A human body waste heat as power option for wireless transmitter for building sensors

M. Oplustil, M. Zalesak.

Abstract**—**This paper deals with an alternative energy source for autonomous wireless transmitters for building management. The electric energy used for supply of this device was harvested by human action or from human impact on the device. In the beginning part of this article was described principles of used energy conversion. The following part of this paper described system design of thermoelectric generator.

Keywords**—**Peltier module, Seebeck effect, step-up DC/DC converter, thermal energy, thermoelectric cooler.

I. Problem Formulation

THERE are a very popular wireless controllers applications in a wide field of the control technology at the present. As the other electrical devices, wireless transmitting elements needs some amount of electrical energy to run. The most common way for powering of autonomous wireless transmitting systems are by utilization of batteries or accumulators. These energy sources are of short time means types and required frequent replacement and in some cases their utilization isn't applicable at all.

There are some other means available at present, which enable generation of necessary electric power by human action – those devices have been called human action energy harvesting systems. The most common way for generate electric energy are those of using an electromagnetic, piezoelectric or thermoelectric principles.

This paper deals with a possible way of utilization of the thermoelectric generator (TEG) for the application in the wireless control systems in buildings, with energy supply by human palm. The specific problems in this application are the way of required power generation from the source of small temperature difference.

The aim of this article is introduce the numerator using thermoelectric generator as a power source for the wireless transmitting systems. The design of the transmitter could be divided in parts as–thermoelectric generator (TEG), electrical transformer, power management and wireless signal generator and transmitter. There are described thermoelectric generator, electrical transformer and power management in this article.

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II. Fundementals

A. Starting points

The thermoelectric power source is based on Peltier's cells. The cells are able to generate electric energy from heat. But in case of use Peltier's module without any supporting device we will have a problem. Because the electric energy on the output of module is too low, only few tens to hundred of milivolts, based on temperature difference and on density of thermoelectric junctions. Temperature difference depends on human physiology (palm temperature) and the surrounding air temperature. This temperature difference is roughly in few centigrade, while density of thermoelectric connections is purely technology mean. It means that the solution of task is only technology matter. But only technology solution is limited by acceptable size of the device. So the limits for the design and construction of the thermoelectric generator for the wireless transmitter supply by energy generated by the heat of human palms are temperature of the palm, (warmer junction), temperature of the surrounding air (colder junction), parameters needed by RF transmitter and the acceptable size of the device.

B. Thermoelectric effect analyses

The thermoelectric effect of the Peltier's module could be described by the (1) and (2).

$$\dot{i} = \sigma_T \cdot (\vec{E} - \alpha \cdot \vec{\nabla} T) \tag{1}$$

$$\vec{q} = \alpha \cdot \dot{i} \cdot \Delta T - \lambda \cdot \vec{\nabla} T \tag{2}$$

Where:

i is density of electric current, in A/m^2;

E electric field, in W/m;

q heat flow density, in W/m^2;

∇T temperature gradient in K;

σ_T electric conduction, in S;

α Seebeck coefficient, in V/(m.K);

λ thermal conductivity of thermocouple wire measured at $E = 0$, in W/(m.K);

ΔT temperature difference of the junctions, in K;

The output power of the thermoelectric generator in case of no load, U_0, could be described as follows:

$$U_0 = \overline{\alpha} \cdot \Delta T \tag{3}$$

Where:

U_0 is output voltage from generator, in V;

$\overline{\alpha}$ average Seebeck coefficient, in V/K;

ΔT temperature difference across the junction in K. Where:

$$\Delta T = T_h - T_c \tag{4}$$

T_h temperature of the warmer junctions, in K;

T_c temperature of the colder junctions, in K.

If a load is connected to the output of the thermoelectric generator, voltage drops as a result of an internal generator resistance and of the load. The current in the load circuits, I, could be expressed as follows:

$$I = \frac{U_0}{R_c + R_l} \tag{5}$$

Where:

I is output current of the generator in load circuits, in A;
U_0 see (3);
R_c internal resistance of the generator, in Ω;
R_l the load circuit resistance, in Ω.

The total heat input to the thermoelectric junction, P_h, is defined as follows from (1) and (2):

$$P_h = S \cdot \left(\alpha \cdot \Delta T \cdot I - 0{,}5 \cdot I^2 \cdot R_c + \frac{\lambda}{l} \cdot \Delta T \right) \tag{6}$$

Where:
P_h is thermal power entering to the generator, in W;
S area of the junction, in m^2;
l distance between thermocouple junctions, in m;
$\alpha, T_h, I, R_c, \lambda, \Delta T$ for explanation see above.

The efficiency of the thermal generator, E_g, could be expressed as:

$$E_g = \frac{U_0 \cdot I}{P_h} \tag{7}$$

The thermoelectric module consists of number of junctions:

$$U_0 = \overline{\alpha_M} \cdot \Delta T \cdot (R_M \cdot R_l) \tag{8}$$

Where:

U_0 is generator voltage output, in V;

α_M module's average Seebeck coefficient, in V/K;

R_M module's average resistance, in Ω;

R_l load circuit resistance, in Ω.

The Seebeck coefficient, α_M, resistance, R_M, and thermal conductivity, λ, are temperature depend and their values must be calculated case to case, otherwise, the values could be selected based on the average temperature of the module, T_{avg} where:

$$T_{avg} = \frac{T_h + T_c}{2} \tag{9}$$

III. Problem Solution

A. Device description

The thermoelectric generator is composed of high density of P-N metallic junctions (tellur-bismuth) between two ceramic plates. The first of the plates represents the warm side of thermoelectric generator (TEG) and the second is cold one. The junctions are formed from several P-N metallic couples shaped orthogonally. The schematic of the TEG shows Fig.1.

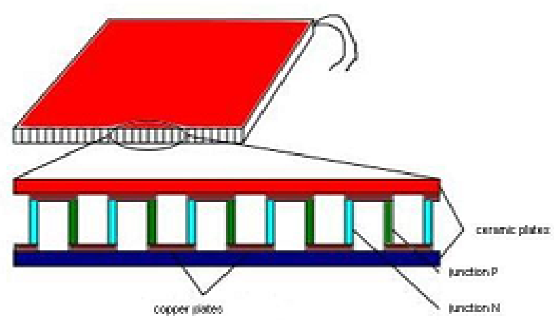

Fig. 1 Cut over TEG module

The output power from the module which contents of NT number of junctions, P_o could be expressed as follows:

$$P_0 = U_0 \cdot I = \frac{NT \cdot (\alpha_M \cdot \Delta T)^2}{4 \cdot R_M} \tag{10}$$

The problem is, that the heat flowing from the warm side to the cold side of the TEG increases temperature of the cold side and thus decrease, the temperature difference, ΔT, and farther decrease the output power of thermocouples, P_o. That is why it is necessary to transfer the heat flowing from the warm side to the cold side of TEG as much to the surrounding area – it means to decrease the thermal resistance of the part of the TEG between the cold plate and the outside colder surface of the TEG and farther from the outside surface to the surrounded environment (air, in case of hand control transmitter or wall, in wall mounted transmitter). The heat flow transferred to the cold side of the TEG by the heat conduction via thermocouples from the warm side, P_c is given.

$$P_c = \left(0,5 \cdot I^2 \cdot R_C + \frac{\lambda}{l} \cdot \Delta T \right) \qquad (11)$$

And heat flow density, q_c is defined as:

$$q_c = \frac{P_c}{A_c} \qquad (12)$$

In relations (11) and (12) stand for

P_c is heat flow, in W;

A_c area of the TEG cold side surface, in m^2.

The maximum allowable thermal resistance, R_T, of the TEG between cold plate and the surrounded air:

$$R_T = \frac{\Delta T_{rise}}{q_c} \qquad (13)$$

Where:

R_T is allowed thermal resistance, in (m^2.K/W);

ΔT_{rise} maximal allowed cold junction temperature increment, in °C;

q_c heat flow density see (12).

According to analyses of the measured data we have found that the output voltage of the relevant TEG are in ranges of tens (TEC1) or hundreds maximally of milivolts (TEC2). This is too low voltage level for power to other devices. It results to the fact, that the TEG could not be used directly, but it requires some means of transfer the output level voltage to higher one. There exists more possibilities how to achieve higher output voltage levels. The simplest way is connect the output of TEG to input of a conversion transformer with a suitably chosen transformation ratio and appropriate resistance of primary windings. But this way would disproportionately load of the TEG. Another way to increase the output voltage level of the generator is to use DC/DC converter. Whereby is possible to achieve an increase in output voltage at the units of volts. This voltage level will be already sufficient to power the connected equipment. Fig.2 described supposed method of adjusting of output voltage.

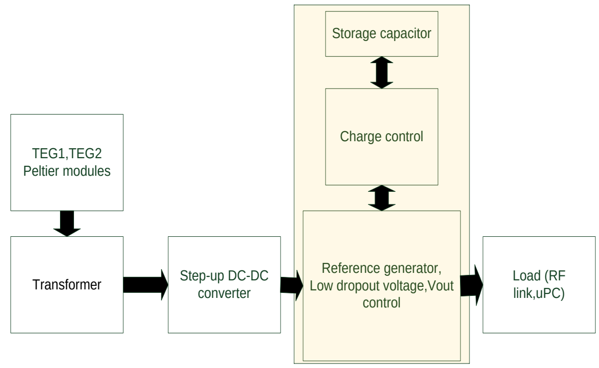

Fig. 2 Device block diagram

A mechanical construction of the device is simple. An input part of the device is formed by Peltier's module (TEC1, TEC2). A voltage output from the Peltier's module is connected to a primary winding of a transformer with transformation ratio in this case 1:100. A secondary winding of this transformer is connected to a first part of step-up DC-DC converter. This first part of this block is synchronous rectifier, second part is composed of shunt voltage regulator. The output voltage of this regulator is used for supply other block of device. The next step of voltage modification is a Power management which consists of reference generator, low dropout voltage, Vout controller, charge control and storage capacitor. As storage capacitor is use ultracap with relatively high capacitance 0,1F. For the level adjusting of voltage is used an ultra low voltage step-up converter and a power manager consisted of LTC 3108-1 from Linear Technology and five supported components. This device operates from inputs of 20 mV which is suitable for our application. The converter power is use for supply a wireless transmission element in building control systems. Based on above stated requirements the device isn't larger than usually used wall switch. Whole device is situated on the one side PCB with dimensions of 55 x 28 mm. Table 1 describes parameters of Peltier‘s modules.

Tab. 1 Parameters of Peltier's cells

Type	I_{max} [A]	ΔT_{max} [K]	*U* [V]	P_{max} [W]	*L* [mm]	*B* [mm]	*H* [mm]
TEC1	**8.5**	**68**	**2.06**	**9.2**	**15**	**15**	**3.3**
TEC2	**8.5**	**68**	**15.4**	**81**	**50**	**50**	**4.5**

With a wall-mounted cold side of the Peltier's module it is possible to obtain temperature difference between the human palm and a wall surface approx. ΔT = 11°C. This temperature difference represents output voltage of 35mV with TEC1and 150mV with TEC2 Peltier module.

The schematic diagram of used DC/DC converter shows Fig.3.

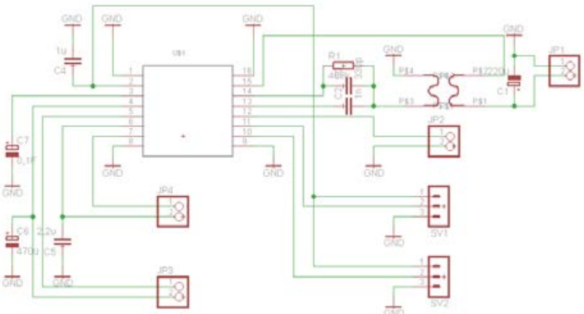

Fig. 3 Schematic diagram of DC/DC converter

Theoretical maximum power output from the used Peltier modules TEC1 and TEC2 could be calculated from (10):

$$P_{0,\max 1} = \frac{(\alpha_M \cdot \Delta T)^2}{4 \cdot R_M} = \frac{(0{,}01257 \cdot 11)^2}{4 \cdot 0{,}364} = 0{,}013W \quad (14)$$

$$P_{0,\max 2} = \frac{(\alpha_M \cdot \Delta T)^2}{4 \cdot R_M} = \frac{(0{,}05150 \cdot 11)^2}{4 \cdot 3.350} = 0{,}023W \quad (15)$$

This voltage output could meet requirements to power low-power broadcasting systems.

The used step-up converter also includes regulated output voltage in range of 2,5V; 3V; 3,7V and 4,5V. The level of output voltage can be changed by connecting pins VS1 and VS2 to V_{AUX} or GND. Device was tested with all options of output voltage. In the application as a transmitter for building control systems voltage level 3V, 3,7V and 4,5V could be used. The voltage level depends on required supply voltage of the transmitter.

IV. Measurement

For a measurement on our tested device the load resistors with values 1kΩ; 10kΩ; 47kΩ were used. The other type of load was represented by three types of Light-Emitting Diodes (LED). The output voltage was set to 3V DC. Temperatures during measurement were as follows: temperature of palm surface (hot side of TEG) at a level of 31,4°C, temperature of cold side of TEG at the level of 19,5°C. TEG2 was used as thermoelectric generator.

A. Load with resistance1kΩ

Fig. 4 shows results of the load value of 1kΩ, which is connected to the output of the generator. As shown on the figure, the level of the load is too low for tested device. And Output voltage does not reach to declared value voltage of 3V DC, but it can provide only 240mV. In this case the output current value was at the level of 0,24mA.

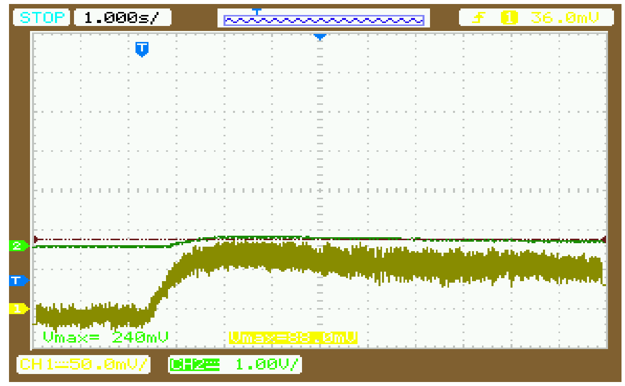

Fig. 4 Output with load 1kΩ

B. Load with resistance 10kΩ

Fig. 5 shows the case with the load value of 10kΩ, which is connected to the output of the generator. In this case it is visible that the output voltage level is higher than that of previous case, but still does not reach the nominal voltage value of 3V DC. In this case the output current value was at the level of 0,284mA.

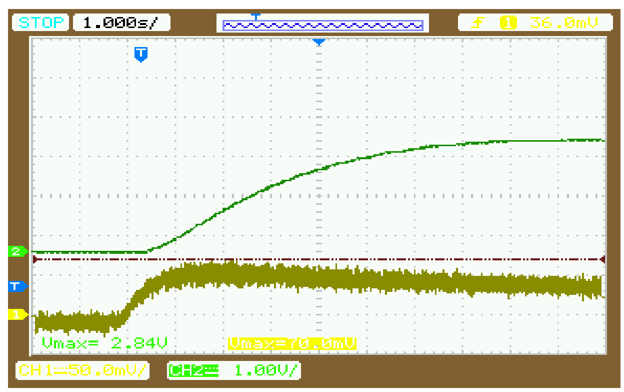

Fig. 5 Output with load 10kΩ

C. Load with resistance 47kΩ

Fig. 6 shows the case with the load value of 47 kΩ, which is connected to the output of the generator. In this case the output voltage level is higher than that the both previous cases and it reaches the required value of 3V with input voltage of 84mV.

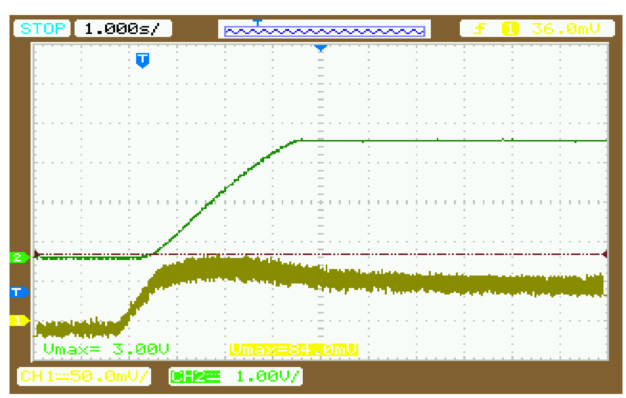

Fig. 6 Output with load 47kΩ

D. *Other case of using load resistance 47kΩ*

Fig. 7 shows the results of the load resistance at the same level as used in C. Fig. 6 - i.e. 47kΩ, but the palm was in longer contact with the surface of the generator – 4 s. It is visible the drop of the output voltage from the device.

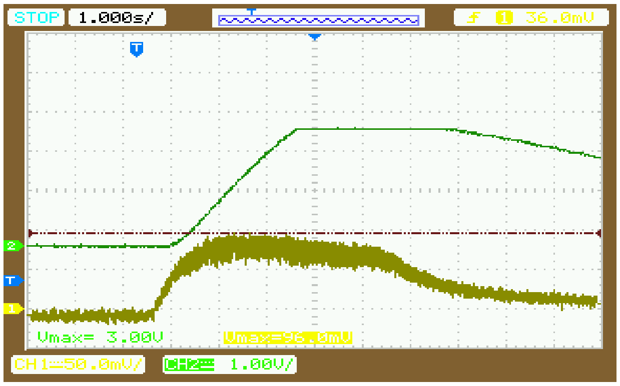

Fig. 7 Output with load 47kΩ

E. *Load old type LED - red color*

The other type of the output load was represented by Light Emitting Diodes (LED). Figs. 8,9 and 10 gives the impact of output DC forward voltage of each LEDs on the output voltage level of the generator.

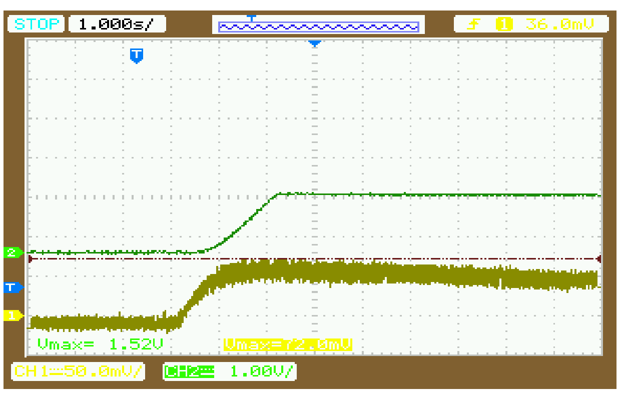

Fig. 8 LED connected to output

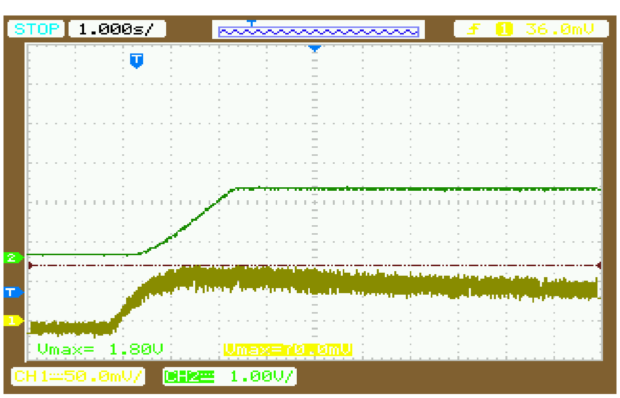

Fig. 9 LED connected to output

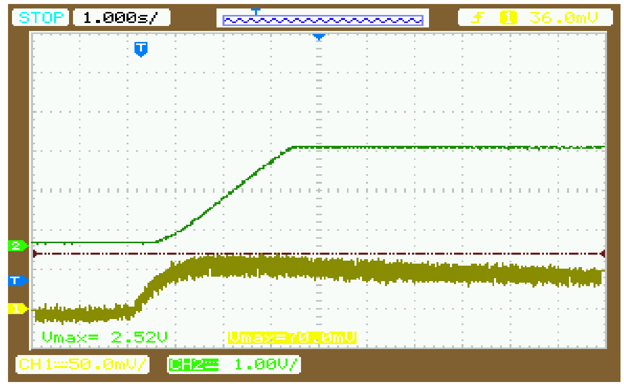

Fig. 10 White LED connected to output

F. *Output voltage with no load*

Fig. 11 shows unload output of the generator.

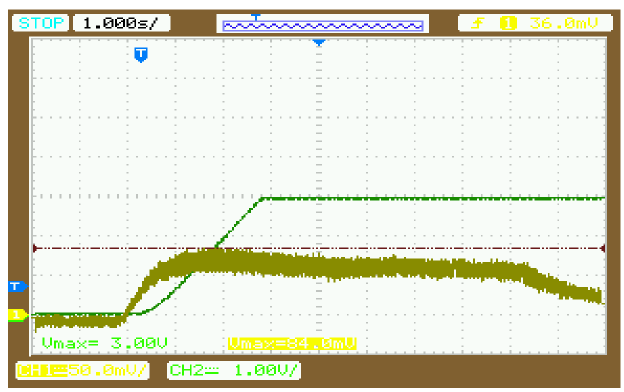

Fig. 11 Output voltage in case of no load

G. *Power Good response*

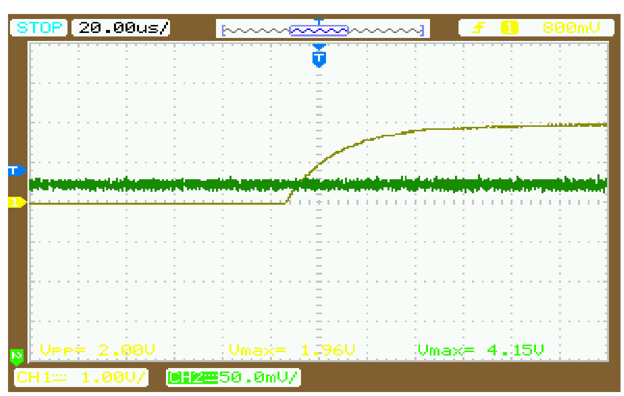

Fig. 12 Power Good output sequencing

Fig. 12 provides responsing of Power Good output to input voltage. The Power Good output of device can be use to drive low current devices as microprocessors and other chip I/O.

H. Designed DC/DC used for measurement

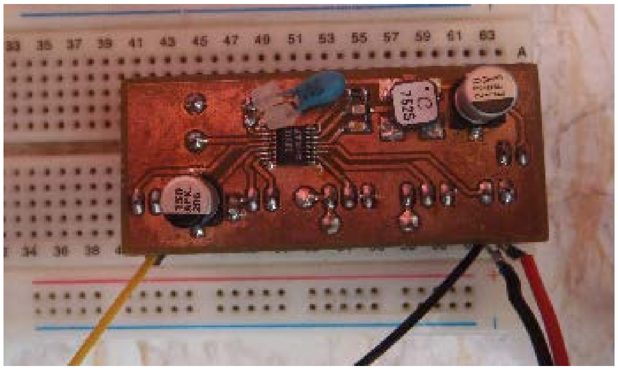

Fig. 13 Photography of designed device

V. Conclusion

This paper describes the construction of the electric energy generator for wireless transmission systems. The main obstacle of the utilization of electric generators of this type is the relatively small value of the temperature difference, ΔT, which is available due to the human palm temperature level and a wall surface temperature. From the measured data follows that even the small temperature difference, enables to get enough electric energy for wireless transmission in building control systems. The thermoelectric generator described above has been designed to be able to supply current 40 mA for the time of 1ms. This time is sufficient enough to transmit a simple telegram. The future work will continue with a design of LonWorks telegram wireless transmission system with the application of thermoelectric generator as described in this paper.

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