VOLTAGE BOOST BOOTSTRAP CONVERTER

VB0410-1,2 (gold)
VB0815-1,2 (silver)
VB1299-1,2 (white)

INTRODUCTION

The VB line of bootstrap converters are self-oscillating DC/DC converters that convert DC power at very low voltages into power at higher, more useful voltages. These converters are specifically designed for use with thermoelectric generators, where temperature gradients that are harvested for power may be only a few degrees, causing generated voltages that are too low for direct use. There are three versions as shown in Figure 1, each designed for different input ranges. For inputs as low as 40 mV, the VB0410-1 unipolar (-2 for bipolar) converter can produce enough output power to light an LED. The VB0815-1 is targeted for input voltages beginning at 80 mV and offers higher conversion efficiency. The VB1299-1 offers still higher efficiency for Vin>150 mV. The three versions are built on an identical printed circuit board but differ in component values. For convenience, a tapped inductor is marked with a color cap to indicate the VB version, gold for the VB0410, silver for the VB0815 and white for the VB1299.

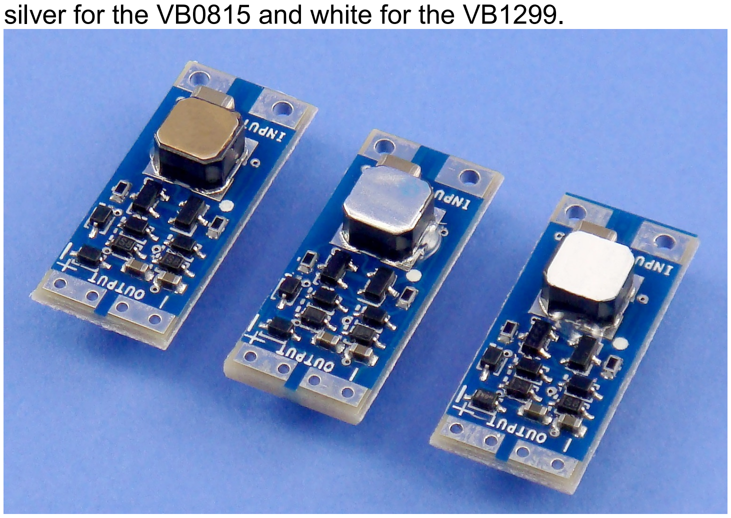

Figure 1 – The VB0410, VB0815 and VB1299 Voltage Boost Bootstrap Converters (Left to Right)

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 2 depicts a commercially available device with the top scaffolding removed. In a heat pumping application, the TE device is often referred to as a Peltier module or cell. The VB line of bootstrap converters can work with TE devices that have been designed for either generation or heat pumping.

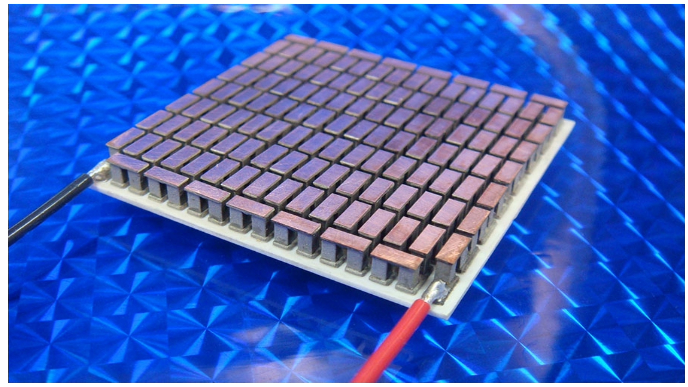

Figure 2 – A 254 Element TE Module (model TXL-127-03L)

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. Assuming 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 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 = 1Ω to R_S = 10Ω which is a common range for commercially available multi-element thermoelectric devices.

UNIPOLAR AND BIPOLAR CONVERSION

The VBXXXX-1 converters are unipolar DC/DC regulators that step up an input voltage of fixed polarity. The VBXXXX-2 converters are bipolar DC/DC converters that can accept voltages of either polarity. Both the unipolar and the bipolar converters are built upon a PC board measuring 0.45 inches by 1.05 inches (11 mm X 26.7 mm). The unipolar converters are 0.21” in thickness. The bipolar converters are 0.35” in thickness. The output polarity for both versions are indicated on the PCB. 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 as shown in Figure 3. For the bipolar units, either input polarity can be used.

VOLTAGE REGULATION

Output power can never exceed the input power and a loaded output 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. If the output is an LED, the turn-on voltage of the LED will also serve to clamp the output. When the load is a capacitor, the capacitor will start from an 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 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 it cannot exceed 10 volts. As an option, a jumper can be selected to impose a 5.1 volt zener diode across the output, reducing the output voltage to no more than 5.1 volts. The location of the jumper to select 5.1 volt output clamping is shown in Figure 3.

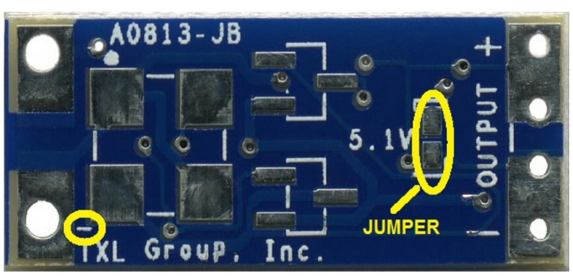

Figure 3 – Jumper Placement on the Backside of the Board to Select 5.1 Volt Regulation

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. One option is the ACC-01 accessory board, available through TXL Group and Custom Thermoelectric, which is a programmable power management tool that works with the VB line of voltage converters.

Figures 5-7 depict the power delivered by the gold, silver and white VB converters to a 3.3 volt Lithium-Ion rechargeable cell as a function of the open circuit (unloaded) voltage, V_{OC}. 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. Figures 8-10 depict the input voltage as a function of open circuit voltage for the gold, silver and white VB converters.

The performance curves in Figures 5-10 were generated from actual measurements using a set-up like that depicted in Figure 4. The dotted box represents the thermoelectric module which can be modeled by 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 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 common, or minus side of the converter input is electrically separate from the minus side of the output..

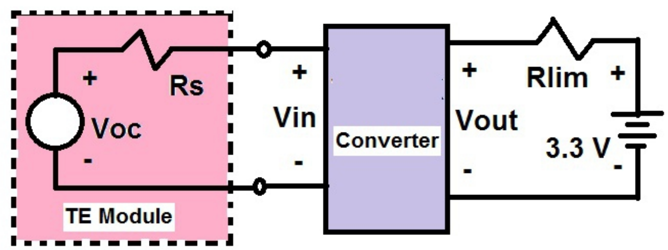

Figure 4 –Measurement Set-up for Performance Curves

A DESIGN EXAMPLE

Equation (1) and Figures 5-10 can be used to estimate power and charge current for a given thermoelectric module, a given converter module and a given ΔT. Consider the TXL Group model TXL-127-03L, 254 element thermoelectric module depicted in Figure 2 and having internal resistance R_S = 6 Ω. The elements are made of n-type and p-type bismuth telluride alloys with an approximate Seebeck coefficient of S = 180 μV/C. For ΔT = 6°C, by equation (1), the open circuit voltage is V_{OC} = 274 mV. For the VB1299 (white) converter, from Figures 7 and 10, 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, 1.9 mW and 160 mV. The charging current delivered to the Li-Ion cell is then 1.9mW/3.3V = 580 μA. The input power is the product of input current and V_{in}, so

$$P_{input} = \frac{0.274 - 0.160}{6} \times 0.160 = 3.0\ mW \quad (3)$$

and the electronic conversion efficiency may be calculated as:

$$\eta = \frac{P_{out}}{P_{input}} = \frac{1.9\ mW}{3\ mW} = 63\% \quad (4)$$

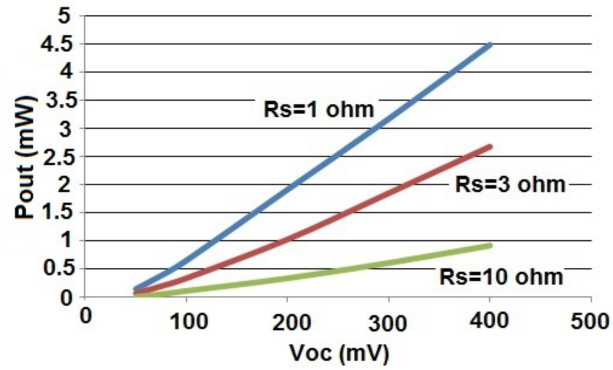

Figure 5 – Power Output vs Voc for VB0410 (Gold)

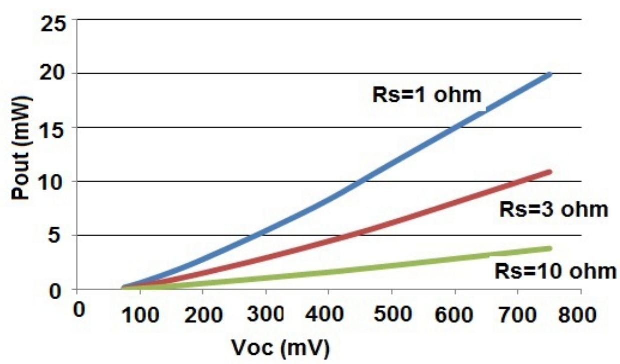

Figure 6 – Power Output vs Voc for VB0815 (Silver)

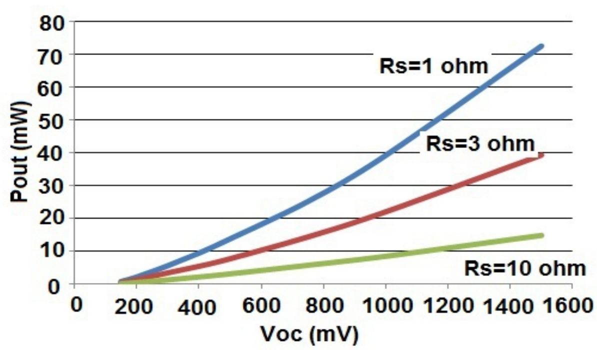

Figure 7 – Power Output vs Voc for VB1299 (White)

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, starting up 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. Alternatively, an intermediary circuit can be used, such as the ACC-01 accessory board.

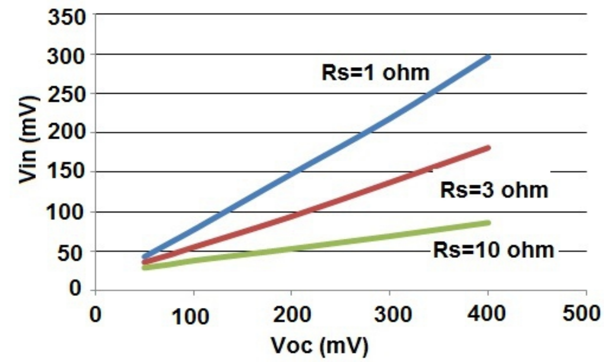

Figure 8 – Vin vs Voc for VB0410 (Gold)

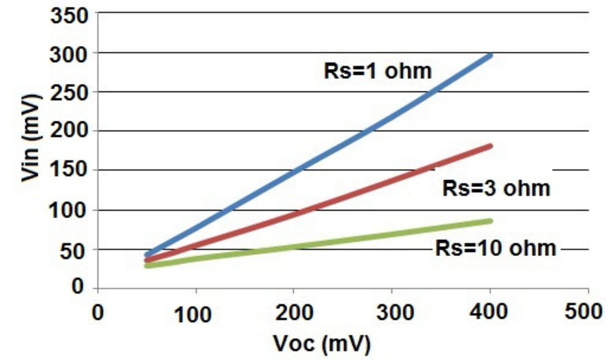

Figure 9 – Vin vs Voc for VB0815 (Silver)

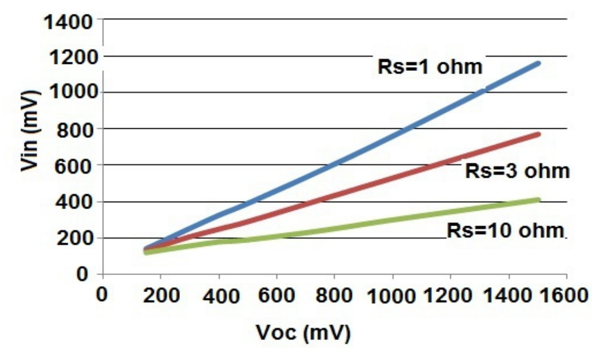

Figure 10 – Vin vs Voc for VB1299 (White)

ABOUT TXL

TXL Group, Inc. is an El Paso, Texas company developing industrial Waste Heat Harvest® solutions[1]. Part of this effort entails developing electronic devices for efficient energy power conversion from the low voltages typical of thermoelectric generation devices. TXL offers a range of thermoelectric devices and electronic conversion solutions from microwatts and up.

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