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Design and Implementation of a Power Supply for Hearing Aids Based on Human Thermal Energy

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ABSTRACT

This paper presents a prototype of a thermoelectric harvester generator designed to convert the waste heat generated by the human body (specifically, the skin) into electrical energy, which.can be used to power a hearing aid unit using renewable energy. The method used for harvesting thermal energy from the human body is based on the principles of the Peltier effect, which is a type of thermoelectric effect. The proposed model consists of three main components: generation, amplification, and hearing aid. The required number of Peltier elements and the skin area have been specified. Additionally, the results demonstrate that the generated energy is influenced by the device's placement on the body and ambient temperature. Additionally, the results demonstrate that the generated energy is influenced by the system's location on the human body and the ambient temperature

1. INTRODUCTION

Standard and rechargeable hearing aid batteries have a lifespan of around one year for rechargeable types, between three and twenty days for standard types, depending on many factors, such as the degree of hearing aid loss, operating time per day, battery size, and battery's average life [1]. Rechargeable hearing aids are a more recent addition to the audiology ranges, with manufacturers utilizing technology to create a convenient method of keeping batteries running without needing to be changed.

Renewable energy has been attracting significant attention in recent years as one of the important techniques used to reduce pollution and at the same time to provide a sustainable and clean source of energy. The most common types of renewable energy are solar, wind, tidal, geothermal and wave. The great developments in the field of renewable energy promote new technologies of renewable energy production as well as encourage a new culture of energy consumption. One of the sustainable and renewable energy resources that has not been widely recognized is the use of human thermal energy. Human power as a domestic energy source can be used to supply electrical equipment namely medical devices, which are wearable or attached to human bodies; this application would expect great impact towards sustainability [1].

An electronic hearing aid is a small device placed in or around the ear to improve the hearing of those with weak hearing. The basic components of a hearing aid are a microphone; signal conditioning, receiver also known as speaker, and a battery. The microphone converts the sound into an electric signal. The signal then undergoes conditioning that can be as simple as amplifying all the sound equally, to more advanced equalization involving a digital signal processor. The receiver converts the electronic signal back to sound, and the battery powers the electronics circuit components [2]. Some hearing aids are beginning to use rechargeable single-cell batteries, but most hearing aids are still powered by primary disposable batteries, which in addition to its cost, has a bad impact on the environment.

Energy harvesting has become an important area of interest in the 21st century for use in, protection, detection, and wearable electronic devices. Also harvesting energy can be used to power long-lasting devices such as portable, flexible/stretchable human-interactive sensors, displays, energy devices, thermoelectric devices and remote sensors. Thermoelectric devices (TEDs) are solid-state energy converters and semiconducting properties allows them to be used to convert waste heat into electricity or electrical power directly from cooling and heating [3].

Thermoelectric power generators (TEGs) are used to convert thermal energy directly into electrical energy using solid state electronic. Therefore, thermoelectric power generation is believed to be one of technologies that will allow harnessing of large amounts of waste heat produced in heat exchange and automotive industries. Currently used TEGs have limited conversion efficiency and do not have capacity to penetrate these highly important industry sectors. Thermoelectric power generators are already successfully used for waste heat energy recovery or for pure power generation in some of the sophisticated fields, such as space applications, scientific equipment and facilities, and lasers. With increasing demand on clean energy sources and advancing thermoelectric technology/materials, the use of thermoelectric devices is becoming more prominent owing to their long lifetime, high reliability, and silent operation.

2 THERMAL ENERGY IN HUMAN BODY

The human body acts as a heat engine that converts the chemical energy from consumed food into heat and mechanical work. The body rejects heat in order to maintain thermal balance. The human body primarily rejects heat to the environment from the body surface by convection, radiation, or evaporation [4]. Equation (1) expresses the total energy production rate:

$$Q+W=M \cdot A_{skin} \quad (1)$$

Where:
Q = heat production rate
W = rate of work
M = metabolic rate
A_{skin} = total surface area of skin

The metabolic rate is customarily expressed in units of mets (or M) Where:

$$1\,M = 1\,\text{met} = 18.4\,\text{Btu}/h\,\text{ft}^2 = 58.2\,W/m^2 \quad (2)$$

Since the area A_{skin} for adults is of the order of 16 to 22 ft^2 (1.5 to 2 m), heat production rates by adults are about 340 Btu/h (110W/h) for typical indoor activities [4].

3. THERMOELECTRIC GENERATOR

TEG is a solid-state device, which converts heat flux into electrical current. TEG produces DC voltage, which depends on the module temperature gradient and the number of thermoelectric elements, or legs, used. A generator module usually consists of a multitude of pairs of alternating p-type and n-type semiconductor legs, which are arranged thermally in parallel and connected electrically in series. Figure.1 shows the main parts of a flat plate type TEG –CAD model of 28 leg. Typical 56 x 56 mm TEG modules can contain from 62 up to 900 legs. The open circuit voltage depends on the number of legs used, therefore itcan range from 0.6 V to over 6 V depending on the module. [5],[6].

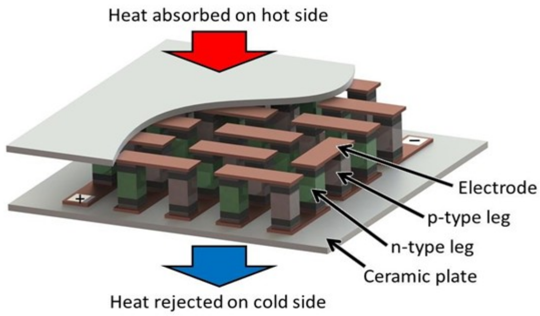

Figure 1 flat plate type TEG module

Temperature differences across the TEG surface plates considered as the most critical factors that must be achieved such that high and stable TEG output voltage can be obtained. For human body applications, the obtainable temperature difference across the device is severely limited by the very large thermal resistance of the surroundings, and the small difference between body temperature and the typical room temperature. Figure 2 shows the schematic diagram of a self-powered wearable TEG with polymer-based flexible heat sink (PHS) [7],[8].

The most common way to reduce thermal resistance is to use a metal heat sink, in which several metal pins are fixed to a thick base metal. In most wearable TEG application, the metal heat sink is attached to the cold side of the thermoelectric generator. However, for the metal heat sink to accomplish sufficient heat exchange with air, it must have a large enough surface area, which inevitably makes it heavy and bulky for wearable devices. Furthermore, the inflexible nature of a metal heat sink makes it unsuitable for human body applications. Instead, a completely new type of heat sink is required for wearable devices. In this work, the polymer-based flexible heat sinks (PHS) is used, in which the polymer particles contain water and the water slowly evaporates over time.

The proposed WTEG for hearing aid consists of the following units:

1. Peltier Cooler

A Peltier cooler, heater, or thermoelectric heat pump is a solid state active heat pump which transfers heat from one side of the device to the other, with consumption of electrical energy, depending on the direction of the current. Such an instrument is also called a Peltier device, Peltier heat pump, solid-state refrigerator, or thermoelectric cooler (TEC) and occasionally a thermoelectric device is shown in

Figure3. Thermoelectric device uses the TEC to create a heat flux at the junction of two different types of materials.

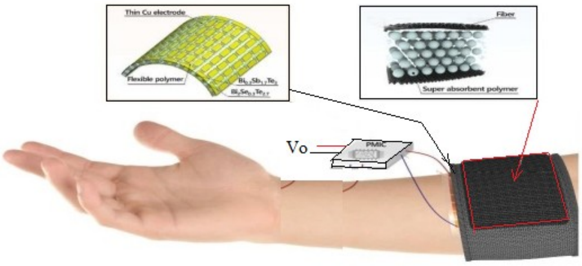

Figure 2 schematic diagram of TEG

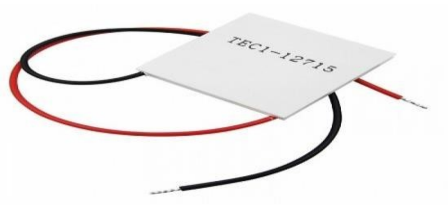

Figure 3: Peltier heat pump

2. DC/DC Booster Circuit

The generated voltage by WTEG at any position on human body is only several tens of mV, which is variable since it depends on temperature deference between skin and ambient temperature. This means that a control circuit with a voltage boost converter is required to drive the WTEG by converting the voltage level to battery charging voltage. The typical voltage boost circuit require more than tens of mV of cold-start voltage, and the conversion efficiency of the power management circuit becomes low when the input voltage is low. Therefore, WTEG must be able to generate not only high-power output but also sufficiently large voltage output to stably drive wearable electronics. The circuit diagram and photo of the booster used in this design is shown in Figure 4, where the input 0.9 V and the output 5 V.

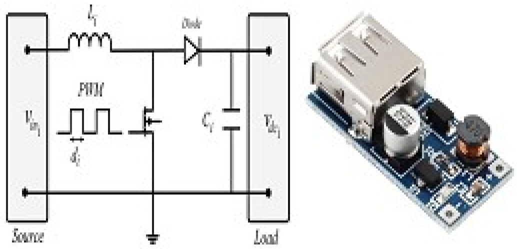

Figure 4: Boost converter

3. Charging Circuit

The charging circuit depends on its design; in this work, the charging unit used is shown in Figure 5. This charger module is powered from the previous booster with a 5 ± 0.5 D.C. volt. Also this charger can be powered from any external constant 5 V- DC power supply such as mobile phone charger which work as another supply option in case of WTEG fail to generate sufficient voltage.

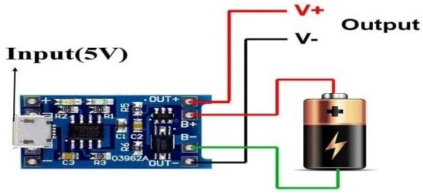

Figure 5 charging unit

3. HEARING AID UNIT

The hearing aid unit represents the load in this work. This device is a simple amplifier circuit that takes audio or sound from microphone module and outputs it with speaker after adjustable amplification. The hearing aid device considered in this paper is shown in the Figure 6, it is rated power is 12 mW.

Figure 6: Hearing Aid unit

4. SYSTEM DESIGN

For a self-powered hearing aid system to use a wearable thermoelectric generator WTEG, the WTEG must be able to generate sufficient electric power from body heat to drive not only the device but also to supply a voltage booster unit and regulator circuit (charging unit, often called Power Management Integrated Circuits (PMIC)). In addition, in order to minimize the power loss in the PMIC, input voltage to the PMIC, which is the output voltage of TEG, must be at least of several tens of mV or higher. The charging circuit is considered to transfer energy to the storage unit, which can be a capacitor or small battery. The proposed system is shown in Figure. 7.

The power needed to drive the selected booster and charging circuit equals 5 mW, making the total load: Load= 12 + 5 =17 mW (12 mW is the hearing aid power). Assuming the overall losses of the system equal 20% of the total load, then the total power needed to be generated is:

Total load= 20.4 mW

From Equation (2) the required skin area, A_{skin}, to generate 20.4 mW equal 3.505 cm^2.

According to this, a TEG unit of 3.844 cm^2 area is selected with the specifications given in Table 1.

5. EXPERIMENTAL RESULTS

Figure 8 shows a photo for the complete setup of WTEG proposed system in the laboratory. A variable output transformer is used to generate a variable temperature at the surface of thermoelectric module (Peltier Effect) to stimulate the cold side plate temperature of the thermoelectric module. The designed WTEG is tested indoor for the output voltage and power at constant ambient temperature and varying temperature difference between the human arm and thermoelectric module surface.

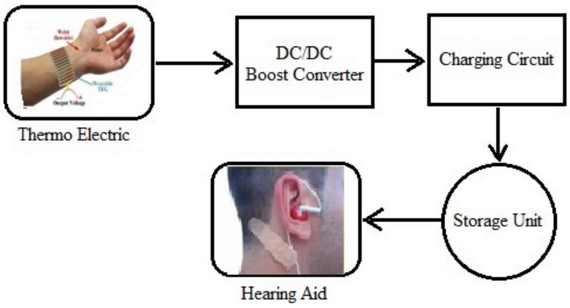

Figure 7: Proposed WTEG arrangement

The result of the current and voltage acquisition with various temperature difference between the thermoelectric module surface and the arm (palm and forearm) are given in Table 2 and 3. The readings are measured at atmosphere temperature (32.3 Celsius) for time duration equal 60 seconds. Figure 9 show the result of output power versus time for the above reading of Table 2 and 3 with time interval 15 second between readings.

Table 1 TEG specifications

TEG geometrical parameters	
L is the thermoelectric leg length, m	1e-3
L_{cw} is the length of ceramic wafer, m	1.5e-3
Height of a TEM, m	$l+2*L_{cw}$
Fill factor	0.518
Area of a TEM, m^2 (a=0.062*0.062)	0.003844
Number of the pair of legs	n=127
Hot side heat exchanger parameters	
Mass of the hot side heat exchanger, kg	0.16128
Heat capacity of the hot side heat exchanger, J/(kg,K)	500
Mass of the illuminate plate, kg	0.024066
Length of the channel, [m]	0.213/2
Width of the channel, [m]	0.1143
Height of the channel, [m]	0.0127
Fin thickness, [m]	0.00032
Cold side heat exchanger parameters	
Mass of the cold side heat exchanger, kg	1.5045
C_{cxr} is the heat capacity of the cold side heat exchanger, J/(kg,K)	950

Figure 10 shows the photo of measuring output voltage of the contact between forearm and the Peltier surface in laboratory, and Figure 11 show the photo of measuring output voltage of the contact between palm and the Peltier surface.

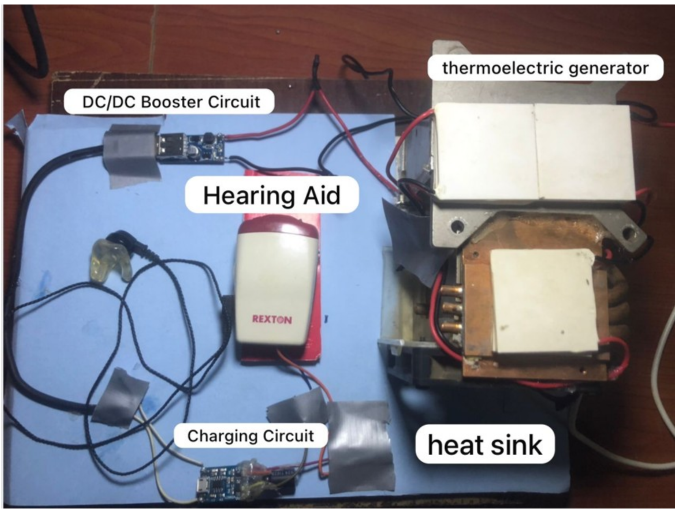

Figure 8: WTEG circuit setup in laboratory

Table 2: Result of Palm current and voltage vs thermoelectric temperature

Amp. temp (°C)	Cold Reservoir (°C)	Hot Reservoir (°C)	Palm Generation	
			Voltage **(V)**	Current **(mA)**
33.60	30.40	32.10	0.42	42.5
33.30	28.10	30.70	0.59	30.7
32.90	25.90	28.80	0.71	38.0
32.80	24.10	26.70	0.81	45.0
32.50	23.60	26.50	0.88	53.8

Table 3 Result of forearm current and voltage vs thermoelectric temperature

Amp. temp (°C)	Cold Reservoir (°C)	Hot Reservoir (°C)	Forearm Generation	
			Voltage **(V)**	Current **(mA)**
33.60	30.40	32.10	0.33	18.5
33.30	28.10	30.70	0.46	24.0
32.90	25.90	28.80	0.60	31.0
32.80	24.10	26.70	0.66	38.45
32.50	23.60	26.50	0.72	46.36

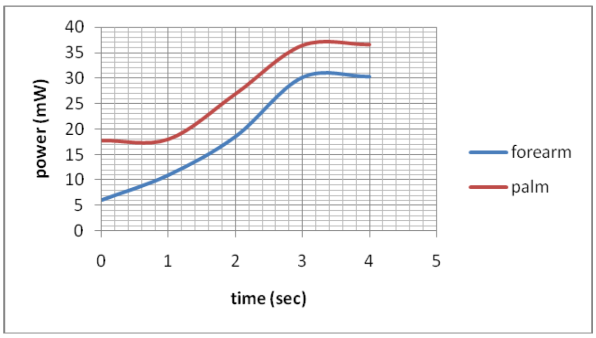

Figure 9: power generated by WTEG during putting on palm and forearm

Figure 10: the output voltage of the contact between forearm and the Peltier surface

Figure 11: the output voltage of the contact between palm and the Peltier surface

5. CONCLUSION

The primary aim of this study is to operate a 12 mW, hearing aid device by harvesting renewable energy from the human body. The result of the proposed system show that the energy harvested from the palm or forearm is quite enough to operate the hearing aid device. The use of polymer-based flexible heat sinks (PHS), and amplification mechanism significantly increase the generated voltagesignificantly increase the generated voltage. Different contact configurations for the WTEG results indicate that the temperature distributions in the human body are unequal and which gives different generation outputs.

The prototype WTEG placed on arm skin heat and generated electrical power 6 - 35 mW when the differences of temperature between the human body and ambient air in the range 2-7 °C. The maximum power generated with the designed thermoelectric generator located on palm reached up to 37 mW.

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