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Noise Impact in Designed Conditioning System for Energy Harvesting Units in Biomedical Applications

Aimé Lay-Ekuakille and Amerigo Trotta
University of Salento, Polytechnic of Bari
Italy

1. Introduction

The human body is subject to the same laws of physics as other objects, gaining and losing heat by conduction, convection and radiation. Conduction between bodies and/or substances in contact; convection involving the transfer of heat from a warm body to a body of air above it or inside the human body and here the blood, gases and other fluids is the medium, radiant heat transfer is a major mechanism of thermal exchange between human body and the surface surrounding environment. These three effects in most situations operate together. In human body, metabolic processes generate its own heat as well, similar to a heat-producing engine. Human body behaviour try to be in stable state therefore, it absorbs and emits energy to be in equilibrium, stimulation is applied to the body surface, this make the activity of metabolism induced to body surface. Human beings and, more generally speaking, warmblooded animals (e.g., dangerous and endangered animals, cattle, and pets), can also be a heat source, by means of a TEG (thermoelectric generator), for the devices attached to their skin. A TEG mounted in a wristwatch is an example for powering a watch using wasted human heat. Practical applications of TEGs have been carried out by different authors. In different works, the changes in a part of human body being have been studied and analyzed before and after stimulation and compared between them, then simulate the bio heat transfer mechanism using 2nd order circuit, which designed based on 1st order introduced by Guotai et al., and analyze the human thermo response. Since the human body emits energy as heat, it follows naturally to try to harness this energy. However, Carnot efficiency puts an upper limit on how well this waste heat can be recovered. This paper illustrates a specific study of the noise limited resolution of certain signal conditioning system concerning a TEG capable of powering biomedical hearing aids. In designing instrumentation system, especially for TEG, it is often necessary to be able to predict the noise limited threshold measurand, or alternately, what input measurand level will produce a given output SNR. The paper shows that, since the inner temperature of the human body is greater than the outer temperature, hence, the trunk is the area of the body where the tissue temperature has the highest value. So this is the area from which it is suitable to locate the sensing device for the sake of extraction and of subsequent conversion from thermal to electric energy. The choice of TG, for the purposes of this research, falls on

MPG-D602 device whose. The TEG "sees" the difference in terms of temperature between the hot side and the cold one, by producing, quickly, an electric power.

2. Electric energy from human body warmth

In different works, the changes, in a part of human body being, have been studied and analyzed before and after stimulation and compared between them, then simulate the bio heat transfer mechanism using 2nd order circuit, which designed based on 1st order introduced by different authors [Jiang, 2004], and analyze the human thermo response. Since the human body emits energy as heat, it follows naturally to try to harness this energy. However, Carnot efficiency puts an upper limit on how well this waste heat can be recovered. Assuming normal body temperature and a relatively low room temperature (20 °C), the Carnot efficiency is

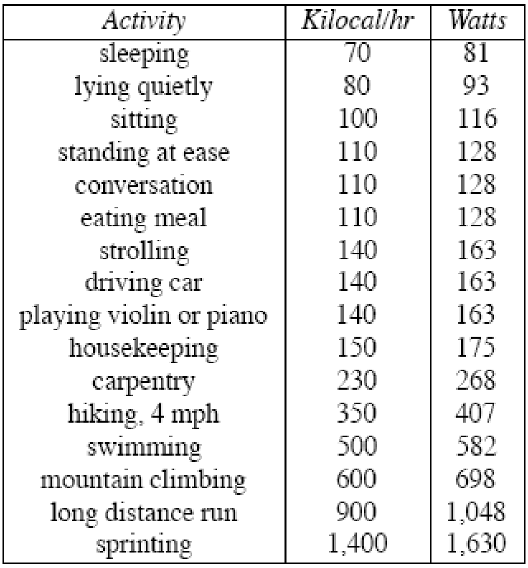
$$\frac{T_{body} - T_{ambient}}{T_{body}} = \frac{(310K - 293K)}{310K} = 5.5\% \tag{1}$$

In a hot environment (27°C) the Carnot efficiency falls to

$$\frac{T_{body} - T_{ambient}}{T_{body}} = \frac{(310K - 300K)}{310K} = 3.2\% \tag{2}$$

This calculation provides an ideal value. Today's thermoelectric generators that might harness this energy do not approach Carnot efficiency in energy conversion. Although work on new materials and new approaches to thermoelectric [Kishi, 1999] promise to somewhat improve conversion efficiencies, today's standard thermopiles are 0.2% to 0.8% efficient for temperature differences of five to 20°C, as expected for a wearable system in temperate environments. For the sake of discussion, the theoretical Carnot limit will be used in the analysis below, hence the numbers are optimistic. Table 1 indicates that while sitting, a total of 116W of power is available. Using a Carnot engine to model the recoverable energy yields 3.7-6.4W of power. In more extreme temperature differences, higher efficiencies may be achieved, but robbing the user of heat in adverse environmental temperatures is not practical. Evaporative heat loss from humans account for 25% of their total heat dissipation (basal, non-sweating) even under the best of conditions. This "insensible perspiration" consists of water diffusing through the skin, sweat glands keeping the skin of the palms and soles pliable, and the expulsion of water-saturated air from the lungs. Thus, the maximum power available without trying to reclaim heat expended by the latent heat of vaporization drops to 2.8-4.8W.

According to mathematical viewpoint, heat diffusion in human body can be represented according to a system of eight differential equations of a structural human body model, and the human body head is the area with the highest temperature. Consequently, we exploit the head skin to locate the sensors for gathering electric energy from body temperature. We used a thin film generator named MPG-D family and specifically MPG-D602 according to the characteristics of Table 2 [micropelt].



Activity	*Kilocal/hr*	*Watts*
sleeping	70	81
lying quietly	80	93
sitting	100	116
standing at ease	110	128
conversation	110	128
eating meal	110	128
strolling	140	163
driving car	140	163
playing violin or piano	140	163
housekeeping	150	175
carpentry	230	268
hiking, 4 mph	350	407
swimming	500	582
mountain climbing	600	698
long distance run	900	1,048
sprinting	1,400	1,630

Table 1. Human energy expenditures per activities

Type	Dimension (mm)	Number of leg pairs	Thermal resistance	Electrical resistance	Substrate type	Thickness
MPG-D602	Cold side: 2.47x2.47 Hot side: 2.47x2.47	450	9.6 K/W	189Ω	Silicon	500µm

Table 2. MPG-D602 characteristics

The MPG-D is a thermoelectric power generator based on the transfer of the thermal energy through a minimum of one leg pair consisting of p-type and n-type thermoelectric material. Micropelt utilizes Bismuth (Bi), Antimony (Sb), Tellurium (Te) and Selenium (Se) compounds that have the best material properties with operating temperatures around room temperature and up to 200 °C. The produced output voltage is direct proportional with the number of leg pairs and the applied temperature difference ΔT over the element. The resulting voltage U is given by the following equation, where α is the Seebeck coefficient in µV/K (material related) that influences the output voltage (see fig 1).

$$U = N_{legpairs} . \Delta T . \alpha \tag{3}$$

The circuit connections of the MPG-D are illustrated in fig. 2 and the real dimensions of MPG-D602 is depicted in fig 3. The efficiency of a thermoelectric device is given by the material properties which are combined in a figure of merit F given by the following equation

$$F = \alpha^2 T \frac{\sigma}{k} \tag{4}$$

where T is the absolute temperature, σ is the electrical conductivity and k the thermal conductivity. As aforementioned, the most widely used material for the fabrication of thermoelectric generators operating at room temperature is BiTe, which exhibits a F of 1. PolySiGe (F=0.12) has also been used, especially for micromachined thermoelectric generators [Leonov, 2007]. Research on nanostructured materials and multilayers is ongoing worldwide in order to optimize thermoelectric properties and F values as large as 3.5 have been reported in many researches. These encouraging results may replace BiTe in the long term. Apart from improving the material properties, miniaturization using micromachining is ongoing and the main challenges of micromachined energy harvesters are known. Selected device results reported in literature [Hagelstein, 2002]. The reported power levels however cannot be directly compared, as output values are often calculated using a well-defined temperature drop across the thermopile (i.e. the temperatures of both plates have been fixed). In real applications the temperature drop across the thermopile is lower than the one between the hot plate and the ambient, and therefore the extrapolated results are too optimistic. It has been shown that the most challenging task in designing an efficient thermoelectric converter consists in maximizing this temperature drop across the thermopiles [Van Herwaarden, 1989].

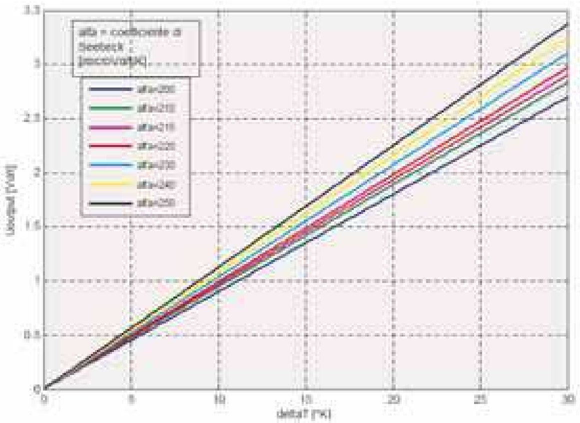


Fig. 1. MPG output in function of Seebeck coefficient

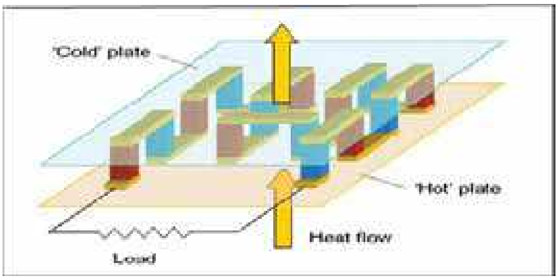


Fig. 2. Circuit connections

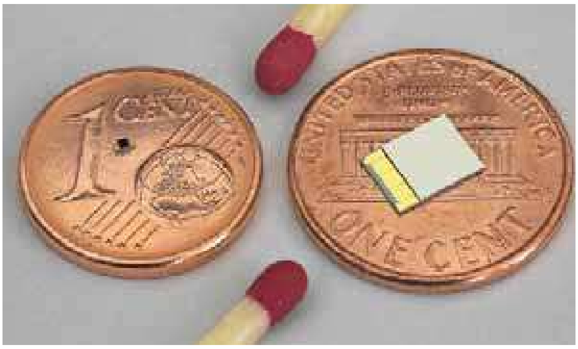


Fig. 3. MPG-D601 real dimensions

3. Conditioning system

3.1 Main Layouts and architectures

Analog conditioning signal system, in its simplest implementation, can be voltage amplification, with a change in impedance level between the conditioning amplifier's input and output. Analog signal conditioning may also involve linear filtering in the frequency domain, such as bandpass filtering to improve signal-to-noise ratio (SNR) at the amplifier's output. In the other cases, the analog input to the signal conditioning system may be processed nonlinearly. For instance, depending on the system specifications, the output of the analog signal conditioner may be proportional to the square root of the input, to the RMS value of the input, to the logarithm of the input, or to the cosine of the input, etc.., Analog signal conditioning is often accomplished by the use of operational amplifiers, as well as special instrumentation amplifiers, isolation amplifiers, analog multipliers, and dedicated nonlinear processing ICs. The output of the MPG-D must be connected to a specific conditioning circuit in order to make available the necessary voltage for hearing aids. The output voltage is an appropriate combination of single voltage released by single sensors. We illustrate two different conditioning circuits for the purposes of this research.

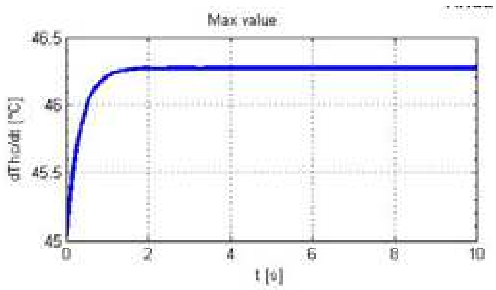


Fig. 4. Heat distribution max value within 10 s

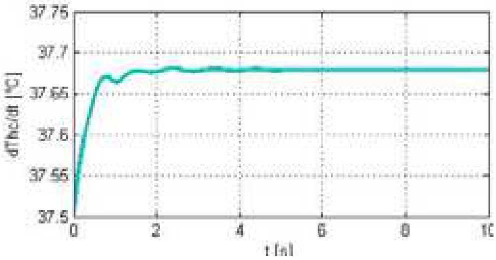


Fig. 5. Heat distribution average value within 10 s

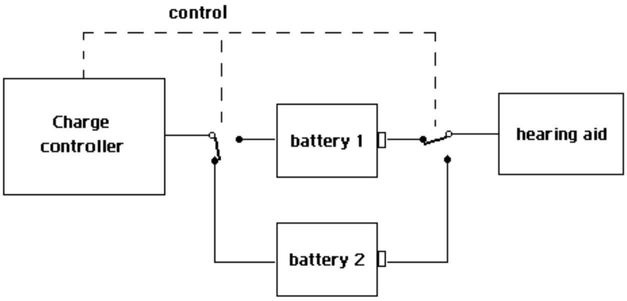


Fig. 6. Charge control architecture

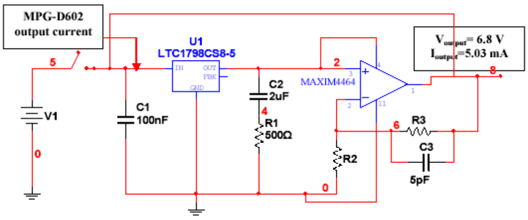


Fig. 7. Conditioning circuit

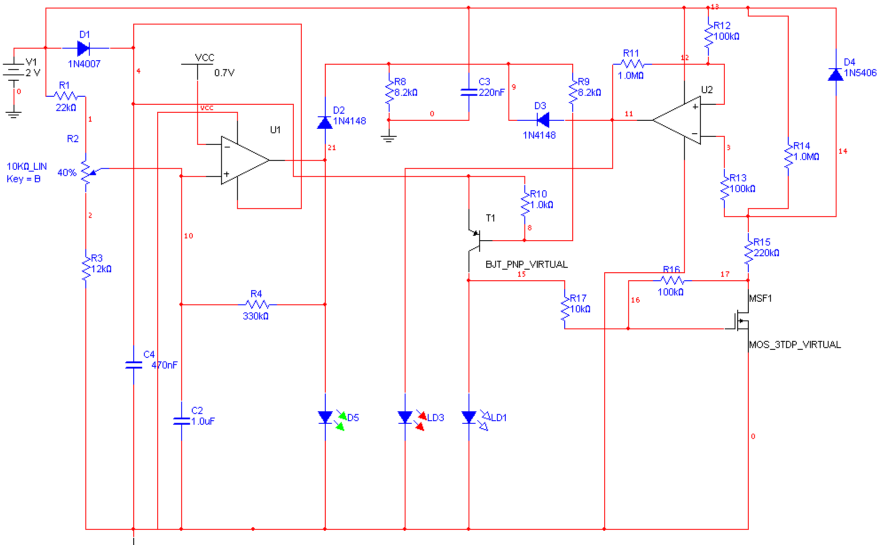


Fig. 8. Conditioning circuit including charge controller

In order to design, in a reliable way, the conditioning unit, a heat distribution for head area [Hirayama, 1998] is used as depicted in fig. 4 and fig. 5. These trends are very important for focusing the amount of heat to be converted in electric power. Since the hearing aid is, in general, supplied by a 1.4 V due to a specific battery, in order to increase the supplying reliability, an additional battery is used according to fig. 6. Hence, a conditioning unit is designed as shown in fig. 7, taking power from the sensor. A further improvement could be obtained from a charger configuration as depicted in fig. 8. In this case, three LEDs are used to simulate the operating mode of the circuit while the hearing aid is supplied.

3.2 Noise impact

The problem to be faced is the sources of noise in such signal conditioning units that can be separated into two major categories: noise from passive resistors and noise from active circuit elements such as bipolar junction transistors, field effect transistors and vacuum tubes. Noise from resistors is called *thermal or Johnson noise*. It has been observed that when dc (or average) current is passed through a resistor, the basic Johnson noise PDS (power density spectrum) is modified by the addition of a 1/f spectrum.

$$S_n(f)=4kTR + AI^2/f \qquad (5)$$

where I is the average or dc component of current through the resistor, and A is a constant that depends on the material from which the resistor is constructed. An important parameter for resistors carrying average current is the crossover frequency, f_c, where the 1/f PDS equals the PDS of the Johnson noise. This is

$$f_c= AI^2/4kTR \qquad (6)$$

It is possible to show that the f_c, of a noisy resistor can be reduced by using a resistor of the same type, but having a higher wattage or power dissipation rating. Noise arising in JFETs, BJTs and other complex IC amplifiers is generally described by the two source input model. The total noise observed at the output of an amplifier, given that its input terminals are short circuited, is accounted for by defining an equivalent short circuited input noise voltage which replaces all internal noise sources affecting the amplifier output under short circuited input conditions [Horowitz, 1989]. The input noise voltage for many low noise, discrete transistors and IC amplifiers is specified by manufacturers.

4. Conclusion

Thermoelectric generators, for supplying autonomous biomedical devices, are necessary because they overcome battery limitations. Their conditioning units are essential to increase as great as possible the quantity of power available to feed the hearing aids. Particular attention must be paid in designing the conditioning and the charger circuits in order to lower the power consumption and the noise.

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