QUANTIFICATION OF THERMOELECTRIC ENERGY SCAVENGING OPPORTUNITY FOR A COMPACT NOTEBOOK

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Abstract: Recently thermoelectric (TE) materials have been used for thermal energy scavenging in various systems. The aim of this project is to quantify the energy scavenging opportunity in a compact notebook computer system. The selected target system has been mechanically and thermally characterized. An off-the-shelf Bi-Te based TE module was thermally and electrically analyzed to identify realistic generation potential. The analysis of the system potential was then extended to other TE materials reported in the literature with varying cost and production complexity. The realistic best generation potential has been estimated between 10s of μWs to 10s of mWs depending on TE technology utilized, which represent two extremes in the power/cost tradeoff curve.

Keywords: energy scavenging, thermoelectric conversion, sustainable energy systems, Seebeck effect, notebook computer.

INTRODUCTION

The purpose of this work is to demonstrate application of a methodology to quantify in detail the thermal energy scavenging opportunity in a compact (small form factor) notebook system using thermoelectric (TE) materials. Energy scavenging opportunity in mobile systems was previously researched [1] using hybrid mode of TE operation. The models used were semi-realistic in nature, but some potential was identified for overall energy efficiency improvement through combination of performance gain and reduction in power consumption. A more recent study [2] calculated upper bound for benefit to notebook systems through TE energy scavenging. Both [1] and [2], as well as other work in this area, concluded that the available energy would be very small for battery life extension in normal modes of operation, but could be significant for context aware computing, distributed sensors, and similar applications. The studies performed so far reported that a more detailed approach was needed. Specifically, it was emphasized in [1] that iterative, empirical, and system dependent approaches would avoid undesired effects, like major performance reduction.

This work uses the methodology flow presented in [3] to demonstrate a viable quantitative analysis on a compact notebook. The analysis of a much larger notebook system with more thermal margin was presented in [3]. However, it is expected in general that thermal energy scavenging would be much more challenging when many of the components operate close to the maximum temperature limit under workloads relevant to performance.

The next section describes mechanical and thermal properties of the target compact notebook system as characterized in our lab. Section III provides a snapshot of the current off-the-shelf TE technology. Maximum realistic power generation potential within system environment is analyzed in Section IV, accounting for variations across different TE technologies. Finally, conclusions and next steps are provided.

SYSTEM PROPERTIES

A compact notebook (Toshiba Portégé R705-P25 [3]) model has been chosen as the control system for this analysis (Fig. 1). This model has been especially chosen to represent the small office type notebooks in every-day use.

Temperature measurements have been performed in selected locations as part of the thermal map development for the system. The measurement points are presented in Fig. 2 where the measurement points can be categorized as:

- Inside of the chassis (with primary prefix I)
- Top of the chassis (with primary prefix T)
- Bottom of the chassis (with primary prefix B)

In the thermocouple naming convention, A-D is for the top of the upper chassis, while E-I is for the lower chassis.

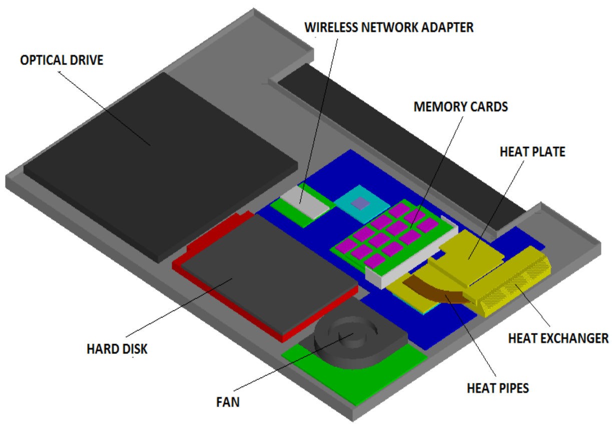

Fig. 1: Inner mechanical map of the target system. (Toshiba Portégé R705-P25)

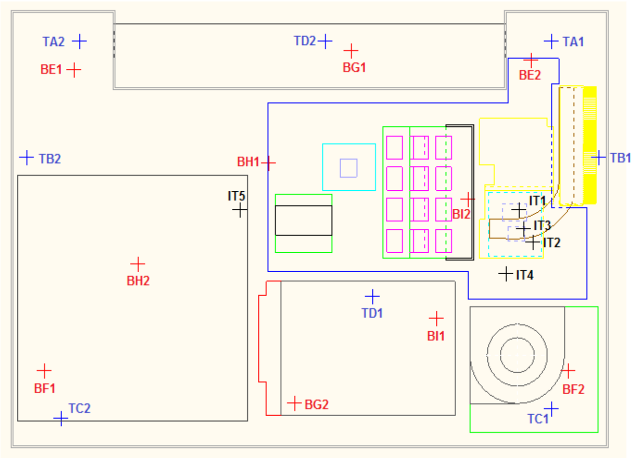

*Fig. 2: Compact notebook temperature measurements (Prefix **T** stands for top layer, **B** for bottom layer and **I** for internal layers)*

The TAT-Tools software from Intel has been used in order to measure the temperature variations of the threads inside the CPU during the thermal data acquisition at the selected points. The software has been adjusted to represent two different conditions where 80 percent workload stands for the more realistic high performance usage condition and 100 percent symbolizes the most extreme condition in which the system operates. After the measurement process, the collected data has been assembled in charts to indicate the temperature distribution within the system in different locations. This step was particularly important to select the optimum points with the maximum temperature difference. Fig. 3 samples the temperature variation of four different points each taken from a different layer while the system was operating with 80 percent workload.

TE PROPERTIES

An off-the-shelf TE module (e.g. FERROTEC Peltier Cooler Model 9500/018/012 M P [4]) was sampled for the realistic analysis of the off-the-shelf capability. In order to determine the thermal specifications and the Seebeck coefficient of the system the model presented in Fig. 4 has been used

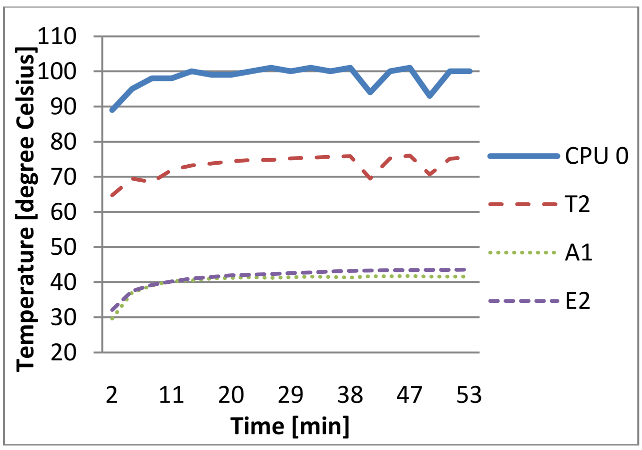

Fig. 3: Temperature variations of selected "hot spots" from inside and outside of the control system

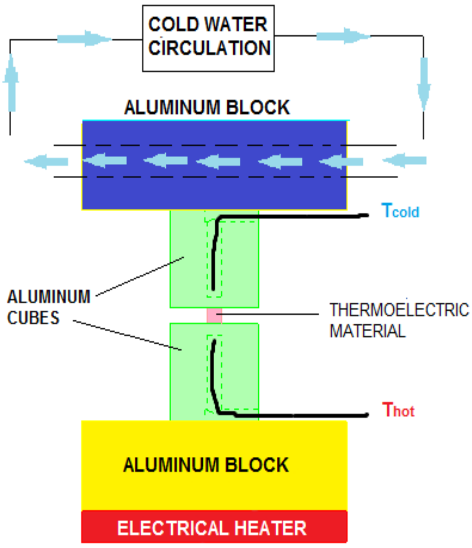

Fig. 4: TE module characterization setup

where the TE has been placed between two aluminum cubes which are drilled from the center in torder to enable the touch of the thermocouple to the cube surface in to obtain the non-linear power generation capacity across a realistic range of temperature potentials (delta-T's).

The TE characterization model also included the usage of temperature controlled metal blocks. While one of them was heated by an electrical heater, the other was cooled with the help of a cold water circulator. The lower aluminum block was lying on an electrical heater to create the hot surface, while the upper block was designed to provide the cold surface. A channel with a 6 mm diameter had been bored through the block, enabling the passage of the distilled water, which served as a coolant during the experiment. The plastic hoses attached to the both sides of the aluminum block were connected to a chiller to keep the temperature constant by pumping chilled water in a preset temperature. A multimeter has been connected to both of the poles of the TE material to measure changes in voltage while the thermocouples placed in the metal cubes provided the temperature

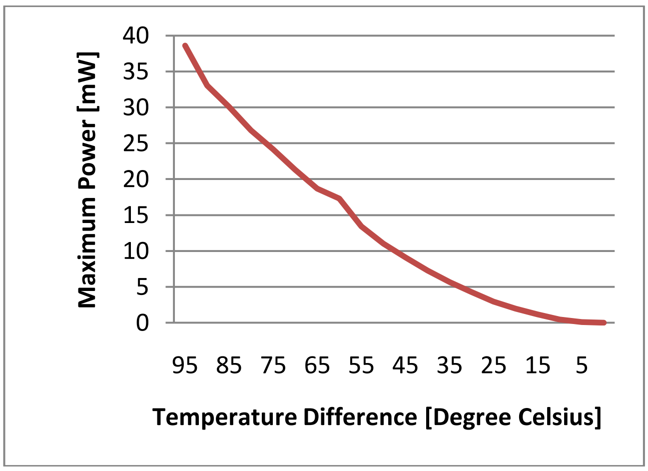

Fig. 5: Maximum power generation capability of the selected TE material in mW vs. degree Celsius

Table 1: Energy scavenging opportunities using FerroTEC module in different locations of the control system

Region	Desciption of vertical heat path	Delta T	x (mm)	y(mm)	z(mm)	Pmax (mW)
1	From top of heat spreader (IT2) to metal each above it (IT3)	29	5	7	3	3.956
2	Metal attach above heat spreader (IT3) to bottom surface (BI2)	6	29	22	4	2.629
3	Main PCB card (IT4) to top surface (TD1)	11	50	12	8	9.852
4	Main PCB card (IT4) to bottom surface (BI2)	13	38	20	7	17.942
5	Bottom metal cage (IT5) to bottom surface (BH1)	5	8	8	9	0.187
		Sum				34.565
		50% Power Electronics Efficiency				**17.283**

difference. The characterization data sample is provided in Fig. 5 where the relationship between the temperature difference and the maximum power generation capability has been shown. The effective Seebeck coefficient was extracted from the data, including dependence on temperature.

QUANTITATIVE ANALYSIS

At this step a quantitative methodology for power analysis has been developed in order to obtain a first-hand insight into the energy conversion opportunities in the system. After mapping the geometrical and thermal characteristics of the target system, possible locations with medium to high temperature difference have been selected in order to convert the temperature difference into electrical power by using the Seebeck effect. The heat dissipation paths in these locations were picked to represent shunt paths for cooling, and not the mainstream cooling paths. This is purposefully followed to avoid significant performance impact. Using the Seebeck coefficient acquired from the TE characterization model, the maximum power generation potential has been calculated for the selected locations. During these calculations it has been assumed that the temperature differences between the selected points are constant and available for the geometrical space between the points.

First estimate of a realistic best case energy harvesting potential was obtained by processing the characterization data. A power electronics efficiency of 50% has been applied to the system based on previous studies, to cover for the energy losses in the circuits. The initial estimate of realistic maximum potential for the targeted system was 17 mW (Table 1) using a readily available off-the-shelf Bi_2Te_3 (Bismium Telluride) based TE material. This is 2.9% of the theoretical maximum predicted in [2]. Note, this is still referred in the previous discussion as realistic “best case”. The reason is threefold: First, the workload characterized represents a realistic performance application, and not an application used, for example, for battery life. Second, future more detailed modeling of the system may indicate that some portion of the selected shunt paths for TE integration does in fact provide a major heat dissipation path, contributing to performance. Third, the measured heat flux through the selected paths may be less than currently assumed, which again will come out in the next steps of this study.

The Seebeck generation in the above data represents an off-the-shelf high-cost component performance. However there are other alternatives for TE energy harvester, including low-cost designs researched at METU MEMS labs [6]. Table 2, for example, depicts a representative sample of normalized figures reported in the literature for three distinct sets of materials. These entries represent three distinct cost corners, when both material cost and production cost are taken into account. A summary of the system realistic best case generation with the added two technologies is shown in Table 3.

Table 2: A comparison of normalized TE efficiency factors among the selected materials

	TE-efficiency factor (uW/K2cm2)
FerroTEC [Bismium Telluride]	12.825
METU MEMS Lateral TE [Ni,Cr] ***[6]***	0.0738
METU MEMS Lateral TE [P Si, N PolySi] ***[6]***	0.4040

Table 3: Energy scavenging opportunities using alternative lower cost TE modules in the target system.

Region	**Desciption of vertical heat path**	**Delta T**	**x (mm)**	**y(mm)**	**z(mm)**	**METU MEMS Lateral TE [Ni, Cr] (mW)**	**METU MEMS Lateral TE [P Si, N PolySi] (mW)**
1	From top of heat spreader (IT2) to metal each above it (IT3)	29	5	7	3	0.022	0.119
2	Metal attach above heat spreader (IT3) to bottom surface (BI2)	6	29	22	4	0.017	0.093
3	Main PCB card (IT4) to top surface (TD1)	11	50	12	8	0.054	0.293
4	Main PCB card (IT4) to bottom surface (BI2)	13	38	20	7	0.095	0.519
5	Bottom metal cage (IT5) to bottom surface (BH1)	5	8	8	9	0.001	0.006
		Sum				0.188	1.030
		50% Power Electronics Efficiency				**0.094**	**0.515**

CONCLUSION

The energy scavenging possibilities in a compact notebook system have been quantitatively analyzed based on empirically supported characterization studies. The resulting potential is identified to be roughly one order of magnitude less than a larger (gaming) notebook analyzed in [3], although the maximum estimated benefit is still significant using latest off-the-shelf TE technology. While the benefit dramatically reduces with low cost MEMS technologies, there may be more attractive cost/benefit tradeoffs between the two ends.

The next step, currently pursued, is the modeling of the realistic notebook system in CAD (ANSYS) environment to correlate heat flow paths with the measurements. Finally, TE integration will be first simulated in the CAD model to ensure no measurable performance degradation, and then prototyped in the target system.

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