

# Single LED Driver in AA Battery-Powered Systems

Eric Xiong

## ABSTRACT

Single light-emitting diode (LED) functions like backlight and lighting are widely used in AA battery (alkaline) powered systems such as portable electronic device or sensors. This application report mainly focuses on ultra-low  $V_{IN}$ , ultra-low  $I_Q$ , true shut down, and pulse-width modulation (PWM) dimming functions, all for which the TPS61021A serves as a good LED driver. This report also addresses how to use the TPS61021A and some of the important considerations to make.

## Contents

1	Application Requirements .....	2
2	Single LED Boost Drive Circuit .....	3
3	Design Considerations .....	7
4	Summary .....	11
5	References .....	11

## List of Figures

1	TPS61021A Internal Block Diagram .....	3
2	Direct Drive With FB Network .....	4
3	Load Efficiency With Different $V_{IN}$ .....	4
4	10% Duty Cycle .....	5
5	50% Duty Cycle .....	5
6	90% Duty Cycle .....	6
7	Figure 4. PWM Dimming and True Disconnect .....	6
8	$V_F$ versus $I_F$ .....	7
9	$V_F$ versus Temperature .....	7
10	Using Voltage and Amplifier to Adjust $V_{FB}$ .....	8
11	Using External Resistor Divider .....	9
12	Error Trend With Lower $V_{FB}$ .....	10

## List of Tables

1	$V_F$ Bins Voltage Range .....	7
---	--------------------------------	---

## Trademarks

All trademarks are the property of their respective owners.

## 1 Application Requirements

### 1.1 Ultra-Low Input Voltage

Single AA battery-powered applications must have an input voltage as low as 0.9 V, which requires a boost topology. In certain cases, designers can use two AA batteries in series to power the system microcontroller (MCU), thus making the minimum  $V_{IN}$  as low as 1.8 V. The voltage of a single new AA battery is approximately 1.6 V; therefore, the LED driver  $V_{IN}$  range must cover 0.9 V to 3.2 V to support both one- and two-AA battery configurations.

### 1.2 True Shutdown Function

Under typical circumstances, boost converters are not capable of shutting down the output after being disabled, which is especially true for an asynchronous converter. However, the LED drive application requires a true shutdown function to turn off the LED after it has been disabled. A true shutdown function is also required for shorts and thermal protection.

### 1.3 PWM Dimming

Some backlight applications require a PWM dimming function. The typical duty cycle is from 10% to 100% with a 100-Hz frequency. The minimal  $T_{ON}$  time is approximately 1 ms. For most switching converters, a slow soft-start function is a requirement to reduce the inrush current. Note that the EN pin may not be suitable for this dimming if the start-up is too slow.

### 1.4 Quiescent Current ( $I_Q$ ) and Shutdown Current ( $I_{SD}$ )

The total system must be less than 20  $\mu$ A to maximize the battery lifetime.  $I_Q$  and  $I_{SD}$  must both be as low as possible. The  $I_{SD}$  value is more important and it must be less than 1  $\mu$ A when disabled.

### 1.5 Forward Current ( $I_F$ ) and Forward Voltage ( $V_F$ )

The forward current ( $I_F$ ) of an LED may be high in lighting mode (up to 100 mA) and low (down to 5 mA) in indicating mode. The forward voltage ( $V_F$ ) varies based on the different colors of an LED; white LEDs typically have a higher  $V_F$  (2.7 V to 3.5 V). The value for  $V_F$  changes with the driving current as well as temperature.

### 1.6 Accuracy and Efficiency

A 10% current accuracy is acceptable for most applications. The efficiency has a direct relation to  $I_Q$  and  $I_{SD}$ . The headroom voltage and the efficiency typically vary based on the usage condition.

### 1.7 Working Temperature

The working temperature is typically specified for portable or home devices. For example, a 0°C to 60°C temperature is suitable for most devices.

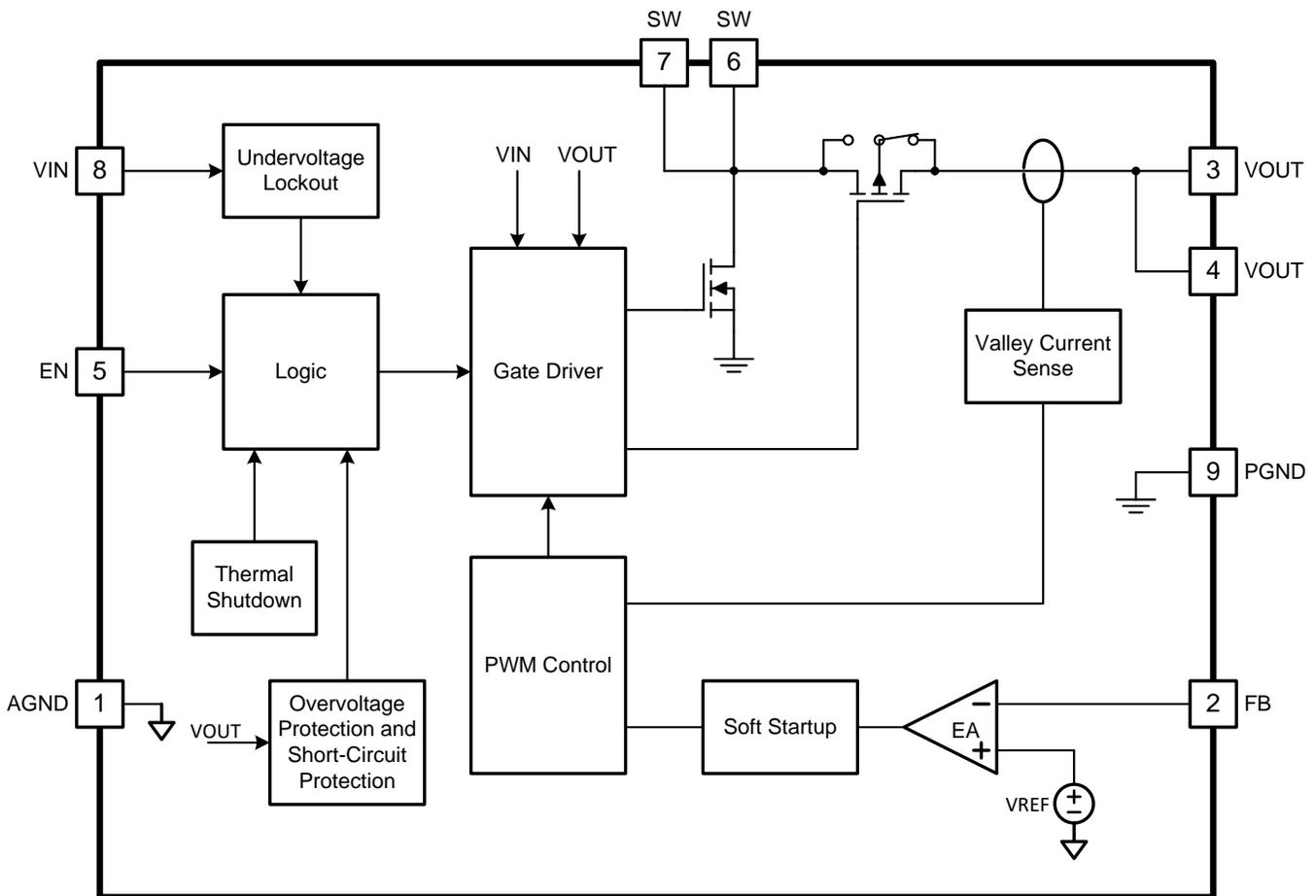
## 2 Single LED Boost Drive Circuit

### 2.1 Why Choose TPS61021A?

The TPS61021A offers the following features:

- Large  $V_{IN}$  range: 0.5 V to 4.4 V covers 0.9 V to 3.2 V
- Low  $I_Q$  and  $I_{SD}$ : 17  $\mu A$  and 0.5  $\mu A$
- True disconnect function: Internal PMOS can shut down when disabled
- Quick soft start: 200  $\mu s$ ; can support minimal 10% duty cycle with a 100-Hz specification
- High current accuracy: 1.8% accuracy FB pin voltage ( $V_{FB}$ ) builds a sufficient constant current source

Figure 1 shows the internal block diagram of the TPS61021A.

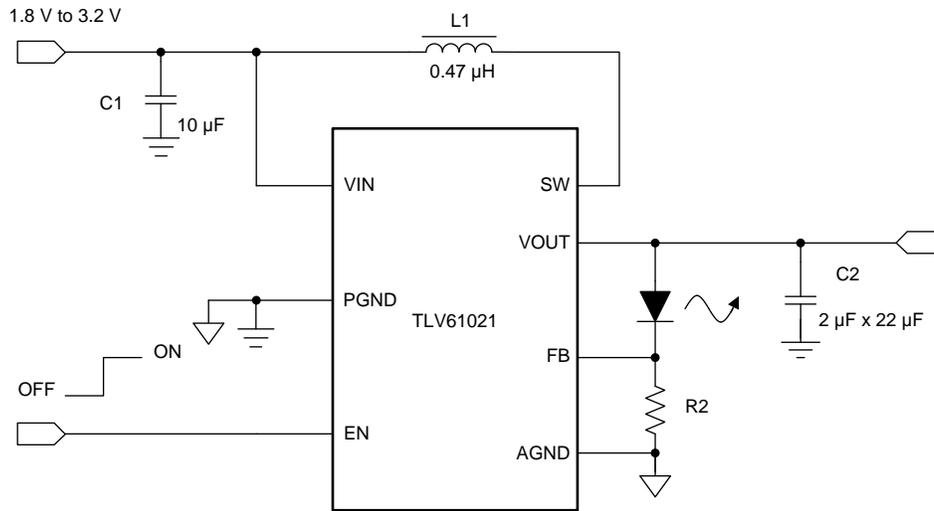


Copyright © 2017, Texas Instruments Incorporated

Figure 1. TPS61021A Internal Block Diagram

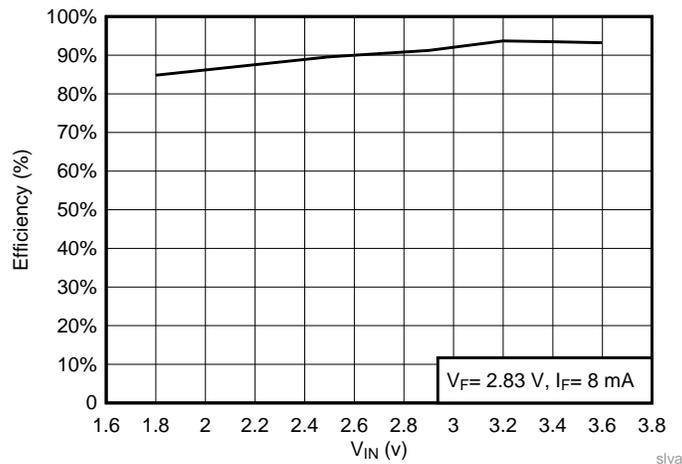
## 2.2 Single LED Drive Circuit

The circuit in [Figure 2](#) has great current accuracy. The  $V_{OUT}$  is 3.2 V to 4.2 V, which means that the boost always works when in boost mode and has good efficiency. When the  $V_{IN}$  is specified from 1.8 V to 3.6 V, the efficiency is above 85% with an 8-mA load (see [Figure 3](#)).



Copyright © 2017, Texas Instruments Incorporated

**Figure 2. Direct Drive With FB Network**



**Figure 3. Load Efficiency With Different  $V_{IN}$**

The PWM dimming function through the enable pin works well and allows the user to easily change the duty cycle from 10% to 90% (see [Figure 4](#), [Figure 5](#), and [Figure 6](#)).

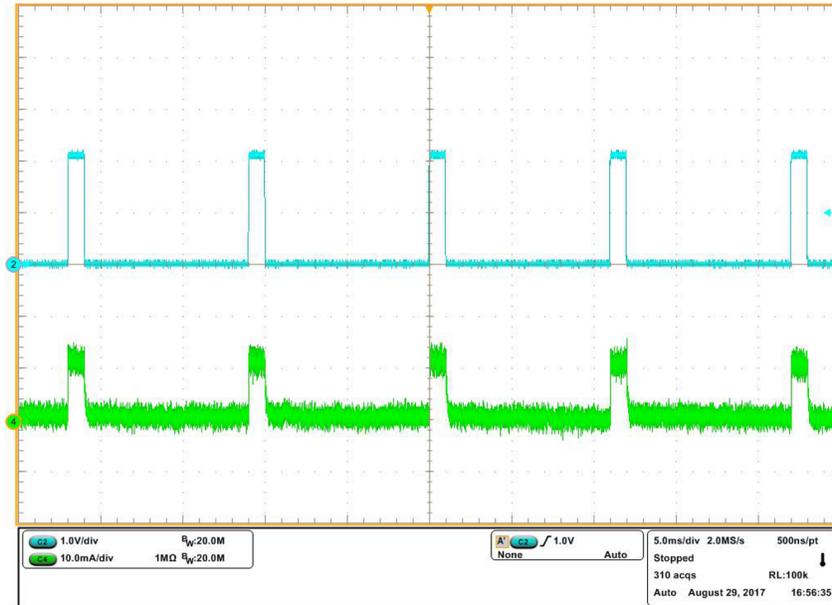


Figure 4. 10% Duty Cycle

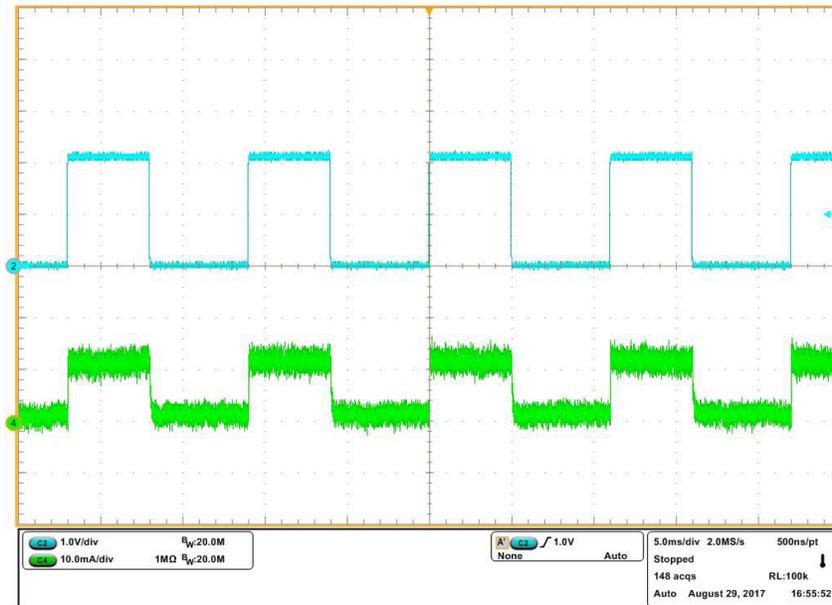


Figure 5. 50% Duty Cycle

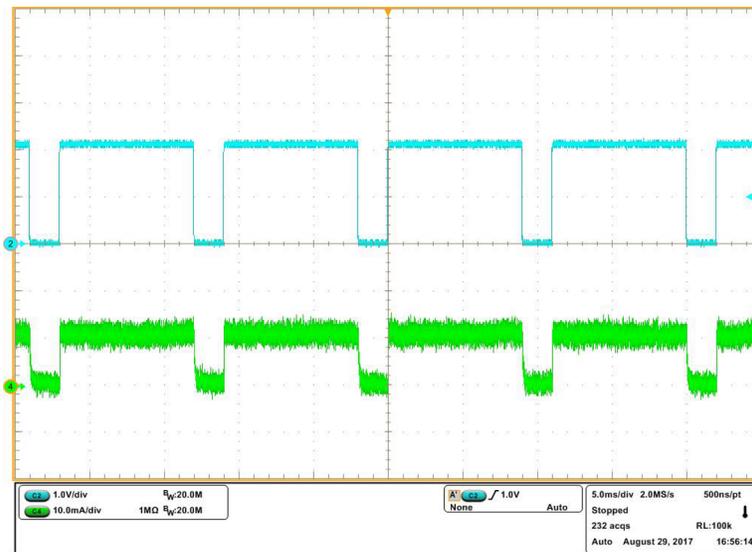
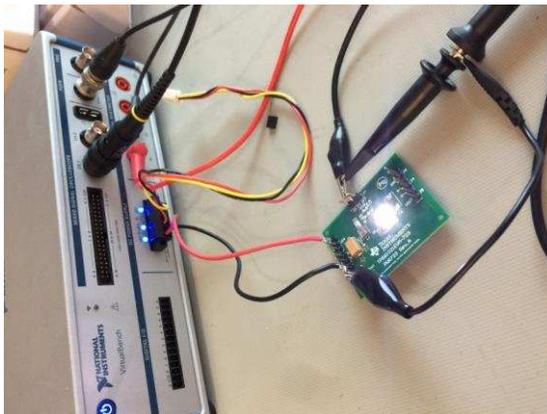


Figure 6. 90% Duty Cycle

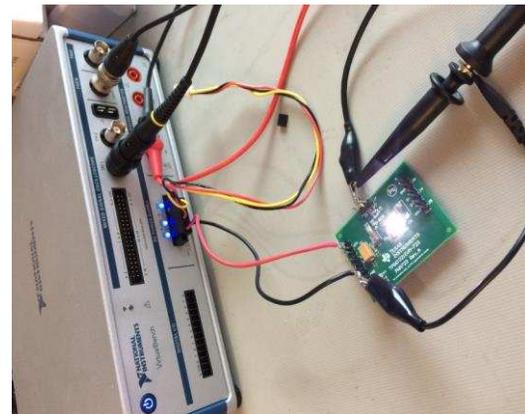
The single LED drive circuit is very capable of using the EN pin for dimming (see Figure 7).

Blue = Enable PWM Signal

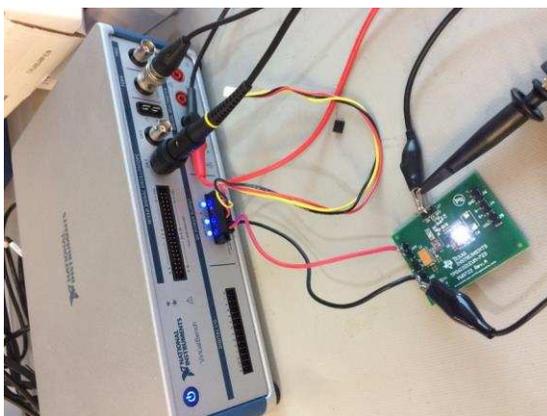
Green = LED Current Signal



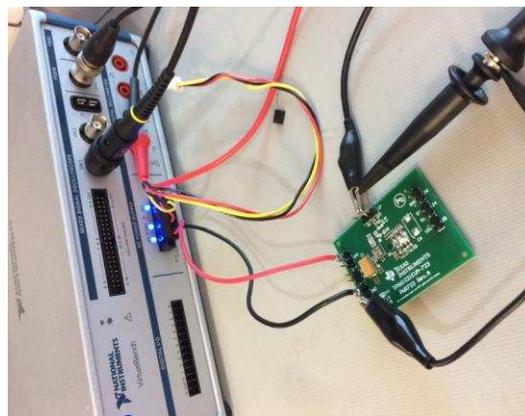
100% Duty Cycle



50% Duty Cycle



10% Duty Cycle



0% Duty Cycle

Figure 7. Figure 4. PWM Dimming and True Disconnect

### 3 Design Considerations

#### 3.1 $V_F$ Variety and Temperature Drift

From the manufacturing process, the  $V_F$  value of the LED follows the Gauss distribution. Table 1 shows that the  $V_F$  range is from 2.7 V to 3.5 V when the  $I_F$  is set to 20 mA in a typical LED specification. The  $V_F$  also changes with  $I_F$  and temperature, as Figure 8 and Figure 9 show. The  $V_F$  must have an approximate 0.2-V additional drift at the full temperature.

Table 1.  $V_F$  Bins Voltage Range

GROUP	BIN	MIN	MAX	UNIT	CONDITION
F	10	2.70	2.90	V	$I_F = 20 \text{ mA}$ $T = 25^\circ\text{C}$
	11	2.90	3.10		
	12	3.10	3.30		
	13	3.30	3.50		

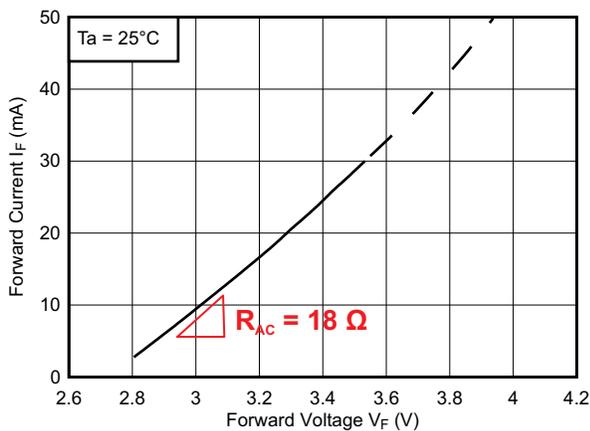


Figure 8.  $V_F$  versus  $I_F$

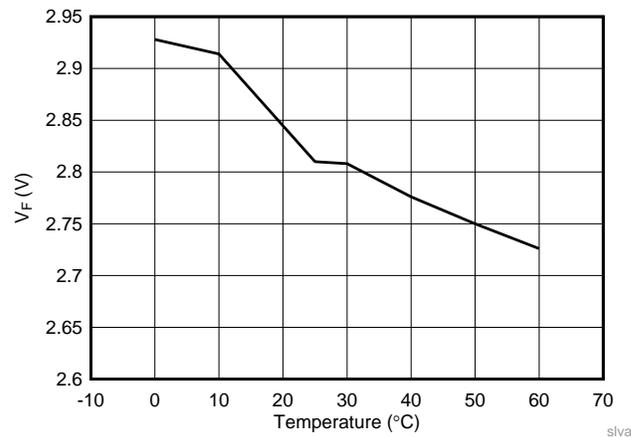


Figure 9.  $V_F$  versus Temperature

Consider all the possible  $V_F$  bins at the full temperature range from  $0^\circ\text{C}$  to  $60^\circ\text{C}$ , as calculated in the following three equations.

$$V_{I_F = 8 \text{ mA}} = V_{I_F = 20 \text{ mA}} - R_{AC} \times (20 \text{ mA} - 8 \text{ mA}) \approx V_{I_F = 20 \text{ mA}} - 0.2 \text{ V} \quad (1)$$

$$\begin{aligned} 2.4 \text{ V} &= V_{I_F = 8 \text{ mA}} \text{ at BIN}_{10_{\min}} \text{ at } 60^\circ\text{C} \\ &= V_{I_F = 20 \text{ mA}} \text{ at BIN}_{10_{\min}} \text{ at } -25^\circ\text{C} - R_{AC} (20 \text{ mA} - 8 \text{ mA}) - K_T (60^\circ\text{C} - 25^\circ\text{C}) \\ &= 2.7 \text{ V} - 0.216 - 0.084 \end{aligned} \quad (2)$$

$$\begin{aligned} 3.4 \text{ V} &= V_{I_F = 8 \text{ mA}} \text{ at BIN}_{13_{\max}} \text{ at } 0^\circ\text{C} \\ &= V_{I_F = 20 \text{ mA}} \text{ at BIN}_{13_{\max}} \text{ at } -25^\circ\text{C} - R_{AC} (20 \text{ mA} - 8 \text{ mA}) + K_T (25^\circ\text{C} - 0^\circ\text{C}) \\ &= 3.5 \text{ V} - 0.216 + 0.118 \end{aligned} \quad (3)$$

The  $V_F$  range is approximately 2.5 V to 3.3 V when  $I_F$  is 8 mA. Accounting for temperature drift, the full range of  $V_F$  is approximately 2.4 V to 3.4 V, which is within the normal  $V_F$  range for an LED backlight application.

### 3.2 LDO Mode When $V_{OUT}$ is Low

The LED driver always works in boost mode for a single AA battery-powered system, where the accuracy is always good and the efficiency is high. However, conditions may vary when using two AA batteries in-series to power a system.

In a two AA battery system, the  $V_{IN}$  is 1.8 V to 3.2 V. The  $V_{OUT}$ , which is  $V_F$  plus  $V_{FB}$ , may be lower than  $V_{IN}$  when the  $I_F$  is low or the temperature is high. This relationship means that using LDO mode is necessary to continue regulating  $V_{OUT}$  and maintain current accuracy; however, doing so decreases efficiency. Alternatively, if the  $V_{FB}$  is too low (such as 0.2 V), then the  $V_{OUT}$  is somewhere between 2.6 V to 3.4 V. This condition requires using LDO mode. The low-pass mode is another option but it features lower accuracy.

The  $V_{FB}$  of the TPS61021A device is high (up to 0.8 V). Use a range of 2.4 V to 3.4 V for the  $V_F$  to ensure that the TPS61021A device always works in boost mode. When using a two AA battery-powered system, be sure to make  $V_{OUT}$  larger than  $V_{IN}$  to obtain good accuracy and efficiency.

### 3.3 Adjust $V_{FB}$ When $V_{OUT}$ is High

When the LDO works on the high  $I_F$  and low temperature, the  $V_{OUT}$  may extend the output range of the driver and trigger overvoltage protection (OVP). The data sheet for the TPS61021A notes that the maximum for  $V_{OUT}$  is 4.0 V and the typical OVP is approximately 4.35 V. If the user is driving the LED with a high  $I_F$  and low temperature, then the  $V_{OUT}$  may be out of range. In this situation, adjust to a lower  $V_{FB}$  to make sure the  $V_{OUT}$  remains in range.

The user can choose from three methods for adjusting the  $V_{FB}$  to a lower value.

1. Use a low-noise-voltage-source low-dropout regulator (LDO) or  $V_{REF}$  as the  $V_{ADJUST}$  (see Figure 10 side A).
2. Use an additional amplifier if the system must reduce the  $V_{FB}$  (see Figure 10 side B).

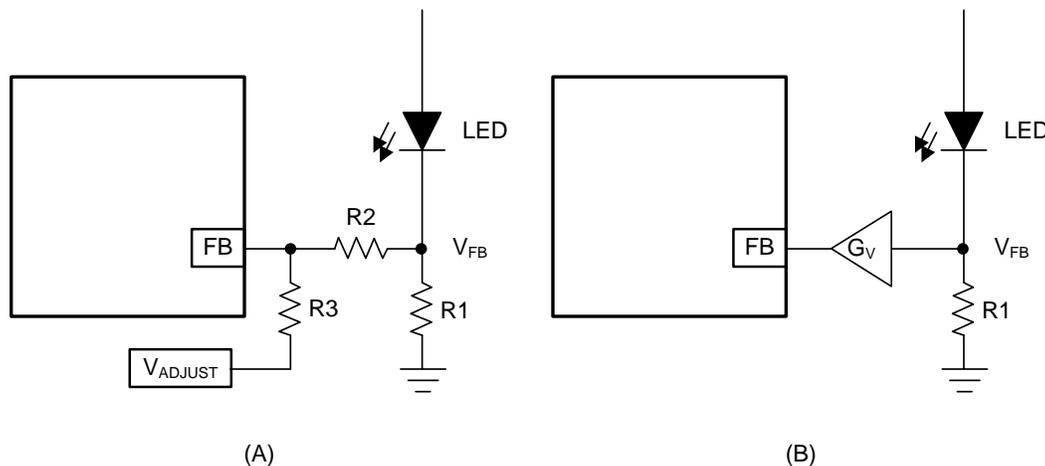
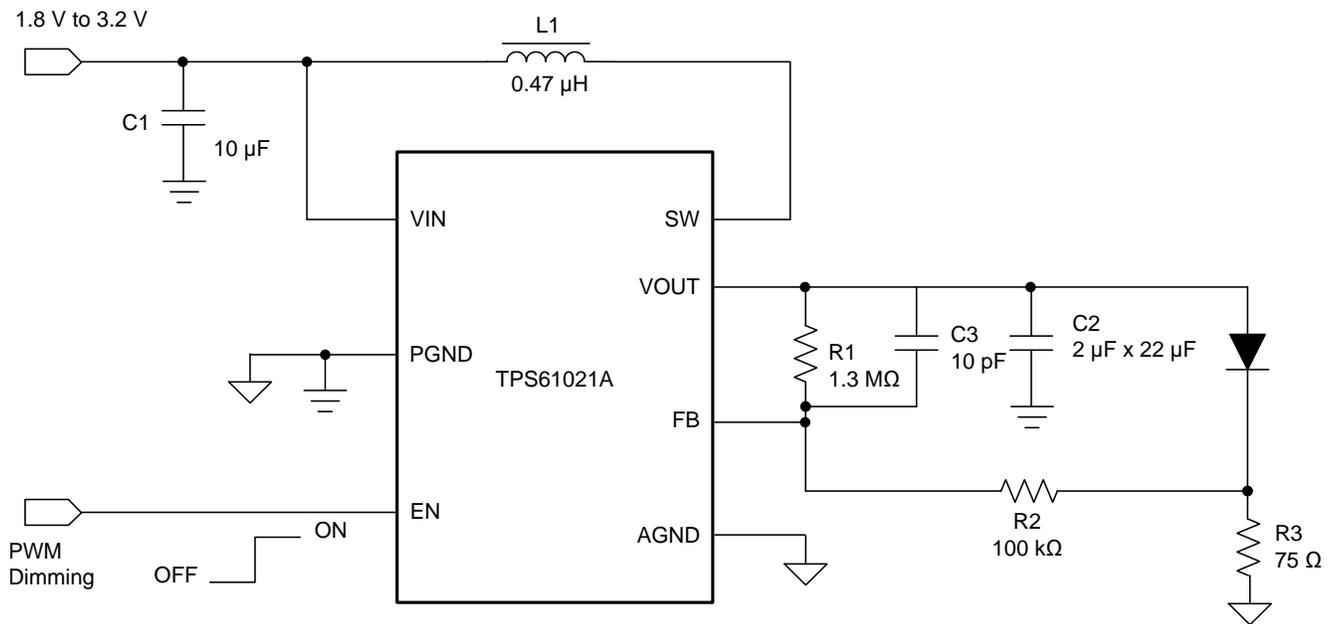


Figure 10. Using Voltage and Amplifier to Adjust  $V_{FB}$

3. Use an R-divider to make the trade-off between accuracy and cost.

If an additional  $V_{ADJUST}$  or amplifier is not available in the system, make a trade-off with current accuracy to simply adjust the  $V_{FB}$  and save on costs. As Figure 11 shows, the  $V_{OUT}$  can function as the  $V_{ADJUST}$ .



Copyright © 2017, Texas Instruments Incorporated

**Figure 11. Using External Resistor Divider**

1. Set the  $V_{SET}$  voltage and  $I_F$ ; for example, set  $V_{SET} = 0.6\text{ V}$  and  $I_F = 8\text{ mA}$ .  
Choose the following values for the LED bin:  $V_F$  at 20 mA = 3.2 V,  $R_{AC} = 18\ \Omega$  (see Equation 4).

$$V_{FB} = V_{FB} - \frac{(V_{ADJUST} - V_{FB}) R_2}{R_3} ; I_{LED} = \frac{V_{FB}}{R_1} - \frac{(V_{ADJUST} - V_{FB}) R_2}{R_3 R_1} \quad (4)$$

2. Choose the values for  $R_3$  according to the  $V_{SET}$  and  $I_F$  values:  $R_3 = 75\ \Omega$  for  $V_{SET} = 0.6\text{ V}$  and  $I_F = 8\text{ mA}$ .
3. Choose the values for  $R_2$  and  $R_1$  (see Equation 5):

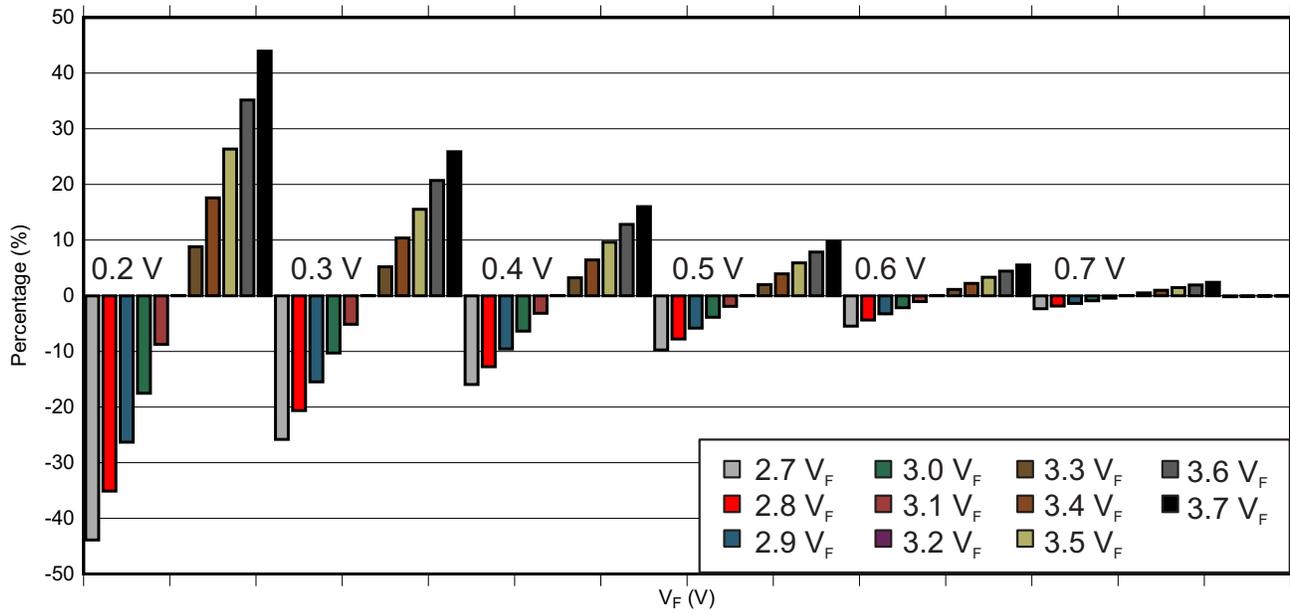
$$V_{FB} = V_{FB} ; I_{LED} = \frac{V_{FB}}{GvR_1}$$

Take  $R_2 = 100\text{ k}\Omega$ ;  $R_1 = 1.3\text{ M}\Omega$ . (5)

4. Calculate the  $I_F$  accuracy change using a different bin  $V_F$  at 20 mA (see Equation 6).

$$V_F \text{ at } 8\text{ mA} = V_F \text{ at } 20\text{ mA} + \frac{R_{AC} (8 - 20)}{1000} = 3.2 - 18 \times \frac{12}{1000} = 2.984\text{ V} \quad (6)$$

A lower  $V_{FB}$  adjustment results in larger error. The histogram in Figure 12 shows this trend. A 10% current accuracy can be a trade-off for applications where ultra-low-power is critical. Use this method to reduce the  $V_{FB}$  to 0.5 V. TI does not recommend setting a lower  $V_{FB}$  due to the resulting bad accuracy.



slva

Figure 12. Error Trend With Lower  $V_{FB}$

## 4 Summary

TPS61021A offers a great solution as a single LED drive circuit in AA battery-powered systems. Be sure to account for problems, such as a  $V_{OUT}$  that fluctuates too low or too high, to ensure a sufficient level of efficiency and accuracy.

## 5 References

1. Texas Instruments, [TPS61021A 3-A Boost Converter with 0.5-V Ultra Low Input Voltage](#), TPS61021A Data Sheet (SLVSDM0)
2. Texas Instruments, [Using TPS61200 as WLED Driver](#), TPS61200 Application Report (SLVA364)

## IMPORTANT NOTICE FOR TI DESIGN INFORMATION AND RESOURCES

Texas Instruments Incorporated ("TI") technical, application or other design advice, services or information, including, but not limited to, reference designs and materials relating to evaluation modules, (collectively, "TI Resources") are intended to assist designers who are developing applications that incorporate TI products; by downloading, accessing or using any particular TI Resource in any way, you (individually or, if you are acting on behalf of a company, your company) agree to use it solely for this purpose and subject to the terms of this Notice.

TI's provision of TI Resources does not expand or otherwise alter TI's applicable published warranties or warranty disclaimers for TI products, and no additional obligations or liabilities arise from TI providing such TI Resources. TI reserves the right to make corrections, enhancements, improvements and other changes to its TI Resources.

You understand and agree that you remain responsible for using your independent analysis, evaluation and judgment in designing your applications and that you have full and exclusive responsibility to assure the safety of your applications and compliance of your applications (and of all TI products used in or for your applications) with all applicable regulations, laws and other applicable requirements. You represent that, with respect to your applications, you have all the necessary expertise to create and implement safeguards that (1) anticipate dangerous consequences of failures, (2) monitor failures and their consequences, and (3) lessen the likelihood of failures that might cause harm and take appropriate actions. You agree that prior to using or distributing any applications that include TI products, you will thoroughly test such applications and the functionality of such TI products as used in such applications. TI has not conducted any testing other than that specifically described in the published documentation for a particular TI Resource.

You are authorized to use, copy and modify any individual TI Resource only in connection with the development of applications that include the TI product(s) identified in such TI Resource. NO OTHER LICENSE, EXPRESS OR IMPLIED, BY ESTOPPEL OR OTHERWISE TO ANY OTHER TI INTELLECTUAL PROPERTY RIGHT, AND NO LICENSE TO ANY TECHNOLOGY OR INTELLECTUAL PROPERTY RIGHT OF TI OR ANY THIRD PARTY IS GRANTED HEREIN, including but not limited to any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI products or services are used. Information regarding or referencing third-party products or services does not constitute a license to use such products or services, or a warranty or endorsement thereof. Use of TI Resources may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

TI RESOURCES ARE PROVIDED "AS IS" AND WITH ALL FAULTS. TI DISCLAIMS ALL OTHER WARRANTIES OR REPRESENTATIONS, EXPRESS OR IMPLIED, REGARDING TI RESOURCES OR USE THEREOF, INCLUDING BUT NOT LIMITED TO ACCURACY OR COMPLETENESS, TITLE, ANY EPIDEMIC FAILURE WARRANTY AND ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, AND NON-INFRINGEMENT OF ANY THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

TI SHALL NOT BE LIABLE FOR AND SHALL NOT DEFEND OR INDEMNIFY YOU AGAINST ANY CLAIM, INCLUDING BUT NOT LIMITED TO ANY INFRINGEMENT CLAIM THAT RELATES TO OR IS BASED ON ANY COMBINATION OF PRODUCTS EVEN IF DESCRIBED IN TI RESOURCES OR OTHERWISE. IN NO EVENT SHALL TI BE LIABLE FOR ANY ACTUAL, DIRECT, SPECIAL, COLLATERAL, INDIRECT, PUNITIVE, INCIDENTAL, CONSEQUENTIAL OR EXEMPLARY DAMAGES IN CONNECTION WITH OR ARISING OUT OF TI RESOURCES OR USE THEREOF, AND REGARDLESS OF WHETHER TI HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES.

You agree to fully indemnify TI and its representatives against any damages, costs, losses, and/or liabilities arising out of your non-compliance with the terms and provisions of this Notice.

This Notice applies to TI Resources. Additional terms apply to the use and purchase of certain types of materials, TI products and services. These include; without limitation, TI's standard terms for semiconductor products (<http://www.ti.com/sc/docs/stdterms.htm>), [evaluation modules](#), and [samples](http://www.ti.com/sc/docs/sampterm.htm) (<http://www.ti.com/sc/docs/sampterm.htm>).

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265  
Copyright © 2017, Texas Instruments Incorporated