Concise Thermal to Electrical Parameters Extraction of Thermoelectric Generator for Spice Modeling

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I. Introduction

The world is running out off fossil fuel resources, such as Oil, Coal, and Natural Gas. New and renewable resources are the alternatives and solutions to the problem. Thermoelectric generators (*TEG*) have the ability to directly convert solar energy or any waste heat into electrical energy. This conversion of energy is achieved via the Seebeck effect, named for the discovery made in 1821 by the German physicist, Thomas J. Seebeck.

TEGs are versatile heat controlled solid-state pn junction devices that have no moving parts and emit zero green house gases (*GHG*) into the environment during the course of their operation [1]. In addition, they can be used for cooling, heating or energy generation. TEGs were primarily used for power production in remote locations or small-scale generation where reliability and durability in the supply are required [2].

The main objective of this paper is twofold:

1) develop a step by step methodology for how to model a thermoelectric module (*TEM*) using the LTspice simulator and
2) extraction of parameters from datasheet and device properties and geometries.

II. Background

The purpose of this work was to first demonstrate the feasibility of an LTspice modeling of a Thermoelectric Module (TEM) and then to investigate how TEG system behaves in real-world. First, the TEM was run as a thermoelectric cooler (*TEC*) by sending it a variable DC voltage. Second, the TEM was simulated by considering the internal intrinsic parameters, such inductance and capacitance.

Among all the physical phenomena that normally take place in a TEM, the most dominant mechanisms were considered (*Seebeck*, *Peltier*, and *Joule effects*).

The Thomson effect was neglected due to its insignificant contribution in this study.

The TEG device in question was purchased from Custom Thermoelectric and has the following electrical characteristics :

- maximum power, P_{max} = 21.6 W;
- maximum voltage, V_{max} = 7.2 V;
- maximum current, I_{max} = 3 A;
- Thermal Conductivity, k = 2.18W/$m{\cdot}K$, and
- optimal efficiency of the module, η = 6.5%.

The intent of this work (parameter extraction) was to actual utilized the calculated values in LTspice simulator software to model the system. The thermal to electrical analogy model is presented in [3].

III. Methods

Thermal	Electrical
^oC/Watt	Ohm (Resistor)
Joules/^oC	Farad (Capacitor)
Watt	Ampere (Current Source)
^{o} C	Volt (Voltage Source)
Ambient Temperature	GND (0V)

THE SEVEN TEG SPICE MODELING STEPS

1. Identify all the Components

2. Calculate the Biot Number (*Bi*)

The Bi value determines the approach to be adopted in the analysis.

- ***Bi** much less than 1, the lumped capacitance method is solely recommended for accuracy in the results.*
- ***Bi** isn't much less than, then some sort of numerical discretization method should be considered.*

3. Calculate the thermal R and C

4. Define and draw parasitic elements (*L, C*)

5. Express the Electrical equivalence of thermal parameters

6. Connect the analogy blocks in series-parallel, then

7. Run the TEG in LTspice

IV. Results

The TE modules were specified by the manufacturer to be bismuth telluride (***Bi_2Te_3***) and the ceramic substrates to be alumina (***Al_2O_3***).

In order to compute the most relevant values, such as thermal resistances and thermal capacities of the various parts, the **material density, heat capacity**, and **thermal conductivity** were needed.

- Thermal Resistance, R_{AL} is 2.29 10^{-2} *K/W*
- Thermal Capacity, C_{AL} is 96.53*J*
- Mass total of the semiconductor, m_T is 4.8.10^{-2}*kg*
- Mass of the ceramic plates, m_{cer} is 2.231 10^{-2} *kg*
- Molar heat capacity of the ceramic plates, C_{cer} was 18.74*J/K*
- The mass of Bi_2Te_3, m_{Bi2Te3} is 2.631 10^{-2} *kg*
- Molar heat capacity of Bi_2Te_3, C_{Bi2Te3} is 4.036*J/K*

The overall heat capacity of the TEM, C_{TEM} is *23J/K*

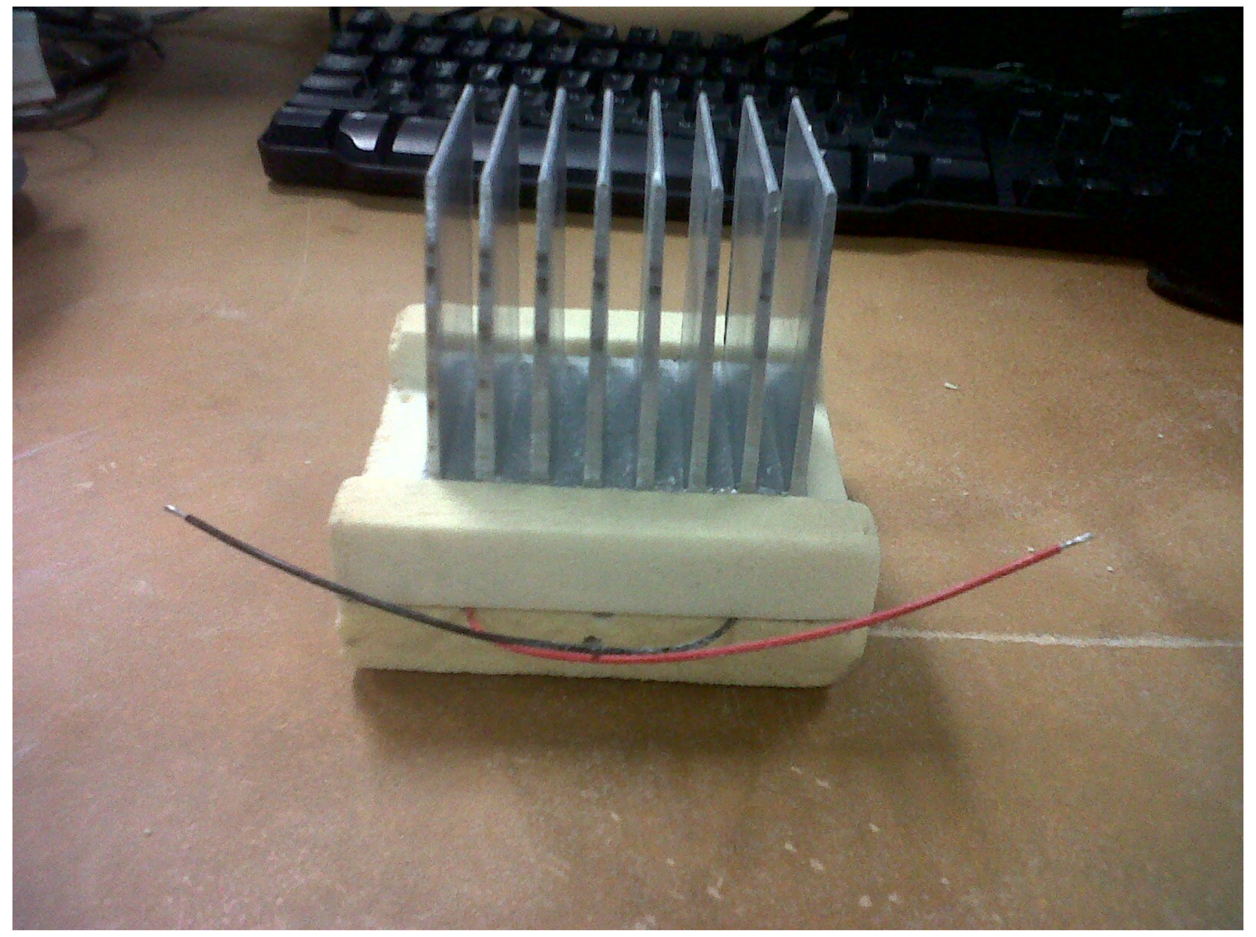

FIGURE 1: Aluminum heat sink mounted on theTEM

V. Conclusions

- An experimental setup was designed and built to characterize and study the performance of a commercial TEM.
- This study was conducted in a laboratory prior to a TEM thermal to electrical SPICE modeling and analysis.
- The main objectives of this paper were successfully achieved.
  a) develop a step by step methodology for how to model a thermoelectric module using the LTspice simulator and
  b) extraction of parameters from datasheet and device properties and geometries
- Also, this research sought to familiarize our selves for a future real-world solar thermoelectric generation system.
- Any error introduce at this stage will be replicated on the actual simulation.

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