Thermoelectric power source for building sensors – analysis and measurement

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Abstract: - This paper deals with using of heat emitted from machinery parts, radiators for human for building automation needs. The most of devices and applications in environment produced some values of waste heat to vicinity. Mostly this heat goes to the surrounded area without any benefits for us and we lose valuable energy that can be still use.

Especially aim of this paper is using of human waste heat as an electric energy source for building sensors and switches. As heat absorber were used the standard low-cost Peltier element. The limitations for this applications are small heat transfer area (human palm, human finger), small mechanical dimensions and low temperature difference. This temperature difference depends on actual temperature of the human skin and on temperature of heat dissipation side of Peltier element. Temperature difference during measurement was only approximately 11 °C.

Key-Words: - Heat transfer, Peltier cell, Seebeck effect, step-up DC/DC converter, voltage, current

1 Introduction

The physical principles on which are thermoelectric coolers based on are actually date back to the early 19^{th} century. The first of the commercial thermoelectric modules were not available until 1960. The thermoelectric semiconductor materials used for the thermoelectric coolers are usually made of the Bismuth Telluride (Bi_2Te_3). There exists also other semiconductor materials e.g. Lead Telluride (PbTe), Silicon Germanium (SiGe) and Bismuth-Antimony (Bi-Sb) which may be used in the specific applications. For the application in temperature range of tens of centigrade are convenient thermoelectric material based on Bismuth Telluride.

The main research works in the field of generating of electric energy from human waste heat have been done in last 10 years. Some experts and companies have done a great deal with this problem. For increase performance it was designed a new type of micro-generator based on nanowire array micro-zones with dimensions of 50 μm x 50 μm [1]. The problem of using of human waste heat as an energy source for wearable micro thermoelectric generator was presented [4].

This paper deals with the design of a prototype of low temperature thermoelectric generator. The main usage of the designed generator is in the field of power supply for building sensors. The input heat to the designed generator is acquired by a human palm.

The energy source for described electric energy generator is represented by the common thermoelectric cooler (TEC) well-known as Peltier cell. The primary usage of this device is for the application in cooling, but it can be used as the electric energy generator as well. Required value of generated energy by described device is not in the same level as the energy generated by the thermoelectric generator (TEG). But production cost of the device is lower and availability is higher than that of TEG cells.

In the relevant device the Peltier type of cells is applied. The amplitude of the output voltage of the used cell, which operates as the thermoelectric generator, depends on the temperature difference between cold side and hot side of the cell. But the application of this cell for voltage generation from human waste heat is limited by the maximum temperature of the human palm available, as it reaches only 31 °C. This temperature represents hot side of the cell and temperature of the cold side of the cell is depends on the application. In this particular case the cold side of the cell is created as a cooler (heat sink), which is exposed to the ambient air.

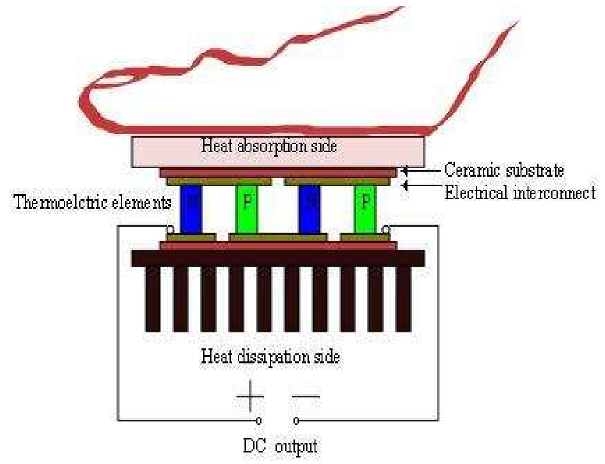

Fig. 1 the structure of the Peltier cell

The thermoelectric cooler consists of the two layers of ceramic substrate, between that are placed thermoelectric elements (thermocouples).The thermocouples used are made of the N-type and P-type material in electrical and thermal connections. Fig. 1 illustrates the structure of the thermoelectric cooler. The human waste heat from palm is absorbed by heat absorption side of Peltier cell.

1.1 Thermoelectric power generation

As long as the hot ends of the N-type and P-type materials are electrically connected the output voltage occurs due to the Seebeck effect [14]. The output voltage depends on the temperature difference and the parameters of the used thermocouples. The voltage at the load is reduced when the electrical circuit is closed by a voltage drop due to internal resistance. The efficiency of the generating power from the Peltier cell depends on the internal resistance of the cell.

1.2 Peltier cell

As a heat converter was used three types of commercial Peltier modules from different producers. The output voltage of Peltier cells is relatively small as a result of low temperature difference between the cells sides. In the measurement process were the cold sides of each cell thermally connected to the heatsink (air cooler) with a thermal resistance of 4.8 K/W. The cold side cells temperature at the start of the measurement equals to the ambient air temperature. The hot side of Peltier cell temperature was at the same level as a palm temperature. Measurement conditions and parameters of used heatsink are listed in Table 1.

Table 1 Measurement conditions

Measurement conditions	
Ambient temperature (°C)	20.3
Palm temperature (°C)	31.9
Dimension of heat sink (mm^3)	50x46x33(h)
Material of heat sink	aluminium
Number of fins (heat sink)	7
Base thickness of heat sink (mm)	4
Fin thickness of heat sink (mm)	2

2 Design a prototype

As shown in Fig. 2 designed device contains three blocks. The first block of the device is formed by the heat converter used as a thermoelectric cooler. The output voltage generated by the cooler is used as start-up voltage for the low input voltage DC/DC converter which creates the second block. This converter is based on the integrated circuit LTC31081 and it is convenient as for the small dimensions which match to the required small dimensions of the whole device. Further advantages of the used integrated circuit are of the low start-up voltage, type of the power management and regulated voltage possibilities. The third blocks represents by a circuit load.

Fig. 2 prototype block diagram

2.1 Thermoelectric coolers used during measurement

The three types of common TEC were used during measurement as the electric generators from the waste heat produced by the human palm. Table 2 lists parameters of used TEC. Parameters with sign (-) was not available from manufacturer information.

Efficiency of the thermoelectric devices is approximately based on parameter device *ZT* (figure of merit). This dimensionless parameter ZT is defined as:

$$ZT = S^2\sigma T/k \qquad (1)$$

Where:
T is absolute temperature [K]
S Seebeck coefficient [$V{*}m^{-1} K^{-1}$]
σ electrical conduction [S]
k thermal conductivity [$W{*}m^{-1}K^{-1}$]

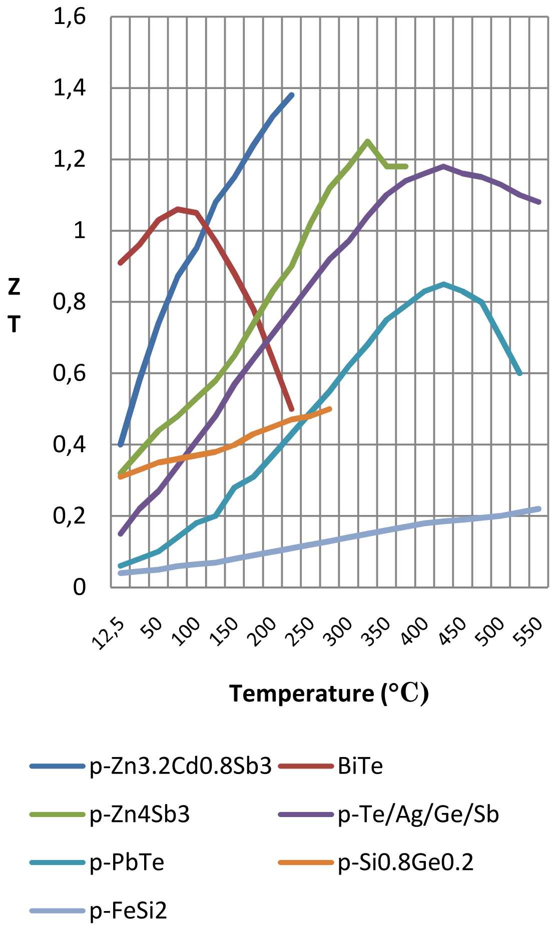

Fig. 3 semiconductors ZT

There are more thermocouple materials used for waste heat energy harvesting. As can be seen from Fig. 3 thermocouple materials with different chemically structure had different figure of merit under the same temperature difference. The most convenient material for human waste heat harvesting is semiconductor based on Bismuth-Telluride material. As plots in Figure 3 there are more materials composition with higher figure of merit based on (ZnCdSB, ZnSb, TeAgGeSb) semiconductors, but this value is under higher temperature difference.

Table 2 parameters of TEC

Model	TEC12708	MCHPE-127-10-08-E	RC 12-4
Dimensions (mm)	50x50x4.5	30x30x3.1	34x30x3.4
Voltage (V)	15.4	15.7	14.6
Current (A)	8.5	6.0	3.7
Maximal Power (W)	81.0	56.7	39.0
Number of Termocouples	127	127	-
Device ZT	0.65	-	0.75
AC Resistance (ohms)	2.7	2.3	3.2

The output voltage at the temperature difference of 11.6 °C in TEC during measurement process, results in tens of mV only. This value of the voltage level obtained is not equivalent to the supply voltage required by the sensors. It is necessary then to transform the output voltage to the higher level by a convertor (second block in Fig.2).

2.2 Low input DC/DC converter

The low input DC/DC converter consists of a boost transformer and a DC/DC boost converter. This device is used for adjust amplitude of output voltage of TEC from value of tens of mV to adjustable units of volt.

The boost transformer is directly connected to the output of TEC and converts amplitude of the output voltage to the required level of the boost converter. The conversion ratio of the boost transformer depends on start-up voltage of the DC/DC converter and on the amplitude of the output voltage from TEC. The required conversion ratio in this case is 1:100.

The function of the DC/DC boost converter contains of power management facility and an energy accumulator (storage capacitor) with a high storage capacity.

2.3 Loads of designed device

The output voltage of described device depends on two parameters: The first one is setup output voltage of DC/DC converter this value is selectable by jumper connection. The output voltage is selectable at values 2.5 V, 3.0 V, 3.5 V and 4.5 V. The second parameter is input resistance of connected load. When load resistance is very low the value of the output could not reach selected values of output voltage from DC/DC converter.

3 Device measurement

In order to evaluate the suitable prototype there were set of measurement prepared. Based on the constant temperature conditions 11,6 °C(apart from *C*) three types of TEC modules as listed in the Table II were tested with different circuits loads. There were used as a load two types of resistors 47 kΩ, 1 kΩ, white LED and the AUREL-SAW RF Transmitter Module. The adjustable voltage output from the DC/DC converter was set to the value of 4.5V.The circuit load is connected with the output of the DC/DC converter after certain time (approximately 4 s) after startup of the charging the device. Further the results of the tests are described.

3.1 TEC module TEC 12708

The Fig. 4 presents the output of the generator in case of load by the AUREL-SAW RF Transmitter Module working on frequency 433 MHz. The amplitude of the output voltage drops to the value of 3.0 V during the first 40 ms of the transmission. The test signal was represented by a log. 1 connected to the input of the module. The area of heat transfer surface is 900 mm^2.

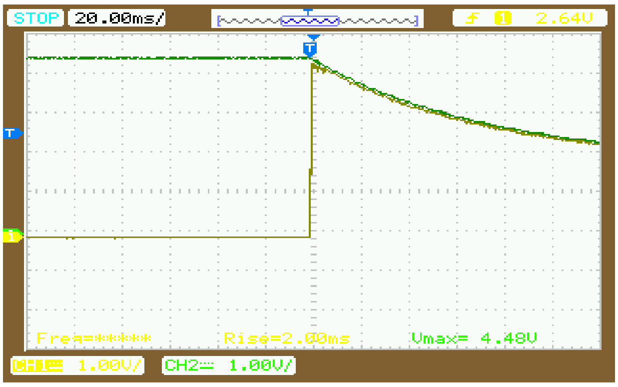

Fig. 4 the output of the device with TEC 12708

3.2 TEC module MCHPE-127-10-08-E

The Fig. 5 presents the output voltage of the generator in case of load by the AUREL-SAW RF Transmitter Module working on frequency 433 MHz. The amplitude of the output voltage drops to the value of 3.0 V during the first 40 ms of the transmission. The test signal was represented by a log. 1 connected to the input of the module. The area of heat transfer surface is 2500 mm^2.

Fig. 5 the output of the device with TEC MCHPE-127-10-08-E

3.3 TEC module RC 12-4

The Fig. 6 shows the output voltage of the generator in case of load by the AUREL-SAW RF Transmitter Module. However the temperature difference was in this case 10.5 °C.

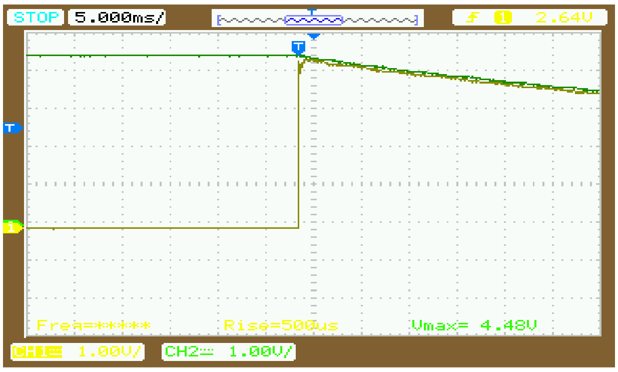

Fig. 6 output of the device with TEC RC 12-4

3.4 Output of DC/DC converter with load 47kΩ and TEC 12708

The Fig. 7 shows the amplitude of the output voltage with the load 47 kΩ. In this case it was used TEC module TEC12708.

Fig. 7 the output voltage sequencing with 47kΩ load

3.5 Output of DC/DC converter with load 47kΩ and TEC MCHPE 127-10-08-E

As can be seen in the Fig. 8 the output voltage in case of use TEC module MCHPE-127-10-08-E was higher than the previous case described in the Fig. 6. (at the same temperature difference). The amplitude of the output voltage rises sharply because of the input voltage rises faster and stops at the value of 92 mV.

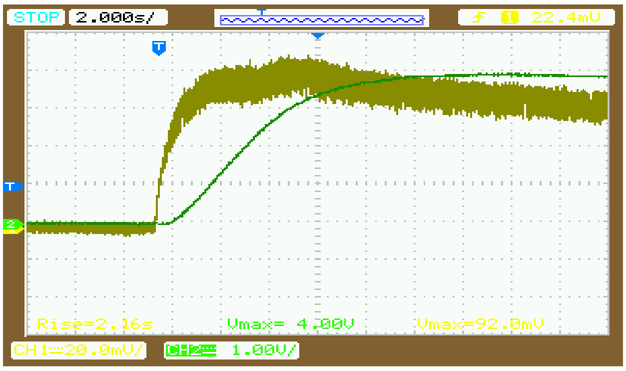

Fig. 8 the output with 47kΩ load and TEC MCHPE 127-10-08-E

3.8 Output of DC/DC converter with load 1kΩ

In the case described in the Fig. 9 the TEC module RC 12-4 was used. As shown the voltage level drops with the lower load resistance. The input voltage stops at the value of 88 mV and the output voltage does not exceed value of 120 mV.

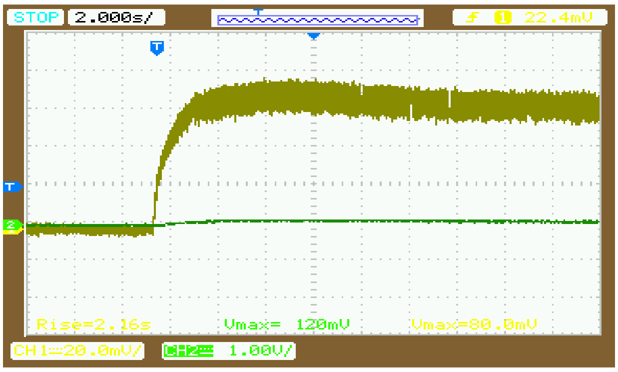

Fig. 9 the output sequencing with load 1kΩ and TEC RC 12-4

3.9 Output of DC/DC converter with white LED as load

In the case described in the Fig. 10 the TEC module RC 12-4 was used with white LED connected as a circuit load. The output voltage stops at the value of the forward voltage of the LED used (2.52 V).

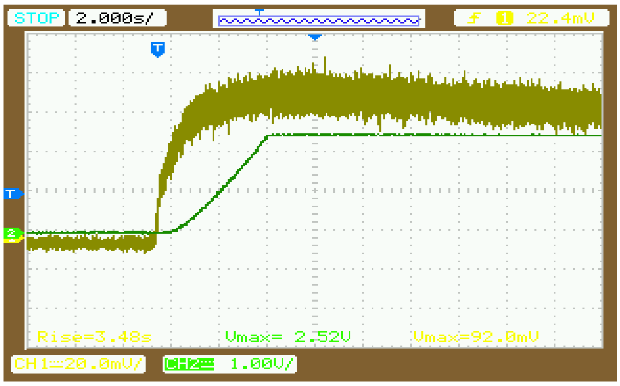

Fig. 10 output sequencing with white LED load

3.10 Output voltage in time with white LED as load

The time delay between the start of heat absorption in the TEC module and the output voltage required level is shown in the Fig. 11. The time delay was approximately 4 seconds with set amplitude of the output voltage at the value of 4.5 V. When the output voltage is set at the higher level, device output voltage time response is longer.

Fig. 11 output of converter in longer time

4 Designed prototype of the device

The prototype of described device was designed on one side PCB with dimensions of 55 mm x 28 mm. PCB contains boost transformer, ultra low input voltage DC/DC boost converter with power management and storage capacitor. Fig. 11 provides PCB of DC/DC converter as a part of designed thermoelectric generator. The used TEC module was connected to pin JP 1. The main output of this device is represented by pin JP 3.

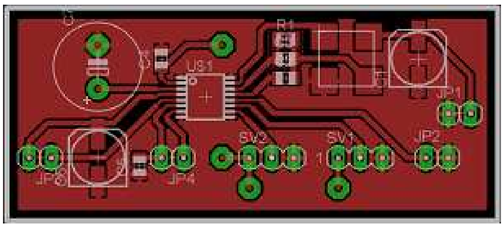

Fig. 12 DC/DC converter PCB

5 Conclusion

This paper describes using of TEC based on the Bismuth-Telluride semiconductors as an electric energy source for the wireless sensors. The amplitude of the output voltage of TEC is not on the required level and that is a reason why the DC/DC converter was designed in order to increase the output voltage, to the adjustable higher values. Designed device was built in the prototype and its parameters were evaluated by experimentally by measurements.

Three types of the Peltier cells as an energy source for prototype of DC/DC converter were compared in the experiment. The time delay between the amplitude of the input voltage and amplitude of the output voltage was studied. The time delay depends on the selected output voltage. Measurement was performed with the load represented by AUREL-SAW RF Transmitter module. The described prototype of the generator was able to provide current of 10 mA during the time of 15 ms. The better performance of described device can be achieved by a modification of the storage capacitor and by the better setup parameters of DC/DC converter according to the requirements of the used load. The future work will deal with optimization of the prototype for demands of the higher output power and longer availability of the output current.

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