ULTRA-LOW VOLTAGE BOOTSTRAP CONVERTER

DATASHEET W0422-1,2

INTRODUCTION

The W0422 line of bootstrap converters are self-oscillating DC/DC converters that convert DC power at very low voltages into power at higher, more usable voltages. These converters are specifically designed for thermoelectric generation, where temperature gradients that are harvested for power may be only a few degrees, causing generated voltages that are too low for direct use.

THERMOELECTRIC GENERATION

Thermoelectric (TE) phenomena arise from the intercoupled electrical and thermal currents in a material. A thermoelectric generator is constructed by connecting multiple N-type and P-type thermoelements in electrical series with all elements in thermal parallel between a heat source and a heat sink. A scaffolding is often used on the top and the bottom of a device to lend mechanical support to the thermoelements. Figure 1 depicts a commercially available device with the top scaffolding removed.

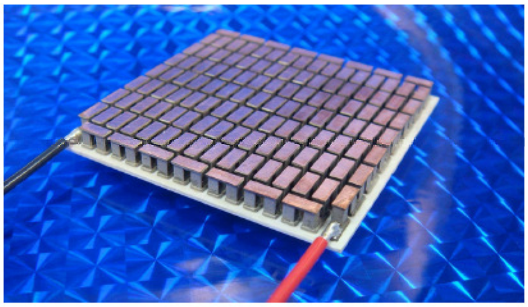

Figure 1 – A 254 Element TE Module
(Courtesy of Custom Thermoelectric)

Any thermoelectric device can be used for either generation or for heat pumping. In a heat pumping application, the TE device is often referred to as a Peltier module or cell. When an electrical current is applied, heat is moved from one side to the other side of the device. The W0422 bootstrap converters can work with TE devices that have been designed for either generation or heat pumping.

TE-GENERATED VOLTAGE

The open circuit voltage that is generated from a temperature differential across a thermoelectric module is a function of the temperature gradient, ΔT, the number of series connected elements, j, and a material constant called the Seebeck coefficient, S. If it is assumed that the N-type and P-type thermoelements have the same magnitude of thermoelectric properties, then the open circuit voltage may be written as

$$V_{oc} = j \times S \times \Delta T \qquad (1)$$

The ΔT in eq. (1) will always be less than the difference between heat source and heat sink temperatures due to thermal resistances between source/sink and the actual thermoelements. These "parasitic" thermal resistances should be minimized to the greatest extent possible.

OBTAINING MAXIMUM POWER

Every generator has an internal electrical impedance, often referred to as the source resistance, R_S. When a thermoelectric module is used for generation, this source resistance is primarily due to the electrical resistance of the individual thermoelectric elements. If we assume that there is a constant resistance, $R_{element}$, for both N-type and P-type thermoelements, then for a generator having a total of j elements, the source resistance is

$$R_s = j \times R_{element} \qquad (2)$$

The source resistance serves to reduce the power that can be delivered to an electrical load. A well-known result from electric circuit theory is that the maximum power that can be delivered by a source to an electrical load is obtained when the load impedance is designed to be the same as the source impedance. This is called impedance matching. The W0422 line of bootstrap generators are designed for operation over the range of $R_S = 1\Omega$ to $R_S = 10\Omega$ with an optimal efficiency for $R_S = 3\Omega$.

THE UNIPOLAR CONVERTER, W0422-1

The W0422-1 is a unipolar DC/DC converter that steps up an input voltage of fixed polarity. The converter measures 0.45 inches by 0.8 inches (11.4 mm X 20.3 mm) and is the size of a standard 16 pin, dual in-line (DIP) socket. When a voltage source with the polarity indicated in Figure 2 is attached to the W0422-1 converter, an output voltage with the indicated polarity will be generated.

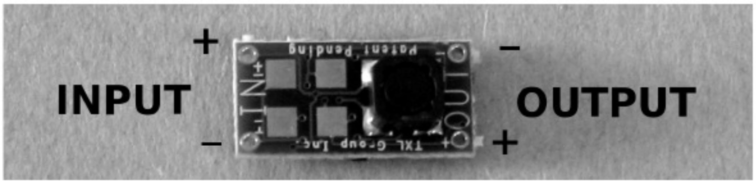

Figure 2 – Input and Output Polarities for the W04022-1

The amount of output power that can be obtained from any thermoelectric device depends upon the open circuit voltage V_{oc}, the internal resistance of the module, R_S, and the nature of the load. In most applications for harvesting energy from environmental heat, fluctuations in ΔT may cause intermittent charging, so it is desirable to continuously charge an electrochemical cell (the load) which then furnishes power for sensing or wireless transmission duties. Figure 3 depicts the power delivered by the W0422 converter to a 3 volt Lithium-Ion rechargeable cell as a function of the open circuit (unloaded) voltage, V_{OC}. The curves in Figure 3 correspond to three cases of TE cell internal resistance. The actual performance that is obtained will depend upon the particular internal resistance, R_S, of the chosen thermoelectric module.

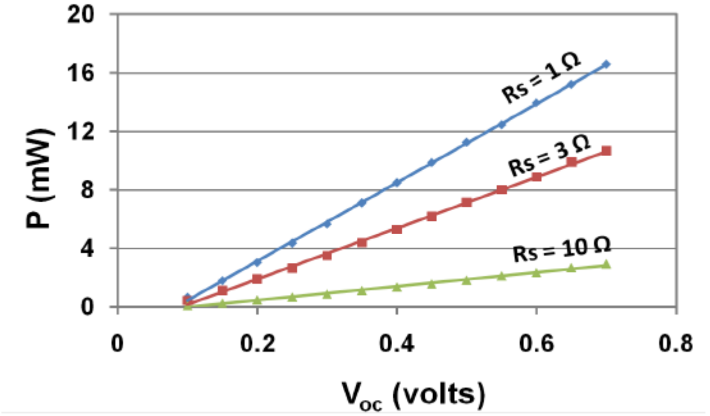

Figure 3 – Output Power vs V_{OC} When Charging a 3V Cell

Figure 4 depicts the input voltage to the W0422-1 module as a function of V_{OC}, when charging a 3 volt cell. The output current delivered to the cell (load) is calculated by dividing the output power by 3. The input current to the W0422-1 is obtained by taking the difference between V_{OC} and V_{in} and dividing by R_S. The input power to the W0422-1 is the product of input current and input voltage.

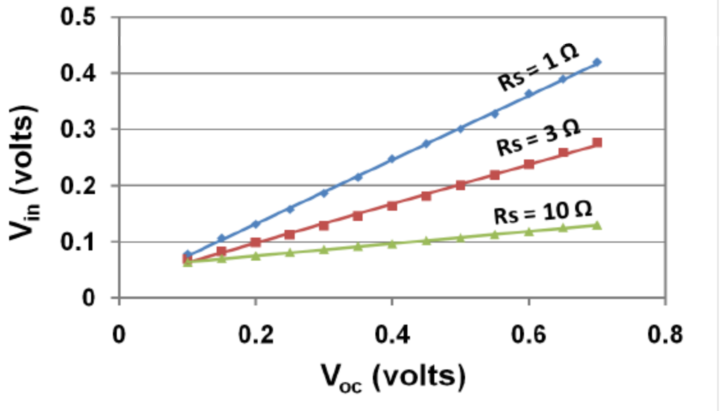

Figure 4 – Input Voltage vs V_{OC} When Charging a 3V Cell

A DESIGN EXAMPLE

Eq. (1) and Figures 3 and 4 may be used to estimate power and charge current for a given thermoelectric module and a given ΔT. Consider the Custom Thermoelectric model 12711-5L31-03CL, 254 element module depicted in Figure 1 with $R_S = 6\ \Omega$. The elements are made of N and P type bismuth telluride alloys with an approximate Seebeck coefficient of $S = 180\ \mu V/C$. For $\Delta T = 6°C$, by equation (1), the open circuit voltage is $V_{OC} = 274$ mV. From Figures 3 and 4, the output power and input voltage (corresponding to V_{OC}=0.274 V and interpolating for R_S =6 Ω) are determined to be, respectively, 2 mW and 100 mV. The charging current delivered to the Li-Ion cell is 2mW/3V = 666 μA. The input power is the product of input current and V_{in}, so

$$P_{input} = \frac{0.283 - 0.100}{6}\times 0.100 = 3.05\,mW \qquad (3)$$

and the electronic conversion efficiency may be calculated as:

$$\eta = \frac{P_{out}}{P_{input}} = \frac{2\ \ mW}{3.05\ \ mW} = 66\% \qquad (4)$$

RESTRICTIONS ON THE LOAD

Other rechargeable cells can be used with this circuit, including series connected NiCad cells with nominal battery voltage of up to six volts. Or, instead of an electrochemical cell, a high capacitance, low leakage, "super cap" can serve as the load[1]. ***The W0422 bootstrap converter yields an unregulated output, so care should be taken not to overcharge a cell or to exceed a capacitor voltage rating.*** **This may be accomplished by adding a zener clamp.**

THE BIPOLAR CONVERTER W0422-2

For energy scavenging from environmental heat sources, it is often desirable to generate from both polarities of temperature gradient, yielding both polarities of V_{OC}. When the thermoelectric generator may be generating either polarity of voltage, the bipolar bootstrap converter W0422-2 is a good option. This converter is built on the same platform as the W0422-1 unipolar converter but is fully populated with the electronic components to allow bipolar conversion (either voltage polarity on the input). Figure 5 depicts the unipolar (left) and bipolar versions (white leads for bipolar input).

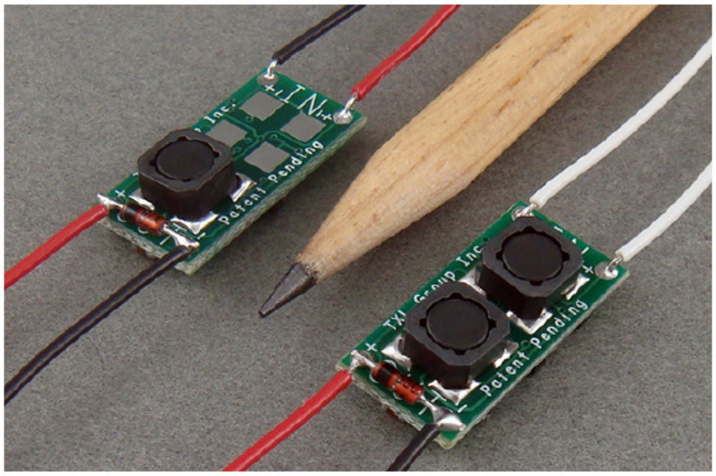

Figure 5 – The W0422-1 and W0422-2 Converters

ABOUT TXL

TXL Group, Inc. is an El Paso, Texas company developing industrial Waste Heat Harvest® solutions[2]. Part of this effort entails developing electronic devices for efficient energy power conversion from the low voltages typical of thermoelectric generation devices. This has led the Company to investigate a range of solutions for scalable thermoelectric power generation. TXL can offer a range of electronic conversion solutions ranging from milliwatts to kilowatts.

---

[1] A series resistance of >100 Ω should be used with a super cap.

[2] *Waste Heat Harvest®* is a U.S. Registered Trademark of TXL Group, Inc.