

SMART SENSORS FOR IOT

Exercise: THERMOELECTRIC GENERATOR MODULE

We want to recover waste heat from the exhaust gas of an industrial machine using a thermoelectric generator (TEG). The harvested energy is stored to power an array of wireless sensors monitoring the operation of the tool. The TEG module has $n=100$ thermocouples connected in series, each one consisting of p-type and n-type thermoelements as depicted in figure 1. The hot junction of the module is maintained in contact with the machine shield at 250°C whereas the temperature of the cold junction is approximately 50°C . As an approximation, we assume similar material properties for the p and n type thermoelements: $\alpha_p = -\alpha_n = 163 \mu\text{V}/\text{K}$, $\rho_p = \rho_n = 1.46 \cdot 10^{-3} \Omega\text{cm}$ and $k_p = k_n = 1.2 \cdot 10^{-2} \text{W}/\text{cmK}$, being respectively the Seebeck coefficients, the resistivity and the thermal conductivity of the materials. The cross-sectional area and length of the thermoelements are $A_n = A_p = 11 \text{mm}^2$ and $L_n = L_p = 4 \text{mm}$.

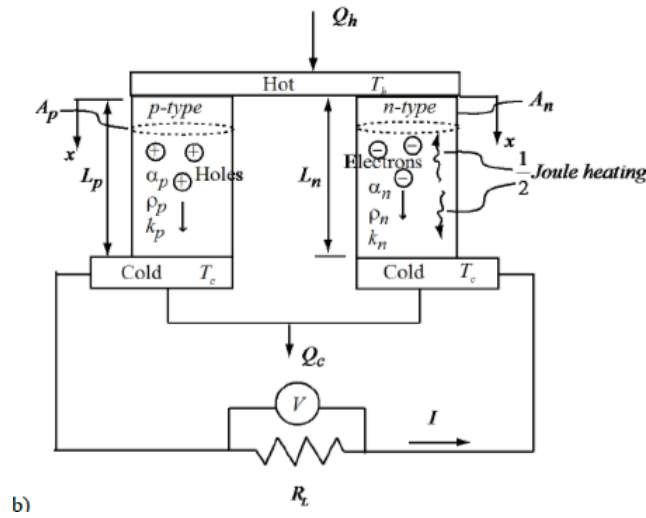


Figure 1: schematic of a single thermocouple included in the TEG module.

It can be demonstrated from thermodynamics considerations that the total output power of the entire module is expressed, in terms of single cell properties, as:

$$W_{module} = n[\alpha I(T_{Hot} - T_{Cold}) - I^2 R], \quad (1)$$

where $\alpha = \alpha_p - \alpha_n$ is the Seebeck coefficient of the thermocouple, I is the current flowing across the load of each cell and R is the internal parasitic resistance of the thermoelements.

Thanks to the superposition of the electrical contribution from each thermocouple, the output power can also be expressed in terms of external load resistance R_L according to:

$$W_{module} = nI^2 R_L \quad (2)$$

Given the numerical data and the equations in the text, answer the following questions.

Questions:

1. Derive the equations for $V_{output}(I)$, $I(R_L, R)$ and $V_{output}(R_L, R)$
2. Derive the analytical expression of the output power for a given internal and load resistance (R , R_L)
3. Compute the internal resistance R of the thermocouple
4. For what value of R_L the output power is maximized? Compute the maximum output power
5. Compute the thermocouple figure of merit (reminder: zT factor, see the slides)