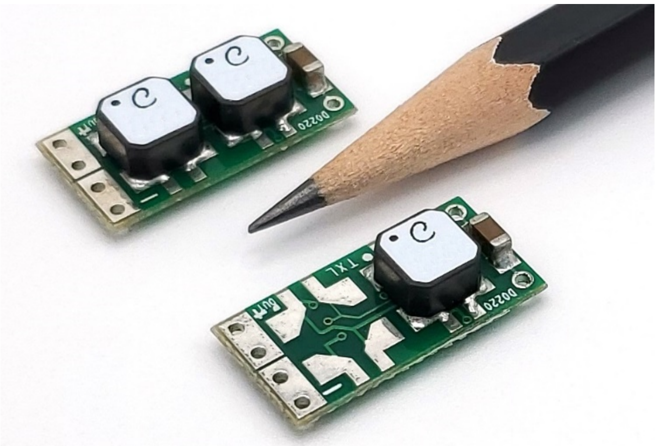
Part #	Input Polarity	$V_{in(min)}$	$V_{in(max)}$	V_{out}
ELC-UVB040	Unipolar	+40 mV	+1.0 V	+1.2 V to +10.0 V
ELC-BVB040	Bipolar	± 40 mV	±1.0 V	+1.2 V to +10.0 V

*** This device is normally supplied without lead wires ***



Notes:
Self-oscillating DC-DC converter. Designed to boost the low level voltages often produced by thermoelectric generators into higher, more usable voltages.

Output is unregulated and internally clamped to +10V. Actual load voltage is dependent upon the type of TE generator and load characteristics.

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 internal series connected elements, j, and a material constant called the Seebeck coefficient, S. If it is assumed that all thermoelements have the same magnitude of thermoelectric properties, then the open circuit voltage may be written as

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

Where ΔT is the temperature difference across the individual thermoelectric elements. 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. For a thermoelectric generator, this is denoted as source resistance, R_S and is primarily due to the electrical resistance of the individual thermoelectric elements. Assuming a constant thermoelectric element resistance, $R_{element}$, 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 reduces 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 VB line of bootstrap generators are specifically designed for operation over the range of $R_S = 1\Omega$ to $R_S = 10\Omega$ which is a common range for commercially available multi-element thermoelectric devices.

UNIPOLAR AND BIPOLAR CONVERSION

The ELC-UVB040 is a unipolar DC/DC voltage converter that boosts an input voltage of fixed polarity to a higher voltage. The ELC-BVB040 is a bipolar DC/DC converter that can accept input voltages of either polarity. The output polarity for both versions are indicated on the printed circuit board as shown in the figure below. For the unipolar version, the positive side of the input is the hole next to the "input" designation on the top of the board. The negative side is indicated by a "-" on the bottom side of the board. For the bipolar units, either input polarity can be used. Other than the input polarity restriction for the ELC-UVB040, the unipolar and bipolar versions perform identically.

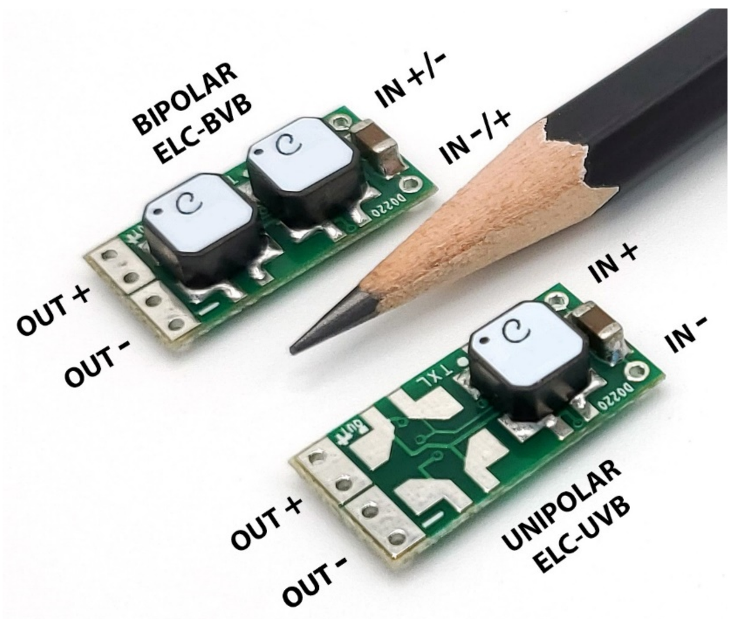


Figure 1 – Input and Output Polarity for Unipolar and Bipolar Versions

The unipolar ELC-UVB040 is well suited to boosting thermoelectrically generated voltages when the thermal gradients applied to the module are in one direction, that is, the module hotside is always the same. The advantage to the bipolar version is that care need not be taken in orienting the polarity of the input connections. In addition, for some applications, such as energy capture from environmental gradients, the thermal gradient and generated voltage may change in polarity depending upon time of day or time of year. The ability of the bipolar version to accept input voltages of either polarity will allow power delivery based only upon the magnitude of the thermal gradient and not the sign.

ELECTRICAL LOADS

Output power can never exceed the input power and the nature of the output load will often limit the magnitude of the output voltage. If the load is an electrochemical cell, then the voltage of the cell will "clamp" the output to that cell voltage. Similarly, if the output is an LED, the turn-on voltage of the LED will serve to clamp the output. When the load is a capacitor, the capacitor will start from its initial voltage and then increase in value as it is charged.

When a load is not attached to the output of a VB converter, there can be a voltage multiplication of a

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factor of 100 or more. To prevent overvoltages that can damage the device, all VB units offer a built-in 10 volt Zener diode at the output. This does not affect the output until the output voltage approaches that 10 volt value, at which time, the Zener diode begins to conduct, serving to clamp the output so that output voltage cannot exceed 10 volts. As an option, a jumper can be selected to impose a 5.1 volt zener diode across the output, clamping the output voltage to be no more than 5.1 volts. The location of the jumper to select 5.1 volt output clamping is shown in Figure 2 for ELC-UBV040 (left) and the ELC-BVB040 (right).

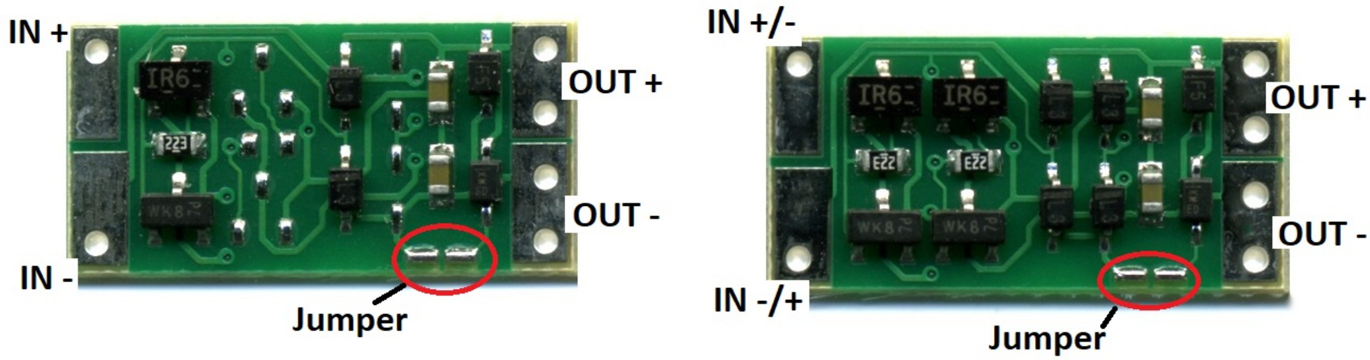

Figure 2 – Reverse Side of ELC-UVB040 and ELC-BVB040

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 variable power generation, so it is desirable to intermittently charge an electrochemical cell or a capacitor which then furnishes power as needed for sensing, actuation or wireless transmission duties during periods where thermoelectric generation levels are low.

Efficiency and power calculations for the VB line of voltage converters will always be a function of both the source and the load, so it is impossible to state a generic efficiency and power conversion figure – it will always be case by case. A common application for the VB boost converters is for adding charge to a rechargeable cell, a circumstance depicted in Figure 2.

In Figure 3, the dotted box represents the thermoelectric module which can be modeled as an ideal voltage source, Voc, in electrical series with an internal resistance, Rs. The thermoelectric module connects to the VB converter as shown. The stepped-up voltage at the output of the converter goes through a limiting resistor, Rlim into a lithium ion cell having a voltage of 3.3 volts. By measuring the electrical current through Rlim, the power delivered to the lithium ion cell can be calculated. The VB converters are diode protected from reverse charge, so when the converter is not generating, there is no discharge current flow out of the load and back into the converter. It is important to note that the minus side of the converter input is electrically separate from the minus side of the output.

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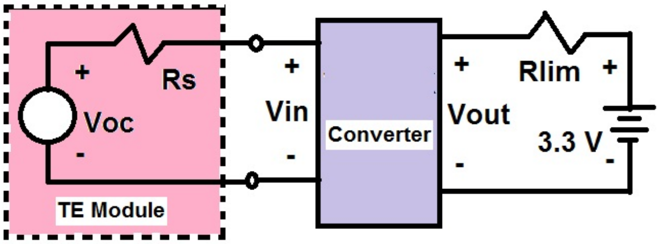

Figure 3 –Measurement Set-up for Performance Curves

Figures 4 depicts the converter input voltage, V_{in}, and the power delivered by the ELC-UVB040 to a 3.3 volt Lithium-Ion rechargeable cell both as a function of the open circuit (unloaded) voltage, V_{OC}. The limiting output resistance (which is optional) is 47 Ω. Each plot contains curves corresponding to three different cases of TE generator internal resistance. The actual performance that is obtained will depend upon the particular internal resistance, R_S, of the chosen thermoelectric module.

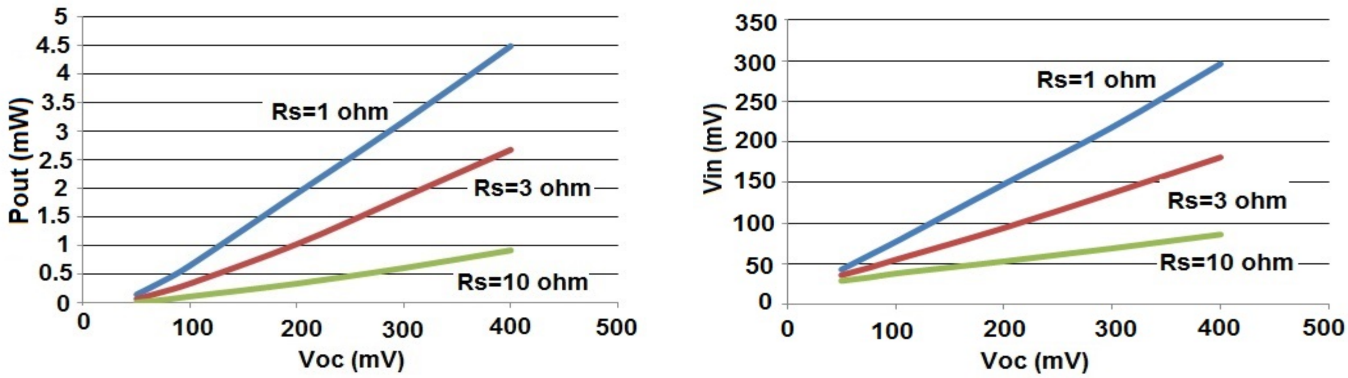

Figure 4 – Performance Curves for Power Delivery to a 3.3V Lithium Ion Cell

A DESIGN EXAMPLE

Equation (1) and Figure 4 can be used to estimate power and charge current for a given thermoelectric module and a given ΔT. Consider the Custom Thermoelectric, 254 element thermoelectric module type 12711-5L31-03CQ which has an internal resistance of R_S = 6 Ω. The elements are made of n-type and p-type bismuth telluride alloys with an approximate Seebeck coefficient of S = 208 μV/C. For ΔT = 5°C, by equation (1), the open circuit voltage is V_{OC} = 264 mV. From Figure 4, the output power and input voltage corresponding to V_{OC}=0.264 V and interpolating for R_S =6 Ω are determined to be, respectively, 1.0 mW and 80 mV. The charging current delivered to the Li-Ion cell is then 1.0mW/3.3V = 303 μA. The input power is the product of input current and V_{in}, so

$$P_{input} = \frac{0.264-0.080}{6} \times 0.080 = 2.4\,mW \qquad (3)$$

and the electronic conversion efficiency may be calculated as:

$$\eta = \frac{P_{out}}{P_{in}} = \frac{1.0\,mW}{2.4\,mW} = 41.7\ \% \qquad (4)$$

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The voltage gain for this converter is the ratio of output voltage to input voltage which is

$$Voltage\ Gain = \frac{V_{out}}{V_{in}} = \frac{3.3 + (303\ \mu A)(47\ \Omega)}{80\ mV} = \frac{3.31}{0.08} = 41. \qquad (5)$$

So, for this case we obtain a gain of 41 and we see that the 47 Ω limiting resistor had little impact on voltage gain. However, while optional, the presence of R_{lim} can be helpful in measuring the current delivered into the 3.3V cell.

LOAD RESTRICTIONS

A range of rechargeable cells can be used on the output of the VB converters, including lithium ion and 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. The VB line of voltage boost converters can provide a high voltage multiplication, self-starting from the input power, without requiring a separate power supply. However, the converters may not power up into a heavily loaded circuit. For these cases, the load should be switched into the circuit after the output has come up.

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