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Bismuth-Silicon Strip Based Battery-Less Implantable Cardioverter Defibrillator

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Abstract: This study proposes a Traditional Power-Source independent Implantable Cardioverter Defibrillator Unit that would run without the need of the conventional lithium-iodine batteries. The whole unit has two parts- the external part, which has the external circuitry generating the current and voltage required, from a strip of dissimilar metals of drastically different Seebeck coefficients, for the proper operation of the unit; and the internal part, which does the most complicated job of storing the current and delivering it to the heart in the form of pulses, as and when it is required. In between, there is a heart-beat analysers integrated with a magnitude comparator, which does the job of analysing the nature of heart beats and triggers a response regarding the decision of whether the electric pulse is required to be given to the heart or not (the decision being taken by a magnitude comparator). The novelty of the unit is that it completely avoids the shortcomings related to the usage of the conventional lithium batteries as these have to be periodically replaced after a certain number of years and these batteries, once they start growing old, also have a risk of developing toxicity in the patient's body. These units are extremely patient-friendly as they do not include much bulk in terms of external components and there is absolutely no need of any kind of dependency on an external power source as otherwise, along with other disadvantages, the failure of such power supplies also become a matter of utmost concern and thus these units find applications in patients who suffer from severe cardiac arrhythmia, where the heart needs an obvious emergency support of such kind in order to maintain perfect electrophysiological coordination.

Key words: Traditional Power-Source-independent · Emergency · Patient-friendly · Electrophysiological coordination

INTRODUCTION

The Heart is one of the few visceral organs located in between the right and left lungs of the human body, in the middle of the chest and slightly towards the left of the breastbone. It is muscular in nature having four chambers- two auricles and two ventricles and its chief function is to pump blood. Talking of its electrophysiology, it is myogenic as its electrical activity is initiated by a special modified heart muscle, called the Sino-Atrial Node. When the electrical activity of the heart becomes abnormal, a phenomenon known occurs, known as fibrillation, which is of two types- Atrial Fibrillation and Ventricular Fibrillation; the Ventricular one being the more fatal type. It is because of these phenomena that the requirement of defibrillators comes in.

In the 1990s, studies related to Tachycardia and Fibrillation detection and concepts like its sequential testing in time domain have been conducted [1] after which Single Event Upsets in Implantable Cardioverter Defibrillators (ICD) were dealt with [2]. Later on in the early 2000s, studies regarding the lead and lead problems of ICDs were conducted [3]. Thereafter, significant attention was given to developing Detection Algorithm of Fatal Arrhythmia as well as characterization of ICD signals [4, 5, 6]. There were studies also conducted regarding application of CMOS technology along with biomedical processors in a single chip, in the pacing module of ICD [7]. New front-end IC-based design for ultra-low power analog ICD along with evaluation of safety and performance of ICDs were all part of different studies [8]. After this, studies regarding Automatic Sensing Test procedure (AST) for evaluating the sensing performances of ICDs were conducted [9]. Thereafter, concepts of synthetic patients based on computer modelling for improving the planning of a CT, were studied with

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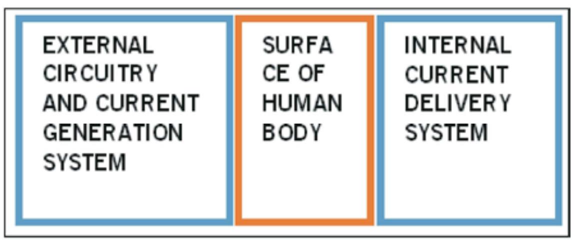
developing yet again, algorithms for arrhythmia detection [10]. Finally, the concept of converting the kinetic energy developed due to the repeated contraction of the heart, into a power source for developing battery-less cardiac implantable electronic devices was studied.

All of the above stated studies did have some or the other very important contribution to the development of ICDs but all of them but one, have one particular feature in common and it is the dependency of the devices on a separate power source such as a battery.

This study attempts to propose a battery-less, i.e., traditional power-source independent implantable cardioverter defibrillator.

System Design: The design of the system consists of two major sections- the external part and the internal part, separated by the surface of the human body.

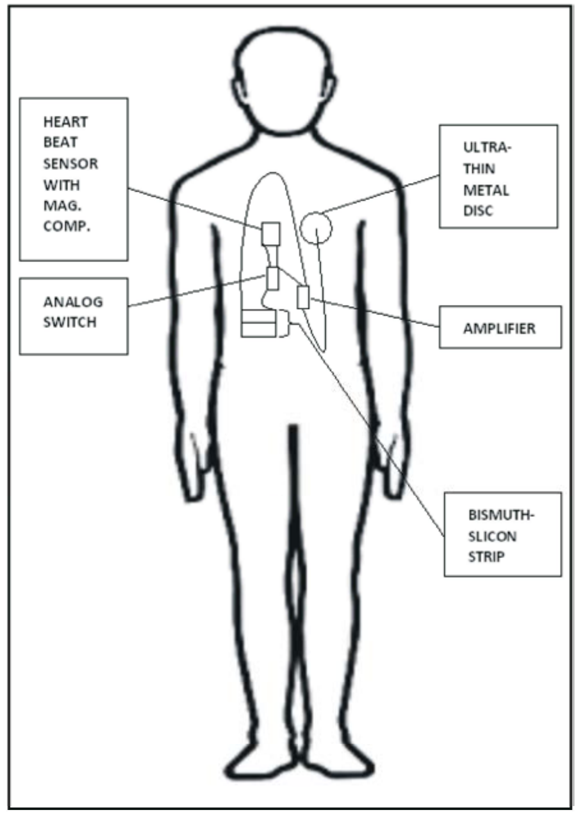


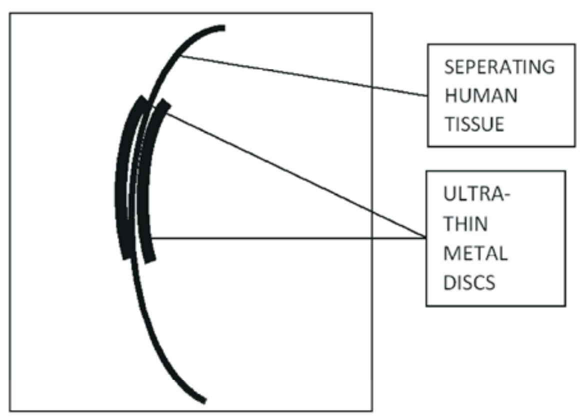
The external part consists of a strip made of strip made out of the junction of two materials- Bismuth and Silicon. Silicon has a Seebeck Coefficient of 440µV/K and Bismuth has a Seebeck Coefficient of -72µV/K. The drastic difference in the coefficients of the two materials makes this combination deliver an appreciable amount of 512µV/K. The matter of the fact is that the sensitivity of this combination is quite high as for each Kelvin of temperature the output of the system is as mentioned above and it is this very sensitivity of this combination that has been intended to put to use over here. This part acts as the heart of the whole unit as it is the very source from where all the current and voltage required for running the system, arises. Alongside, an amplifier is integrated with this part which primarily scales up the magnitude of the current parameters. A heart-beat sensor is placed in the external circuitry which primarily senses the heart beat. A programmed chip is attached with this sensor which receives the heart-beat signal and analyses the rhythm of the same with the help of the magnitude comparator integrated with it.

The internal part of this system has a simple job of delivering the current (with the help of spoon-shaped electrodes) in the form of pulses to the heart and thus consists of wires made of biocompatible materials like polyurethane or any other of such type and property.

System Operation

External Circuitry and Current Generation System: Two separate strips of Bismuth and Silicon are used and a junction is made out of them.





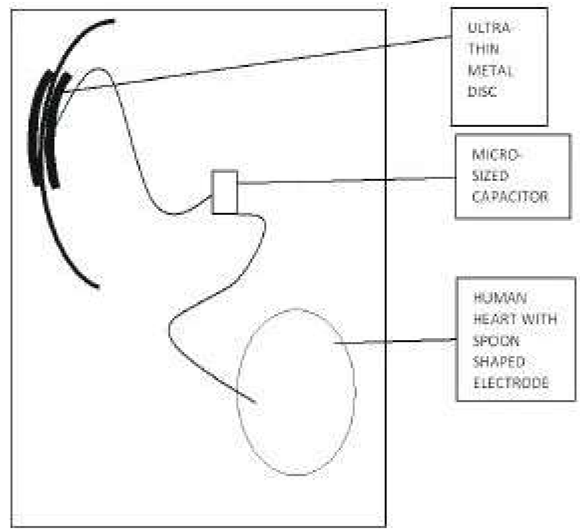
By definition, the Seebeck effect is a phenomenon in which a temperature difference between two dissimilar electrical conductors or semiconductors produces a voltage difference between the two substances. This is the main principle based on which the generation of current takes place. The ability of a material to produce electricity in presence of a temperature gradient can be termed here as "Seebeck Efficiency" and this property is directly proportional to the magnitude of the Seebeck Coefficient of the material.

Silicon has a Seebeck Coefficient of 440µV/K and Bismuth has a Seebeck Coefficient of -72µV/K. The drastic difference in the coefficients of the two materials makes this combination deliver an appreciable amount of 512µV/K. The material strip of the device is placed on the upper torso of the patient and so the least difference in temperature between the surface of the human body and the outer environment is considered to be 1°C. With regard to that, 1°C = 274.15K and so for such a temperature difference, nearly about 0.14 V of potential difference is created. Taking in consideration, an approximate resistance of the human skin at around 75000 Ohms, the effective current obtained is around 1.87µA. In order to allow the set up to work properly, the current has to be scaled up to between a range of 10-20µA. For this, an amplifier chip, having a capacity of current multiplication in the order of 10 times, is employed. This amplifier amplifies the current even before it enters the patient's body so that once it does so, even after encountering the resistance of the human skin, the effective current remains in the above stated range. The wire connecting the material strip and the amplifier has an analog micro-switch. This switch is specially employed to control the event of current delivery from the material strip.

There is a heart-beat sensor, made out of a comparator (having a threshold) integrated with a magnitude comparator that is placed over the patient's chest. This integrated combination is further attached with a micro-signal generator mounted on a programmed chip.

The heart-beat sensor senses the beats of the heart while the magnitude comparator, which is logic based circuit and has a set of reference signals (pertaining to the fibrillating heart-beat signals), compares the signal received from the heart-beat sensor and on comparison, if it finds the signal to be matching with any of the references, it sends a positive feedback to the programmed chip which then sends a positive analog signal to the analog switch. As soon as the switch receives the signal, the switch goes to the ON state and it is then when the current starts getting produced and immediately transferred, after amplification, into the patient's interior through a set of ultra-thin metal disc placed on the patient's chest. The disc marks the end of the external circuitry of the system. Once the heart beat becomes stable, the heart-beat sensor senses it and then magnitude comparator compares it which on finding no match, sends a negative feedback to the analog switch. On receiving negative feedback, the analog switch goes to OFF state and the current delivery automatically gets discontinued.

Internal Current Delivery System: The working of the Internal Current Delivery System is very simple in nature.



The internal system starts with a second ultra-thin metal disc placed right under the same kind of a disc placed right over, on the external part of the patient's body. The current reaches the upper disc and gets immediately conducted onto the lower disc. The wires connected onto this lower disc, passes the current onto a micro-sized capacitor. This capacitor is specially fabricated in a way that its charging and discharging time is such that the current is delivered in pulsed fashion with the timing between successive pulses being same as that between the discharging and charging of the capacitor.

Once the capacitor gets charged, it rapidly discharges in order to efficiently deliver the current pulse onto the fibrillating cardiac muscles through the attached spoon-shaped electrodes.

DISCUSSIONS

The study presented above clearly shows that the Traditional Power-Source independent Implantable Cardioverter Defibrillator Unit has a very simple working-principle which can be easily segregated into its two operational parts. The start of the operation of this unit is done with a very simple process based on a very common yet important physical principle- the Seebeck Effect.

The novelty of this integrated device lies in the fact that it is free from the traditional power supply-the lithium iodine batteries. This, in turn, also excludes the health-risks and other issues related to these power sources like the need of periodical replacement, tissue toxicity, etc. This integrated device is extremely patient friendly and its effective cost stands to be nearly about 70-80 times lesser than the presently available Implantable Cardioverter Defibrillators as the components with which this device is made, are basic components that are quite readily available.

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