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SUSTAINABLE PYROELECTRIC ENERGY AND POWER TRANSMISSION SYSTEM FOR MAINTENANCE-FREE HEART PACEMAKERS

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ABSTRACT:

A number of medical devices can be implanted inside the human body that has to be powered by battery, is the concern in this work. The medical costs become really high due to required maintenance after few years (about 7 years), associated with the battery replacement. A new solution is found where the pyroelectric materials can be used to recharge the battery of the implanted pacemakers that essentially increases the life of the battery beyond 10 times. So we create an 'everlasting' life of a pacemaker which can last for the lifetime and thus becomes maintenance-free without a need of surgery. This novel technique for an energy harvesting circuit is designed and results found to be very promising and applicable. The basic idea is to place cluster of pyroelectric materials over the skin of the patient, using specially fabricated clothes or body mask patches. These pyroelectric materials convert subtle differences in temperature across the span of the clothing into electricity and its voltage is boosted by a tiny electronic booster circuit. The interconnection is made to transmit electrical energy wirelessly to recharge the battery of implanted pacemaker by a coreless transformer. A relationship of power output and the distance of separation of the coils of coreless transformer are established and the data plot is presented in this paper. Also a set of data has been collected and plotted for both the generated power from the pyroelectric material and the voltage booster.

KEY WORD: *Pyroelectric materials, Pacemaker, Integrated circuit, Fabricated electric clothes, Voltage booster.*

INTRODUCTION:

The pacemaker is an electronic biomedical device that can regulate the human heartbeat when its natural regulating mechanisms break down. It is a small device surgically implanted in the chest under skin and has electrodes that are in direct contact with the heart (in figure 1). First developed in 1950s, the pacemaker has undergone various design changes and has found new applications since its invention. Today, pacemakers are widely used and implanted in many thousands of patients annually.

Functioning of Pacemaker: The pacemaker unit delivers an electrical pulse with the proper intensity to the proper location for stimulating the heart at a desired rate. The cardiac pacemaker comprises of a pulse generator and a lead system. The pulse generator houses electrical components responsible for generating the pulse (via output circuits) at the proper time (via timing and control circuits) based on events sensed (via sensing circuits) [Greatbatch, W., 2000]. It also contains a power supply (battery) and may include other elements such as telemetry for testability and programmability and memory (ROM or RAM) to store data for diagnostic purposes.

Impulses are transmitted to the heart by means of a lead, which is attached to the pulse generator via the connector block. A lead is either unipolar or bipolar; a unipolar lead contains one insulated coil, whereas a bipolar lead contains two coils, separated by an inner insulation. An outer insulation shields a lead from the environment. The tip of a lead, which contains an electrode, is implanted into the inner, endocardial surface of the heart; the actual location depends on the type of pacemaker. The pacemaker unit is usually implanted in the pectoral region, with the lead running through the right subclavian vein to the internal surface of the heart. A pacemaker is programmed by means of a programmer, a computer with a special user interface for data entry and display, and with special software to communicate with the pacemaker [Hiroko B., 2010]. The telemetry head is placed above the location of the pacemaker; information from the programmer to the pacemaker, and back, is transmitted by means of telemetry.

Battery of the pacemaker: The usage of implanted pacemakers has been rapidly increasing, since the battery occupies major portion of the pulse generator in terms of weight, volume, and size (in figure 2). The most important factor for a cardiac pacemaker battery is its reliability. Unlike batteries in implantable devices cannot be replaced there was a desperate search for a power source that would enable the pacemaker to last as long as the expected lifetime of the average patient. This paper presents a technique to power the pacemaker with an everlasting battery meeting the requirements of the pacemaker.

Pyroelectric materials: Pyroelectricity as a phenomenon has been known for 24 centuries, Pyroelectric materials (in figure 3) convert changes in absolute temperatures into electrical energy, unlike thermoelectric which need a gradient of temperature across the material; Pyroelectric materials require temporal changes (time vs. spatial variation).

The pyroelectric effect can be used for harvesting thermal energy during temperature increases (heating) and decreases (cooling) and thus creating a difference in temperature of surfaces of the pyroelectric crystals. The pyroelectricity is the ability of crystals to generate a temporary voltage and current when there is difference of temperature. The change in temperature slightly modifies portions of the atoms within the crystal structure of the crystal causing a polarization. The change in polarization, strictly dependent on time, gives rise to voltage across the crystal. If the temperature stays unchanged based on the material's critical time, then pyroelectric voltage gradually disappears due to internal charge leakage.

MATERIALS AND METHODS:

It is very important and essential to run the pacemakers for the lifetime instead of relying on battery replacements. Using energy harvesting technique of body temperatures, we can greatly reduce the number of surgical procedures for people with pacemaker. A new type of high density charge collector and storage device is found, called super capacitor. It is a semiconductor material and it has a very long life unlike rechargeable batteries that are made with chemicals.

Electronic systems today are used for many applications in Biology; a new idea is presented here with the help of the idea established on [Stuart G., 2003]. The technique here is to recharge the battery of the pacemaker by making use of the pyroelectric materials which are in a good shape in today's world. The new system is described below.

Pyroelectric Device: The pyroelectric devices (in figure 3) are made with special crystal materials which produce energy due to difference in surface temperatures. These materials can be placed on a living body on a patch or fabricated electric cloths. Thus it makes a contact to the warm body and the ambient temperature employing differential thermal effects. As a result of thermal exchange within the material causes charge collection and potential difference on the surface of the device. The energy produced from one device is very low, so a number of such devices can be placed in parallel circuit connection to serve sufficient power to a medical device i.e. pacemakers. An arbitrary dimension of the pyroelectric crystal $LiTaO_3$ is taken. Single pyroelectric $LiTaO_3$ crystal can generate around 0.3V at a ΔT of 10°K with an output current of 6μA to 7μA of current, so a cluster of pyroelectric materials which generate an output current of 150μA is used in the current circuit with a power output of 45μW.

Here, $\Delta T = T_{skin} - T_{ambient}$ & $i_p(t) = P^* A \, \Delta T$,

Where P* is the pyroelectric coefficient and A is the surface area of the material.

Body mask patch or the electric clothes: This electric cloth (in figure 4) is made of materials or devices that can produce electricity from heat. The body patch contains both the pyroelectric material and the booster circuit making it as a simple element to collect the energy via the difference in temperatures caused by the body.

In this new system, we require 24 pyroelectric devices in parallel connection cluster in the patch that can be placed on skin. These pyroelectric devices are very small size between 5mmx5mm to 10mmx10mm. The system can easily have a patch of 7x7 matrix i.e. 49 or 14x7 matrix *i.e*. 98 pyroelectric devices. Additional pyroelectric devices can ensure a fault-free power harvesting from body. The patch size is small it is less than 90mmx90mm.

Coreless Transformer: This is the main part of the circuit to transmit power continuously to recharge the pacemaker's charge storage device or battery. Coreless transformers are used in many special applications of contact-less biomedical instruments. They are used to transfer energy by means of a transcutaneous transformer [Nishimura, T., 1994]. This circuit is basically coreless transformers that are used to transfer energy from the voltage booster to the implanted device [Alberto M., 2007]. A coreless transformer consists of a primary coil (in figure 5) and a secondary coil separated by a coreless medium, in this circuit both coils are separated by the skin and body tissue. The implanted pacemaker consists of a secondary coil of the coreless transformer with the electronic circuit of the pacemaker. The secondary winding must be made with non-toxic biocompatible material. Challenges to design the coreless transformer for under-skin pacemakers are described below.

(i) The distance between the primary coil and the secondary coil depends on the magnetic component. It's response for effective power transfer varies in every patient.

(ii) The secondary coil should be a biocompatible material and the electronic implanted device must comply with existing normative of biocompatibility.

(iii) By using secondary coil [Tang, S. C., 2000] no ferrites can be used because it is not a biocompatible material.

The secondary coil design is made along with the pacemaker, which has its fixed maximum possible value diameter of 30mm and is made with circular thin flat-sheet platinum. On the skin, the separation between the coils can vary approximately from 1mm to 12mm depending on the patient [Xiong, H., 2010]. The secondary side of the coil is connected to a high frequency bridge rectifier with a boost converter where it is needed ensuring optimized voltage level even at weak transformer energy signal received.

Voltage Booster: A simple and small efficient electronic voltage booster circuit (in figure 6) is used to boost the voltage where it is attached to the clustered pyroelectric device in the pyroelectric patch. This is a simple electronic circuit which consists of tiny electronic components. This circuit ensures by providing required voltage level at the output to the primary coil for transmitting energy as high frequency signal. The secondary coil, placed on the surface of the pacemaker inside the body, receives energy signal wirelessly from the patch. Then the received signal is boosted again to the level where the battery or super capacitor can store the energy to run the pacemaker smoothly.

Pacemaker: The complete pacemaker system (in figure 7) consists of a pulse generator and a lead system with a battery. The pulse generator has the control circuit, sensing circuit, output circuit. The output of the pulse generator circuit has lead's which are used to transmit the electrical signal to the heart. The battery should meet the pacemaker pulse requirements in the range of 25µJ, the circuit minimal voltage as 2.2V, control circuit current drain as 10µA, EOL battery resistance as 10Kohms and the storage capacitance of 10µF.

RESULTS AND DISCUSSION:

The power to recharge the battery of the pacemaker is applied by the secondary or the internal coil of the coreless tranformer. The power generated from the single pyroelectric device is very low which is at about 1.8μW for ΔT = 20^{o}K. The parallel connection using a number of such devices make equivalent of a single pyroelectric device which generates an output of 45μW. After determining the voltage and current requirements of the pacemaker, 24 pyroelectric materials were decided to be minimum for the cluster. Data of the power ouput of the pyroelectric device and power requirement of the pacemaker were collected. A simple pyroeletric circuit is modeled in pspice for determining the working states of pyroelectric materials. The cluster of pyroelectric devices are connected to the combined circuit of the voltage booster and the charging frequency driver. The driver is then connected to the primary coil of the coreless transformer.

A second set of circuit with the voltage booster, connected to the secondary or internal coil, is employed to convert the voltage generated to recharge the battery of the pacemaker. A high frequency bridge converter is used to convert the AC to DC voltage to charge the battery.

The distance between the primary and secondary coil can vary from 1mm to 12mm depending on the patient. Data were plotted in relation to distance between the coils, the voltage and the power output (in figure 8 and figure 9). From these data and plots, it is found that the transformer can be as low as 50% efficient. So a patch with 7x7 matrix or 49 pyroelectric devices can ensure the adequate power to the pacemaker.

The plotted simulations show that the power to the pacemaker can be maintained at about 23μJ by keeping the distance between the primary and secondary coil at 6mm to 8mm. The required voltage to the pacemaker is provided at 5V which is sufficient to recharge the battery.

CONCLUSSION:

This new technique of harvesting energy and recharging the battery of pacemakers is designed and plotted successfully in this research work. The Sample, Pyroelectric material, a very commonly found crystal with regular dimensions is used in this experiment for harvesting the energy. The subtle differences in temperatures were found and required numbers of pyroelectric materials were connected in parallel. It can be concluded that this design can be used easily as a simple efficient circuit to recharge the battery of the pacemakers. In this research work the change in temperature is taken as ΔT at 20°F and also the regular pacemaker ratings were taken into consideration. Required amount of energy is supplied to recharge the battery of the pacemaker. The research provides a technical advancements and a new technique where a coreless transformer can recharge wirelessly and a rechargeable device has replaced the conventional one-time battery in the pacemaker; this study presents the results of the change in dimension between coils to the output power and the output voltage. A general method is proposed how pyroelectric materials can be placed on the body mask patches and fabricated electric clothes. The challenge for future improvements includes finding a technique or a newer material that can maintain ΔT in the specific time, the temperature fluctuation is maintained to avoid constant temperature zone based on time or material poling can set back as energy utilized.

ACKNOWLEDGEMENT:

Few online illustrations are made available here in this paper for clarifying the existing systems and technologies. The concept of sustainable power application to pacemakers was developed based on the technical challenges of author for resolving issues of his implanted pacemaker's battery and its replacement required after 7 years.

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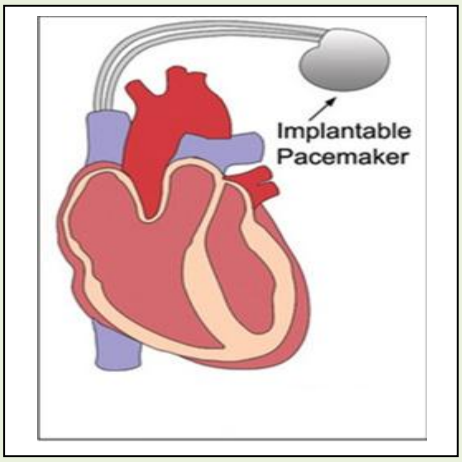

Figure 1: Implantable pacemaker

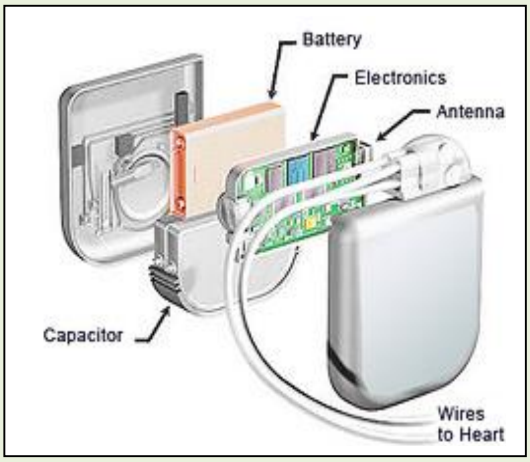

Figure 2 : Battery in a pacemaker

Figure 3: A pyroelectric device

Figure 4: Fabricated electric clothes

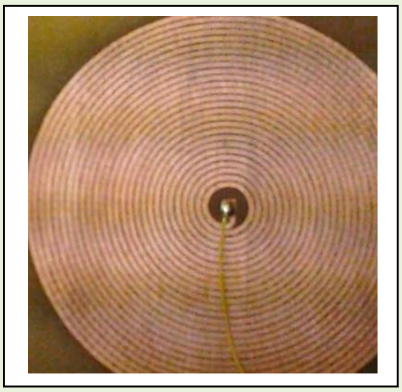

Figure 5: Primary coil of coreless transformer

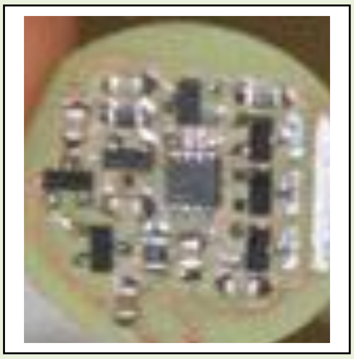

Figure 6: Tiny voltage booster

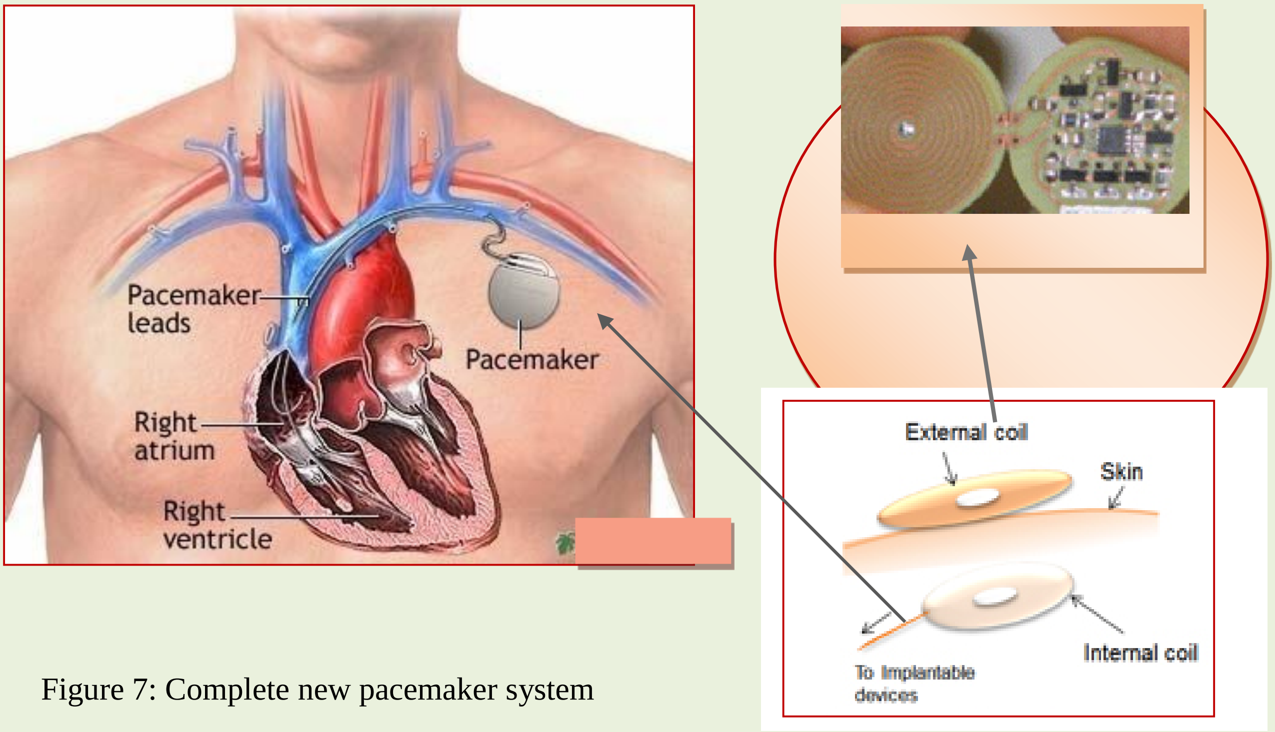

Figure 7: Complete new pacemaker system

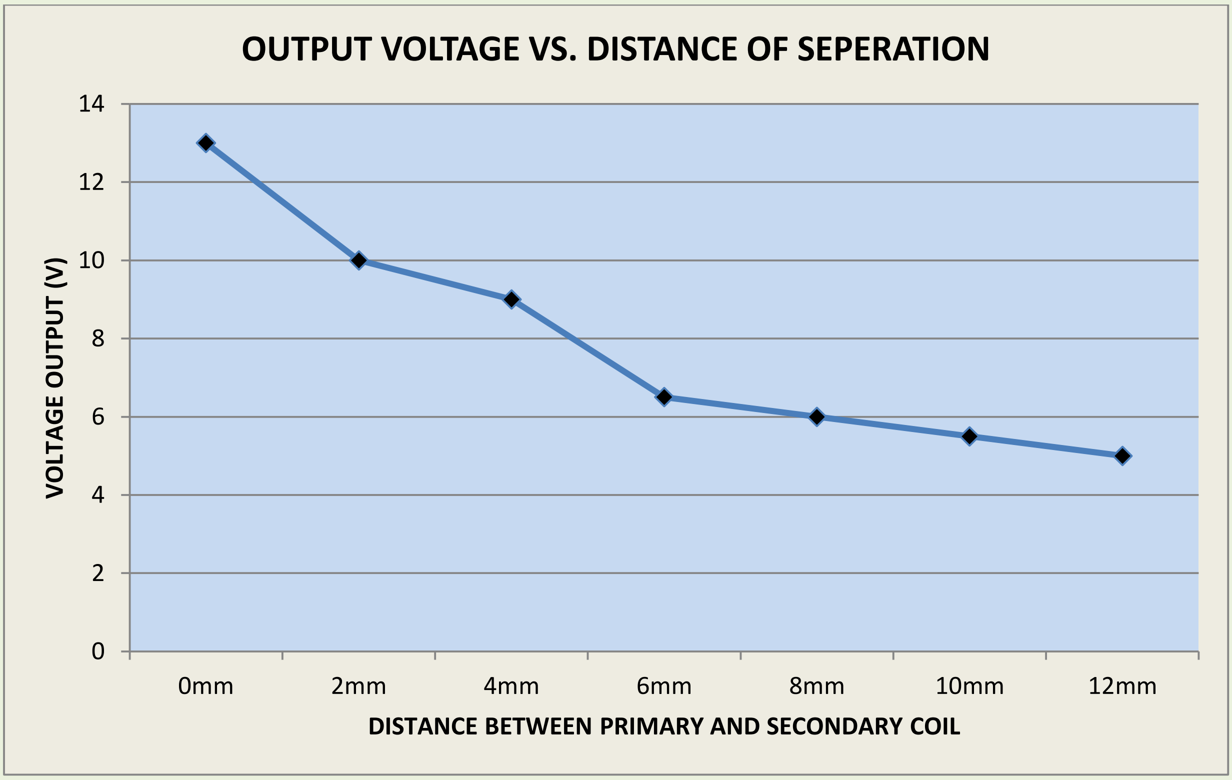

Figure 8: Voltage response due to the separation of coils

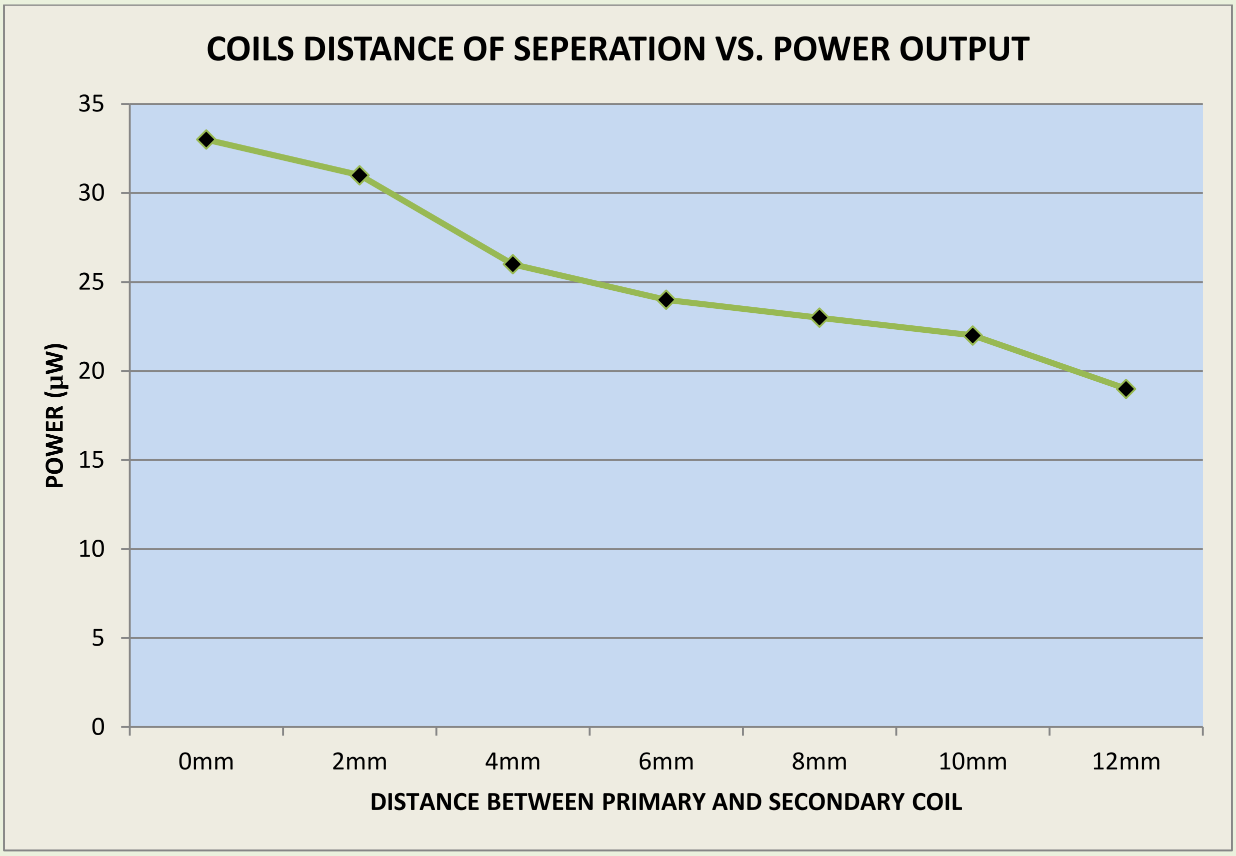

Figure 9: Power output due to the separation of coils