes as the effect and result of the particular experiment appear as the informatic evidence for the discussion.

4.1 The high-voltage circuit experiment

4.1.1 Theory simulation in the related program



(a) (b) (c)

Fig.4.1 The model charging-discharging circuit by manual switching in EveryCircuit program construct with particular capacitance (a) 48.7 uF capacitor performance (b) 156 uF capacitor performance (c) 165 uF capacitor performance

4.1.2 Oscilloscope measurement for low-voltage behavior observation

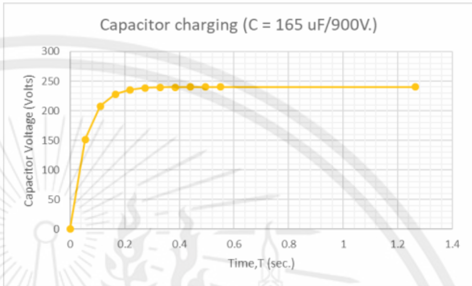
(a) (b) (c)

Fig.4.2 The graph result in oscilloscope with low voltage of each capacitance value following (a) 48.7 uF capacitor performance (b) 156 uF capacitor performance (c) 165 uF capacitor performance

4.1.3 Experimental result in high-voltage application

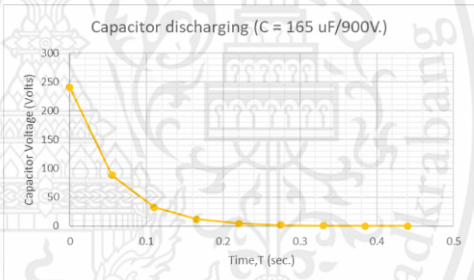
The part of the experiment to elaborate with the calculated estimation of the RC time constant from the relevant formulation and concluded the actual result in practical progress as shown in Table 4.1 to Table 4.3.

Time	Time,T	Capacitor Voltage
	0	0
1T	0.055	151.71
2T	0.11	207.52
3T	0.165	228.05
4T	0.22	235.604
5T	0.275	238.38
6T	0.33	239.405
7T	0.385	239.781
8T	0.44	239.92
9T	0.495	239.97
10T	0.55	239.989
23T	1.265	240



(a)

Time	Time,T	Capacitor Voltage
	0	240
1T	0.055	88.291
2T	0.11	32.48
3T	0.165	11.949
4T	0.22	4.396
5T	0.275	1.617
6T	0.33	0.595
7T	0.385	0.21885
8T	0.44	0.0805



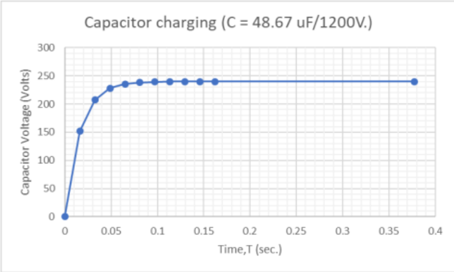
(b)

Manual experiment		
	Charging time (sec)	Discharing time (sec)
1	1.5	1
2	1	1
3	1.5	1

(c)

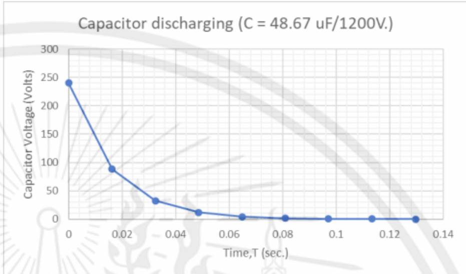
Table 4.1 The table result of calculation charging and discharging time from the formula by using 165 uF capacitor with manual assessment (a) Theocratical computed charging time (b) Theocratical computed discharging time (c) charging and discharging time by manual switching

Time	Time,T	Capacitor Voltage
	0	0
1T	0.0162	151.71
2T	0.0324	207.52
3T	0.0486	228.05
4T	0.0648	235.604
5T	0.081	238.38
6T	0.0971	239.405
7T	0.1134	239.781
8T	0.1296	239.92
9T	0.1458	239.97
10T	0.162	239.989
23T	0.3776	240



(a)

Time	Time,T	Capacitor Voltage
	0	240
1T	0.0162	88.291
2T	0.0324	32.48
3T	0.0486	11.949
4T	0.0648	4.396
5T	0.081	1.617
6T	0.0971	0.595
7T	0.1134	0.21885
8T	0.1296	0.0805



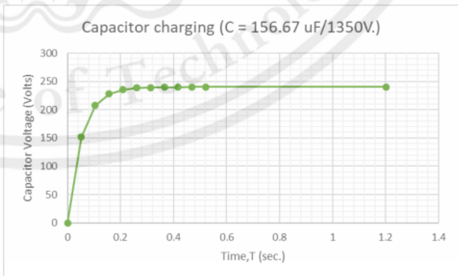
(b)

Manual experiment		
	Charging time (sec)	Discharing time (sec)
1	1.6	1
2	1.3	1.1
3	1.5	1.1

(c)

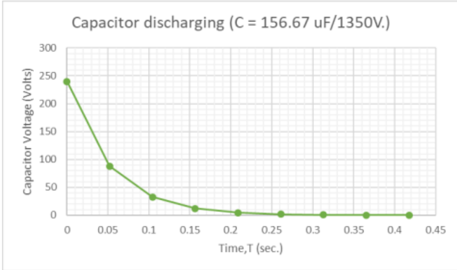
Table 4.2 The table result of calculation charging and discharging time from the formula by using 48.67 uF capacitor with manual assessment (a) Theocratical computed charging time (b) Theocratical computed discharging time (c) charging and discharging time by manual switching

Time	Time,T	Capacitor Voltage
	0	0
1T	0.0522	151.71
2T	0.1044	207.52
3T	0.1566	228.05
4T	0.2088	235.604
5T	0.261	238.38
6T	0.3132	239.405
7T	0.3654	239.781
8T	0.4176	239.92
9T	0.4698	239.97
10T	0.522	239.989
23T	1.2006	240



(a)

Time	Time,T	Capacitor Voltage
	0	240
1T	0.0522	88.291
2T	0.1044	32.48
3T	0.1566	11.949
4T	0.2088	4.396
5T	0.261	1.617
6T	0.3132	0.595
7T	0.3654	0.21885
8T	0.4176	0.0805



(b)

Manual experiment		
	Charging time (sec)	Discharing time (sec)
1	1.55	1.29
2	1.98	1.39
3	1.68	1.26

(c)

Table 4.3 The table result of calculation charging and discharging time from the formula by using 156.67 uF capacitor with manual assessment (a) Theocratical computed charging time (b) Theocratical computed discharging time (c) charging and discharging time by manual switching

According to the result, we proceed the capacitance with 156.75 uF to the next step due to the satisfaction result show in the properties observation.

4.1.4 The electrical discharging to the reference load

The experiment proceeds in the capacitive electrical energy discharge to the specific load show the significant observation for the outcome. We assume that the burnt area on the result represents the presence of the electrical-shock effect on the meat in Fig.4.3. We utilize chicken breast as a load instead of human flesh with approximately 500 ohms in impedance for the observation as shown in Fig.4.4.

Fig.4.3 The burnt mark observation on the chicken breast as a load.

Fig.4.4 The comparison of the shocked meat between before and after. (a) the prepared chicken breast before shocking (b) the chicken breast after release the shocking.

4.1.5 The calibration unit measurement

The experiment conducts the electrical discharging toward the calibration unit observes the energy-releasing as a measurement shown in Fig.4.5. We utilize the existing facilities calibration, including Bio-Tek's and Fluke's calibrators to observe the result shown in Table 4.4 to Table 4.6.

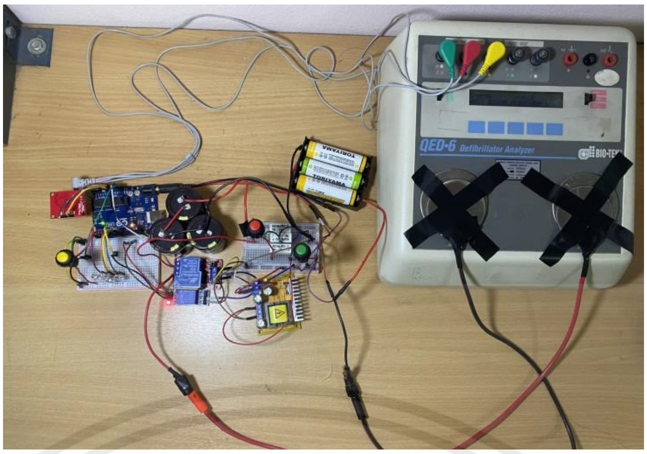


Fig.4.5 The observation over the shocking result with Bio-Tek calibration module

Round	Voltage Charging (V)	Energy (J)	Calculated Energy (J)
1	851	112.1	56.73
2	846	117.8	56.06
3	841	116.3	55.4
4	840	114.7	55.27
5	842	113.3	55.54
6	841	114.6	55.4

Table 4.4 The comparison of the shocking result between calculated and result energy from 12 V with 3 A for stepping up voltage to capacitance 156.75 uF with specific charging time at 5 second

Round	Voltage Charging (V)	Energy (J)	Calculated Energy (J)
1	522	45.7	21.35
2	522	47.1	21.35
3	522	47	21.35
4	522	47	21.35
5	521	46.4	21.26
6	522	46.9	21.35

Table 4.5 The comparison of the shocking result between calculated and result energy from 14 V with 3 A for stepping up voltage to capacitance 156.75 uF with specific charging time at 5 second

Round	Voltage Charging (V)	Energy (J)	Calculated Energy (J)
1	523	46.9	21.42
2	523	46.8	21.42
3	523	46.9	21.42
4	523	47.1	21.42
5	523	47	21.42
6	523	47	21.42

Table 4.6 The comparison of the shocking result between calculated and result energy from 16 V with 3 A for stepping up voltage to capacitance 156.75 uF with specific charging time at 5 second

4.2 The electro cardiogram detection circuit

4.2.1 The detection of the completed module AD8232

the electrocardiogram detection with real-time signal creation from the Bio-Tek module calibration unit with different in wavelength shown in Fig.4.6 to Fig.4.8.

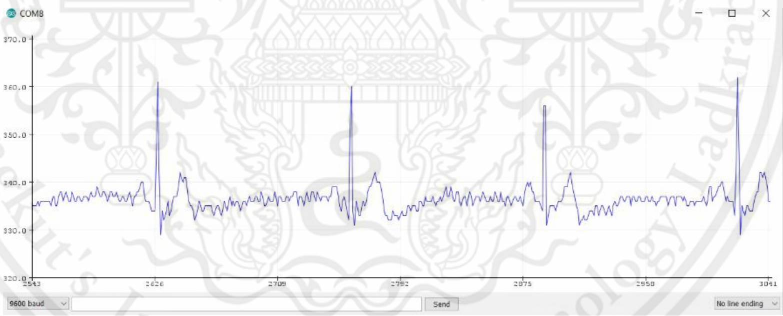


Fig.4.6 The generated 30 bpm of the electrocardiogram measuring result.

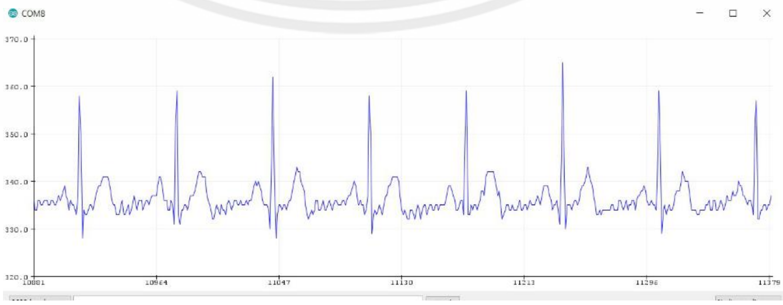


Fig.4.7 The generated 60 bpm of the electrocardiogram measuring result.

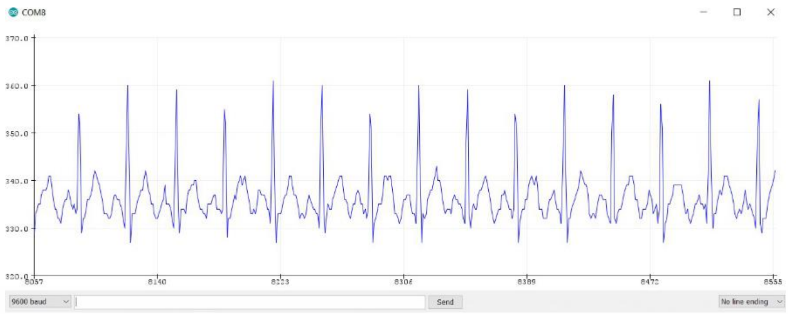


Fig.4.8 The generated 120 bpm of the electrocardiogram measuring result.

4.2.2 The measurement of the electrocardiogram through apex and sternum position

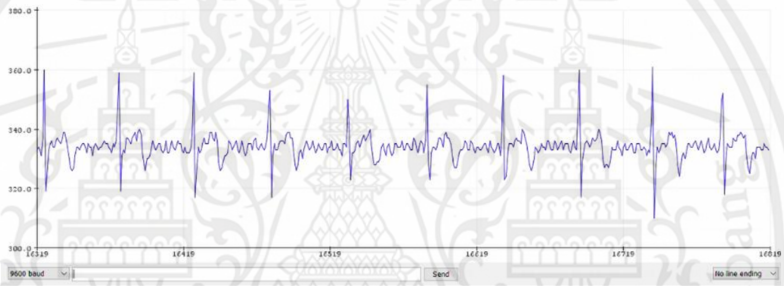


Fig.4.9 The measurement of the electrocardiogram to attaching pad reference for AED application

4.2.3 The application of the real-time electrocardiogram measuring

The application applied whenever the value reading on the corresponding axis reach a setting threshold show significant output to be observed.

4.2.3.1 The auto-shocking status reference

Every R wave detecting with corresponding threshold given command one led on the arranging circuit to activate one by one after another. When all 4 is activated, the last blink up refers to shocking status. The mechanism result in Fig.4.10 to Fig.4.14.

Both of the result show in these following figures conduct in both of the created pulse and the AED attachment area measuring. The final LED activation on the fifth one arranging on protoboard response with the electrical connectivity providing from the transistor.

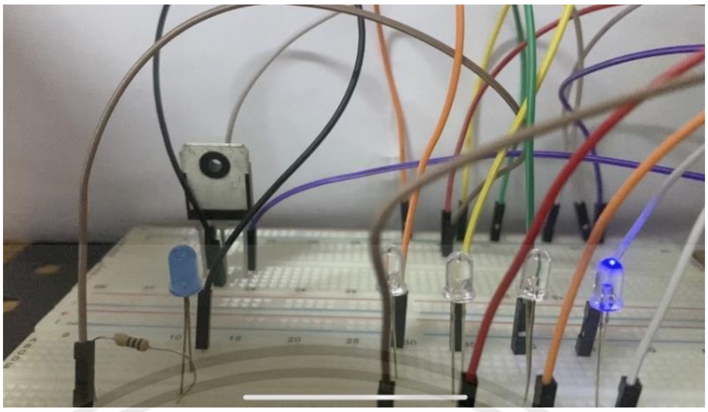


Fig.4.10 The led activation for one R-peak in ECG detected.

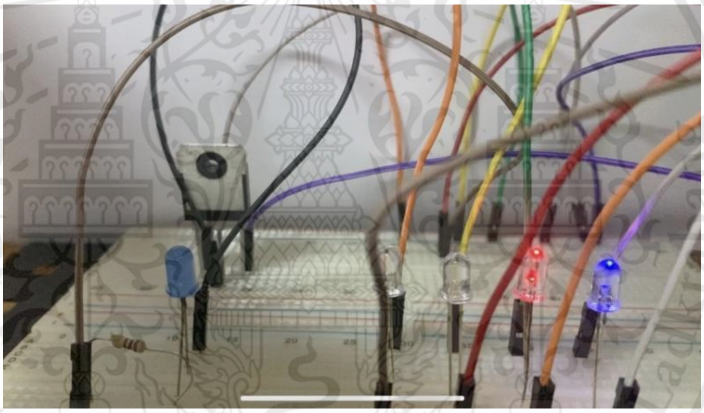


Fig.4.11 The led activation for two R-peaks in ECG detected.

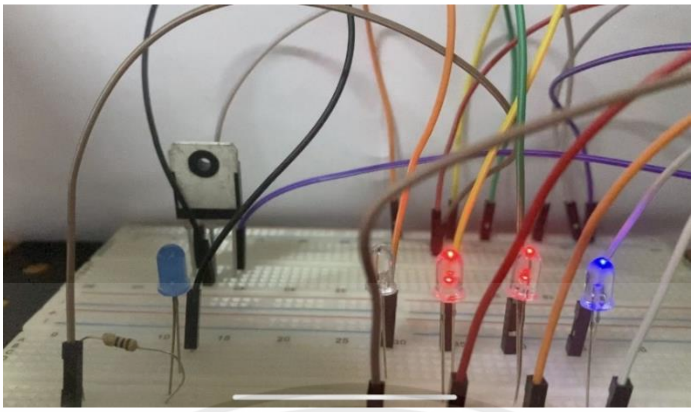


Fig.4.12 The led activation for three R-peaks in ECG detected.

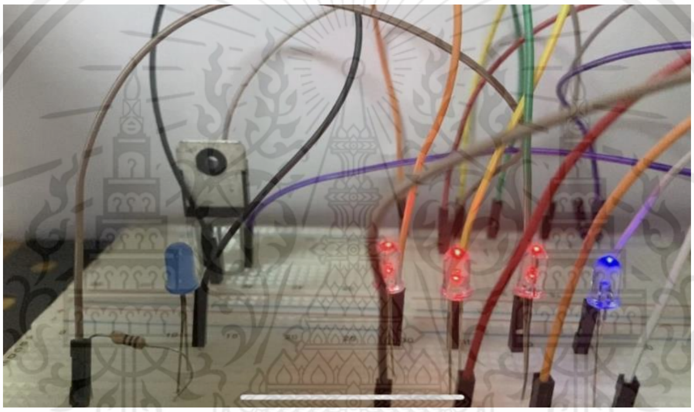


Fig.4.13 The led activation for four R-peaks in ECG detected.

Fig.4.14 The led activation for five R-peaks in ECG detected and conducting shocking signal

4.3 The overall circuit combination experimenting result

The designated function with the combination of the overall circuit conduct to collect the experimental results accordingly. The aggregate form of the circuit with the high-voltage, ECG detection, and voice support constitutes the result evaluation. These significant outputs influence by the utilization of the designated input value. The input is the 12 V transforming to the high-voltage level charging in the capacitance with 156.67 microfarads. The particular charging time is approximately 7 seconds utilizing the process of the output gathering with coveted input level. The displaying output on the calibration unit interface occupies the experimenting result conducting ten times with the input variable fixed as shown in Table 4.7. with corresponding signal detected in Fig.4.15 and Fig.4.16.

Input = 12V, 3A || DC-DC = 780 V || Capa = 156.67 uF, 1350V charging-time = 7 second			
Round	Voltage Charging (V)	Energy (J)	Calculated Energy (J)
1	851	112.1	56.73
2	846	117.8	56.06
3	841	116.3	55.4
4	840	114.7	55.27
5	842	113.3	55.54
6	841	114.6	55.4
7	840	112.2	55.27
8	842	117.8	55.53
9	850	114.8	56.59
10	843	112.1	55.66

Table 4.7 The experimental result collecting from the overall circuit test for 10 rounds of the operation with 156.67 uF capacitor charging with 780 V input in 7 second.

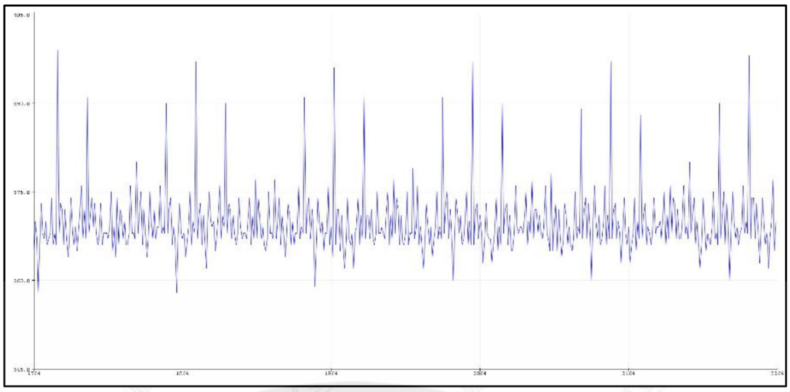


Fig.4.15 ECG detection first diagram during the overall testing sample one with 90 bpm rate.

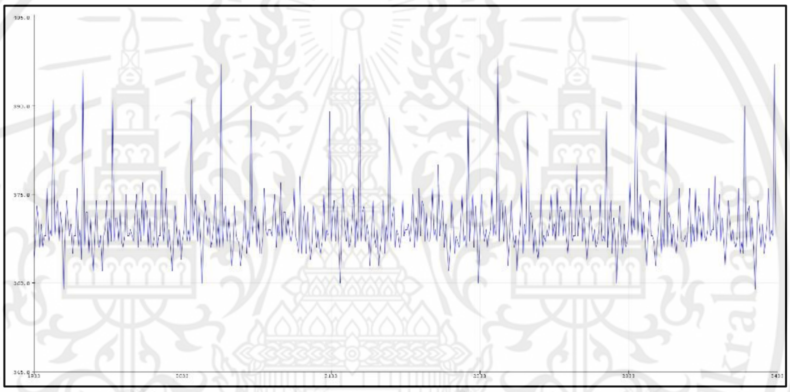


Fig.4.16 ECG detection second diagram during the overall testing sample one with 90 bpm rate.

The corresponding voice support framework plays the recording file that relevant to the AED transaction. The recording files associated with the operating description play with a specific action to communicate with the users. The result appears that the fundamental announcement works together with the circuit equably.

CHAPTER 5
CONSLUSION AND DISCUSION

5.1 Experiment evaluation and conclusion

1) The conclusion in the high-voltage circuit

The high voltage circuit compartment consists of the charge collecting with the corresponding releasing part. In the charging framework, the step-up transformer adjustment applies to the maximum value of the unit capabilities. So, it amplifies specific input to the 780-volt direct current. However, the difference in the voltage input offers different results in the capacitance charging and threshold. The experiment applies the range of voltage from 12 to 16 volts 12 volts result provides the most distinguished consequence in charging time and energy output. That result produces the charging amount of voltage in the capacitor up to the threshold that we coveted.

The related capacitors select for the capability experiment. The observation pulls through the linearity of the voltage from low voltage circuit to high voltage circuit through Ohm's law that describes the voltage, current, and resistance of a relevant circuitry. Initially, the capacitance value includes 48, 156.67, and 165 microfarads. All the capacitors possess a voltage threshold of up to a thousand in all particular subjects. We decide on the 156.67 microfarads as the charging section due to charging time and displaying graph in a demonstration on the utilization of itself. Moreover, the accumulating energy reaches the value desire in the standard when computing in the energy formula approximately 120-200 joules.

For the alternating circuit part, changing from the charging to discharging framework requires the circuit shifting unit. In the project, we apply relays to commend this task. One of them connects to the High-voltage flow. Therefore, this relay requires input to 12V. We combine it with another low voltage relay to manipulate the function of another relay. So, we can utilize the shifting unit with the Arduino command corresponding to the ECG detection framework. Consequently, the shifting task applies with another framework effectively to change from the charging mechanism into the voltage releasing pads.

The last part of the high-voltage is electrode pad extension in the discharging framework. The pad constructs with stainless steel that considers conducting metal. The thickness of the electrode pad implement in the application is a flat circular shape. With wide-area can generate more surface appended to the calibrated unit. Still, the application on a human's chest is ineffective. According to material inelasticity, it creates a gap between the chest and the related testing pad.

In conclusion, the result of this particular circuit concedes as the leading operator of the AED with 12 volts input can create 80 joules as a result of energy. This relevant energy measures at the capacitive storing approximately 1000 volts. Due to the standard comparison, the releasing output practically reaches 120 joules as the standard distinguishes the specific option of AED. Moreover, we test the discharging progress on the meat. The result shows no burnt mark leftover on the chicken's flesh while the calibrated unit addresses 80 joules observe. With this point, we summaries that the electrical activity passes through the flesh efficiently without any heat-accumulating to create burnt-on skin.

2) The conclusion in the ECG detection framework and voice support

The ECG detection separates into bipolar lead detection. The attachment of the bipolar lead two utilizes the located electrode on the left hand and right leg. Therefore, it can complement the appendage of the Apex and Sternum location. That location of the electrode pad refers to a traditional AED pad appending. In our experiment, we utilize both the signal generator and human source from ourselves for the observation. With the bipolar lead result, the signal interferes with noise displaying a coarse ECG waveform. Receiving an output from a related method considers as unable to recognize the traditional pattern of ECG. The reason for these consequences is the absence of virtual ground the reference by the right leg. The waveform becomes identifiable when the tester touches the circuit directly while grounded with a floor. The signal from the generator is incapable of application for further analysis. Then we utilize the limb lead ECG detection in our experiment. Attaching Einthoven's triangle with the tester body or the relevant site in the generator with the corresponding lead for signal analysis. We conduct this attachment of an electrode to recognize the fundamental efficiency of ECG detection. So, the limb-lead detection is replacing the bipolar lead in the ECG analysis for the automated process. The ECG detecting in this method is observable for the coding process to create the automating discharging.

The automatic discharging with related ECG for the AED application applies the ability to detect the R wave from Arduino as counting for performing discharge simultaneously. The fundamental part of ECG to identify for elementary arrhythmia treatment is to surging the electricity whenever R wave present. The Arduino application performs the ECG analysis with a particular threshold value. We can identify the ECG and validate the condition by implementing the waveform variable. The Arduino serial plotter interface provides the required input for the specified method. Unfortunately, the complex arrhythmia is incapable of the current set of apprehension. The different cardiac arrhythmia requires a specific time and discharging to complete the elementary treatment as life-saving. Accordingly, we can arrange the performing condition in an automated system of constructed diagrams that correlate with R wave appearance. In this project, the requirement of the discharging activation is whenever the R wave is detected. The counting continues to collect the variable for the application of the Arduino. The discharging activation transpires simultaneously with the fifth R wave present. Additionally, the button adds to create an appropriate requirement to activate the R wave identification and discharging manner. Consequently, the setting condition performance performs identically with the ECG wave demonstrate on the monitor.

The announcing system grants the assisting task for the user in any case. In this project, the application of the voice system conducts with a specific sound module. This module receives the microcontroller command to manipulate the files inside. Besides, it displays the announcing sentence for user assisting purposes in each step for the application acknowledgment. Each button applies to the essential circuitry response with the sound module individually. The announcement operates when the starting the performance, enables charging progress, and enables discharging mechanism.

5.2 Discussion

1) The complexity in the supplement obtaining

AED is a crucial device in a life-saving device that without a basement for a national production site. Moreover, the equipment or the compartment of the actual AED are importing parts and commercial-grade material. According to this point, we are barely obtaining the practical component in the construction of the circuit. Hence, we attempt to work with parts that consist essentially function to the actual one instead.

2) The distinction in the capacitive characteristic and property

Due to the hardship in achieving essential compartments, the ordinary capacitor is currently using in the application for the AED performance research. The super-capacitor secures the standard characteristic of the AED that relatively expeditious in charging and discharging. Compare to a regular capacitor, the property in the discharging requires discharging time more than the super-capacitor. The regular one needs additional time to deplete all the electrical charging inside. Also, the performance of a super-capacitor is more comprehensive than the regular one. However, the observation of the AED constructed circuit can utilize a general capacitor for research. Still, it achieves less efficiency than the appropriate component.

3) The limitation in arrhythmia recognition and identification.

The difference in the arrhythmia occurs in the patient's vital sign require a specific and precise operation. In the current status of the project, the restorable arrhythmias are those the R wave appearance mattered. For example, Tachycardia and Bradycardia consist of the distinguish R wave in the detection. Although, fibrillation in the ventricular chamber is a complicated example for the R wave identification. According to these issues, the condition that constructs appropriate treatments is ineffectual toward the variety of the arrhythmia occurrence.

4) Require more in the standard regulation endorsement.

The result for the AED displays the demonstration of the original device performing in simple circuit construction. Only some experimental output proceeds in the experiment that is comparable to the standard regulation. For example, we can utilize the transformer to create 780 volts as input but in regular AED applies up to 1200 volts and above. The output energy for standard AED is approximately 120-200 joules. We can manipulate the output up to 80 joules at maximum. It is the point of the assessment to practical components that provide actual output as the standard set. We can't observe the fundamental status of the constructed circuit. Such as current leakage or other safety factors isn't conducted. This circuit can utilize utmost in the study of the AED performing instead of the practical application in real-field.

5) Biphasic phase issue

The current AED and defibrillator device performing section displays graphical data in the biphasic phase. It is the properties that allow the electrical current to surge into the patient. Then, create the passageway to allows the current to flow back to the device. It minimizes the burden toward the patient more diminutive than the monophasic phase that delivers one-way electrical discharging. The construction of the biphasic mode in our project now is unobservable. Due to the insufficient facilities, we are unobservable the pattern of graphical data for determining the output property.

5.3 Further Possibilities

1) The complex ECG status recognition

The recognition of the ECG of this project conserves within the capability of only R wave identification. Therefore, the sudden cardiac aliment and the arrhythmia that concern in need of the AED is more difficult with this set of the ECG basic comprehension. The more we understand and set up the base recognition toward the irregular heart rhythm benefits in the emergency case assisting further.

2) The generated energy output enhancement

It is the point that we are unable to achieve a suitable compartment. So, we are unable to generate the particular value to the standard of the AED requirement currently. However, the specific parts that can create the exact output can redeem the inefficiency toward the output aspect, likewise the safety factor to increase as well.

3) Phase characteristic adjustment

The current status of the AED mode is monophasic that utilizes significantly massive one-way energy deliver to the patient. This mode advantage is more limited than the biphasic phases. If we can achieve that characteristic, it will provide a two-way electrical path as the energy conservative and hinder the side effect toward the patient during the particular treatment.

4) The circuit minimization

The construction of the current prototype circuit is massively huge. It is the inefficiency in the portable characteristics of the AED. The minimization of the compartment inside and the related equipment function contribute advantages more in various aspects.

5) The corresponding work of the ECG detection and the shocking deliver in the same electrode

Currently, we are unable to utilize the shocking probe with ECG detection correspondingly. Due to the incompetent level of function in the shocking deliverance and safety compartment for other low-voltage components inside from high-voltage activity appears as the issue for the research. The condition can manage further in the delicate operation of the detecting and shocking framework within a short period of the heart activity. The electrical pathway allowance and prohibition can create protection over the rest of the components.

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APPENDICES

PROGRAM FOR ECG DETECTION WITH SHOCKING

```
// the corresponding set up for related pin and component
const int buttonPin = 4;
int val = 0; // the value obtain to observer R wave
int ecg = A0; // the pin to set as the ECG detection
int shock = 10;
int c = 0;
int sign1 = 6;
int sign2 = 7;
int sign3 = 8;
int sign4 = 9;
int buttonState = 0;
int STATUS = 0;

void setup() {
  Serial.begin(9600);
  pinMode(buttonPin, INPUT_PULLUP); //describing the corresponding button work
  pinMode(shock, OUTPUT);
  pinMode(sign1, OUTPUT);
  pinMode(sign2, OUTPUT);
  pinMode(sign3, OUTPUT);
  pinMode(sign4, OUTPUT); //the setup for all pin as output accordingly
}
//the specific condition create to detect the consider value of the R wave in the serial plotter
and apply for the condition based on the obtain value.
void loop() {

  buttonState = digitalRead(buttonPin); //Read the action toward the button
  val = analogRead(ecg); //Observe the ECG and transmit the data into set variable

  Serial.println(val); //show according value on the serial plotter or serial monitor
```

```
 if (buttonState == LOW) {
  if (val >= 350) {
    /*digitalWrite(count, HIGH);*/
   Serial.println(val);
    delay (1000);
    c++; //the condition create then the threshold value detection, it will initial the
           related condition
}
  if (c == 1) {
    digitalWrite(sign1, HIGH);
    digitalWrite(sign2, LOW);
    digitalWrite(sign3, LOW);
    digitalWrite(sign4, LOW);
}
//the condition operate when the count of R wave reach 1, it will light up the first LED
  if (c == 2) {
    digitalWrite(sign1, HIGH);
    digitalWrite(sign2, HIGH);
    digitalWrite(sign3, LOW);
    digitalWrite(sign4, LOW);
}
//the condition operate when the count of R wave reach 2, it will light up the second LED
  if (c == 3) {
    digitalWrite(sign1, HIGH);
    digitalWrite(sign2, HIGH);
    digitalWrite(sign3, HIGH);
    digitalWrite(sign4, LOW);
}
//the condition operate when the count of R wave reach 3, it will light up the third LED

  if (c == 4) {
```

```
      digitalWrite(sign1, HIGH);
      digitalWrite(sign2, HIGH);
      digitalWrite(sign3, HIGH);
      digitalWrite(sign4, HIGH);
}
```

//the condition operate when the count of R wave reach 4, it will light up the fourth LED

```
    if (c == 5) {
      digitalWrite(sign1, LOW);
      digitalWrite(sign2, LOW);
      digitalWrite(sign3, LOW);
      digitalWrite(sign4, LOW);
      digitalWrite(shock, HIGH);
      Serial.println("Shocking!!");
}
```

//the condition operate when the count of R wave reach 5, it will operate corresponding attached unit. Initially, we test as the LED to observe the result. Then, replace with the core component. As, this project, we replace the last LED with relay in the switching circuit.

```
else {
      digitalWrite(sign1, LOW);
      digitalWrite(sign2, LOW);
      digitalWrite(sign3, LOW);
      digitalWrite(sign4, LOW);
      digitalWrite(shock, LOW);}
  }

  delay (100);
```

//to let the operation run over again if the condition met with 100 ms as delay

```
}
```

PROGRAM FOR VOICE SUPPORT

```
const int BUTTON_CH = 2;
const int RELAY_CH  = 8;
const int BUTTON_DISCH = 4;
const int SOUND_ONOFF = 9;
const int SOUND_CH = 10;
const int SOUND_DISCH = 11;
// defined all pin for the input button and output relay
void setup() {
  Serial.begin(9600);
  pinMode(BUTTON_CH, INPUT_PULLUP);
  pinMode(RELAY_CH, OUTPUT);
  pinMode(BUTTON_DISCH, INPUT_PULLUP);
  pinMode(SOUND_CH, OUTPUT);
  pinMode(SOUND_DISCH, OUTPUT);
  pinMode(SOUND_ONOFF, OUTPUT);
// setting all the pin for input and output between button and relay
  digitalWrite(SOUND_CH, HIGH);
  digitalWrite(SOUND_DISCH, HIGH);
  digitalWrite(SOUND_ONOFF, LOW);
  delay(8000);
  digitalWrite(SOUND_ONOFF, HIGH);
}
// setting the relay for opening the ON-OFF(first) sound (ButtonON-OFF)

void loop() {
  int buttonState = digitalRead(BUTTON_CH);
  int buttonState1 = digitalRead(BUTTON_DISCH);
//Read the action toward the button of charging and discharging by the defined buttonState is charging button and buttonState1 is discharging button for opening the sound file in JQ6500 module
```

```
  if (buttonState == LOW && buttonState1 == HIGH) {
    digitalWrite(RELAY_CH, LOW);
    digitalWrite(SOUND_ONOFF, HIGH);
    digitalWrite(SOUND_CH, LOW);
    digitalWrite(SOUND_DISCH, HIGH);
    }
// The condition of charging button to control 2 relays when to press the button, one relay for opening the second sound file and other one for releasing the power from dc-dc high voltage module to charging at the capacitor.
  if (buttonState == HIGH && buttonState1 == LOW) {
    digitalWrite(RELAY_CH, HIGH);
    digitalWrite(SOUND_ONOFF, HIGH);
    digitalWrite(SOUND_CH, HIGH);
    digitalWrite(SOUND_DISCH, LOW);
    }
// The condition of discharging button for opening the third sound file.
  else if (buttonState == HIGH && buttonState1 == HIGH) {
    Serial.println("Unpressed");
    digitalWrite(RELAY_CH, HIGH);
    digitalWrite(SOUND_CH, HIGH);
    digitalWrite(SOUND_ONOFF, HIGH);
    digitalWrite(SOUND_DISCH, HIGH);
  }
// The final condition for rechecking when the 2 buttons isn't pressed, all relay will not work.
}
```

CARDIAC SCIENCE AEDs

POWER7HEART@EDDD *Pro*

automated external defibrillator

Instructions for Use

AED OVERVIEW

Become familiar with the controls and how to use the AED properly before operating the product.

CONTENTS:

AED DESCRIPTION:

The AED is a self-testing, battery-operated automated external defibrillator (AED). After applying the AEDs defibrillation electrodes (pads) to the patient's chest, the AED automatically analyzes the patient's electrocardiogram (ECG) and advises the operator to push the button and deliver a shock if needed. The AED guides the operator through the rescue using a combination of voice prompts, audible alerts, and visible indicators. At the discretion of Advance Life Support (ALS) personnel, the AED can be converted to manual override mode, and deliver a shock by pushing the shock button to deliver therapy. The AED can also provide non-diagnostic ECG monitoring.

Persons authorized to operate AEDs must have training in accordance to state, province or country regulations.

OPERATING MODES

The AED has three operating modes. The AED is pre-set to AED mode, but the user can change the mode during each unique rescue. The energy delivered is determined by the Medical Director and programmed into the AED prior to the rescue.

AED MODE (DEFAULT)

For patients exhibiting signs of sudden cardiac arrest. Once defibrillation electrodes are placed on the patient, the AED analyzes the heart rhythm. If a shockable rhythm is detected, the AED automatically charges to the pre-set variable energy protocol and prompts rescuer to push the SHOCK button to deliver therapy.

MANUAL MODE

For patients exhibiting signs of sudden cardiac arrest. Once the defibrillation electrodes are placed on the patient, a trained ALS rescuer may wish to read the ECG display to determine whether or not a shock is required. This mode is activated by pushing the manual button once then again to confirm; the device will begin charging. If the rescuer deems that the rhythm is shockable, therapy can be delivered by pressing the SHOCK button. Then, the AED reverts back to AED mode. By entering this mode, the rescuer is taking responsibility to identify a shockable rhythm and to administer a shock.

REMAIN IN MANUAL MODE – (this optional mode can be enabled using MDLink software) with Remain in Manual Mode enabled and the user enters manual mode, the AED will remain in manual mode and not revert to the AED mode.

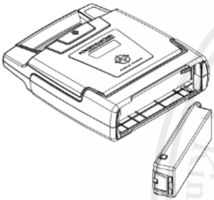
ECG MONITORING MODE

For patients who require basic ECG monitoring. Non-diagnostic ECG patient monitoring can be activated by inserting the ECG patient monitoring cable into the electrode socket on the AED, connecting the 3-lead patient cables to the specialized ECG electrodes and placement as directed onto the patient. Should the AED detect a shockable rhythm, defibrillation electrodes should be placed on the patient and the connector should be plugged into the electrode socket on the AED to enable a defibrillation shock.

BATTERIES

The 9300P is shipped with either an IntelliSense Battery (model 9145) or a rechargeable battery (model 9144). Confirm which battery is included with the AED and see the applicable instructions below.

INSTALLATION



- Insert battery as shown.
- Push firmly to snap into place.
- Open the lid for 5 seconds.
- The Status Indicator turns GREEN

INTELLISENSE BATTERY

- When the last battery indicator (LED) is red, the battery is low. Replace the battery right away.
- A new battery typically takes 10 seconds to charge the AED to maximum energy.
- Output voltage: 12VDC (max)
- Batteries are non-rechargeable
- Lithium contents: 9.2g (max)
- Check local regulations for disposal information

MODEL	FULL OPERATIONAL REPLACEMENT GUARANTEE	TYPICAL SHOCKS
9145 Lithium	1 year from date of installation or 12 hours of use, whichever is sooner	Up to 290

RECHARGEABLE BATTERY

Either the non-rechargeable battery (model 9145) or the re-chargeable battery (model 9144) may come standard with the Powerheart Pro (model 9300P). The battery charger (model 9044) is sold separately. The re- chargeable battery meets all respective IEC standards. All configurations comply with system standard, IEC 60601-1-1.

DIRECTIONS FOR USE:

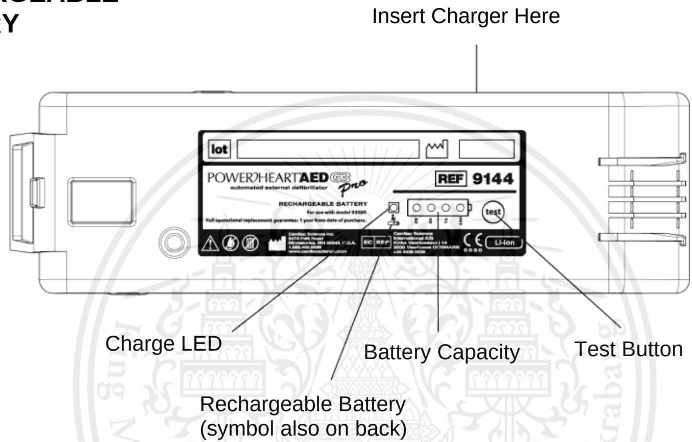
- The rechargeable battery is shipped half-charged. Charge battery fully before using.
- To charge, remove the rechargeable battery from the AED; the rechargeable battery can only be recharged when removed from the Powerheart AED G3 Pro.
- Plug the charger into an appropriate electrical outlet.
- Insert the charger cable into the rechargeable battery and ensure the yellow LED above the rechargeable battery symbol is on. **Charging is complete when the yellow Charge LED goes out, and the four green Fuel Gauge LEDs are continuously lit.**
- Remove the charger cable from the battery when done charging. Charging may be terminated early by removing the charger cable from the battery. If the battery is charged for a minimum of 3 hours, the stated capacities will be met.

Note: It is recommended that you keep a spare, non-rechargeable battery nearby. For longest battery life, when storing battery, discharge half-way. Do not store for extended periods at high temperature.

- The Powerheart AED G3 Pro will first indicate "Low Battery" while there is still sufficient charge remaining to perform at least one rescue. It is recommended to recharge the battery as soon as practical after the "Low Battery" indication. It is considered normal operation for the battery capacity gauge to show some remaining capacity when the "Low Battery" indication first occurs.

If the yellow Charge LED blinks continuously, a charging error has occurred. Contact the customer service in the event of a charging error.

RECHARGEABLE BATTERY



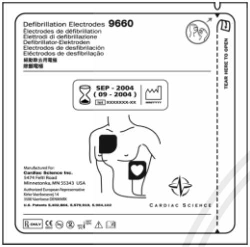
SPECIFICATIONS

Battery Voltage:	11.1 V
Chemistry:	Lithium-ion. Refer to local regulations.
Compatibility:	Powerheart AED G3 Pro model 9300P
Battery Capacity: display	60 shocks minimum (100 shocks typical) or 3 hours minimum of ECG time (6 hours typical).
Battery Charge Time: depleted	3 hours for stated capacity, 4.5 hours to fully charge completely battery.
Battery Standby:	6 months
Battery Life:	2.5 years or 300 Battery charge-discharge cycles, whichever comes

first.

Battery Weight:	1 lb. 3 oz

ELECTRODES (DEFIBRILLATION)



The defibrillation electrodes are already installed in the AED when shipped to you. Confirm that they are installed. Then, ensure that the expiration date is visible through the clear window of the lid. Make sure the **STATUS INDICATOR** is **GREEN.**

ABOUT THE ELECTRODES (DEFIBRILLATION)

- Self-adhesive, disposable defibrillation electrodes
- Minimum combined surface area: $228 cm^2$
- Extended length of lead wire: 1.3m

Electrodes refer to as "Defibrillation Electrodes". ECG electrodes are referred to as "ECG electrodes".
Pediatric electrodes are referred to as "Pediatric Attenuated Defibrillation Electrodes" or "Pediatric Electrodes".

RESCUEREADY® STATUS INDICATOR

When this **STATUS INDICATOR** is **GREEN**, the AED is RescueReady. This indicates the AED self-tests have verified the following:

- Battery has an adequate charge.
- Pads are properly connected and are functional.
- Integrity of the internal circuitry is good.

When the **STATUS INDICATOR** is **RED** check AED pads, battery and/or call customer service.

AUDIBLE MAINTENANCE INDICATOR

When the daily, weekly, or monthly self-test determines maintenance is required, an audible beep is sounded every 30 seconds until the lid is opened, or the battery power is depleted. Opening and closing the lid will deactivate the beep. If the next automatic self-test does not correct the error, the beep will be reactivated.

AFTER A RESCUE ATTEMPT

After transferring the patient to Advanced Life Support personnel, prepare the AED for the next rescue:

1. Retrieve the rescue data stored in the internal memory of the AED.
2. Erase the internal memory of the AED.
3. Connect a new pair of pads to the AED.
4. Close the lid.

5. Verify the **STATUS INDICATOR** on the AED handle is **GREEN.**

SYMBOL DESCRIPTIONS

The following symbols may appear in this resource guide, on the AED, or on its optional components. Some of the symbols represent standards and compliances associated with the AED and its use. Symbols for separately sold, optional accessories such as the Rechargeable Battery Option and the ECG Patient Cable Kit can be located on the literature shipped with these products.

Dangerous Voltage: The defibrillator output has high voltage and can present a shock hazard. Please read and understand all safety alerts in this manual before attempting to operate the AED.

Attention!: Identifies important information in this resource guide, in the manual, on the AED, or on its component parts regarding the safe and proper use of the AED.

Defibrillator Proof Type BF Equipment: The AED, when connected to the patient's chest by the pads, can withstand the effects of an externally applied defibrillation shock.

0086 CE Mark: This equipment conforms to essential requirements of the Medical Device Directive 93/42/EEC.

IP24 The AED is protected against the effects of splashing water in accordance with IEC 60529.

Classified by ETL Semko with respect to electric shock, fire and mechanical hazards only in accordance with UL 60601-1, CAN/CSA C22.2 No.601.1-M90, EN60601-1 and EN60601-2-4. Conforms to UL Standard UL60601-1. Certified to CAN/CSA Standard C22.2 No. 601.1-M90.

International symbol for ON. Open the lid to turn on the

AED.  Open the lid to turn ON the AED.

Indicates the AED battery status. The illuminated areas indicate the remaining battery capacity.

SYMBOL DESCRIPTIONS (CON'T)


Indicates AED requires maintenance by authorized service personnel.

When the **SHOCK** indicator is lit, push this button to deliver a defibrillation shock. 

When pushed and confirmed, activates manual mode.


A red indicator with a BLACK X means the AED requires operator attention or maintenance, and is not RescueReady. This symbol will be referred to as **RED** in the remainder of this manual.


A green indicator without a BLACK X means the AED is RescueReady. This symbol will be referred to as **GREEN** in the remainder of this manual.


Use electrodes by this date.

Date of manufacture, year and month.

Date of factory recertification (R)

Latex free.


Disposable. Single patient use only.


Tear here to open.


Do not recharge battery.

1. Position of pads on the chest of patient.
2. If flashing, check electrodes. The electrodes are missing, not connected or have compromised functionality.

For use by or on the order of a Physician, or persons licensed by state law.

Dispose of properly in accordance with all state, province, and country regulations.

Do not incinerate or expose to open flame.

Explosion Hazard: Do not use in the presence of a flammable gas, including concentrated oxygen.

Upper and lower temperature limits.

Device model number, battery model number

Lot number

Lithium sulfur dioxide

Additional information is provided in the AED Operation and Service Manual.

Points to important information regarding the use of the AED.

Lift here

Manufacturer

Authorized European Representative

The Z-Bar provides a relative visual indicator of the total transthoracic impedance between the two defibrillation pads.

Indicates placement of ECG leads and ECG electrodes.

C-UL US Classification Mark: indicates compliance with US and Canadian safety requirements.

E150854
8M28

GS Mark: indicates compliance with German safety requirements.

Li-ion Lithium Ion

Rechargeable Battery

Charge LED: Solid yellow indicates battery charging, blinking yellow indicates charging error.

Battery Capacity: Indicates the AED battery status. The illuminated areas indicate the remaining battery capacity when the test button is pressed.

test Test Button: Push to view battery capacity

Symbol for the marking of electrical and electronic equipment that must be recycled.

SAFETY PERFORMANCE STANDARDS

DIMENSIONS

Measurement	Dimension
Height	8 cm (3.3 in)
Width	27 cm (10.6 in)
Depth	31 cm (12.4 in)

WEIGHT

Model	Weight with Batteries and Pads
9300P	3.20 kg (7.0 lb)

ENVIRONMENTAL OPERATION AND STANDBY CONDITIONS

Atmosphere	Condition
Temperature	0°C to 50°C (32°F to 122°F)
Humidity	5% to 95% (non-condensing)
Pressure	57kPa (+15,000ft) to 103kPa (-500ft)

SHIPMENT AND TRANSPORT ENVIRONMENTAL CONDITIONS (for up to 1 week)

Atmosphere	Condition
Temperature	-30°C to 65°C (-22°F to 149°F)
Humidity	5% to 95% (non-condensing)
Pressure	57kPa (+15,000ft) to 103kPa (-500ft)

AED MODEL 9300P

The AED has been designed and manufactured to conform to the highest standards of safety and performance including electromagnetic compatibility (EMC). The Cardiac Science AED Model 9300P and pads conform to the applicable requirements of the following:

CE
CE Marked by BSI 0086 per the Medical Device Directive 93/42/EEC of European Union.

ETL
Classified by ETL Semko with respect to electric shock, fire and mechanical hazards only in accordance with UL 60601-1, CAN/CSA C22.2 No.601.1-M90, EN60601-1 and EN60601-2-4. Conforms to UL Standard UL60601-1. Certified to CAN/CSA Standard C22.2 No. 601.1-M90.

Electrical, Construction, Safety and Performance
IEC 60601-1 (1998), Amendments 1 (1991) & 2 (1995)
IEC 60601-2-4 (2002)
ANSI/AAMI DF-39 (1993)

Electromagnetic Compatibility (EMC)
IEC 60601-1-2 (2001)
IEC 60601-2-4 Section 36
ANSI/AAMI DF-39 (1993) Section 3.3.21

EMISSIONS

Field Compliance	Standard or
E-M	EN 55011/CISPR 11, Group 1, Class B
Magnetic	ANSI/AAMI DF39, <0.5mT on surface, except for within 5cm of the lid magnet and the speaker

IMMUNITY

Field	Standard or Compliance

E-M	IEC 61000-4-3, Level X, (20V/m) IEC 60601-2-4, Section 36.202.3 (20V/m) AAMI DF39, Section 3.3.21.2.1

IMMUNITY (CON'T)

Field	Standard or Compliance
Magnetic	IEC 61000-4-8 (2001) IEC 60601-2-4 (2002), Section 36.202.8 AAMI DF39, Section 3.3.21.2.3 80A/m, 47.5Hz – 1,320Hz
ESD	IEC 61000-4-2, Level 3 IEC 60601-2-4 (2002), Section 36.202.2 6KV contact discharge, 8KV air gap discharge

ENVIRONMENTAL CONDITIONS

Condition	Standard or Compliance
Free Fall Drop	IEC 60068-2-32 (1975) AM 2 (1990), 1 meter
Bump	IEC 60068-2-29 (1987), 40g and 6000 bumps
Vibration (Random)	IEC 60068-2-64 (1993): 10Hz – 2KHz, 0.005 – 0.0012 g^2/Hz
Vibration (Sine)	IEC 60068-2-6 (1995): 10Hz – 60Hz, 0.15 mm and 60Hz – 150Hz, 2g
Enclosure Protection	IEC 60529 (2001), IP24

SHIPPING AND TRANSPORTATION CONDITIONS

ISTA Procedure 2A

STORAGE AND SHIPPING CONDITIONS – RECHARGABLE BATTERY

Condition	Standard or Compliance
Shock and Vibration:	The Battery, as installed in the Powerheart AED G3 Pro, meets

the following: Bump: (IEC 60068-2-29): 40g, 6 ms duration, 1.5 m/s ⊗V, 1000 bumps in each direction. Random Vibration: (IEC 60068-2-64): 10hz - 2khz @ 0.005 - 0.0012 g2/Hz.

Transport: Passes testing per UN "Recommendations of the Transport of Dangerous Goods, Manual of Test and Criteria" (ST/SG/AC.10/11/Rev.3) Addendum 2 (ST/SG/AC.10/27/Add.2)

BATTERY CHARGER

Power Requirements: 90 to 132 VAC or 198 to 264 VAC at 47 to 63 Hz

The Charger operates from, and accepts standard IEC mains power cables.

HOW TO PERFORM A RESCUE

Step 1: ASSESS

CALL EMERGENCY MEDICAL SERVICES

The patient is

unresponsive. AND

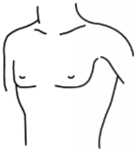
The patient is not breathing.

CALL EMERGENCY MEDICAL SERVICES

When the patient is under 8 years of age or weighs less than 55lbs (25kg), the AED should be used with the Pediatric Attenuated Defibrillation Electrodes. Therapy should not be delayed to determine the patient's exact age or weight. See the directions for use accompanying pediatric electrodes for procedure on changing adult electrodes to pediatric and the Medical Director can change energy protocols if necessary.

STEP 2: PREPARE

- Open the AED lid.



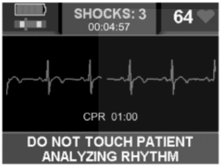
- Remove clothing from the patient's chest.
- Ensure the skin site is clean and dry.
- Dry the patient's chest and shave excessive hair if necessary.

STEP 3: PLACE PADS

- Tear open package and remove pads.
- Peel one pad from plastic liner.
- Place one pad on bare upper chest.
- Peel second pad and place on bare lower chest as shown.

Note: When using polarized pads (P/N 9660) see the diagram on the pads for specific placement of each pad.

STEP 4: ANALYZE AND SHOCK DELIVERY (AED MODE)



The voice and text prompts will guide you through.

- *"DO NOT TOUCH PATIENT! ANALYZING RHYTHM."*

If a shockable rhythm is detected, follow these instructions:

- *"SHOCK ADVISED."*
- *"CHARGING"*
- *"STAND CLEAR! PUSH FLASHING BUTTON TO DELIVER SHOCK."*

If the patient's rhythm changes to a non-shockable rhythm before the actual shock is delivered, the AED will advise that the rhythm has changed and issue the prompt *"RHYTHM CHANGED, SHOCK CANCELLED."* The AED will override the charge and prompt the user to start CPR.

STEP 5: CPR

- When instructed, start CPR
- Give 30 compressions followed by 2 breaths.

At the end of the CPR period, the voice prompts will direct you to repeat steps 4 and 5 if required.

USING MANUAL OVERRIDE (MANUAL MODE)

For use by qualified ALS personnel only. The AED has a manual override feature which overrides the AED's automatic analysis protocol. By entering this mode, the rescuer is taking responsibility to identify a shockable rhythm and to administer a shock. The default setting for the manual override is "enabled". When enabled, the Manual Override function allows the user to charge the AED and deliver a shock at the user's discretion. After the shock button is pushed or 30 seconds has elapsed, the device will automatically exit the manual mode and return to the AED mode.

Optionally, after entering manual override, it may be desirable to have the AED remain in the manual override mode for the duration of the rescue. This feature can be enabled during the initial set up of the AED using MDLink software and checking the box, "Remain in Manual Mode".

STEP 1: Please refer to steps 1 – 3 on pages 17-19

STEP 2: Lift blue plastic cover on far left of diagnostic panel.

STEP 3: Push the MANUAL button once to initiate. The voice prompt and corresponding text prompts will indicate

"Entering manual mode. Press button again to confirm".

STEP 4: The MANUAL button must be pushed again to confirm and convert to manual mode. The voice prompts will indicate, *"Manual Mode".*

STEP 5: The voice prompts and corresponding text prompts will indicate, *"If rhythm is shockable, press SHOCK button to deliver therapy"*. Read the ECG and determine if the rhythm is shockable. If so, press the **SHOCK** button to delivery therapy.

Note: The RHYTHMx analysis algorithm is disabled in manual mode. It is the rescuer's responsibility to determine if a shock is necessary.

STEP 6: The AED will revert to AED MODE and prompt the user to begin CPR. Follow the voice prompts.

If “REMAIN IN MANUAL MODE” has been enabled (using MDLink software) The AED will remain in Manual Mode and not revert to the AED mode. When this option is enabled, after a manual shock is delivered, or the operator does not press the shock button for 30 seconds, the device will remain in manual mode. The text display will show “Manual Mode”, and the operator may press the “Manual Mode” button to initiate charging again if the operator determines that a shock is necessary.

STEP 7: To re-enter manual mode, press the MANUAL button ONCE.

Note: Should the rescuer initiate manual mode and decide that AED MODE is more appropriate, the AED will revert back to AED MODE 30 seconds after charging is complete. (This does not apply if “REMAIN IN MANUAL MODE” has been enabled – see step 6 above.

EXITING MANUAL MODE

Default: The device will return to AED mode after:

- Pushing the shock button
- 30 seconds has elapsed without pushing the shock button
- Closing the AED lid momentarily
- Attaching the optional 3-lead ECG monitoring cable
- Disconnecting the pads from the AED
- Removing the pads from the patient

EXITING MANUAL MODE WHEN “REMAIN IN MANUAL MODE” IS ENABLED:

- Closing the AED lid momentarily
- Attaching the optional 3-lead ECG monitoring cable (upon reattaching the defibrillation pads the AED will be in manual mode).

ECG DISPLAY FOR ONGOING MONITORING (ECG MONITORING MODE)

At the discretion ALS personnel, the AED can be used for ongoing ECG monitoring. By using a separately sold ECG Patient Monitoring Kit, the AED provides non-diagnostic ECG display of the patient's heart rhythm for attended patient monitoring. It is not necessary to turn the device off prior to connecting the ECG cable. While connected to the AED, the shock capability is disabled.

Indications for use:
A conscious or breathing patient, regardless of age.

Contraindications:
No known contraindications.

The separately sold ECG Monitoring Cable Kit is required to use this feature. The Kit is designed for connection to ECG electrodes per AAMI or IEC color convention. Once connected the AED displays and evaluates the patient's ECG (Lead II). Follow all prompts from the AED.

See the Directions for Use included in the ECG Patient Monitoring Kit for specific instructions.

SAFETY TERMS AND DEFINITIONS

BEFORE OPERATING THE POWERHEART AED G3 PRO

Become familiar with the various safety alerts in this section.

Safety alerts identify potential hazards using symbols and words to explain what could potentially harm you, the patient, or the Powerheart AED G3 Pro.

INDICATIONS FOR USE

The AED with STAR Biphasic Waveform is intended to be used by personnel who have been trained in its operation. The operator should be qualified by training in basic life support, CPR/AED or other physician-authorized emergency medical response. The device is indicated for emergency treatment of victims exhibiting symptoms of sudden cardiac arrest who are unresponsive and not breathing. If the victim is breathing post-resuscitation, the AED should be left attached to allow for acquisition and detection of the ECG rhythm. If a shockable ventricular tachyarrhythmia recurs, the device will charge automatically and advise the operator to deliver therapy; or when in manual override mode, ALS personnel will monitor the ECG display and deliver a shock by pushing the shock button to deliver therapy.

When the patient is a child under 8 years of age or weighs less than 55 lbs (25kg), the AED should be used with the Model 9730 Pediatric Attenuated Defibrillation Electrodes. Therapy should not be delayed to determine the patient’s exact age or weight.

SAFETY TERMS AND DEFINITIONS

The triangle attention symbol shown below, left, identifies the potential hazard categories. The definition of each category is as follows:

DANGER: This alert identifies hazards that will cause serious personal injury or death.

WARNING: This alert identifies hazards that may cause serious personal injury or death.

CAUTION: This alert identifies hazards that may cause minor personal injury, product damage, or property damage.

SAFETY ALERT DESCRIPTIONS

The following is a list of Cardiac Science AED safety alerts that appear in this section and throughout this resource guide. You must read, understand, and heed these safety alerts before attempting to operate the AED.

⚠ ***DANGER:*** Fire and Explosion Hazard
Exercise caution when operating the AED close to flammable gases (including concentrated oxygen) to avoid possible explosion or fire hazard.

⚠ ***WARNING:*** Shock Hazard
Defibrillation shock current flowing through unwanted pathways is potentially a serious electrical shock hazard. To avoid this hazard during defibrillation abide by all of the following:

- Do not touch the patient, unless performance of CPR is indicated
- Do not touch metal objects in contact with the patient
- Keep defibrillation electrodes clear of other electrodes or metal parts in contact with patient
- Disconnect all non-defibrillator proof equipment from the patient before defibrillation

⚠ ***WARNING:*** Shock and Possible Equipment Damage
Disconnect all non-defibrillator proof equipment from the patient before defibrillation to prevent electrical shock and potential damage to the equipment.

⚠ ***WARNING:*** Battery (P/N: 9145) is **NOT** Rechargeable
Do not attempt to recharge the battery. Any attempt to recharge the battery may result in an explosion or fire hazard. **Only battery (P/N: 9144) is rechargeable.**

⚠ ***WARNING:*** Shock Hazard
Do not disassemble the AED! Failure to observe this warning can result in personal injury or death. Refer maintenance issues to Cardiac Science authorized service personnel.

WARNING: Battery Serviceability
Do not disassemble the battery! Failure to observe this warning can result in personal injury or death. Refer maintenance issues to authorized service personnel.

SAFETY ALERT DESCRIPTIONS (CON'T)

CAUTION: Use only Approved Equipment
The Rechargeable battery is made solely for Powerheart AED G3 Pro, and is NOT to be used with any other AED models. Using batteries, pads, cables, or optional equipment other than those approved by the manufacturer may cause the AED to function improperly during a rescue.

CAUTION: Temperature Extremes
Exposing the AED to extreme environmental conditions outside of its operating parameters may compromise the ability of the AED to function properly. The RescueReady® daily self-test verifies the impact of extreme environmental conditions on the AED. If the daily self-test determines environmental conditions outside of the AEDs operating parameters, a "SERVICE REQUIRED" alert will be issued to prompt the user to move the AED to environmental conditions within the acceptable operating parameters at once. See page 10.

CAUTION: Lithium Sulfur Dioxide Battery
Pressurized contents: Never recharge, short circuit, puncture, deform, or expose to temperatures above 65°C (149°F). Remove the battery when discharged.

CAUTION: Lithium-ion Battery
Never short circuit, puncture, deform, or expose to temperatures above 65°C (149°F).

CAUTION: Battery Disposal
Recycle or dispose of the lithium battery in accordance with all federal, state and local laws. To avoid fire and explosion hazard, do not burn or incinerate the battery.

CAUTION: Possible Improper AED Performance
Using electrodes that are damaged or expired may result in improper AED performance.

CAUTION: Possible Radio Frequency (RF) Susceptibility
RF susceptibility from cellular phones, CB radios and FM 2-way radio may cause incorrect rhythm recognition and subsequent shock advisory. When attempting a rescue using the AED, do not operate wireless radiotelephones within 1 meter of the AED – turn power OFF to the radiotelephone and other like equipment near the incident.

CAUTION: Possible Interference with Implanted Pacemaker
Therapy should not be delayed for patients with implanted pacemakers and a defibrillation attempt should be made if the patient is unconscious and not breathing. The AED has pacemaker detection and rejection, however, with some pacemakers the AED may not advise a defibrillation shock.[1]

Placing Electrodes:

- Do not place the electrodes directly over an implanted device.
- Place the electrode pad at least one inch from any implanted device.

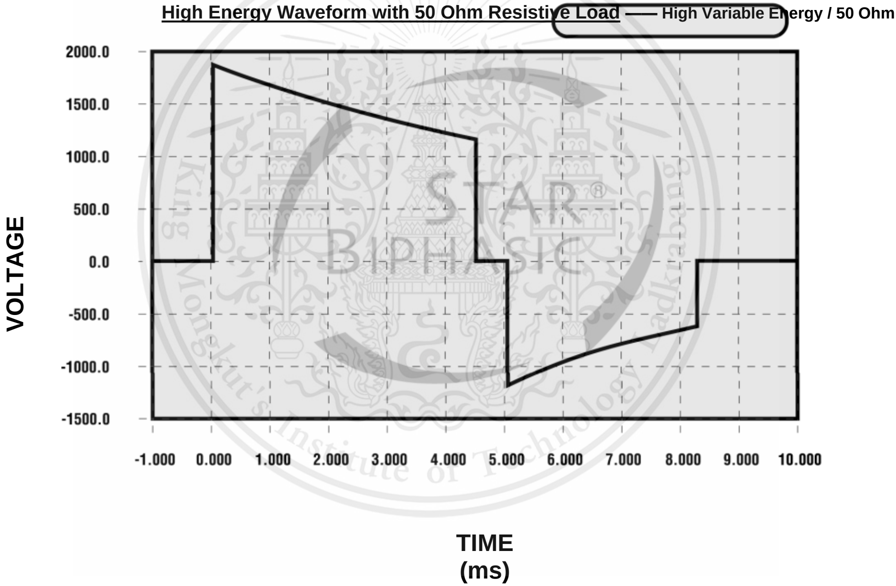
CAUTION: Moving the Patient During a Rescue
During a rescue attempt, excessive jostling or moving of the patient may cause AEDs to improperly analyze the patient's cardiac rhythm. Stop all motion or vibration before attempting a rescue.

CAUTION: Case Cleaning Solutions
When disinfecting the case, use a non-oxidizing disinfectant, such as ammonium salts or a glutaraldehyde based cleaning solution, to avoid damage to the metal connectors.

[1] *Cummins, R., ed., Advanced Cardiac Life Support; AHA (1994): Ch. 4.*

STAR BIPHASIC WAVEFORM

The waveform generated by the AED is a Biphasic Truncated Exponential waveform that is compliant with ANSI/AAMI DF2 and DF39. The following is a graph of the waveform voltage as a function of time when the AED is connected to a 50 Ohm resistive load.



The Biphasic Truncated Exponential (BTE) waveform uses variable energy. The actual energy delivered will vary with the patient's impedance and the device will deliver a shock when impedance is between 25-180 Ohms. Energy will be delivered at three different levels referred to as ultra-low variable energy, low variable energy, and high variable energy as shown in the waveform tables on the following pages.

ENERGY LEVELS

Table A1 - Ultra-Low Variable Energy (150 VE) Powerheart AED Models 9300P Waveform

Patient's Impedance (Ohms)	Phase 1		Phase 2		Energy** (Joules)
	Voltage* (Volts)	Duration* (ms)	Voltage* (Volts)	Duration* (ms)	
25	1393	3.3	743	3.2	145-196
50	1420	4.5	909	3.2	128-173
75	1430	5.8	973	3.2	116-156
100	1434	7.0	1007	3.2	108-146
125	1437	8.3	1027	3.2	102-138
150	1439	9.5	1040	3.2	98-132
175	1441	10.8	1049	3.2	95-128

Table A2 - Low Variable Variable Energy (200 VE) Powerheart AED Models 9300P Waveform

Patient's Impedance (Ohms)	Phase 1		Phase 2		Energy ** (Joules)
	Voltage* (Volts)	Duration* (ms)	Voltage* (Volts)	Duration* (ms)	
25	1609	3.3	858	3.2	193-260
50	1640	4.5	1050	3.2	170-230
75	1651	5.8	1124	3.2	155-209
100	1656	7.0	1163	3.2	144-194
125	1660	8.3	1186	3.2	136-184
150	1662	9.5	1201	3.2	131-176
175	1663	10.8	1212	3.2	126-170

ENERGY LEVELS (CON'T)

Table A3 - High Variable Energy (300 VE) Powerheart AED Models 9300P Waveform

Patient's Impedance (Ohms)	Phase 1		Phase 2		Energy ** (Joules)
	Voltage* (Volts)	Duration* (ms)	Voltage* (Volts)	Duration* (ms)	
25	1869	3.3	997	3.2	260-351
50	1906	4.5	1220	3.2	230-311
75	1918	5.8	1306	3.2	210-283
100	1925	7.0	1351	3.2	195-263
125	1928	8.3	1378	3.2	184-248
150	1931	9.5	1396	3.2	176-238
175	1933	10.8	1408	3.2	170-230

* All values are typical.
** Allowable energy range.

CONTACT INFORMATION

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Germany

CARDIAC science™

P/N 112-0100-501 Rev A

ANALOG DEVICES

Single-Lead, Heart Rate Monitor Front End

Data Sheet **AD8232**

FEATURES

- Fully integrated single-lead ECG front end
- Low supply current: 170 µA (typical)
- Common-mode rejection ratio: 80 dB (dc to 60 Hz)
- Two or three electrode configurations
- High signal gain (G = 100) with dc blocking capabilities
- 2-pole adjustable high-pass filter
- Accepts up to ±300 mV of half cell potential
- Fast restore feature improves filter settling
- Uncommitted op amp
- 3-pole adjustable low-pass filter with adjustable gain
- Leads off detection: ac or dc options
- Integrated right leg drive (RLD) amplifier
- Single-supply operation: 2.0 V to 3.5 V
- Integrated reference buffer generates virtual ground
- Rail-to-rail output
- Internal RFI filter
- 8 kV HBM ESD rating
- Shutdown pin
- 20-lead 4 mm × 4 mm LFCSP package

APPLICATIONS

- Fitness and activity heart rate monitors
- Portable ECG
- Remote health monitors
- Gaming peripherals
- Biopotential signal acquisition

FUNCTIONAL BLOCK DIAGRAM

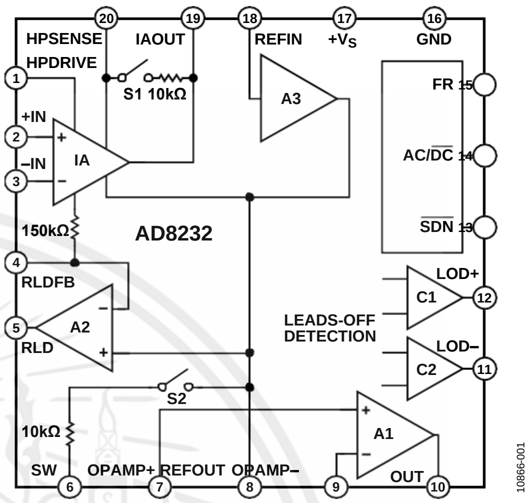


Figure 1.

GENERAL DESCRIPTION

The AD8232 is an integrated signal conditioning block for ECG and other biopotential measurement applications. It is designed to extract, amplify, and filter small biopotential signals in the presence of noisy conditions, such as those created by motion or remote electrode placement. This design allows for an ultralow power analog-to-digital converter (ADC) or an embedded microcontroller to acquire the output signal easily.

The AD8232 can implement a two-pole high-pass filter for eliminating motion artifacts and the electrode half-cell potential. This filter is tightly coupled with the instrumentation architecture of the amplifier to allow both large gain and high-pass filtering in a single stage, thereby saving space and cost.

An uncommitted operational amplifier enables the AD8232 to create a three-pole low-pass filter to remove additional noise. The user can select the frequency cutoff of all filters to suit different types of applications.

To improve common-mode rejection of the line frequencies in the system and other undesired interferences, the AD8232 includes an amplifier for driven lead applications, such as right leg drive (RLD).

The AD8232 includes a fast restore function that reduces the duration of otherwise long settling tails of the high-pass filters. After an abrupt signal change that rails the amplifier (such as a leads off condition), the AD8232 automatically adjusts to a higher filter cutoff. This feature allows the AD8232 to recover quickly, and therefore, to take valid measurements soon after connecting the electrodes to the subject.

The AD8232 is available in a 4 mm × 4 mm, 20-lead LFCSP package. Performance is specified from 0°C to 70°C and is operational from −40°C to +85°C.

Rev. A Document Feedback

One Technology Way, P.O. Box 9106, Norwood, MA 02062-9106, U.S.A.
Tel: 781.329.4700
Technical Support www.analog.com

TABLE OF CONTENTS

REVISION HISTORY

2/13—Rev. 0 to Rev. A

Changes to Table 1 ... 4
Changes to Table 2 ... 6
Change to Figure 17 ... 9
Changes to Figure 22 and Figure 25 ... 11
Changes to Figure 34 and Figure 36 ... 14
Changes to Figure 45, Architecture Overview Section, and Instrumentation Amplifier Section ... 17
Changes to Right Leg Drive Amplifier Section, Reference Buffer Section, Fast Restore Circuit Section, and Figure 48; Added Figure 46, Renumbered Sequentially ... 18
Changes to Figure 49 ... 19
Changes to AC Leads Off Detection Section and Standby Operation Section ... 20
Changes to Input Referred Offsets Section ... 21
Changes to Figure 53 and High-Pass Filtering Section ... 22
Changes to Additional High-Pass Filtering Options Section; Added Table 4 ... 23
Changes to Low-Pass Filtering and Gain Section; Added Driving Analog-to-Digital Converters Section and Figure 61 ... 24
Changes to Figure 62, Figure 64, and Heart Rate Measurement Next to the Heart Section ... 25
Changes to Exercise Application: Heart Rate Measured at the Hands and Figure 66 ... 26
Changes to Figure 68. ... 27

8/12—Revision 0: Initial Version

SPECIFICATIONS

V_S = 3 V, V_{REF} = 1.5 V, V_{CM} = 1.5 V, T_A = 25°C, FR=low, SDN=high, $\overline{AC}$/DC = low, unless otherwise noted.

Table 1.

Parameter	Symbol	Test Conditions/Comments	Min	Typ	Max	Unit
INSTRUMENTATION AMPLIFIER						
Common-Mode Rejection Ratio, DC to 60 Hz	CMRR	V_{CM} = 0.35 V to 2.85 V, V_{DIFF} = 0 V	80	86		dB
		V_{CM} = 0.35 V to 2.85 V, V_{DIFF} = ±0.3 V		80		dB
Power Supply Rejection Ratio	PSRR	V_S = 2.0 V to 3.5 V	76	90		dB
Offset Voltage (RTI)	V_{OS}					
Instrumentation Amplifier Inputs				3	8	mV
DC Blocking Input[1]				5	50	µV
Average Offset Drift						
Instrumentation Amplifier Inputs				10		µV/°C
DC Blocking Input[1]				0.05		µV/°C
Input Bias Current	I_B			50	200	pA
		T_A = 0°C to 70°C		1		nA
Input Offset Current	I_{OS}			25	100	pA
		T_A = 0°C to 70°C		1		nA
Input Impedance						
Differential				10||7.5		GΩ||pF
Common Mode				5||15		GΩ||pF
Input Voltage Noise (RTI)						
Spectral Noise Density		f = 1 kHz		100		nV/√Hz
Peak-to-Peak Voltage Noise		f = 0.1 Hz to 10 Hz		12		µV p-p
		f = 0.5 Hz to 40 Hz		14		µV p-p
Input Voltage Range		T_A = 0°C to 70°C	0.2		$+V_S$	V
DC Differential Input Range	V_{DIFF}		−300		+300	mV
Output						
Output Swing		R_L = 50 kΩ	0.1		$+V_S$ − 0.1	V
Short-Circuit Current	I_{OUT}			6.3		mA
Gain	A_V			100		V/V
Gain Error		V_{DIFF} = 0 V		0.4		%
		V_{DIFF} = −300 mV to +300 mV		1	3.5	%
Average Gain Drift		T_A = 0°C to 70°C		12		ppm/°C
Bandwidth	BW			2		kHz
RFI Filter Cutoff (Each Input)				1		MHz
OPERATIONAL AMPLIFIER (A1)						
Offset Voltage	V_{OS}			1	5	mV
Average TC		T_A = 0°C to 70°C		5		µV/°C
Input Bias Current	I_B			100		pA
		T_A = 0°C to 70°C		1		nA
Input Offset Current	I_{OS}			100		pA
		T_A = 0°C to 70°C		1		nA
Input Voltage Range			0.1		$+V_S$ − 0.1	V
Common-Mode Rejection Ratio	CMRR	V_{CM} = 0.5 V to 2.5 V		100		dB
Power Supply Rejection Ratio	PSRR			100		dB
Large Signal Voltage Gain	A_{VO}			110		dB
Output Voltage Range		R_L = 50 kΩ	0.1		$+V_S$ − 0.1	V
Short-Circuit Current Limit	I_{OUT}			12		mA
Gain Bandwidth Product	GBP			100		kHz
Slew Rate	SR			0.02		V/µs
Voltage Noise Density (RTI)	e_n	f = 1 kHz		60		nV/√Hz
Peak-to-Peak Voltage Noise (RTI)	$e_{n\ p\text{-}p}$	f = 0.1 Hz to 10 Hz		6		µV p-p
		f = 0.5 Hz to 40 Hz		8		µV p-p

Parameter	Symbol	Test Conditions/Comments	Min	Typ	Max	Unit
RIGHT LEG DRIVE AMPLIFIER (A2)						
Output Swing		R_L = 50 kΩ	0.1		$+V_S - 0.1$	V
Short-Circuit Current	I_{OUT}			11		mA
Integrator Input Resistor			120	150	180	kΩ
Gain Bandwidth Product	GDP			100		kHz
REFERENCE BUFFER (A3)						
Offset Error	V_{OS}	R_L > 50 kΩ		1		mV
Input Bias Current	I_B			100		pA
Short-Circuit Current Limit	I_{OUT}			12		mA
Voltage Range		R_L = 50 kΩ	0.1		$+V_S - 0.7$	V
DC LEADS OFF COMPARATORS						
Threshold Voltage				$+V_S - 0.5$		V
Hysteresis				60		mV
Propagation Delay				0.5		µs
AC LEADS OFF DETECTOR						
Square Wave Frequency	F_{AC}		50	100	175	kHz
Square Wave Amplitude	I_{AC}			200		nA p-p
Impedance Threshold		Between +IN and −IN	10	20		MΩ
Detection Delay				110		µs
FAST RESTORE CIRCUIT						
Switches		S1 and S2				
On Resistance	R_{ON}		8	10	12	kΩ
Off Leakage				100		pA
Window Comparator						
Threshold Voltage		From either rail		50		mV
Propagation Delay				2		µs
Switch Timing Characteristics						
Feedback Recovery Switch On Time	t_{SW1}			110		ms
Filter Recovery Switch On Time	t_{SW2}			55		ms
Fast Restore Reset	t_{RST}			2		µs
LOGIC INTERFACE						
Input Characteristics						
Input Voltage (AC/DC and FR)						
Low	V_{IL}			1.24		V
High	V_{IH}			1.35		V
Input Voltage (SDN)						
Low	V_{IL}			2.1		V
High	V_{IH}			0.5		V
Output Characteristics		LOD+ and LOD− terminals				
Output Voltage						
Low	V_{OL}			0.05		V
High	V_{OH}			2.95		V
SYSTEM SPECIFICATIONS						
Quiescent Supply Current				170	230	µA
		T_A = 0°C to 70°C		210		µA
Shutdown Current				40	500	nA
		T_A = 0°C to 70°C		100		nA
Supply Range			2.0		3.5	V
Specified Temperature Range			0		70	°C
Operational Temperature Range			−40		+85	°C

[1] Offset referred to the input of the instrumentation amplifier inputs. See the Input Referred Offsets section for additional information.

ABSOLUTE MAXIMUM RATINGS

Table 2.

Parameter	Rating
Supply Voltage	3.6 V
Output Short-Circuit Current Duration	Indefinite
Maximum Voltage, Any Terminal[1]	$+V_S$ + 0.3 V
Minimum Voltage, Any Terminal[1]	−0.3 V
Storage Temperature Range	−65°C to +125°C
Operating Temperature Range	−40°C to +85°C
Maximum Junction Temperature	140°C
θ_{JA} Thermal Impedance[2]	48°C/W
θ_{JC} Thermal Impedance	4.4°C/W
ESD Rating	
Human Body Model (HBM)	8 kV
Charged Device Model (FICDM)	1.25 kV
Machine Model (MM)	200 V

[1] This level or the maximum specified supply voltage, whichever is the lesser, indicates the superior voltage limit for any terminal. If input voltages beyond the specified minimum or maximum voltages are expected, place resistors in series with the inputs to limit the current to less than 5 mA.
[2] θ_{JA} is specified for a device in free air on a 4-layer JEDEC board.

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.

PIN CONFIGURATION AND FUNCTION DESCRIPTIONS

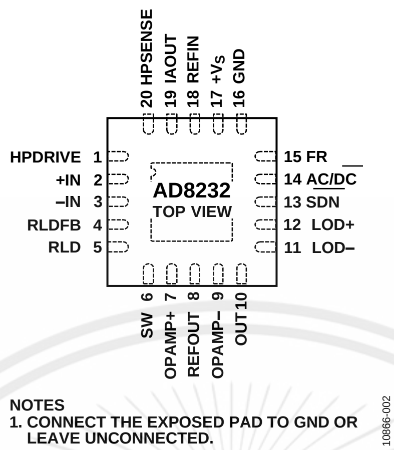


Figure 2. Pin Configuration

Table 3. Pin Function Descriptions

Pin No.	Mnemonic	Description
1	HPDRIVE	High-Pass Driver Output. Connect HPDRIVE to the capacitor in the first high-pass filter. The AD8232 drives this pin to keep HPSENSE at the same level as the reference voltage.
2	+IN	Instrumentation Amplifier Positive Input. +IN is typically connected to the left arm (LA) electrode.
3	−IN	Instrumentation Amplifier Negative Input. −IN is typically connected to the right arm (RA) electrode.
4	RLDFB	Right Leg Drive Feedback Input. RLDFB is the feedback terminal for the right leg drive circuit.
5	RLD	Right Leg Drive Output. Connect the driven electrode (typically, right leg) to the RLD pin.
6	SW	Fast Restore Switch Terminal. Connect this terminal to the output of the second high-pass filter.
7	OPAMP+	Operational Amplifier Noninverting Input.
8	REFOUT	Reference Buffer Output. The instrumentation amplifier output is referenced to this potential. Use REFOUT as a virtual ground for any point in the circuit that needs a signal reference.
9	OPAMP−	Operational Amplifier Inverting Input.
10	OUT	Operational Amplifier Output. The fully conditioned heart rate signal is present at this output. OUT can be connected to the input of an ADC.
11	LOD−	Leads Off Comparator Output. In dc leads off detection mode, LOD− is high when the electrode to −IN is disconnected, and it is low when connected. In ac leads off detection mode, LOD− is always low.
12	LOD+	Leads Off Comparator Output. In dc leads off detection mode, LOD+ is high when the +IN electrode is disconnected, and it is low when connected. In ac leads off detection mode, LOD+ is high when either the −IN or +IN electrode is disconnected, and it is low when both electrodes are connected.
13	$\overline{SDN}$	Shutdown Control Input. Drive $\overline{SDN}$ low to enter the low power shutdown mode.
14	AC/$\overline{DC}$	Leads Off Mode Control Input. Drive the AC/$\overline{DC}$ pin low for dc leads off mode. Drive the AC/$\overline{DC}$ pin high for ac leads off mode.
15	FR	Fast Restore Control Input. Drive FR high to enable fast recovery mode; otherwise, drive it low.
16	GND	Power Supply Ground.
17	$+V_S$	Power Supply Terminal.
18	REFIN	Reference Buffer Input. Use REFIN, a high impedance input terminal, to set the level of the reference buffer.
19	IAOUT	Instrumentation Amplifier Output Terminal.
20	HPSENSE	High-Pass Sense Input for Instrumentation Amplifier. Connect HPSENSE to the junction of R and C that sets the corner frequency of the dc blocking circuit.
	EP	Exposed Pad. Connect the exposed pad to GND or leave it unconnected.

TYPICAL PERFORMANCE CHARACTERISTICS

V_S = 3 V, V_{REF} = 1.5 V, V_{CM} = 1.5 V, T_A = 25°C, unless otherwise noted.

INSTRUMENTATION AMPLIFIER PERFORMANCE CURVES

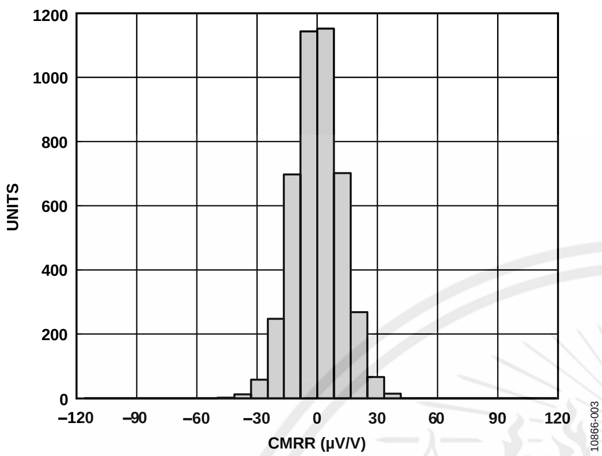


Figure 3. Instrumentation Amplifier CMRR Distribution

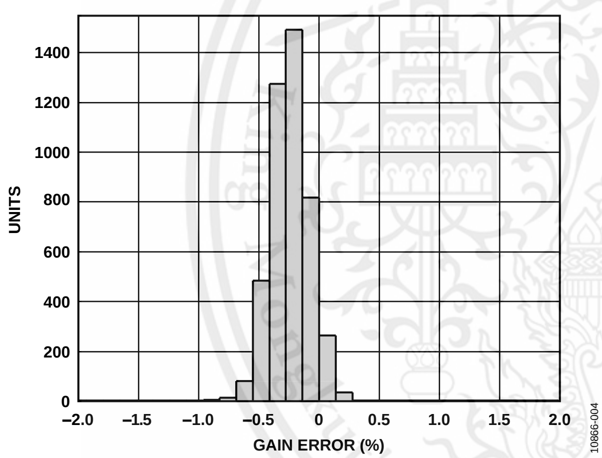


Figure 4. Instrumentation Amplifier Gain Error Distribution

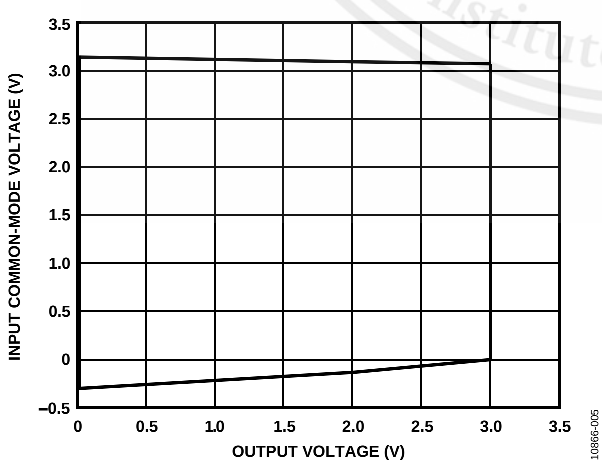


Figure 5. Instrumentation Amplifier Input Common-Mode Range vs. Output Voltage

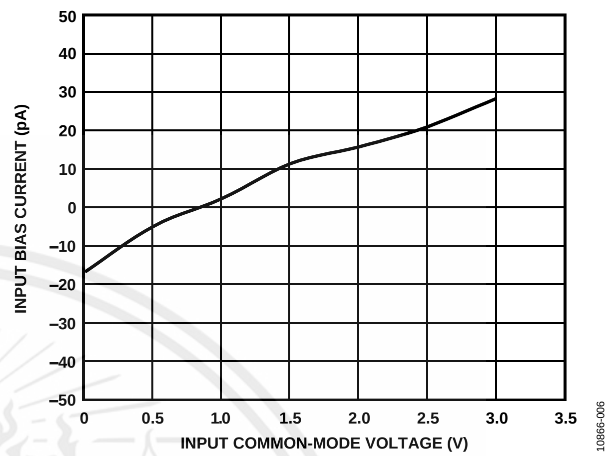


Figure 6. Instrumentation Amplifier Input Bias Current vs. CMV

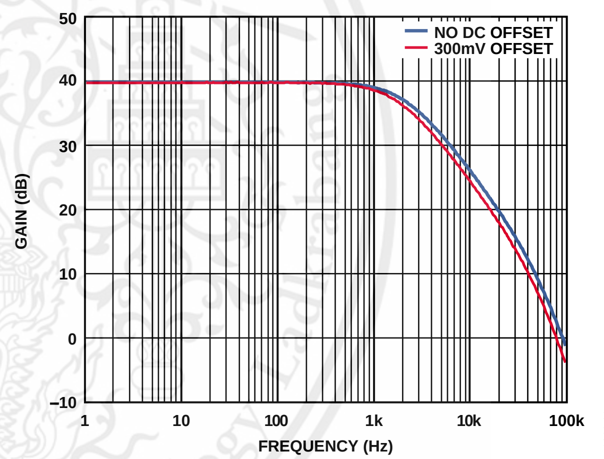


Figure 7. Instrumentation Amplifier Gain vs. Frequency

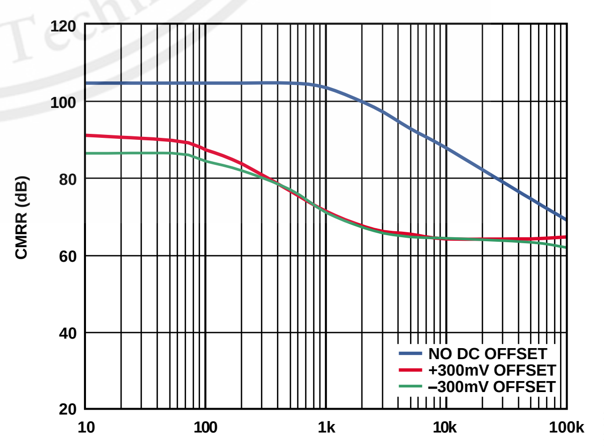


Figure 8. Instrumentation Amplifier CMRR vs. Frequency, RTI

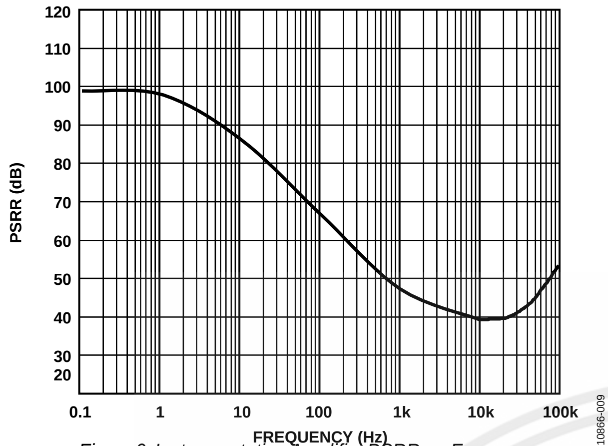


Figure 9. Instrumentation Amplifier PSRR vs. Frequency

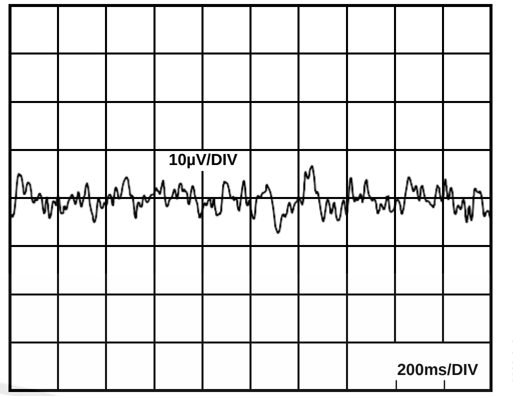


Figure 12. Instrumentation Amplifier 0.5 Hz to 40 Hz Noise

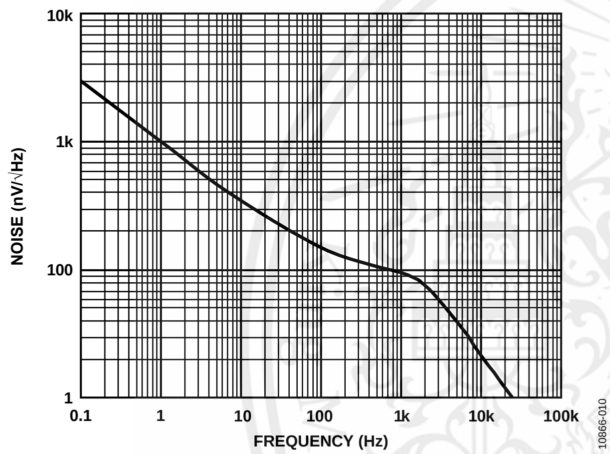


Figure 10. Instrumentation Amplifier Voltage Noise Spectral Density (RTI)

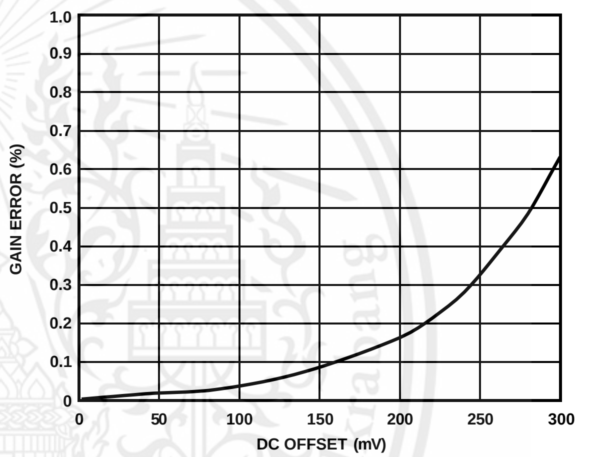


Figure 13. Instrumentation Amplifier Gain Error vs. DC Offset

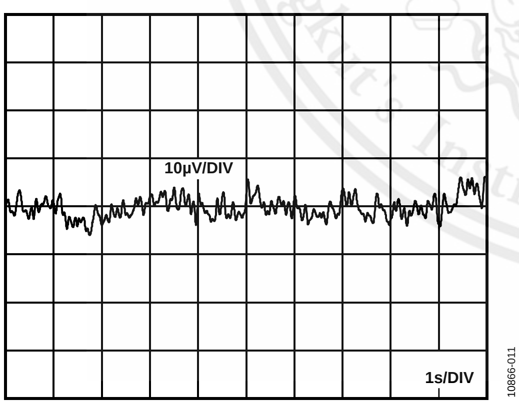


Figure 11. Instrumentation Amplifier 0.1 Hz to 10 Hz Noise

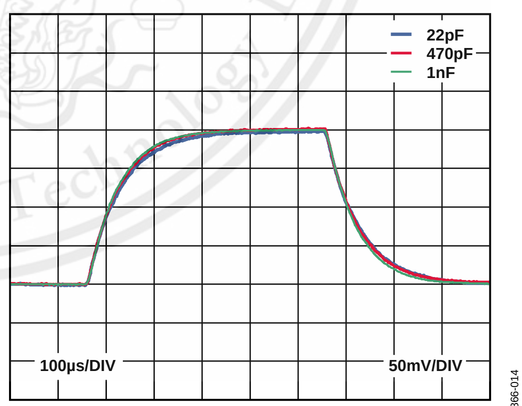


Figure 14. Instrumentation Amplifier Small Signal Pulse Response

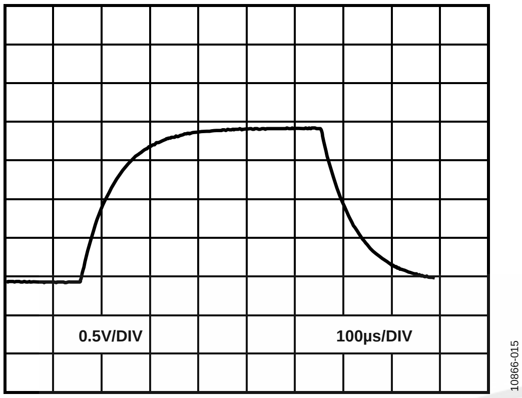


Figure 15. Instrumentation Amplifier Large Signal Pulse Response

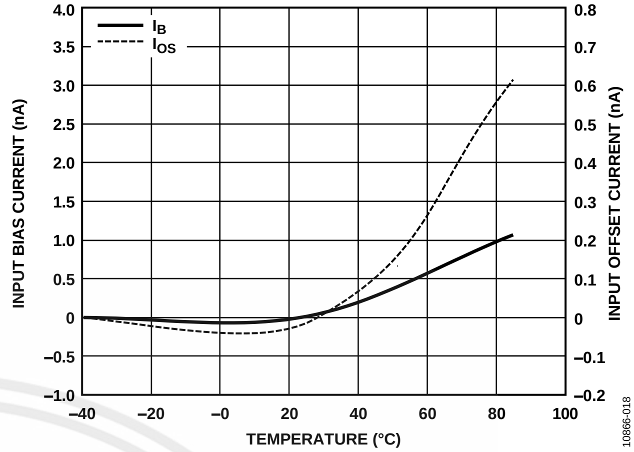


Figure 18. Instrumentation Amplifier
Input Bias Current and Input Offset Current vs. Temperature

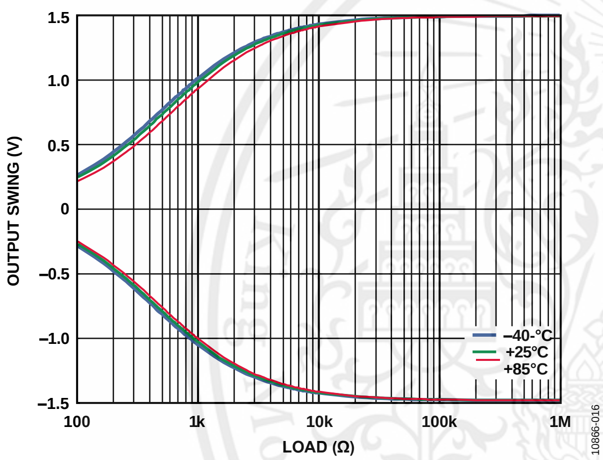


Figure 16. Instrumentation Amplifier Output Swing vs. Load

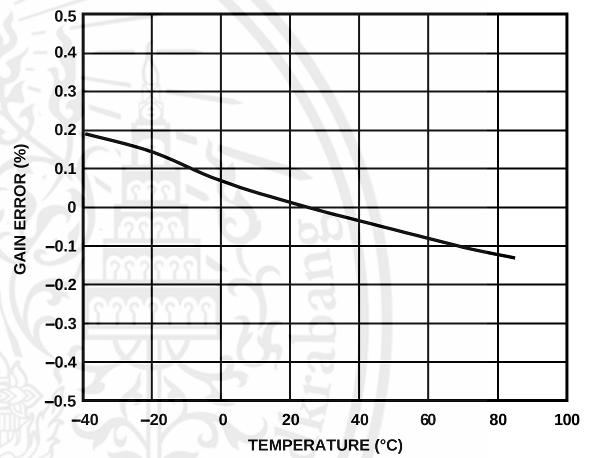


Figure 19. Instrumentation Amplifier Gain Error vs. Temperature

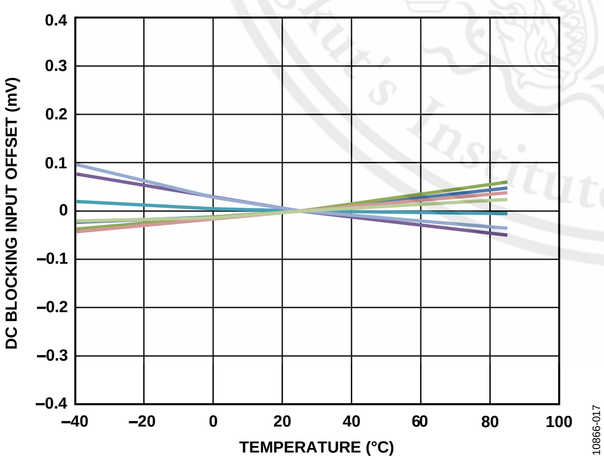


Figure 17. Instrumentation Amplifier DC Blocking Input Offset Drift

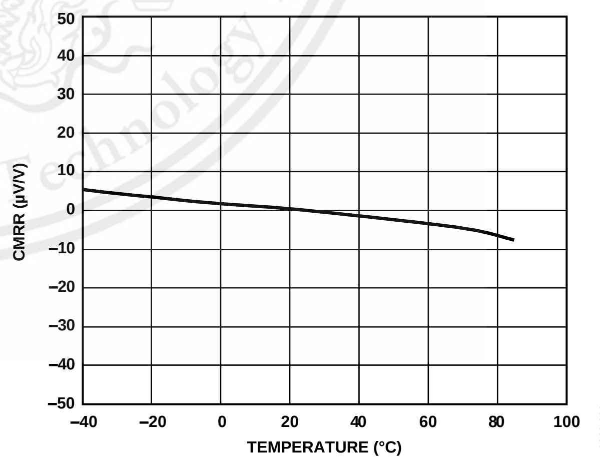


Figure 20. Instrumentation Amplifier CMRR vs. Temperature

OPERATIONAL AMPLIFIER PERFORMANCE CURVES

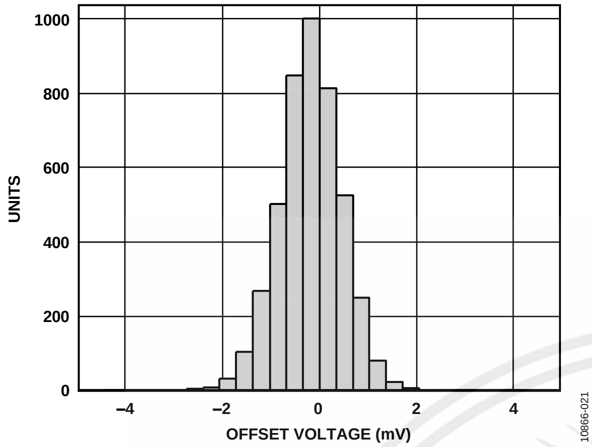


Figure 21. Operational Amplifier Offset Distribution

Figure 24. Operational Amplifier Large Signal Transient Response

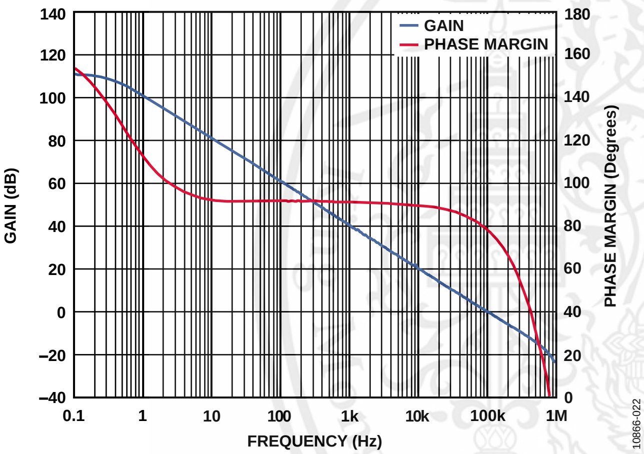


Figure 22. Operational Amplifier Open-Loop Gain and Phase vs. Frequency

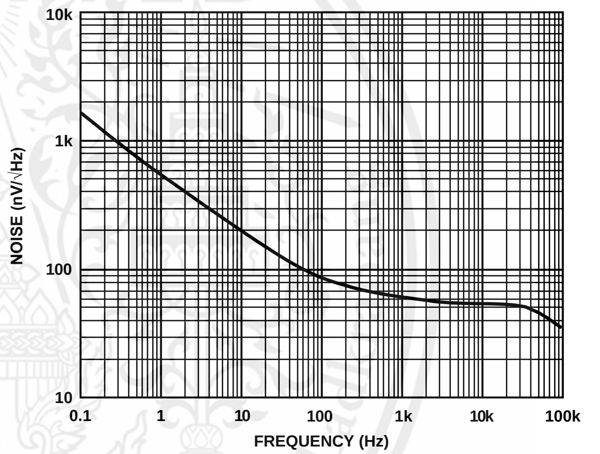


Figure 25. Operational Amplifier Voltage Spectral Noise Density vs. Frequency

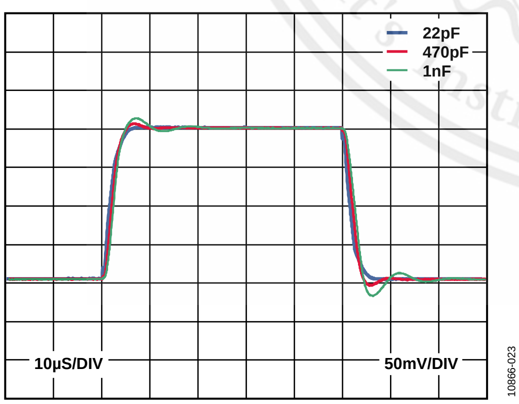


Figure 23. Operational Amplifier Small Signal Response for Various Capacitive Loads

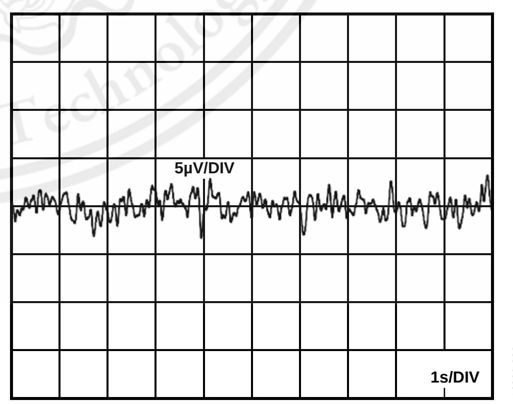


Figure 26. Operational Amplifier 0.1 Hz to 10 Hz Noise

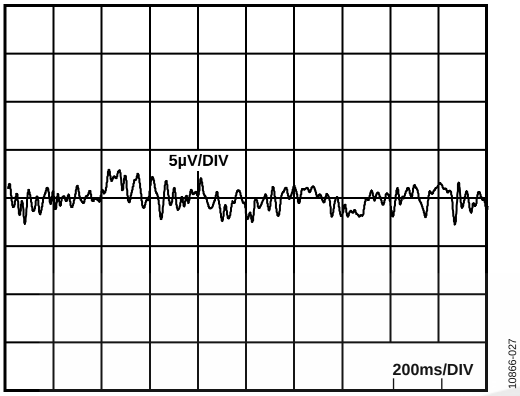


Figure 27. Operational Amplifier 0.5 Hz to 40 Hz Noise

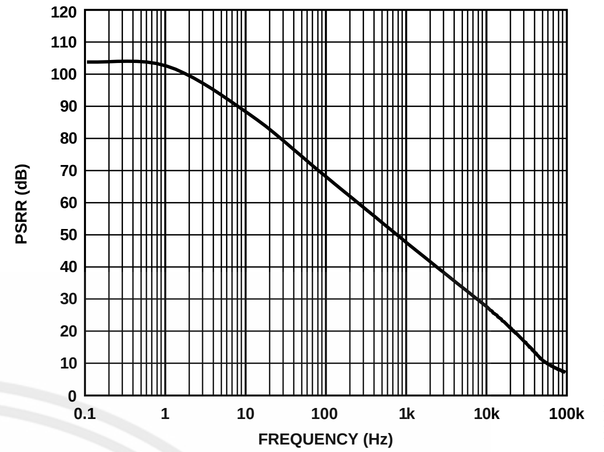


Figure 30. Operational Amplifier Power Supply Rejection Ratio

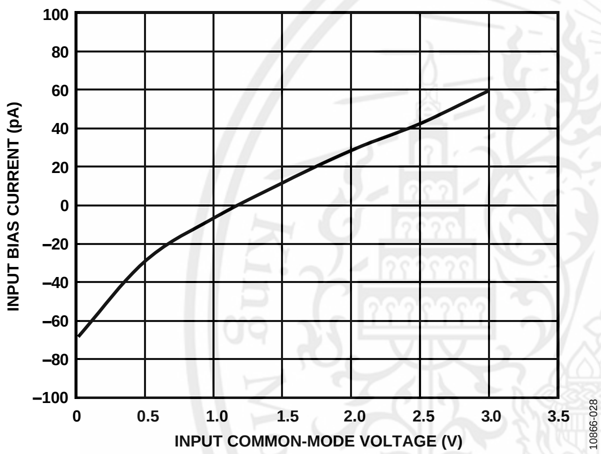


Figure 28. Operational Amplifier Bias Current vs. Input Common-Mode Voltage

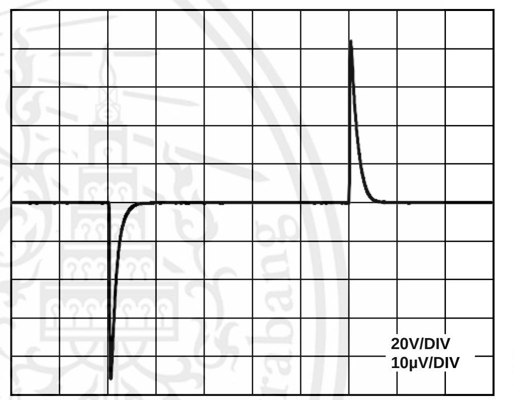


Figure 31. Operational Amplifier Load Transient Response (100 µA Load Change)

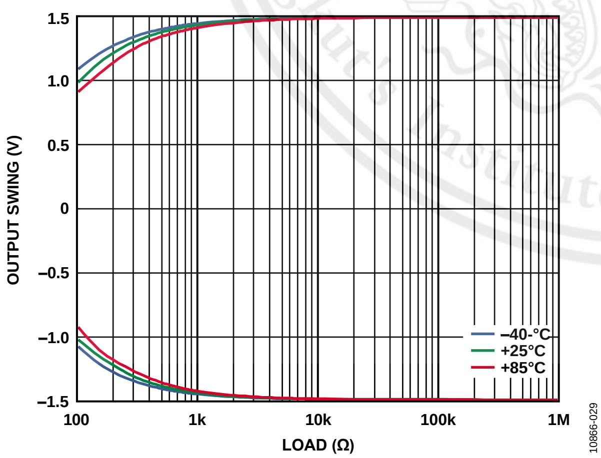


Figure 29. Operational Amplifier Output Voltage Swing vs. Output Current

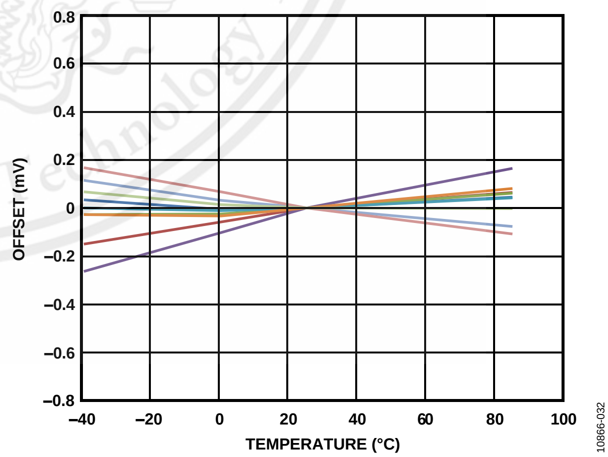


Figure 32. Operational Amplifier Offset vs. Temperature

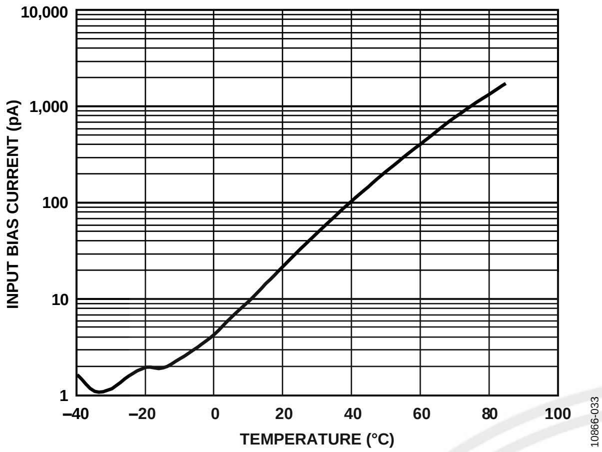


Figure 33. Operational Amplifier Bias Current vs. Temperature

RIGHT LEG DRIVE (RLD) AMPLIFIER PERFORMANCE CURVES

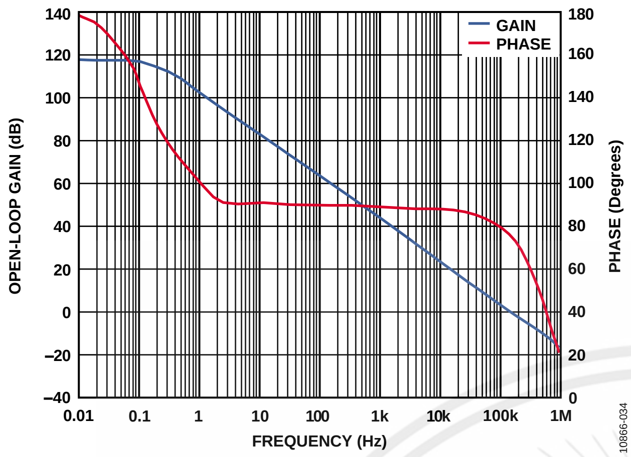


Figure 34. RLD Amplifier Open-Loop Gain and Phase vs. Frequency

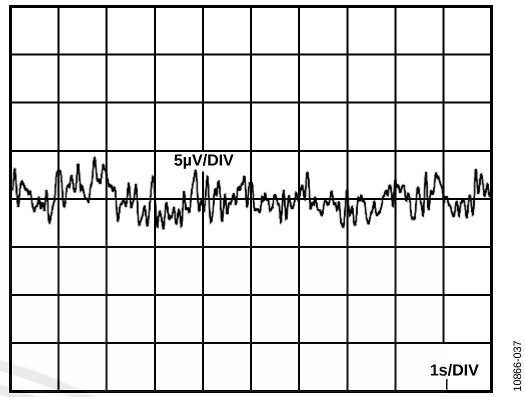


Figure 37. RLD Amplifier 0.1 Hz to 10 Hz Noise

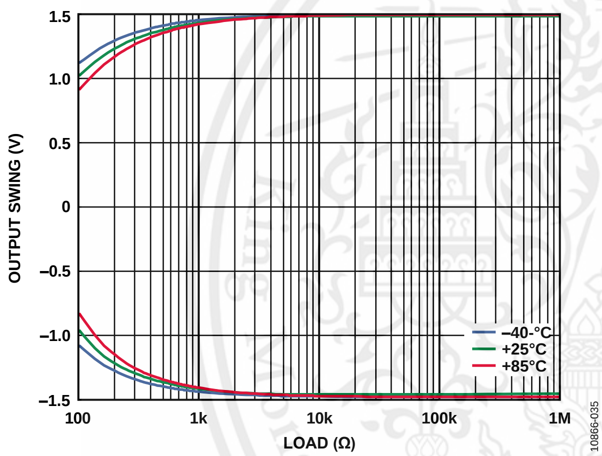


Figure 35. RLD Amplifier Output Voltage Swing vs. Output Current

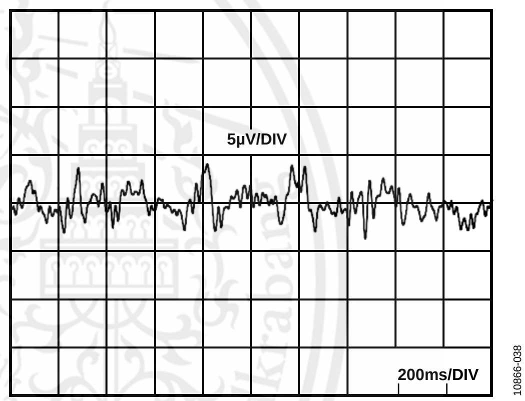


Figure 38. RLD Amplifier 0.5 Hz to 40 Hz Noise

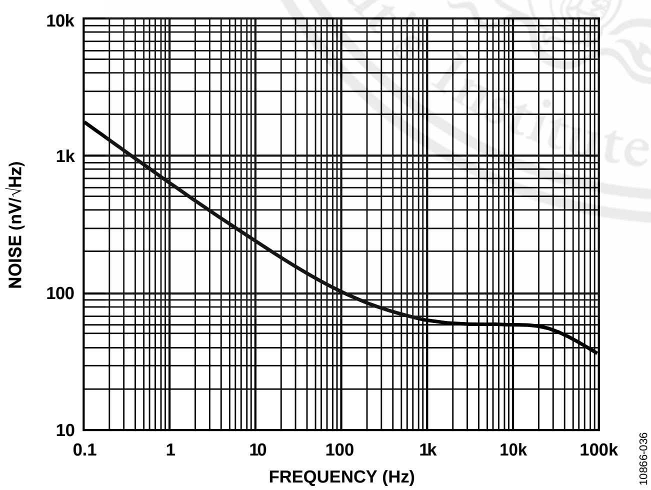


Figure 36. RLD Amplifier Voltage Spectral Noise Density vs. Frequency

REFERENCE BUFFER PERFORMANCE CURVES

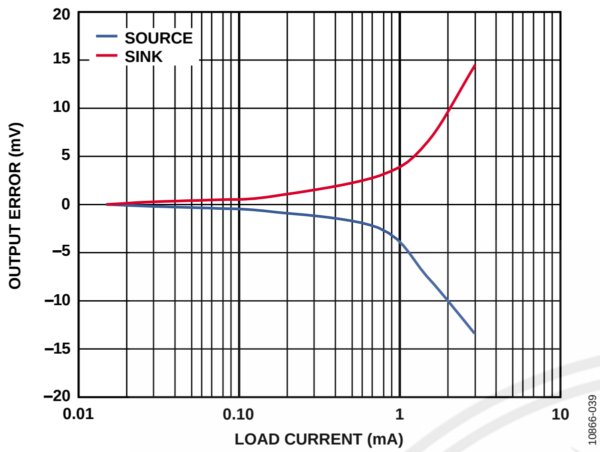


Figure 39. Reference Buffer Load Regulation

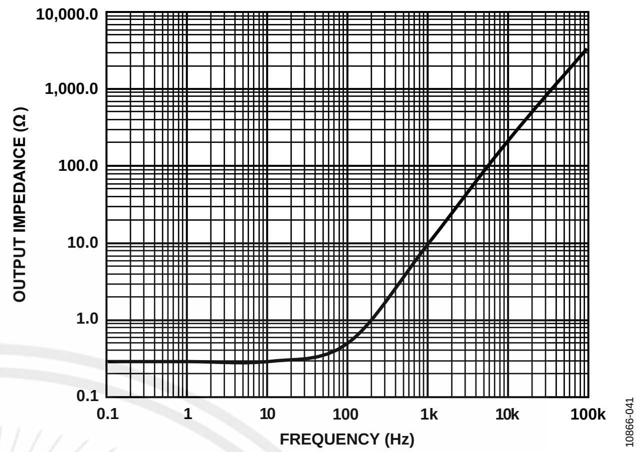


Figure 41. Reference Buffer Output Impedance vs. Frequency

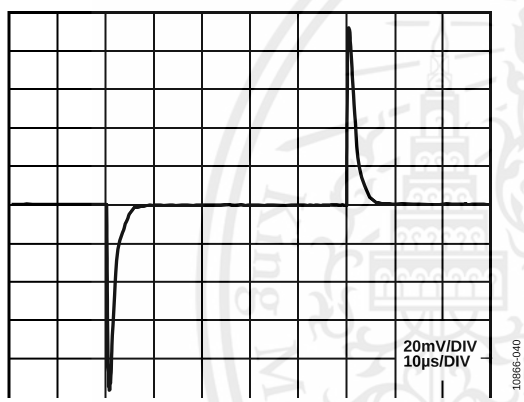


Figure 40. Reference Buffer Load Transient Response (100 µA Load Change)

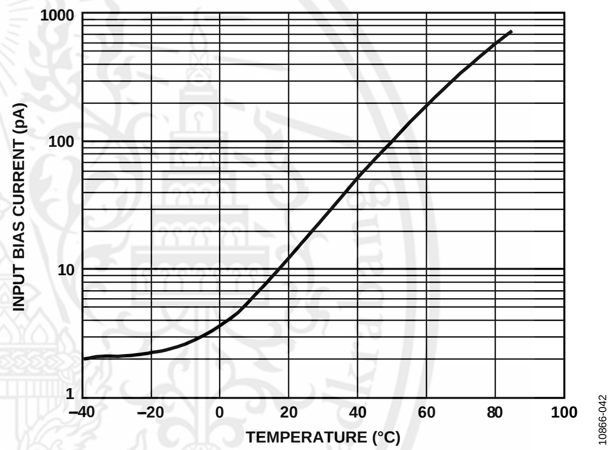


Figure 42. Reference Buffer Bias Current vs. Temperature

SYSTEM PERFORMANCE CURVES

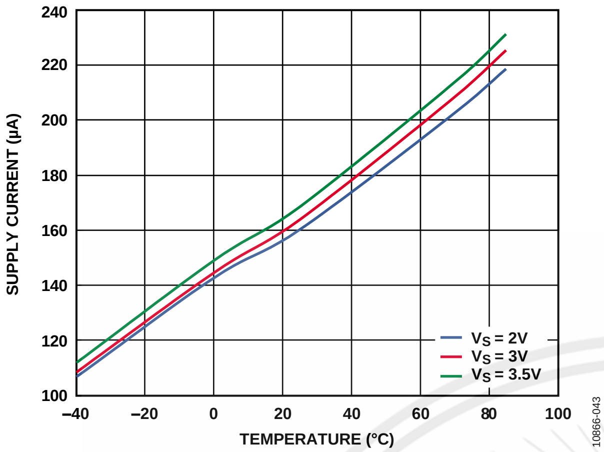


Figure 43. Supply Current vs. Temperature

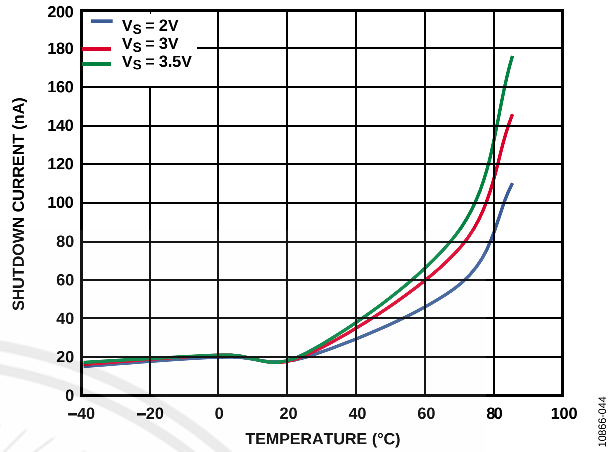


Figure 44. Shutdown Current vs. Temperature

THEORY OF OPERATION

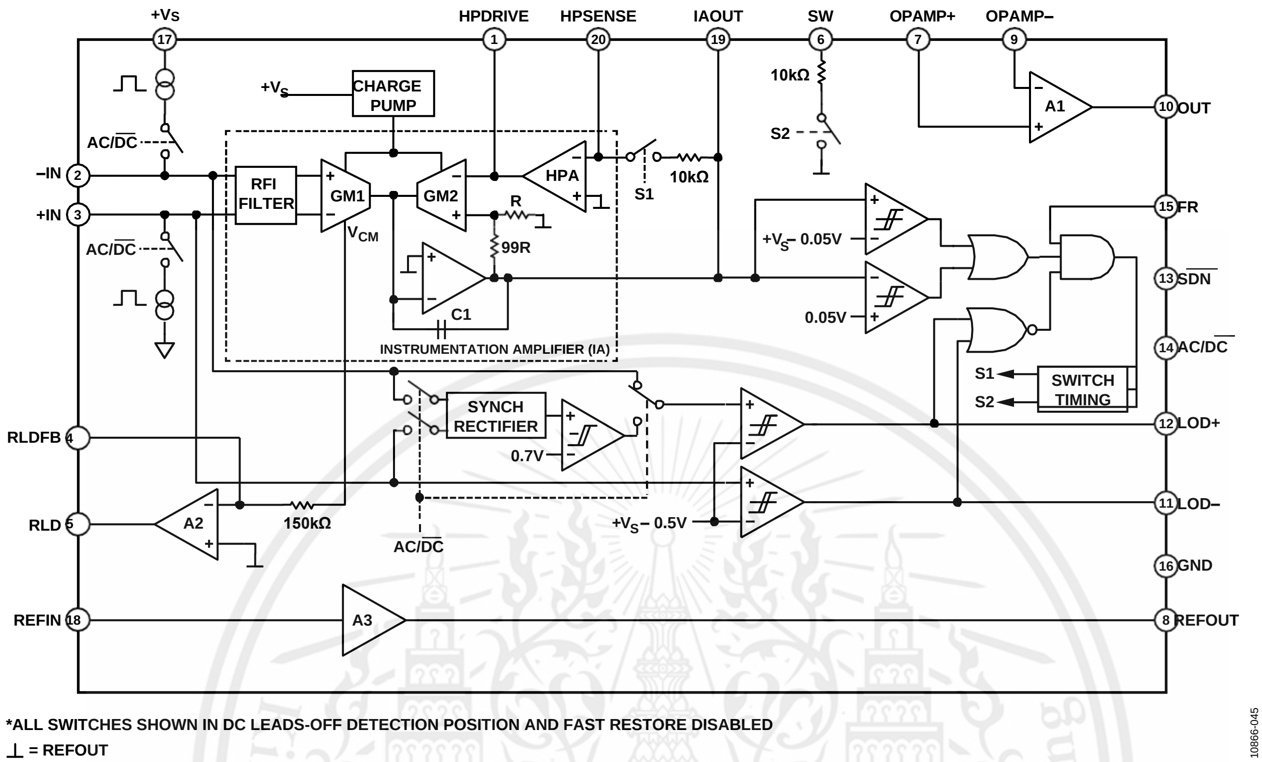


Figure 45. Simplified Schematic Diagram

ARCHITECTURE OVERVIEW

The AD8232 is an integrated front end for signal conditioning of cardiac biopotentials for heart rate monitoring. It consists of a specialized instrumentation amplifier (IA), an operational amplifier (A1), a right leg drive amplifier (A2), and a midsupply reference buffer (A3). In addition, the AD8232 includes leads off detection circuitry and an automatic fast restore circuit that brings back the signal shortly after leads are reconnected.

The AD8232 contains a specialized instrumentation amplifier that amplifies the ECG signal while rejecting the electrode half-cell potential on the same stage. This is possible with an indirect current feedback architecture, which reduces size and power compared with traditional implementations

INSTRUMENTATION AMPLIFIER

The instrumentation amplifier is shown in Figure 45 as comprised by two well-matched transconductance amplifiers (GM1 and GM2), the dc blocking amplifier (HPA), and an integrator formed by C1 and an op amp. The transconductance amplifier, GM1, generates a current that is proportional to the voltage present at its inputs. When the feedback is satisfied, an equal voltage appears across the inputs of the transconductance amplifier, GM2, thereby matching the current generated by GM1. The difference generates an error current that is integrated across Capacitor C1. The resulting voltage appears at the output of the instrumentation amplifier.

The feedback of the amplifier is applied via GM2 through two separate paths: the two resistors divide the output signal to set an overall gain of 100, whereas the dc blocking amplifier integrates any deviation from the reference level. Consequently, dc offsets as large as ±300 mV across the GM1 inputs appear inverted and with the same magnitude across the inputs of GM2, all without saturating the signal of interest.

To increase the common-mode voltage range of the instrumentation amplifier, a charge pump boosts the supply voltage for the two transconductance amplifiers. This further prevents saturation of the amplifier in the presence of large common-mode signals, such as line interference. The charge pump runs from an internal oscillator, the frequency of which is set around 500 kHz.

OPERATIONAL AMPLIFIER

This general-purpose operational amplifier (A1) is a rail-to-rail device that can be used for low-pass filtering and to add additional gain. The following sections provide details and example circuits that use this amplifier.

RIGHT LEG DRIVE AMPLIFIER

The right leg drive (RLD) amplifier inverts the common-mode signal that is present at the instrumentation amplifier inputs. When the right leg drive output current is injected into the subject, it counteracts common-mode voltage variations, thus improving the common-mode rejection of the system.

The common-mode signal that is present across the inputs of the instrumentation amplifier is derived from the transconductance amplifier, GM1. It is then connected to the inverting input of A2 through a 150 kΩ resistor.

An integrator can be built by connecting a capacitor between the RLD FB and RLD terminals. A good starting point is a 1 nF capacitor, which places the crossover frequency at about 1 kHz (the frequency at which the amplifier has an inverting unity gain). This configuration results in about 26 dB of loop gain available at a frequency range from 50 Hz to 60 Hz for common-mode line rejection. Higher capacitor values reduce the crossover frequency, thereby reducing the gain that is available for rejection and, consequently, increasing the line noise. Lower capacitor values move the crossover frequency to higher frequencies, allowing increased gain. The tradeoff is that with higher gain, the system can become unstable and saturate the output of the right leg amplifier.

Note that when using this amplifier to drive an electrode, there should be a resistor in series with the output to limit the current to be always less than 10uA even in fault conditions. For example, if the supply used is 3.0V, this resistor should be greater than 330kΩ to account for component and supply variations.

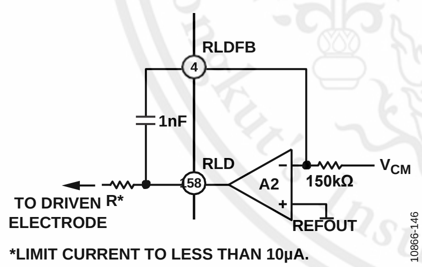


Figure 46. Typical Configuration of Right-Leg Drive Circuit

In two-electrode configurations, RLD can be used to bias the inputs through 10MΩ resistors as described in the Leads Off Detection section. If left unused, it is recommended to configure A2 as a follower by connecting RLDFB directly to RLD.

REFERENCE BUFFER

The AD8232 operates from a single supply. To simplify the design of single-supply applications, the AD8232 includes a reference buffer to create a virtual ground between the supply voltage and the system ground. The signals present at the output of the instrumentation amplifier are referenced around this voltage. For example, if there is zero differential input voltage, the voltage at the output of the instrumentation amplifier is this reference voltage.

The reference voltage level is set at the REFIN pin. It can be set with a voltage divider or by driving the REFIN pin from some other point in the circuit (for example, from the ADC reference). The voltage is available at the REFOUT pin for the filtering circuits or for an ADC input.

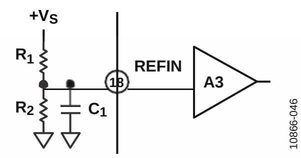


Figure 47. Setting the Internal Reference

To limit the power consumption of the voltage divider, the use of large resistors is recommended, such as 10 MΩ. The designer must keep in mind that high resistor values make it easier for interfering signals to appear at the input of the reference buffer. To minimize noise pickup, it is recommended to place the resistors close to each other and as near as possible to the REFIN terminal. Furthermore, use a capacitor in parallel with the lower resistor on the divider for additional filtering, as shown in Figure 47. Keep in mind that a large capacitor results in better noise filtering but it takes longer to settle the reference after power-up. The total time it takes the reference to settle within 1% can be estimated with the formula

$$t_{SETTLE\_REFERENCE} = 5 \times \frac{R1R2C1}{R1+R2}$$

Note that disabling the AD8232 with the shutdown terminal does not discharge this capacitor.

FAST RESTORE CIRCUIT

Because of the low cutoff frequency used in high-pass filters in ECG applications, signals may require several seconds to settle. This settling time can result in a frustrating delay for the user after a step response: for example, when the electrodes are first connected.

This fast restore function is implemented internally, as shown in Figure 48. The output of the instrumentation amplifier is connected to a window comparator. The window comparator detects a saturation condition at the output of the instrumentation amplifier when its voltage approaches 50 mV from either supply rail.

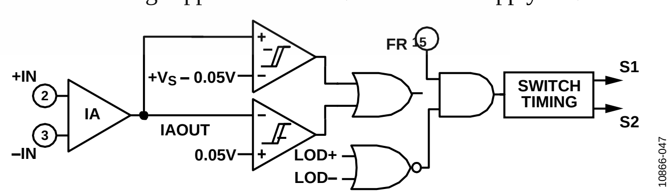


Figure 48. Fast Restore Circuit

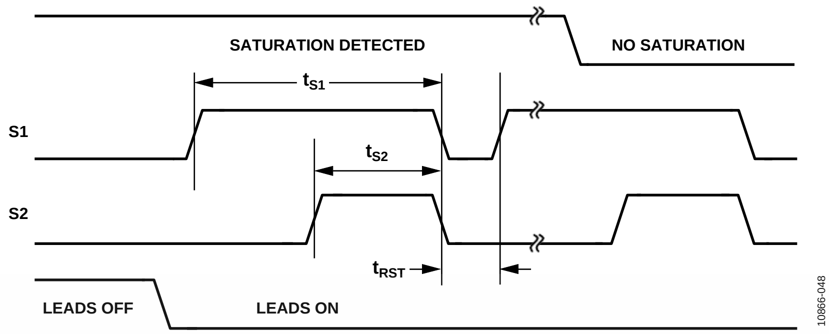


Figure 49. Timing Diagram for Fast Restore Switches (Time Base Not to Scale)

If this saturation condition is present when both input electrodes are attached to the subject, the comparator triggers a timing circuit that automatically closes Switch S1 and Switch S2 (see Figure 49 for a timing diagram).

These two switches (S1 and S2) enable two different 10 kΩ resistor paths: one between HPSENSE and IAOUT and another between SW and REFOUT. During the time Switch S1 and Switch S2 are enabled, these internal resistors appear in parallel with their corresponding external resistors forming high-pass filters. The result is that the equivalent lower resistance shifts the pole to a higher frequency, delivering a quicker settling time. Note that the fast restore settling time depends on how quickly the internal 10 kΩ resistors of the AD8232 can drain the capacitors in the high-pass circuit. Smaller capacitor values result in a shorter settling time.

If, by the end of the timing, the saturation condition persists, the cycle repeats. Otherwise, the AD8232 returns to its normal operation. If either of the leads off comparator outputs is indicating that an electrode has been disconnected, the timing circuit is prevented from triggering because it is assumed that no valid signal is present. To disable fast restore, drive the FR pin low or tie it permanently to GND.

LEADS OFF DETECTION

The AD8232 includes leads off detection. It features ac and dc detection modes optimized for either two- or three-electrode configurations, respectively.

DC Leads Off Detection

The dc leads off detection mode is used in three-electrode configurations only. It works by sensing when either instrumentation amplifier input voltage is within 0.5 V from the positive rail. In this case, each input must have a pull-up resistor connected to the positive supply. During normal operation, the subject's potential must be inside the common-mode range of the instrumentation amplifier, which is only possible if a third electrode is connected to the output of the right leg drive amplifier.

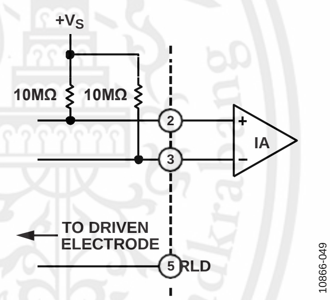


Figure 50. Circuit Configuration for DC Leads Off Detection

Because in dc leads off mode the AD8232 checks each input individually, it is possible to indicate which electrode is disconnected. The AD8232 indicates which electrode is disconnected by setting the corresponding LOD− or LOD+ pin high. To use this mode, connect the AC/DC pin to ground.

AC Leads Off Detection

The ac leads off detection mode is useful when using two electrodes only (it does not require the use of a driven electrode). In this case, a conduction path must exist between the two electrodes, which is usually formed by two resistors, as shown in Figure 51.

These resistors also provide a path for bias return on each input. Connect each resistor to REFOUT or RLD to maintain the inputs within the common-mode range of the instrumentation amplifier.

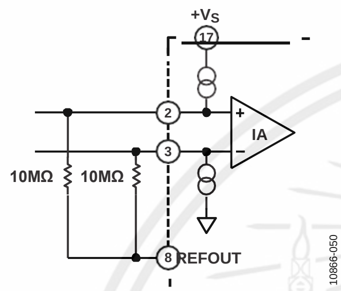


Figure 51. Circuit Configuration for AC Leads Off Detection

The AD8232 detects when an electrode is disconnected by forcing a small 100 kHz current into the input terminals. This current flows through the external resistors from IN+ to IN− and develops a differential voltage across the inputs, which is then synchronously detected and compared to an internal threshold. The recommended value for these external resistors is 10 MΩ. Low resistance values make the differential drop too low to be detected and lower the input impedance of the amplifier. When the electrodes are attached to the subject, the impedance of this path should be less than 3 MΩ to maintain the drop below the comparator's threshold.

As opposed to the dc leads off detection mode, the AD8232 is able to determine only that an electrode has lost its connection, not which one. During such an event, the LOD+ pin goes high. In this mode, the LOD− pin is not used and remains in a logic low state. To use the ac leads off mode, tie the AC/DC pin to the positive supply rail.

Note that while REFOUT is at a constant voltage value, using the RLD output as the input bias may be more effective in rejecting common-mode interference.

STANDBY OPERATION

The AD8232 includes a shutdown pin ($\overline{\text{SDN}}$) that further enhances the flexibility and ease of use in portable applications where power consumption is critical. A logic level signal can be applied to this pin to switch to shutdown mode, even when the supply is still on.

Driving the $\overline{\text{SDN}}$ pin low places the AD8232 in shutdown mode and draws less than 200 nA of supply current, offering considerable power savings. To enter normal operation, drive SDN high; when not using this feature, permanently tie SDN to $+V_S$.

During shutdown operation, the AD8232 is not able to maintain the REFOUT voltage, but it does not drain the REFIN voltage, thereby maintaining this additional conduction path from the supply to ground.

When emerging from a shutdown condition, the charge stored in the capacitors on the high-pass filters can saturate the instrumentation amplifier and subsequent stages. The use of the fast restore feature helps reduce the recovery time and, therefore, minimize on time in power sensitive applications.

INPUT PROTECTION

All terminals of the AD8232 are protected against ESD. In addition, the input structure allows for dc overload conditions that are a diode drop above the positive supply and a diode drop below the negative supply. Voltages beyond a diode drop of the supplies cause the ESD diodes to conduct and enable current to flow through the diode. Therefore, use an external resistor in series with each of the inputs to limit current for voltages beyond the supplies. In either scenario, the AD8232 safely handles a continuous 5 mA current at room temperature.

For applications where the AD8232 encounters extreme overload voltages, such as in cardiac defibrillators, use external series resistors and gas discharge tubes (GDT). Neon lamps are commonly used as an inexpensive alternative to GDTs. These devices can handle the application of large voltages but do not maintain the voltage below the absolute maximum ratings for the AD8232. A complete solution includes further clamping to either supply using additional resistors and low leakage diode clamps, such as BAV199 or FJH1100.

As a safety measure, place a resistor between the input pin and the electrode that is connected to the subject to ensure that the current flow never exceeds 10 µA. Calculate the value of this resistor to be equal to the supply voltage across the AD8232 divided by 10 µA.

RADIO FREQUENCY INTERFERENCE (RFI)

Radio frequency (RF) rectification is often a problem in applications where there are large RF signals. The problem appears as a dc offset voltage at the output. The AD8232 has a 15 pF gate capacitance and 10 kΩ resistors at each input. This forms a low-pass filter on each input that reduces rectification at high frequency (see Figure 53) without the addition of external elements.

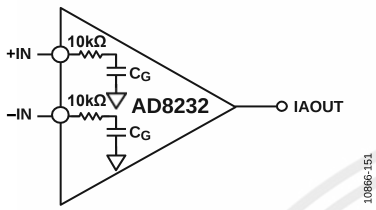


Figure 52. RFI Filter Without External Capacitors

For increased filtering, additional resistors can be added in series with each input. They must be placed as close as possible to the instrumentation amplifier inputs. These can be the same resistors used for overload and patient protection.

POWER SUPPLY REGULATION AND BYPASSING

The AD8232 is designed to be powered directly from a single 3 V battery, such as CR2032 type. It can also operate from rechargeable lithium-ion batteries, but the designer must take into account that the voltage during a charge cycle may exceed the absolute maximum ratings of the AD8232. To avoid damage to the part, use a power switch or a low power, low dropout regulator, such as ADP150.

In addition, excessive noise on the supply pins can adversely affect performance. As in all linear circuits, bypass capacitors must be used to decouple the chip power supplies. Place a 0.1 µF capacitor close to the supply pin. A 1 µF capacitor can be used farther away from the part. In most cases, the capacitor can be shared by other integrated circuits. Keep in mind that excessive decoupling capacitance increases power dissipation during power cycling.

INPUT REFERRED OFFSETS

Because of its internal architecture, the instrumentation amplifier should be used always with the DC blocking amplifier, shown as HPA in Figure 45.

As described in the Theory of Operation section, the dc blocking amplifier attenuates the input referred offsets present at the inputs of the instrumentation amplifier. However, this is true only when the dc blocking amplifier is used as an integrator. In this configuration, the input offsets from the dc blocking amplifier dominate appear directly at the output of the instrumentation amplifier.

If the dc blocking amplifier is used as a follower instead of its intended function as an integrator, the input referred offsets of the in-amp are amplified by a factor of 100.

LAYOUT RECOMMENDATIONS

It is important to follow good layout practices to optimize system performance. In low power applications, most resistors are of a high value to minimize additional supply current. The challenge of using high value resistors is that high impedance nodes become even more susceptible to noise pickup and board parasitics, such as capacitance and surface leakages. Keep all of the connections between high impedance nodes as short as possible to avoid introducing additional noise and errors from corrupting the signal.

To maintain high CMRR over frequency, keep the input traces symmetrical and length matched. Place safety and input bias resistors in the same position relative to each input. In addition, the use of a ground plane significantly improves the noise rejection of the system.

APPLICATIONS INFORMATION

ELIMINATING ELECTRODE OFFSETS

The instrumentation amplifier in the AD8232 is designed to apply gain and to filter out near dc signals simultaneously. This capability allows it to amplify a small ECG signal by a factor of 100 yet reject electrode offsets as large as ±300 mV.

To achieve offset rejection, connect an RC network between the output of the instrumentation amplifier, HPSENSE, and HPDRIVE, as shown in Figure 53.

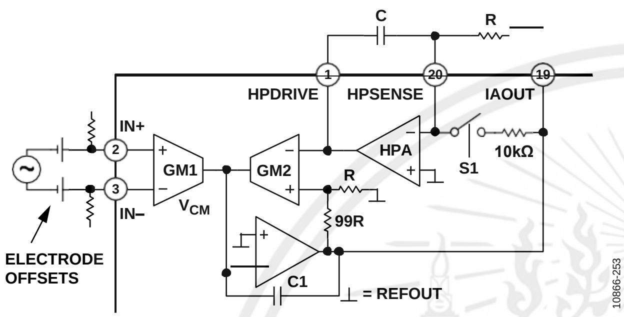


Figure 53. Eliminating Electrode Offsets

This RC network forms an integrator that feeds any near dc signals back into the instrumentation amplifier, thus eliminating the offsets without saturating any node and maintaining high signal gain.

In addition to blocking offsets present across the inputs of the instrumentation amplifier, this integrator also works as a high-pass filter that minimizes the effect of slow moving signals, such as baseline wander. The cutoff frequency of the filter is given by the equation

$$f_{-3dB} = \frac{100}{2\pi RC}$$

where R is in ohms and C is in farads.

Note that the filter cutoff is 100 times higher than is typically expected from a single-pole filter. Because of the feedback architecture of the instrumentation amplifier, the typical filter cutoff equation is modified by the gain of 100 of the instrumentation amplifier.

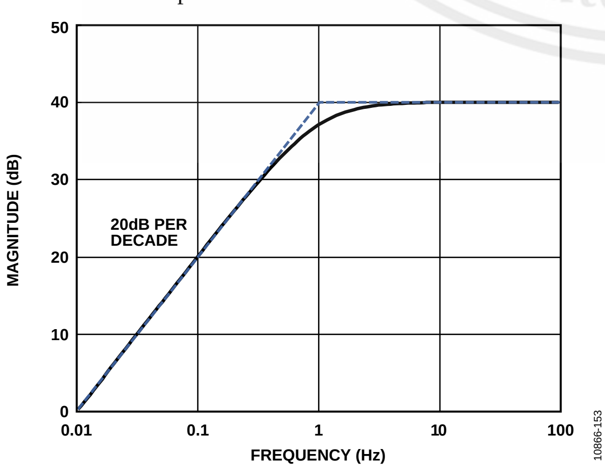


Figure 54. Frequency Response of Single-Pole DC Blocking Circuit

Just like with any high-pass filter with low frequency cutoff, any fast change in dc offset takes a long time to settle. If such change saturates the instrumentation amplifier output, the S1 switch briefly enables the 10 kΩ resistor path, thus moving the cutoff frequency to

$$f_{-3dB} = \frac{100(R + 10^4)}{2\pi RC(10^4)} \quad (1)$$

For values of R greater than 100 kΩ, the expression in Equation 1 can be approximated by

$$f_{-3dB} = \frac{1}{200\pi C}$$

This higher cutoff reduces the settling time and enables faster recovery of the ECG signal. For more information, see the Fast Restore Circuit section.

HIGH-PASS FILTERING

The AD8232 can implement higher order high-pass filters. A higher filter order yields better artifact rejection but at a cost of increased signal distortion and more passive components on the printed circuit board (PCB).

Two-Pole High-Pass Filter

A two-pole architecture can be implemented by adding a simple ac coupling RC at the output of the instrumentation amplifier, as shown in Figure 55.

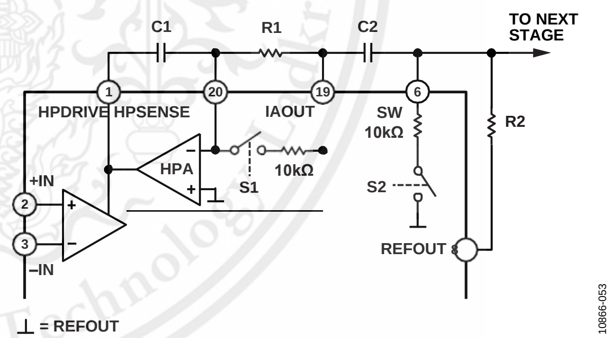


Figure 55. Schematic for a Two-Pole High-Pass Filter

Note that the right side of C2 connects to the SW terminal. Just like S1, S2 reduces the recovery time for this ac coupling network by placing 10 kΩ in parallel with R2. See the Fast Restore Circuit section for additional details on switch timing and trigger conditions.

Keep in mind that if this passive network is not buffered, it exhibits higher output impedance at the input of a subsequent low-pass filter, such as with Sallen-Key filter topologies. Careful component selection can yield good results without a buffer. See the Low-Pass Filtering and Gain section for additional information on component selection.

Additional High-Pass Filtering Options

In addition to the topologies explained in the previous sections, an additional pole may be added to the dc blocking circuit for additional rejection of low frequency signals. This configuration is shown in Figure 56.

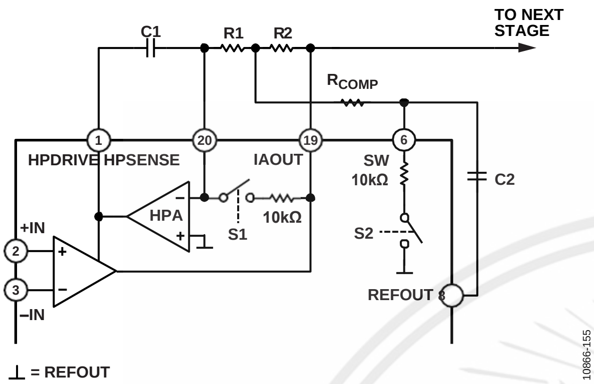


Figure 56. Schematic for an Alternative Two-Pole High-Pass Filter

An extra benefit of this circuit topology is that it allows lower cutoff frequency with lower R and C values and the resistor, R_{COMP}, can be used to control the Q of the filter to achieve narrow band-pass filters (for heart rate detection) or maximum pass-band flatness (for cardiac monitoring).

With this topology, the filter attenuation reverts to a single pole roll off at very low frequencies. Because the initial roll off was 40 dB per decade, this reversion to 20 dB per decade has little impact on the ability of the filter to reject out-of-band low frequency signals.

The designer may choose different values to achieve the desired filter performance. To simplify the design process, use the following recommendations as a starting point for component value selection.

$$R1 = R2 \geq 100\ k\Omega$$

$$C1 = C2$$

$$R_{COMP} = 0.14 \times R1$$

The cutoff frequency is located at

$$f_C = \frac{10}{2\pi\sqrt{R1\ C1\ R2\ C2}}$$

The selection of R_{COMP} to be 0.14 times the value of the other two resistors optimizes the filter for a maximally flat pass band. Reduce its value to increase the Q and, consequently, the peaking of the filter. Keep in mind that a very low value of R_{COMP} can result in an unstable circuit. The selection of values based on these criteria result in a transfer function similar to the one shown in Figure 58.

When additional low frequency rejection is desired, a high-order high-pass filter can be implemented by adding an ac coupling network at the output of the instrumentation amplifier, as shown in Figure 57. The SW terminal is connected to the ac coupling network to obtain the best settling time response when fast restore engages.

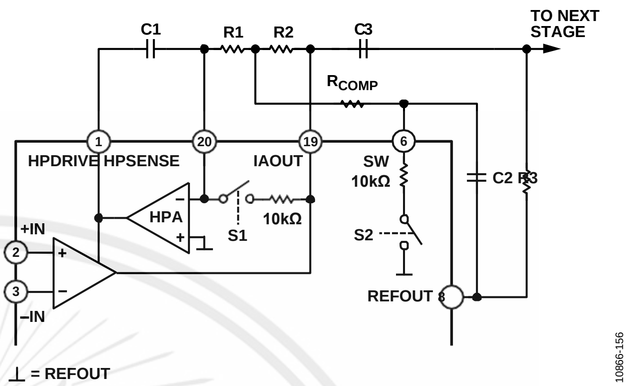


Figure 57. Schematic for a Three-Pole High-Pass Filter

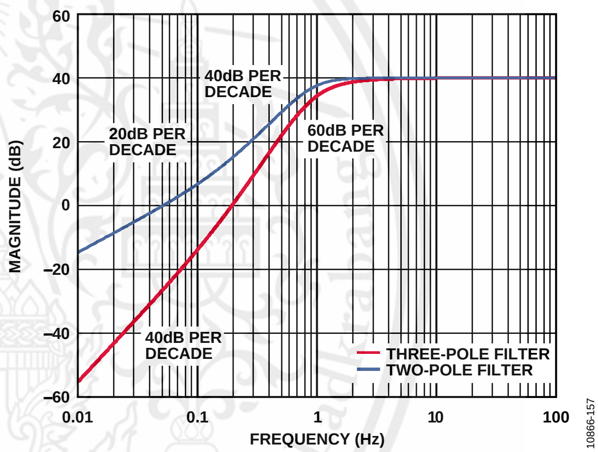


Figure 58. Frequency Response of Circuits in Figure 56 and Figure 57

Careful analysis and adjustment of all of the component values in practice is recommended to optimize the filter characteristics. A useful hint is to reduce the value of R_{COMP} to increase the peaking of the active filter to overcome the additional roll off introduced by the ac coupling network. Proper adjustment can yield the best pass-band flatness.

The design of the high-pass filter involves tradeoffs between signal distortion, component count, low frequency rejection, and component sizes. For example, a single-pole high-pass filter results in the least distortion to the signal, but its rejection of low-frequency artifacts is the lowest Table 4 compares the recommended filtering options.

Table 4. Comparison of High-Pass Filtering Options

	Filter Order	Component Count	LowFrequencyRejection	Capacitor Sizes/Values	Signal Distortion[1]	Output Impedance[2]
Figure 53	1	2	Good	Large	Low	Low
Figure 55	2	4	Better	Large	Medium	Higher
Figure 56	2	5	Better	Smaller	Medium	Low
Figure 57	3	7	Best	Smaller	Highest	Higher

[1] For equivalent corner frequency location.
[2] Output impedance refers to the drive capability of the high-pass filter before the low-pass filter. Low output impedance is desirable to allow flexibility in the selection of values for a low-pass filter, as explained in the Low-Pass Filtering and Gain section.

LOW-PASS FILTERING AND GAIN

The AD8232 includes an uncommitted op amp that can be used for extra gain and filtering. For applications that do not require a high-order filter, a simple RC low-pass filter should suffice, and the op amp can buffer or further amplify the signal.

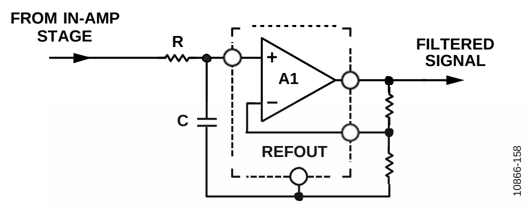


Figure 59. Schematic for a Single-Pole Low-Pass Filter and Additional Gain

Applications that require a steeper roll off or a sharper cut off, a Sallen-Key filter topology can be implemented, as shown in Figure 60.

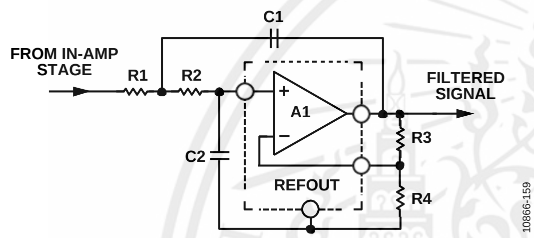


Figure 60. Schematic for a Two-Pole Low-Pass Filter

The following equations describe the low-pass cut off frequency, gain, and Q:

$$f_C = 1/(2\pi\sqrt{(R1\ C1\ R2\ C2)})$$

$$Gain = 1 + R3/R4$$

$$Q = \frac{\sqrt{R1 \times C1 \times R2 \times C2}}{R1 \times C2 + R2 \times C2 + R1 \times C1(1 - Gain)}$$

Note that changing the gain has an effect on Q and vice versa. Common values for Q are 0.5 to avoid peaking or 0.7 for maximum flatness and sharp cut off. A high value of Q can be used in narrow-band applications to increase peaking and the selectivity of the band-pass filter.

A common design procedure is to set R1 = R2 = R and C1 = C2 = C, which simplifies the expressions for cutoff frequency and Q to

$$f_C = 1/(2\pi RC)$$

$$Q = \frac{1}{3 - Gain}$$

Note that Q can be controlled by setting the gain with R3 and R4; however, this limits the gain to be less than 3. For gain values equal to or greater than 3, the circuit becomes unstable. A simple modification that allows higher gains is to make the value of C2 at least four times larger than C1.

It is important to note that these design equations only hold true in the case that the output impedance of the previous stage is much lower than the input impedance of the Sallen-Key filter. This is not the case when using an ac coupling network between the instrumentation amplifier output and the input of the low-pass filter without a buffer.

To connect these two filtering stages properly without a buffer, make the value of R1 at least ten times larger than the resistor of the ac coupling network (labeled as R2 in Figure 55).

DRIVING ANALOG-TO-DIGITAL CONVERTERS

The ability of AD8232 to drive capacitive loads makes it ideal to drive an ADC without the need for an additional buffer. However, depending on the input architecture of the ADC, a simple low-pass RC network may be required to decouple the transients from the switched-capacitor input typical of modern ADCs. This RC network also acts as an additional filter that can help reduce noise and aliasing. Follow the recommended guidelines from the ADC data sheet for the selection of proper R and C values.

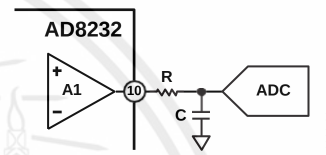


Figure 61. Driving an ADC

DRIVEN ELECTRODE

A driven lead (or reference electrode) is often used to minimize the effects of common-mode voltages induced by the power line and other interfering sources. The AD8232 extracts the common-mode voltage from the instrumentation amplifier inputs and makes it available through the RLD amplifier to drive an opposing signal into the patient. This functionality maintains the voltage between the patient and the AD8232 at a near constant, greatly improving the common-mode rejection ratio.

As a safety measure, place a resistor between the RLD pin and the electrode connected to the subject to ensure that current flow never exceeds 10 µA. Calculate the value of this resistor to be equal to the supply voltage across the AD8232 divided by 10 µA.

The AD8232 implements an integrator formed by an internal 150 kΩ resistor and an external capacitor to drive this electrode. Choice of the integrator capacitor is a tradeoff between line rejection capability and stability. The capacitor should be small to maintain as much loop gain as possible, around 50 Hz and 60 Hz, which are typical line frequencies. For stability, the gain of the integrator should be less than unity at the frequency of any other poles in the loop, such as those formed by the patient's capacitance and the safety resistors. The suggested application circuits use a 1 nF capacitor, which results in a loop gain of about 20 at line frequencies, with a crossover frequency of about 1 kHz.

In a two-lead configuration, the RLD amplifier can be used to drive the bias current resistors on the inputs. Although not as effective as a true driven electrode, this configuration can provide some common-mode rejection improvement if the sense electrode impedance is small and well matched.

APPLICATION CIRCUITS

HEART RATE MEASUREMENT NEXT TO THE HEART

For wearable exercise devices, the AD8232 is typically placed in a pod near the heart. The two sense electrodes are placed underneath the pectoral muscles; no driven electrode is used. Because the distance from the heart to the AD8232 is small, the heart signal is strong and there is less muscle artifact interference.

In this configuration, space is at a premium. By using as few external components as possible, the circuit in Figure 62 is optimized for size.

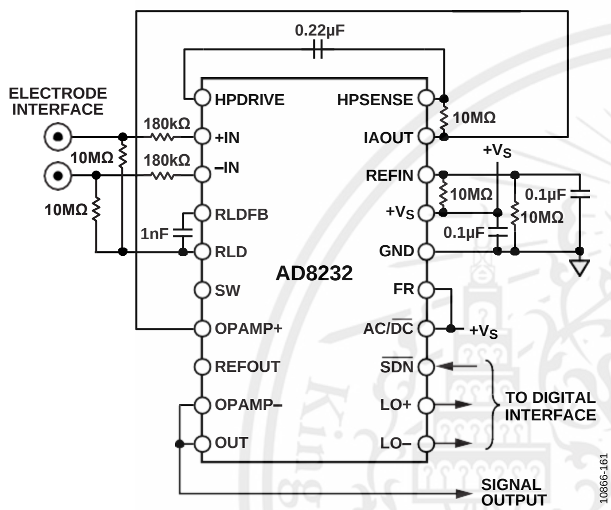


Figure 62. Circuit for Heart Rate Measurement Next to Heart

A shorter distance from the AD8232 to the heart makes this application less vulnerable to common-mode interference. However, since RLD is not used to drive an electrode, it can be used to improve the common-mode rejection by maintaining the midscale voltage through the 10 MΩ bias resistors.

A single-pole high-pass filter is set at 7 Hz, and there is no low-pass filter. No gain is used on the output op amp thereby reducing the number of resistors for a total system gain of 100.

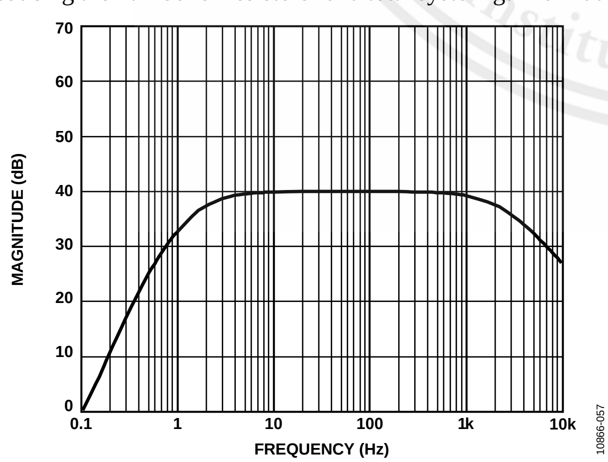


Figure 63. Frequency Response for HRM Next to Heart Circuit

The input terminals in this configuration use two 180 kΩ resistors, to protect the user from fault conditions. Two 10 MΩ resistors provide input bias. Use higher values for electrodes with high output impedance, such as cloth electrodes.

The schematic also shows two 10 MΩ resistors to set the midscale reference voltage. If there is already a reference voltage available, it can be driven into the REFIN input to eliminate these two 10 MΩ resistors.

EXERCISE APPLICATION: HEART RATE MEASURED AT THE HANDS

In this application, the heart rate signal is measured at the hands with stainless steel electrodes. The user's arm and upper body movement create large motion artifacts and the long lead length makes the system susceptible to common-mode interference. A very narrow band-pass characteristic is required to separate the heart signal from the interferers.

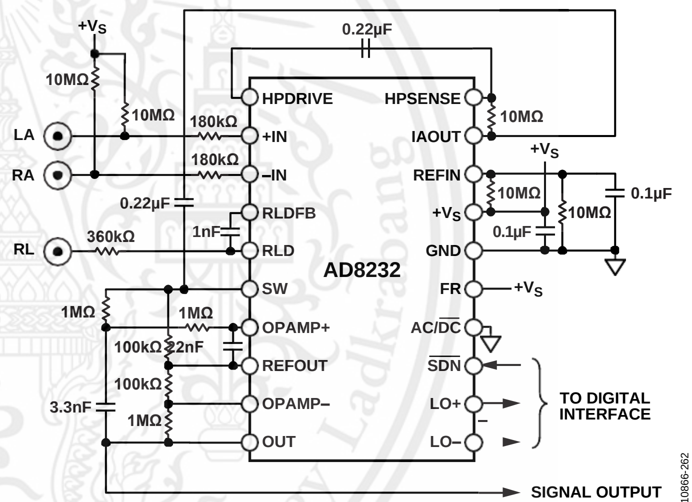


Figure 64. Circuit for Heart Rate Measurement at Hands

The circuit in Figure 64 uses a two-pole high-pass filter set at 7 Hz. A two-pole low-pass filter at 24 Hz follows the high-pass filters to eliminate any other artifacts and line noise.

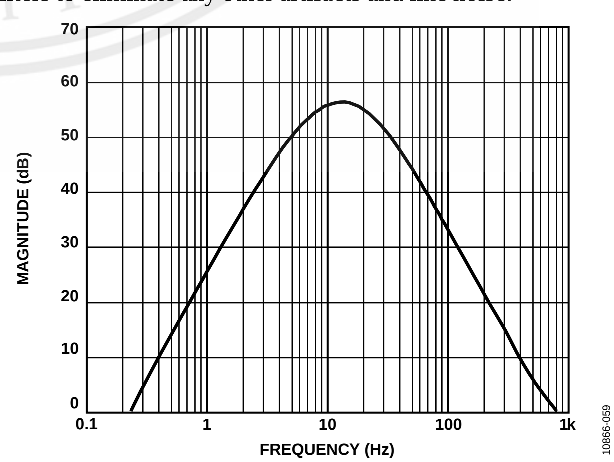


Figure 65. Frequency Response for HRM Circuit Taken at the Hands

The overall narrow-band nature of this filter combination distorts the ECG waveform significantly. Therefore, it is only suitable to determine the heart rate, and not to analyze the ECG signal characteristics.

The low-pass filter stage also includes a gain of 11, to bring the total system gain close to 1100 (note that the filter roll off prevents the maximum gain from reaching this value). Because the ECG signal is measured at the hands, it is weaker than when measured closer to the heart.

The RLD circuit drives to the third electrode, which can also be located at the hands, to cancel common-mode interference.

CARDIAC MONITOR CONFIGURATION

This configuration is designed for monitoring the shape of the ECG waveform. It assumes that the patient remains relatively still during the measurement, and therefore, motion artifacts are less of an issue.

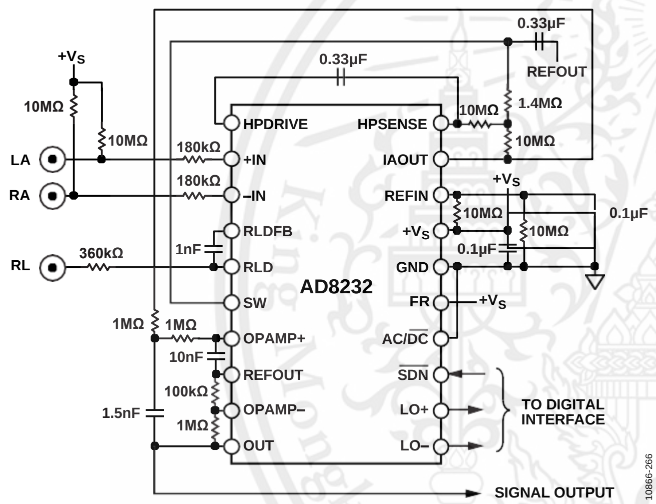


Figure 66. Circuit for ECG Waveform Monitoring

To obtain an ECG waveform with minimal distortion, the AD8232 is configured with a 0.5 Hz two-pole high-pass filter followed by a two-pole, 40 Hz, low-pass filter. A third electrode is driven for optimum common-mode rejection.

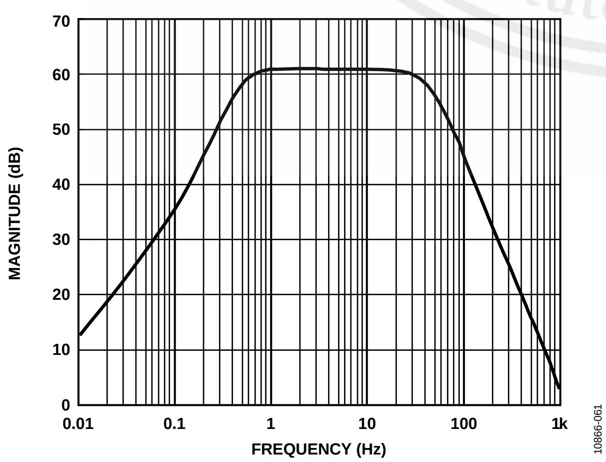


Figure 67. Frequency Response of Cardiac Monitor Circuit

In addition to 40 Hz filtering, the op amp stage is configured for a gain of 11, resulting in a total system gain of 1100. To optimize the dynamic range of the system, the gain level is adjustable, depending on the input signal amplitude (which may vary with electrode placement) and ADC input range.

PORTABLE CARDIAC MONITOR WITH ELIMINATION OF MOTION ARTIFACTS

The circuit in Figure 68 shows an implementation of a battery-powered embedded system for monitoring heart rate in applications where the patient engages in moderate activity, such as with a Holter monitor. The AD8232 uses a three-electrode patient interface and implements a two-pole high-pass filter with a cutoff at 0.3 Hz, and a two-pole low-pass filter with a cutoff frequency of 37 Hz. The total signal gain in the pass band is 400. The fully conditioned signal is sampled by the sigma-delta ADC integrated on the low power microcontroller, ADuCM360. The wide dynamic range of this ADC provides flexibility to reduce the signal gain to avoid saturation, depending on electrode placement.

Because the pass band is relatively wide for ambulatory applications, the ADXL346 accelerometer signal can be used to further minimize the noise introduced by the motion of the patient. Moreover, the microcontroller can use the motion information to monitor inactivity and to issue a system shutdown to save battery power.

The low dropout regulator ensures that the maximum of 3 V is not exceeded, especially during charge cycles of the battery, which can be a lithium-ion cell.

In this application, the ADuCM360 uses its Port 0 to perform DMA transfers to the host communication interface or to an on-board memory, if recording the waveform for later transfer. However, in any particular application, this port should be used for the busiest interface to minimize CPU cycles and maintain low power operation.

Note that this circuit is shown to demonstrate the capabilities of AD8232 and other system components. It is not a complete system design and additional effort must be made to ensure compliance with medical safety guidelines from regulatory agencies.

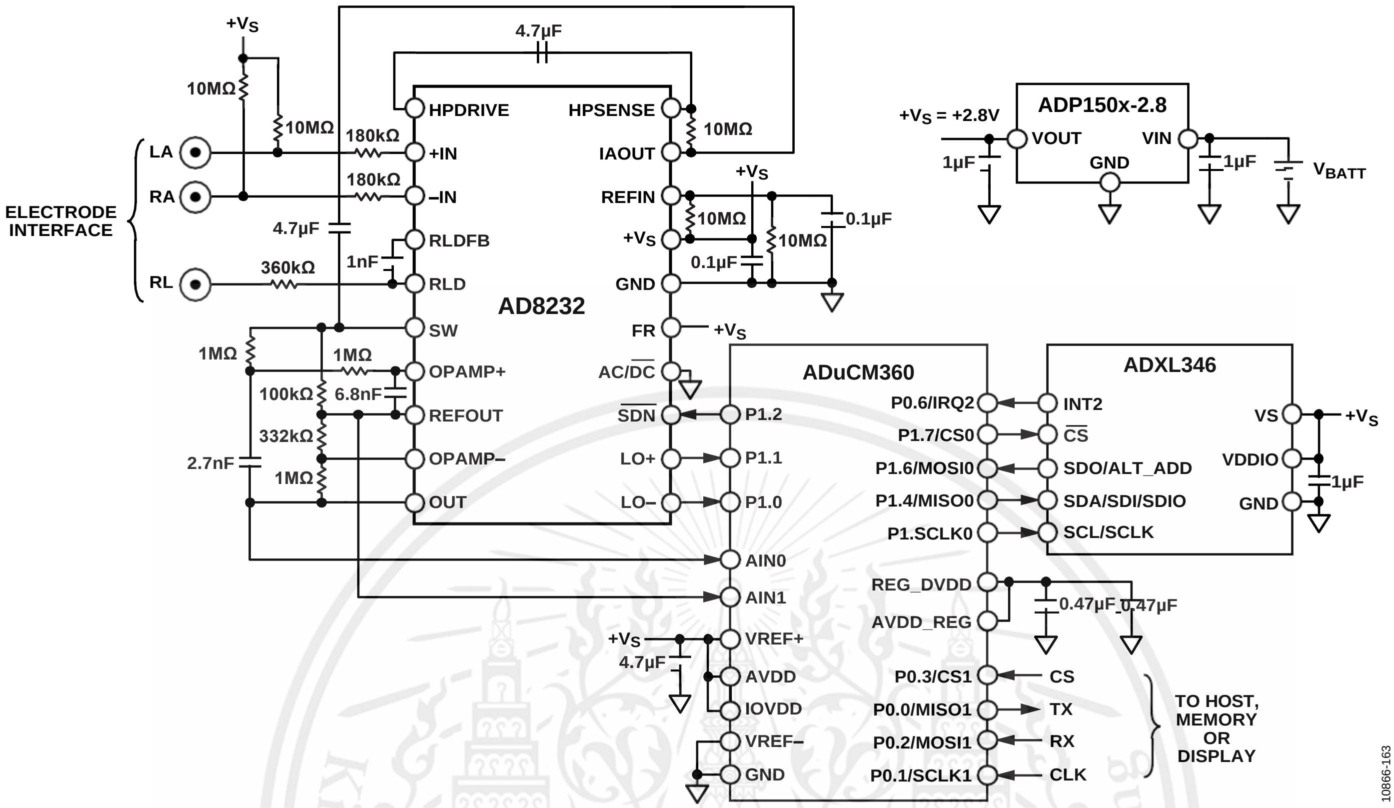


Figure 68. Low Power Portable Cardiac Monitor

PACKAGING AND ORDERING INFORMATION

OUTLINE DIMENSIONS

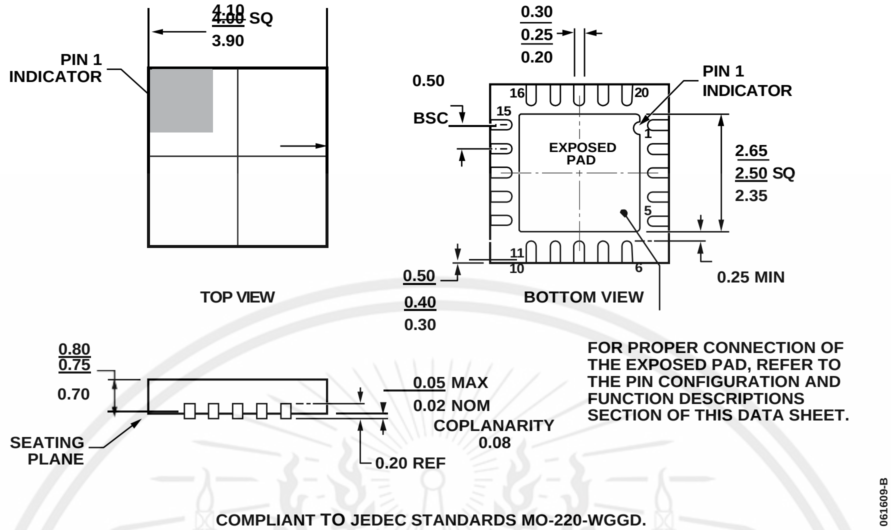


Figure 69. 20-Lead Lead Frame Chip Scale Package [LFCSP_WQ]
4 mm × 4 mm Body, Very Very Thin Quad
(CP-20-10)
Dimensions shown in millimeters

ORDERING GUIDE

Model[1]	Temperature Range	Package Description	Package Option
AD8232ACPZ-R7	−40°C to +85°C	20-Lead Lead Frame Chip Scale Package [LFCSP_WQ]	CP-20-10
AD8232ACPZ-RL	−40°C to +85°C	20-Lead Lead Frame Chip Scale Package [LFCSP_WQ]	CP-20-10
AD8232ACPZ-WP	−40°C to +85°C	20-Lead Lead Frame Chip Scale Package [LFCSP_WQ]	CP-20-10
AD8232-EVALZ		Evaluation Board	

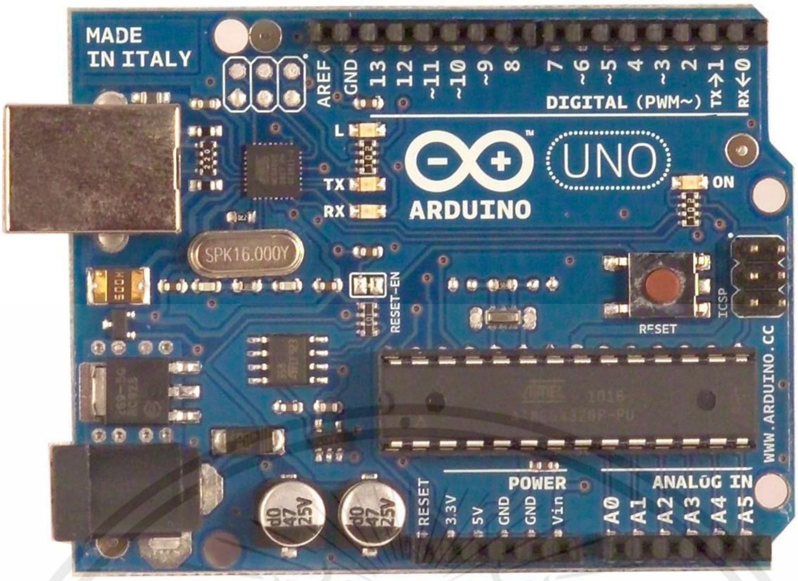
[1] Z = RoHS Compliant Part.

NOTES

ANALOG DEVICES

www.analog.com/AD8232

Arduino UNO



Product Overview

The Arduino Uno is a microcontroller board based on the ATmega328 (datasheet). It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started. The Uno differs from all preceding boards in that it does not use the FTDI USB-to-serial driver chip. Instead, it features the Atmega8U2 programmed as a USB-to-serial converter.

"Uno" means one in Italian and is named to mark the upcoming release of Arduino 1.0. The Uno and version 1.0 will be the reference versions of Arduno, moving forward. The Uno is the latest in a series of USB Arduino boards, and the reference model for the Arduino platform; for a comparison with previous versions, see the index of Arduino boards.

Index

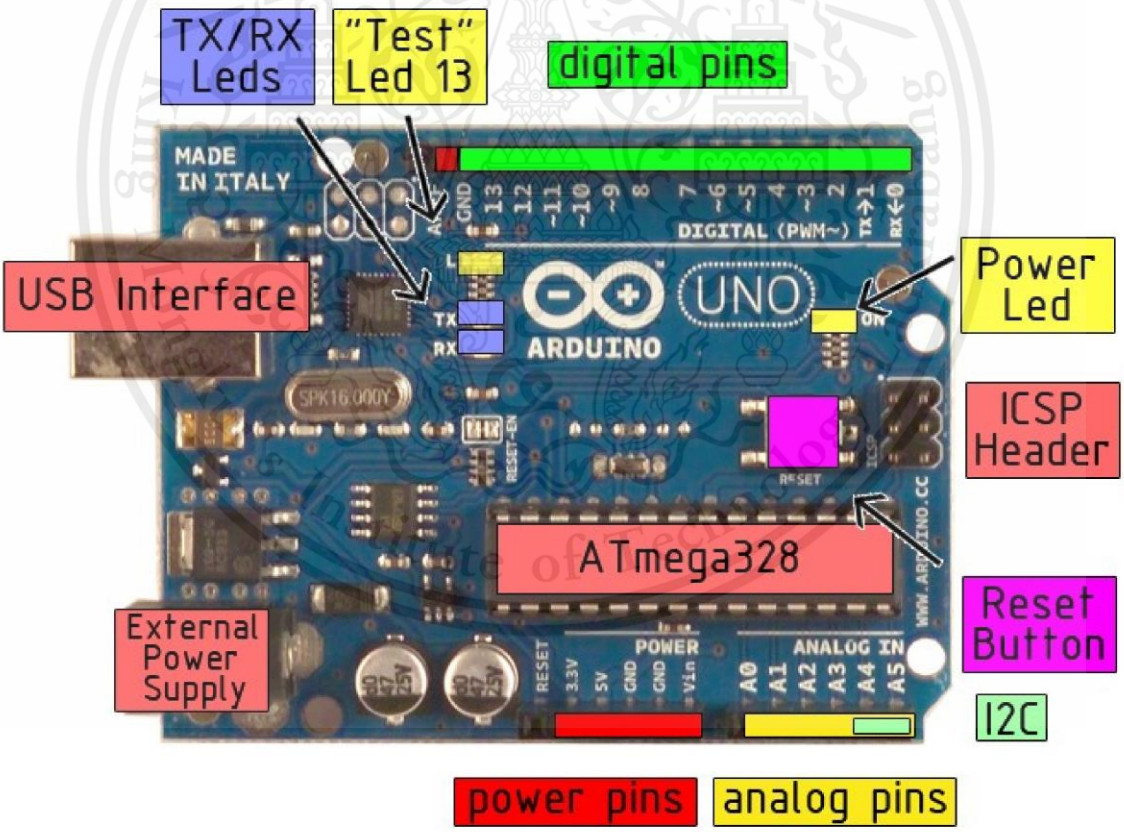
Technical Specification

EAGLE files: arduino-duemilanove-uno-design.zip Schematic: arduino-uno-schematic.pdf

Summary

Microcontroller	ATmega328
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limits)	6-20V
Digital I/O Pins	14 (of which 6 provide PWM output)
Analog Input Pins	6
DC Current per I/O Pin	40 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	32 KB of which 0.5 KB used by bootloader
SRAM	2 KB
EEPROM	1 KB
Clock Speed	16 MHz

the board



Power

The Arduino Uno can be powered via the USB connection or with an external power supply. The power source is selected automatically.

External (non-USB) power can come either from an AC-to-DC adapter (wall-wart) or battery. The adapter can be connected by plugging a 2.1mm center-positive plug into the board's power jack. Leads from a battery can be inserted in the Gnd and Vin pin headers of the POWER connector.

The board can operate on an external supply of 6 to 20 volts. If supplied with less than 7V, however, the 5V pin may supply less than five volts and the board may be unstable. If using more than 12V, the voltage regulator may overheat and damage the board. The recommended range is 7 to 12 volts.

The power pins are as follows:

- **VIN.** The input voltage to the Arduino board when it's using an external power source (as opposed to 5 volts from the USB connection or other regulated power source). You can supply voltage through this pin, or, if supplying voltage via the power jack, access it through this pin.
- **5V.** The regulated power supply used to power the microcontroller and other components on the board. This can come either from VIN via an on-board regulator, or be supplied by USB or another regulated 5V supply.
- **3V3.** A 3.3 volt supply generated by the on-board regulator. Maximum current draw is 50 mA.
- **GND.** Ground pins.

Memory

The Atmega328 has 32 KB of flash memory for storing code (of which 0,5 KB is used for the bootloader); It has also 2 KB of SRAM and 1 KB of EEPROM (which can be read and written with the EEPROM library).

Input and Output

Each of the 14 digital pins on the Uno can be used as an input or output, using pinMode(), digitalWrite(), and digitalRead() functions. They operate at 5 volts. Each pin can provide or receive a maximum of 40 mA and has an internal pull-up resistor (disconnected by default) of 20-50 kOhms. In addition, some pins have specialized functions:

- **Serial: 0 (RX) and 1 (TX).** Used to receive (RX) and transmit (TX) TTL serial data. TThese pins are connected to the corresponding pins of the ATmega8U2 USB-to-TTL Serial chip .
- **External Interrupts: 2 and 3.** These pins can be configured to trigger an interrupt on a low value, a rising or falling edge, or a change in value. See the attachInterrupt() function for details.
- **PWM: 3, 5, 6, 9, 10, and 11.** Provide 8-bit PWM output with the analogWrite() function.
- **SPI: 10 (SS), 11 (MOSI), 12 (MISO), 13 (SCK).** These pins support SPI communication, which, although provided by the underlying hardware, is not currently included in the Arduino language.

- **LED: 13.** There is a built-in LED connected to digital pin 13. When the pin is HIGH value, the LED is on, when the pin is LOW, it's off.

The Uno has 6 analog inputs, each of which provide 10 bits of resolution (i.e. 1024 different values). By default they measure from ground to 5 volts, though is it possible to change the upper end of their range using the AREF pin and the analogReference() function. Additionally, some pins have specialized functionality:

- **I²C: 4 (SDA) and 5 (SCL).** Support I²C (TWI) communication using the Wire library.

There are a couple of other pins on the board:

- **AREF.** Reference voltage for the analog inputs. Used with analogReference().
- **Reset.** Bring this line LOW to reset the microcontroller. Typically used to add a reset button to shields which block the one on the board.

See also the mapping between Arduino pins and Atmega328 ports.

Communication

The Arduino Uno has a number of facilities for communicating with a computer, another Arduino, or other microcontrollers. The ATmega328 provides UART TTL (5V) serial communication, which is available on digital pins 0 (RX) and 1 (TX). An ATmega8U2 on the board channels this serial communication over USB and appears as a virtual com port to software on the computer. The '8U2 firmware uses the standard USB COM drivers, and no external driver is needed. However, on Windows, an *.inf file is required..

The Arduino software includes a serial monitor which allows simple textual data to be sent to and from the Arduino board. The RX and TX LEDs on the board will flash when data is being transmitted via the USB-to-serial chip and USB connection to the computer (but not for serial communication on pins 0 and 1).

A SoftwareSerial library allows for serial communication on any of the Uno's digital pins.

The ATmega328 also support I2C (TWI) and SPI communication. The Arduino software includes a Wire library to simplify use of the I2C bus; see the documentation for details. To use the SPI communication, please see the ATmega328 datasheet.

Programming

The Arduino Uno can be programmed with the Arduino software (download). Select "Arduino Uno w/ ATmega328" from the **Tools > Board** menu (according to the microcontroller on your board). For details, see the reference and tutorials.

The ATmega328 on the Arduino Uno comes preburned with a bootloader that allows you to upload new code to it without the use of an external hardware programmer. It communicates using the original STK500 protocol (reference, C header files).

You can also bypass the bootloader and program the microcontroller through the ICSP (In-Circuit Serial Programming) header; see these instructions for details.

The ATmega8U2 firmware source code is available . The ATmega8U2 is loaded with a DFU bootloader, which can be activated by connecting the solder jumper on the back of the board (near the map of Italy) and then resetting the 8U2. You can then use Atmel's FLIP software (Windows) or the DFU programmer (Mac OS X and Linux) to load a new firmware. Or you can use the ISP header with an external programmer (overwriting the DFU bootloader).

Automatic (Software) Reset

Rather than requiring a physical press of the reset button before an upload, the Arduino Uno is designed in a way that allows it to be reset by software running on a connected computer. One of the hardware flow control lines (DTR) of the ATmega8U2 is connected to the reset line of the ATmega328 via a 100 nanofarad capacitor. When this line is asserted (taken low), the reset line drops long enough to reset the chip. The Arduino software uses this capability to allow you to upload code by simply pressing the upload button in the Arduino environment. This means that the bootloader can have a shorter timeout, as the lowering of DTR can be well-coordinated with the start of the upload.

This setup has other implications. When the Uno is connected to either a computer running Mac OS X or Linux, it resets each time a connection is made to it from software (via USB). For the following half-second or so, the bootloader is running on the Uno. While it is programmed to ignore malformed data (i.e. anything besides an upload of new code), it will intercept the first few bytes of data sent to the board after a connection is opened. If a sketch running on the board receives one-time configuration or other data when it first starts, make sure that the software with which it communicates waits a second after opening the connection and before sending this data.

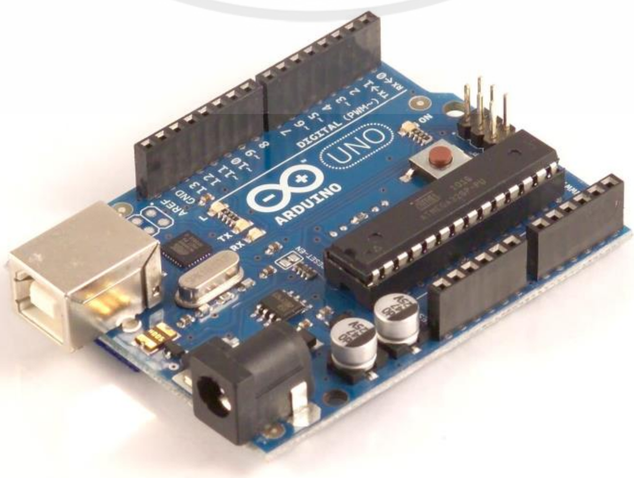
The Uno contains a trace that can be cut to disable the auto-reset. The pads on either side of the trace can be soldered together to re-enable it. It's labeled "RESET-EN". You may also be able to disable the auto-reset by connecting a 110 ohm resistor from 5V to the reset line; see this forum thread for details.

USB Overcurrent Protection

The Arduino Uno has a resettable polyfuse that protects your computer's USB ports from shorts and overcurrent. Although most computers provide their own internal protection, the fuse provides an extra layer of protection. If more than 500 mA is applied to the USB port, the fuse will automatically break the connection until the short or overload is removed.

Physical Characteristics

The maximum length and width of the Uno PCB are 2.7 and 2.1 inches respectively, with the USB connector and power jack extending beyond the former dimension. Three screw holes allow the board to be attached to a surface or case. Note that the distance between digital pins 7 and 8 is 160 mil (0.16"), not an even multiple of the 100 mil spacing of the other pins.



How to use Arduino

Arduino can sense the environment by receiving input from a variety of sensors and can affect its surroundings by controlling lights, motors, and other actuators. The microcontroller on the board is programmed using the Arduino programming language (based on Wiring) and the Arduino development environment (based on Processing). Arduino projects can be stand-alone or they can communicate with software on running on a computer (e.g. Flash, Processing, MaxMSP).

Arduino is a cross-platoform program. You'll have to follow different instructions for your personal OS. Check on the Arduino site for the latest instructions. *http://arduino.cc/en/Guide/HomePage*

Linux Install

Windows Install

Mac Install

Once you have downloaded/unzipped the arduino IDE, you can Plug the Arduino to your PC via USB cable.

Blink led

Now you're actually ready to "burn" your first program on the arduino board. To select "blink led", the physical translation of the well known programming "hello world", select

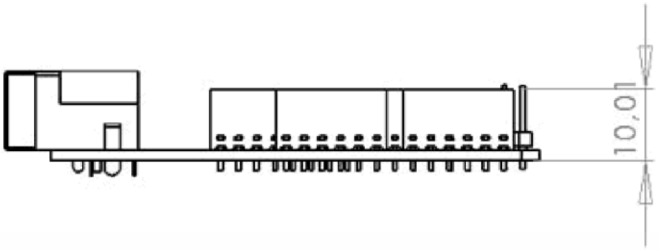
File>Sketchbook> Arduino-0017>Examples> Digital>Blink

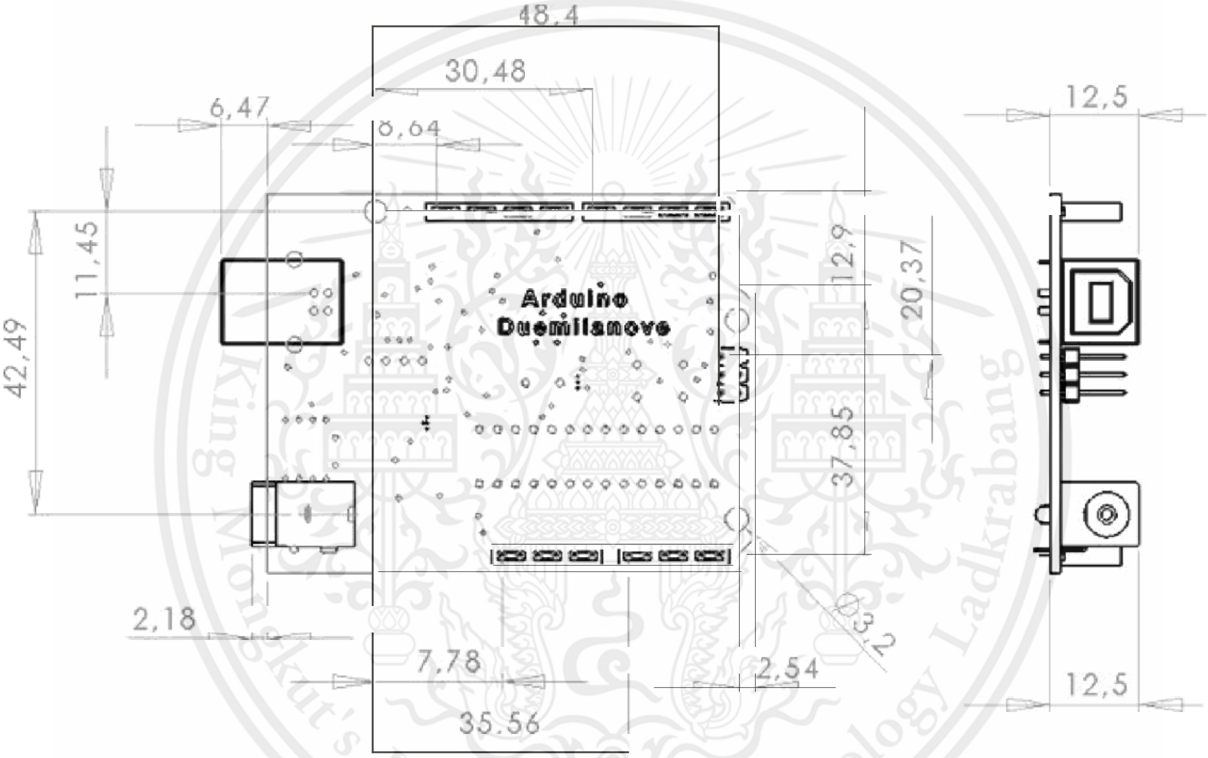
Once you have your skecth you'll see something very close to the screenshot on the right.

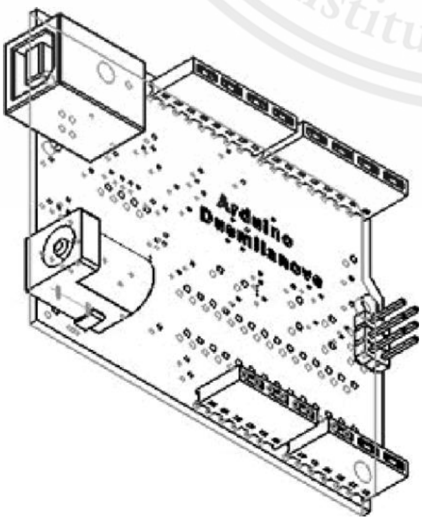
In **Tools>Board** select

Now you have to go to **Tools>SerialPort** and select the right serial port, the one arduino is attached to.

Dimensioned Drawing







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1.2 If any products fail to conform to the warranty set forth above, the producer's sole liability shall be to replace such products. The producer's liability shall be limited to products that are determined by the producer not to conform to such warranty. If the producer elects to replace such products, the producer shall have a reasonable time to replacements. Replaced products shall be warranted for a new full warranty period.

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