Application Report
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# Adding Hysteresis to Low-Battery Input on the TPS62113

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## ABSTRACT

The low-battery input (LBI), available on several step-down converters, is often used to shut down the converter when the input voltage falls below a set threshold. This prevents damage to the battery and signals that the battery is at the end of its life and must be charged or replaced. Batteries have internal resistance that causes the voltage to drop as the load increases. This internal resistance introduces a challenge when monitoring the battery level. When the converter shuts off and current draw drops to zero, the reduced current flow through the internal resistance of the battery causes the battery's terminal voltage to increase. In many cases, the voltage increases above the LBI threshold, which causes the device to turn on and begin drawing current. This then leads to a drop across the internal resistance that trips the LBI threshold again and turns off the device, and the process repeats. This adds an unwanted oscillation to the output as the converter turns on and off. Adding hysteresis to the low-battery input eliminates this oscillatory behavior. This application report describes how to add hysteresis to the LBI circuitry for the TPS62113 converter.

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## 1 Basic Operation

The TPS62113 is a synchronous, step-down converter with a low-battery input that produces a signal when the input voltage drops below a set threshold. The low-battery input (LBI) pin compares the voltage on the pin to an internal reference voltage of 1.256 V. If the LBI voltage is greater than the reference voltage, the low-battery output (LBO) pin has high impedance. When the LBI voltage drops below the internal reference, the open-drain LBO pin is pulled low indicating a low battery. The LBO output is typically used to signal the devices being powered that the input voltage has dropped below the level required to maintain regulation. The TPS62113 features an enhanced low-battery detector that disables the device when LBI is below the threshold in addition to asserting the LBO flag. The device operates as normal when LBI is above the threshold.

## 2 Need for Hysteresis

When using a battery to power the device, the LBI is useful for shutting off the system when the battery is close to the end of its life. Once the input voltage falls below the trip point, the LBO flag is asserted and for the TPS62113, operation is suspended. As the current decreases, the battery voltage increases due to reduced current flow through the internal resistance of the battery. If the voltage increase is high enough to exceed the LBI threshold voltage, the LBO signal is unasserted and, in the case of the TPS62113, the converter resumes operation. As operation resumes, the current drawn from the battery causes the battery voltage to drop below the LBI threshold voltage once again. This cycle continues, draining the battery further and potentially damaging the battery or the system. Ideally, the system turns back on only when a battery with adequate capacity is powering the system. This is achieved by adding hysteresis to the LBI pin, which increases the threshold voltage that turns the converter back on while maintaining the falling LBI threshold.

## 3 Adding Hysteresis to LBI

### 3.1 Governing Equations

The LBI input for the TPS62113 converter has an internal hysteresis of 15 mV, but this is inadequate for some applications. The hysteresis is increased by adding one resistor (R7) to the LBI and LBO circuitry. Figure 1 shows the schematic for increased hysteresis on LBI.

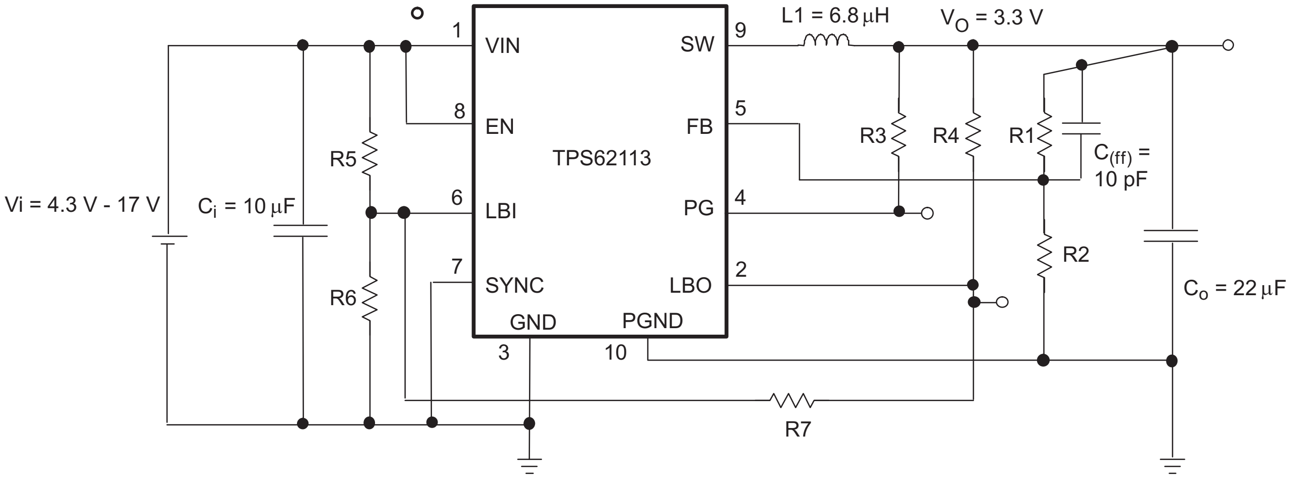


**Figure 1. External Circuitry for Increased LBI Hysteresis**

Figure 2 shows the LBI circuitry, which incorporates the internal comparator and pulldown transistor. The reference voltage (VREF) is internally fixed at 1.256 V. Resistors R5 and R6 act as the voltage divider from the input voltage of the battery (VBAT) to the voltage on the LBI input (VLBI). The resistor R4 acts as a pullup resistor for the LBO voltage (VLBO) when the drain is open. The resistor R7 is the key component to the hysteresis.

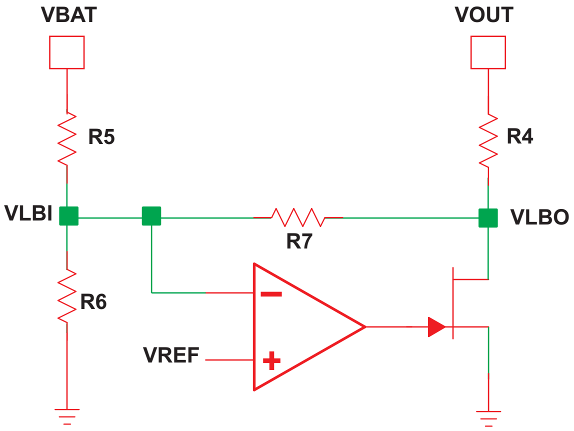
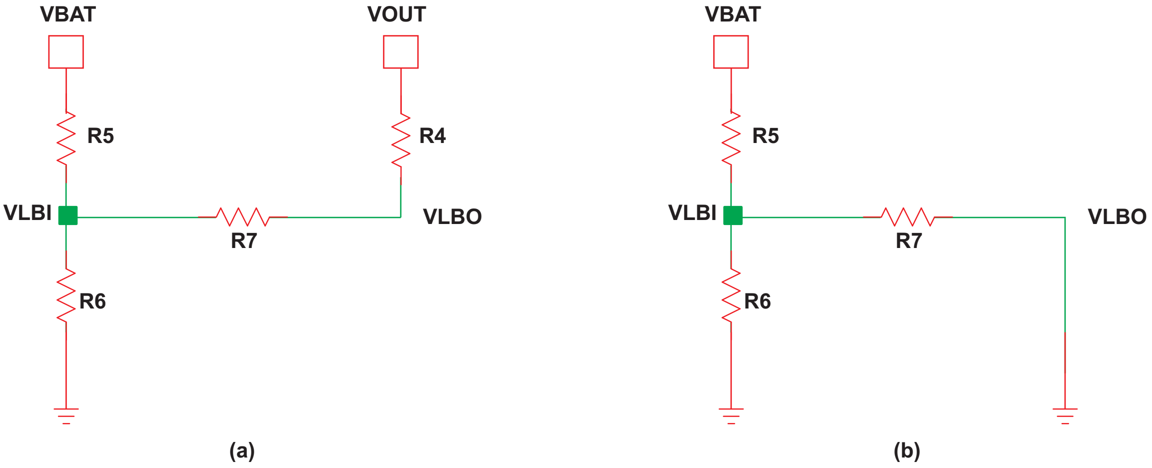


**Figure 2. Hysteresis Circuit**

As shown in Figure 3, the two states that this circuit exhibits are (a) VLBI is above VREF and VLBO is high impedance, or (b) VLBI is below VREF and VLBO is pulled to ground.



(a)

(b)

**Figure 3. Hysteresis Circuit**

Kirchhoff's Current Law (KCL) is applied to these circuits to calculate the resistor values of R4, R5, R6, and R7 that give the desired hysteresis. Using the known output voltage (VOUT), the desired low-battery trip point of VBAT, and the fixed trip point of VLBI, use Equation 1 and Equation 2 to determine the appropriate resistor values.

$$\frac{\text{VBAT} - \text{VLBI}}{\text{R5}} + \frac{\text{VOUT} - \text{VLBI}}{\text{R4} + \text{R7}} = \frac{\text{VBLI}}{\text{R6}} \tag{1}$$

$$\frac{\text{VBAT} - \text{VLBI}}{\text{R5}} = \frac{\text{VLBI}}{\text{R6}} + \frac{\text{VLBI}}{\text{R7}} \tag{2}$$

## 3.2 *Choosing Initial Values*

Choosing initial values involves four unknown variables (R4, R5, R6, and R7) and only two equations. Two of the resistor values must be chosen in order to solve the system of equations for the other two values. In the MathCAD™ program and Excel™ spreadsheet(1) that do this calculation for the TPS62113, the user chooses R4 and R6. R4 determines the VLBO voltage and must be chosen such that the high value of

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(1) Both the MathCAD program and Excel spreadsheet can be downloaded from the Tools & Software section of each TPS62113 product folder on the TI Web site.

VLBO is above the input high threshold ($V_{IH}$) for the input to which the LBO is connected. Additionally, the value of R4 must be on the order of 100 kΩ so that when VLBO is pulled low, a relatively small amount of current is drawn through the resistor. Choose 100 kΩ as the initial value of R6 to limit the current from the battery under normal operation. R6 can be smaller as long as the sum of R5 and R6 is on the order of 100 kΩ.

The low trip voltage (VtripL) and desired high trip voltage (VtripH) of the battery voltage depend on the voltage range of the battery. Use the capacity and voltage characteristics of the battery over the application's full operating temperature range to choose appropriate trip points.

## 3.3 Calculating Resistor Values

Once the two resistor values have been chosen, the KCL equations for the two states are used to calculate the remaining resistor values. In the first state (VLBO high impedance), when VBAT is at VtripL, VLBI is 1.281 V. In the second state (VLBO low), VBAT is at VtripH, and VLBI is 1.256 V, which incorporates the internal hysteresis. Substituting these values into Equations 1 and 2 yields Equation 3 and Equation 4, respectively.

$$\frac{\text{VtripL} - 1.256\text{ V}}{\text{R5}} + \frac{\text{VOUT} - 1.256\text{ V}}{\text{R4} + \text{R7}} = \frac{1.256\text{ V}}{\text{R6}} \tag{3}$$

$$\frac{\text{VtripH} - 1.281\text{ V}}{\text{R5}} = \frac{1.281\text{ V}}{\text{R6}} + \frac{1.281\text{ V}}{\text{R7}} \tag{4}$$

Using the known value of VOUT, the desired values of VtripL and VtripH, and the two chosen resistor values, solve the system of equations for the other two resistor values. If you chose R4 and R6 as your initial values, the Mathcad and Excel sheets are available to solve for R5 and R7. Otherwise, use a symbolic solver to solve for the two unknown values.

## 3.4 Adjustments

If your resistor values are unrealistic for your application, adjust the input resistor values accordingly, but keep in mind power losses and effects on overall efficiency. These calculated values most likely will not be standard industry resistor values; so, choose the closest industry standard values. Then, use Equation 3 and Equation 4 to calculate the more accurate VtripL and VtripH values.

## 3.5 Example

As an example, consider a system with the requirements outlined in Table 1.

**Table 1. Example System Requirements**

| | | |
|---|---|---|
| Output Voltage | Vout | 3.3 V |
| Low Trip Point of LBI | VtripL | 6 V |
| Hysteresis on LBI | Hysteresis | 0.5 V |
| High Trip Point of LBI | VtripH | 6.5 V |

Choosing R4 = 1000 kΩ and R6 = 25 kΩ as the initial values in the MathCAD worksheet(1) yields the ideal values R7 = 505.07 MΩ and R5 = 97.05 kΩ. Depending on the supplies available in the laboratory, choose the closest available resistor values. In this case, use R7 = 499 kΩ and R5 = 97.6 kΩ. Using the MathCAD worksheet, recalculate the trip points and hysteresis based on the actual resistor values, which yields VtripL = 6.046 V, VtripH = 6.553 V, and Hysteresis = 0.507 V.

Using a TPS62113 evaluation module and 1%-tolerance resistors of the values previously stated, the trip points and hysteresis were measured. The results are summarized in Table 2.

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(1) The MathCAD worksheet and Excel sheet do the same calculations, but the Excel uses a simplified version of the ideal calculations for the trip points.

### Table 2. Calculated vs Measured Trip Points

| Variable | Calculated (V) | Measured, Avg (V) |
|---|---|---|
| VtripL | 6.046 | 6.044 |
| Hysteresis | 0.507 | 0.506 |
| VtripH | 6.553 | 6.550 |

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