TEH-1D Ultra-Low Voltage DC-DC Boost Converter

INTRODUCTION

Thermoelectric energy harvesting provides a powerful tool in the ability to harness waste heat from industrial or even biological processes for the purposes of powering low-power devices. The recent emergence of wearable technology has prompted many individuals to monitor their vital statistics or power simple devices that allow them to connect to their environment via the “internet-of-things”. The *TEH-1D Ultra-Low Voltage DC-DC Boost Converter* is able to convert small voltages, obtained from thermoelectric generator (TEG) modules that are exposed to small temperature differences in an ambient environment, into a constant 3.3V output for powering a variety of sensors, LEDs, microcontrollers, and other solid state electronics. With its small form factor of only 0.36 square inches, it is the perfect solution for the implementation of size-constrained wearable technology and monitoring systems.

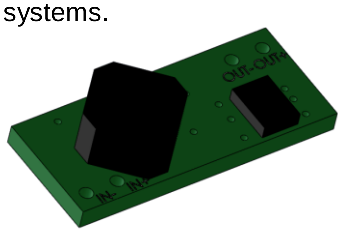

Figure 1: TEH-1D Ultra-Low Voltage Boost Converter Board

THERMOELECTRIC ENERGY HARVESTING

While this board can be used to boost millivolt-level voltages from any source, its primary purpose is to be paired with a TEG module so that the required energy can come from the temperature differential experienced between the module and its ambient surroundings. Thermoelectric modules are simplistic in design; they have a number of thermocouples which are essentially cubed pairs of semiconductor material that are bonded between metals to be electrically in series and thermally in parallel. In the presence of a temperature difference across the faces of the module, a voltage develops based on the well-known thermoelectric property; the Seebeck effect. The open-circuit Seebeck voltage is as follows:

(1) $$V_{oc} = N\alpha\Delta T$$

Where N is the total number of the cubed thermoelectric legs, α is the average Seebeck coefficient of the material used in their composition (in V/K) and ΔT is the temperature difference in K that is maintained across the module. Although the output voltage is strictly a function of temperature, the amount of power that can be extracted from a module is greatly affected by its internal resistance. A TEG module acts as a dependent voltage source with an internal resistance in series. Figure 2 displays the premise of operation of a TEG in open circuit, with R_{TEG} being the internal resistance of the TEG module.

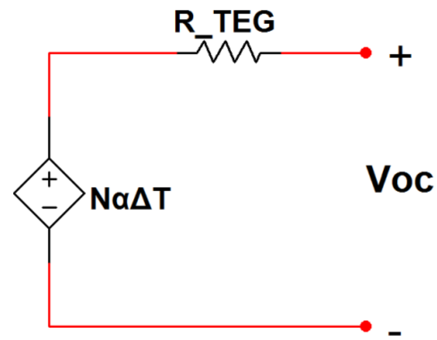

Figure 2: Equivalent circuit diagram of a TEG in the open-circuit condition.

Power cannot be drawn, however, from a TEG in open circuit and thus the module needs to be loaded so that current can flow. The output voltage at the load, V_o, output current, I_o, and output power, P_o, are then denoted by the following equations:

(2) $$V_o = \frac{V_{oc}R_{Load}}{R_{TEG}+R_{Load}} = \frac{N\alpha\Delta T \cdot R_{Load}}{R_{TEG}+R_{Load}}$$

(3) $$I_o = \frac{V_{oc}}{R_{TEG}+R_{Load}} = \frac{N\alpha\Delta T}{R_{TEG}+R_{Load}}$$

(4) $$P_o = V_o I_o = \frac{(N\alpha\Delta T)^2 \cdot R_{Load}}{(R_{TEG}+R_{load})^2}$$

The equivalent loaded circuit is given in Figure 3.

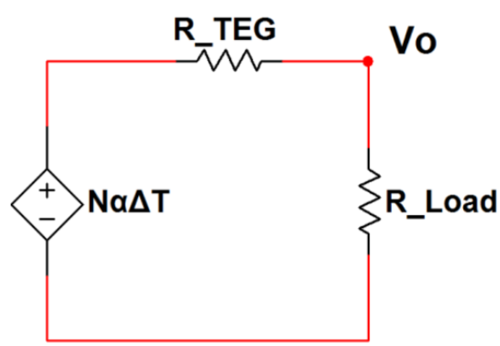

Figure 3: Equivalent circuit diagram of a TEG in the closed-circuit condition.

It is evident from the arrangement in Figure 3 that the output voltage, and therefore power, is optimized when R_{TEG} = R_{Load}. This criterion is known as load matching and always guarantees maximum power output delivered to the load when it is met. Thus, it is always ideal for the value of R_{TEG} to be as close to the load resistance as possible. When using the TEH-1D to boost TEG output voltages, it takes the place of the load resistor, and its input impedance is used instead to determine the voltage, current, and ultimately power delivered to its input terminals. The input impedance of the TEH-1D varies with input current (Figure 4).

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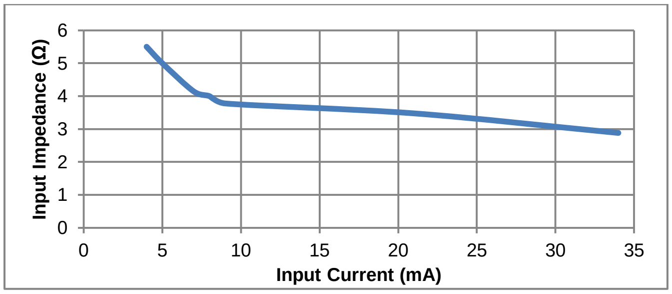

Figure 4: TEH-1D Input impedance vs. input current.

It is vital to note that based on Figure 4, a higher input current to the TEH-1D input results in a lower input impedance and more power delivered to the output.

TYPICAL PERFORMANCE

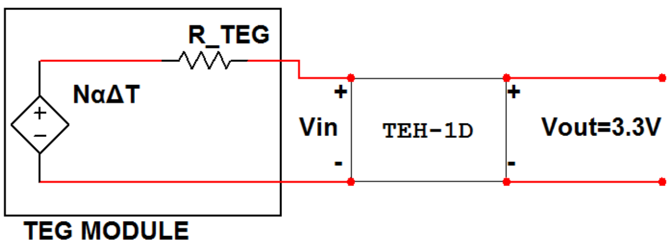

Figure 5: Basic connections between a TEG module, the TEH-1D, and the resulting output voltage.

As previously mentioned, the *TEH-1D Ultra-Low Voltage DC-DC Boost Converter* boosts low voltages into a usable 3.3V supply. Its standard setup with a TEG module is depicted in Figure 5. The output power is equal to 3.3V multiplied by the output current. The input power to the TEH-1D is given by equation (4), which is the TEG module output power to any load. Therefore, the efficiency, η, is equal to:

(5) $$\eta = \frac{P_{out}}{P_{in}} \cdot 100\%$$

Typical performance curves involving the output power and efficiency are given in the following figure for a sample range of input currents.

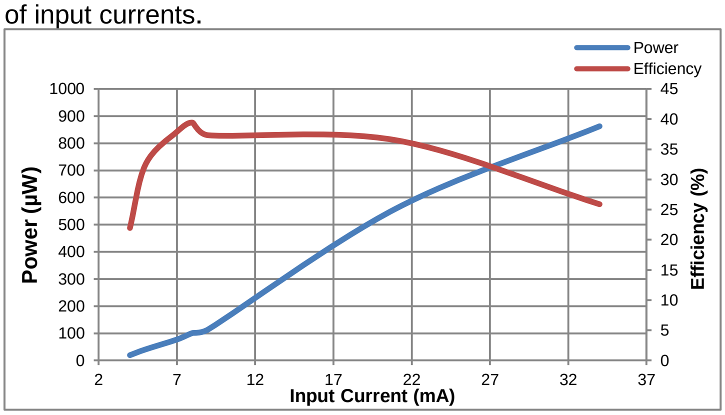

Figure 6: Output power and efficiency vs. input current

DESIGN CASE STUDY

Thermal Electronics Corp. can provide a multitude of TEG modules to fit any waste energy harvesting application. The following example forecasts the performance of the TEH-1D with the 40mm x 40mm flat plate TEG modules that are offered by the manufacturer. The following considerations will be made. Each of these modules has a slightly different internal resistance that will limit the amount of voltage and therefore current to the TEH-1D module during operation. The Seebeck coefficient for each module, α, was determined from their open-circuit voltages given in their datasheets at the lowest hot and cold side temperatures. The number of TEG elements, N, in each of them is known to be 252. The four model numbers are denoted in the legends of the following figures, and their given output powers and input voltages, are provided for the interface with the TEH-1D Ultra-Low Voltage DC-DC Boost Converter.

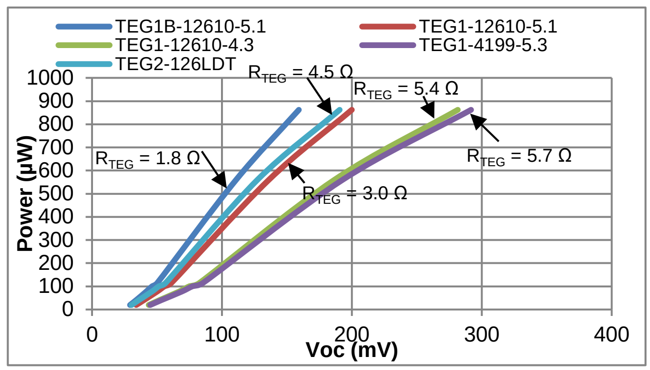

Figure 7: Output powers of the TEH-1D vs the open-circuit voltages of four TEG modules provided by Thermal Electronics Corp.

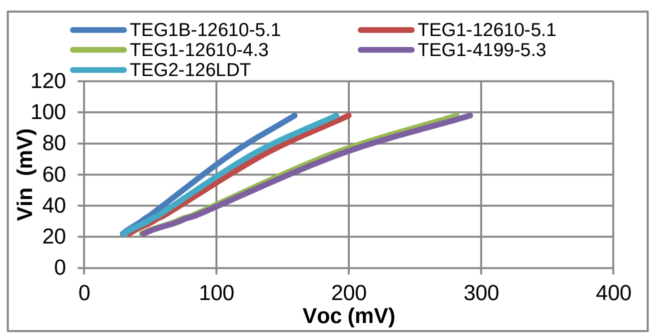

Figure 8: Input voltage to the TEH-1D vs. open-circuit voltage of four TEG modules provided by Thermal Electronics Corp.

The current drawn from the TEG modules is dependent on their open-circuit voltage, which is the simplest parameter to measure in-situ. Figures 7 and 8 can be correlated to Figure 6 using the equations 2 to 5, i.e. the power and efficiency of the entire system can be determined for any TEG module used.

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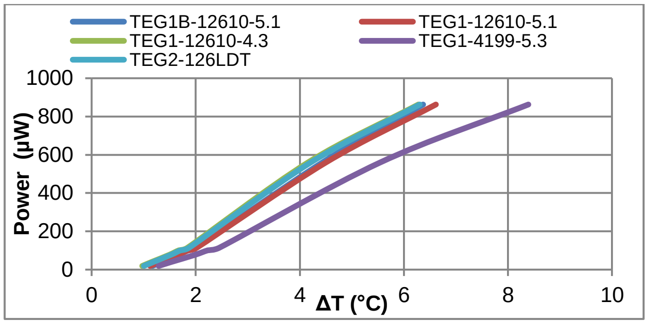
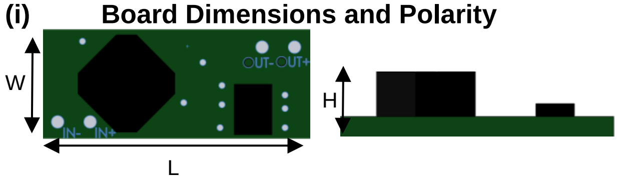


Figure 9: Output power vs. approximate ΔT across a module in ambient conditions.

TECHNICAL SPECIFICATIONS

(i) Board Dimensions and Polarity



L = 21.5 ± 0.5 mm
W = 10.5 ± 0.5 mm

H = 5.5 ± 0.5 mm

(ii) Electrical Specifications

Parameter	*Value*	*Units*
Minimum Input Voltage	25	mV
Maximum Input Voltage	500	mV
Nominal Output Voltage	3.3	V
Typical Input Current at Minimum V_{IN}	3	mA

NOTES

The values represented in this datasheet are to be taken as guidelines, as many different operating conditions, both thermal and electrical could influence the power output for the end user. Caution must be taken such that the polarity of the input and output to the board must be maintained to be electrically consistent as per the drawings given in the "Technical Specifications" section. The TEH-1D can be utilized with any low power source that can output voltages within the ranges given in the "Electrical Specifications" of this document. The formulae and sample data presented also allows the user to calculate the projected output power of the TEH-1D when connected to any TEG module assuming (1) the number of thermocouples and therefore, thermoelements is known (2) a good approximation of the average Seebeck coefficient for the TEG material and (3) the number of elements within the module.

The TEH-1D will operate best when a TEG is applied a constant temperature difference across its faces, i.e. it is in steady-state.

ORDERING INFORMATION AND TECHNICAL INQUIRIES

Please visit Thermal Electronics Corp. online at www.tecteg.com for ordering, associated product literature, and detailed contact information. There are other TEG modules available in the online shop that can suit a variety of applications which contain strict size constraints. For low ΔT applications, and if size permits, the TEG2-126LDT module is recommended to use with the TEH-1D as it was designed for use in environments where the supply of heat is low. Thermal Electronics Corp. can be reached by email at tecteg@rogers.com.