Application Report
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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.

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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 µA 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 µA 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℃ to 60℃ 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 µA and 0.5 µA
- True disconnect function: Internal PMOS can shut down when disabled
- Quick soft start: 200 µs; 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.

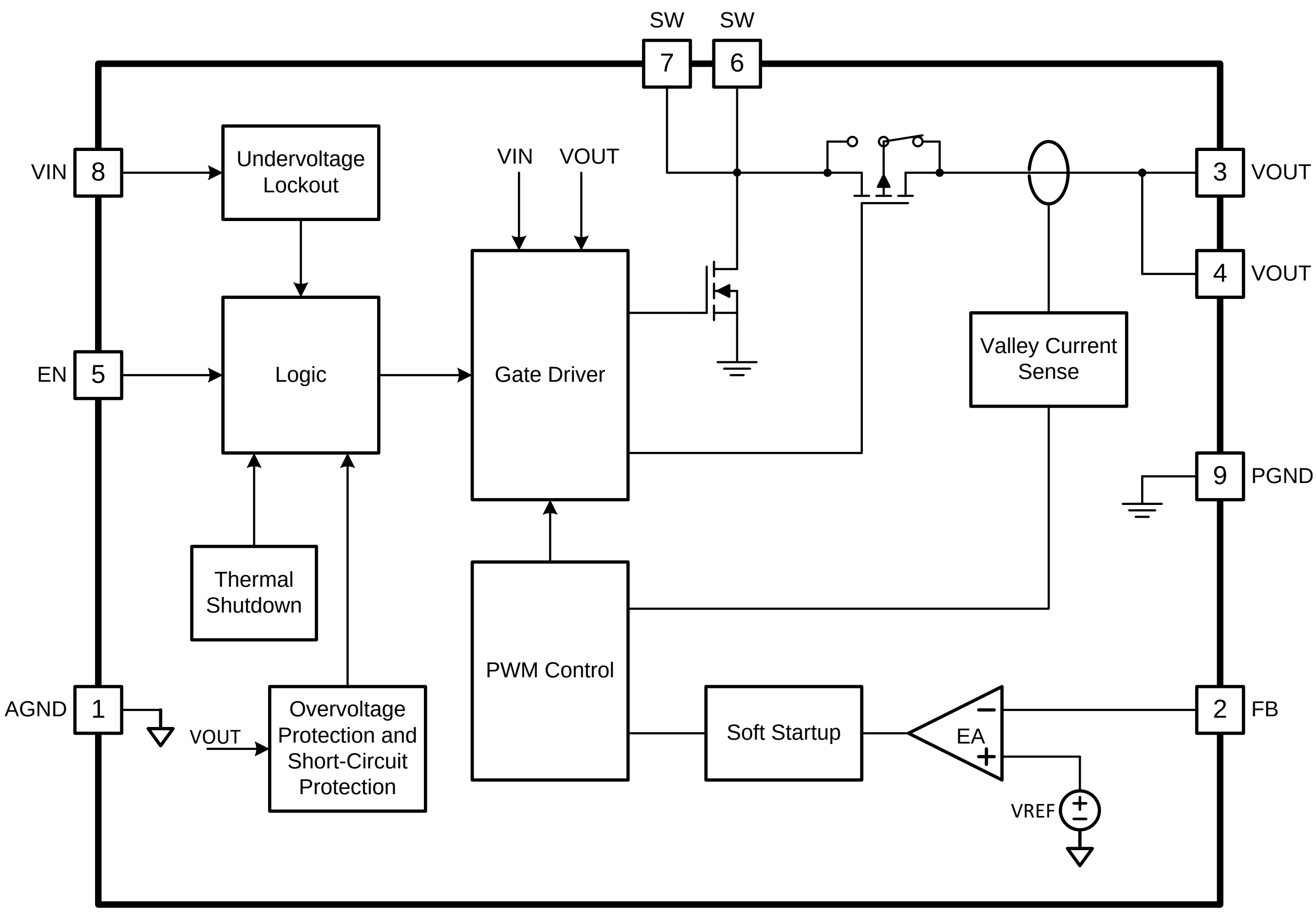


Figure 1. TPS61021A Internal Block Diagram

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).

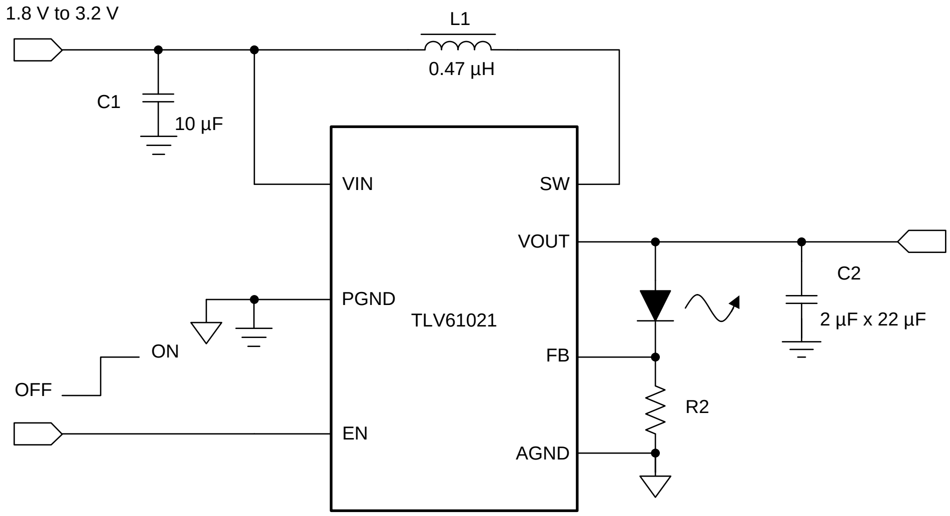


Figure 2. Direct Drive With FB Network

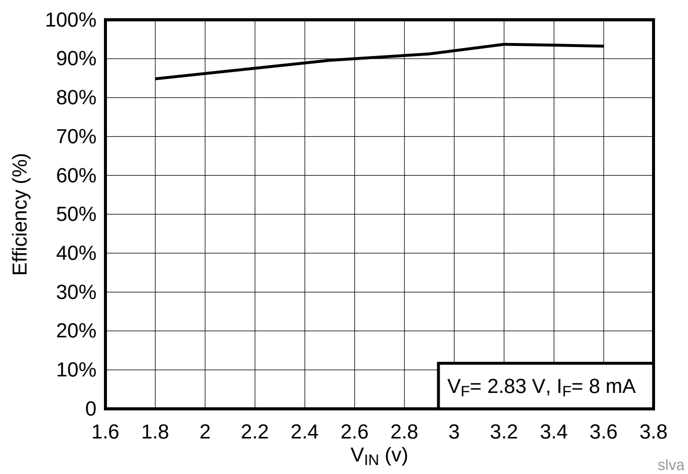


Figure 3. Load Efficiency With Different V_{IN}

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).

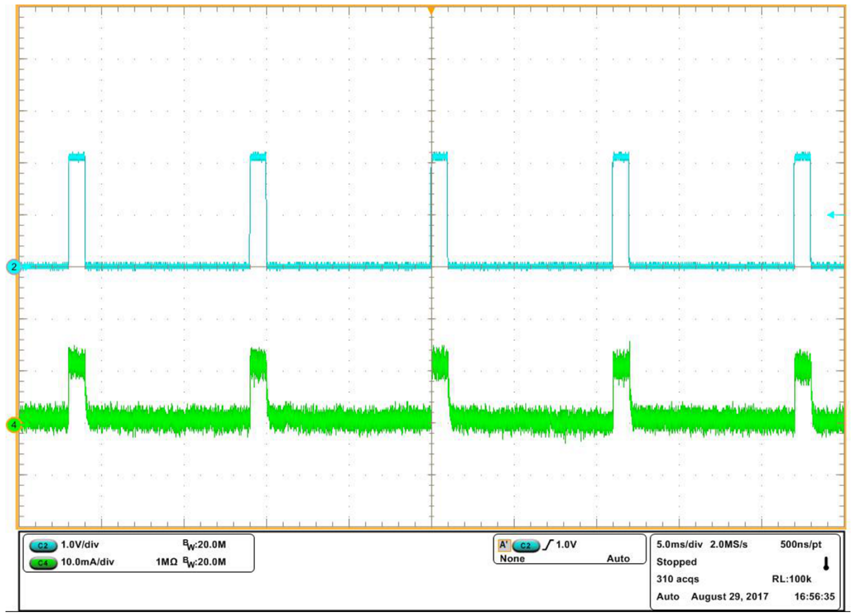


Figure 4. 10% Duty Cycle

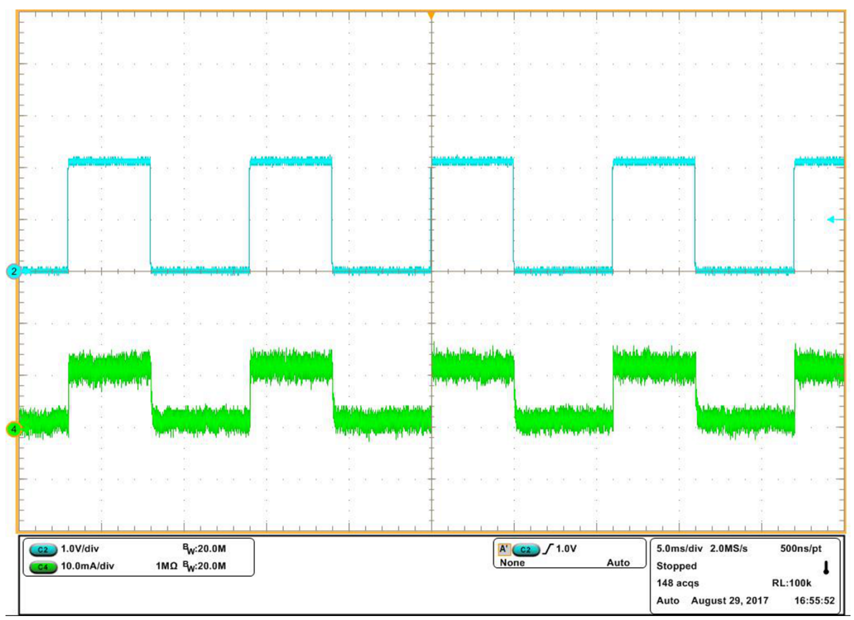


Figure 5. 50% Duty Cycle

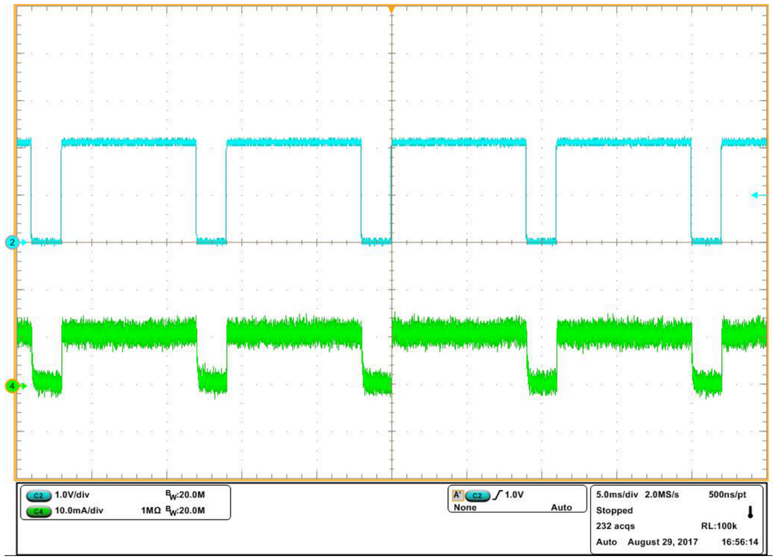
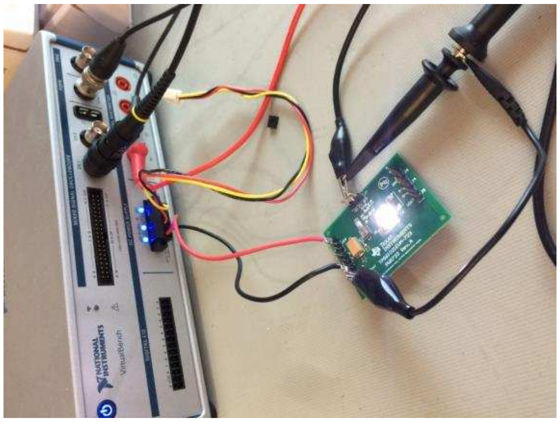


Figure 6. 90% Duty Cycle

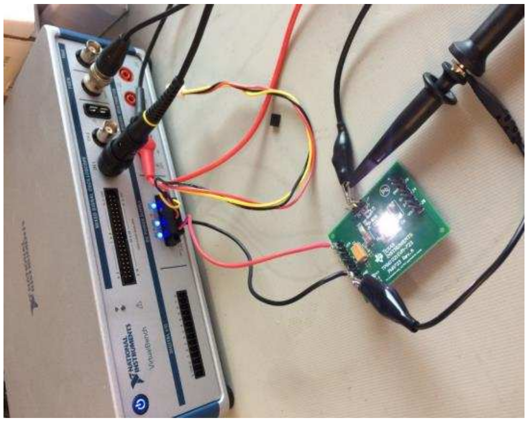
The single LED drive circuit is very capable of using the EN pin for dimming (see Figure 7).

Blue = Enable PWM Signal

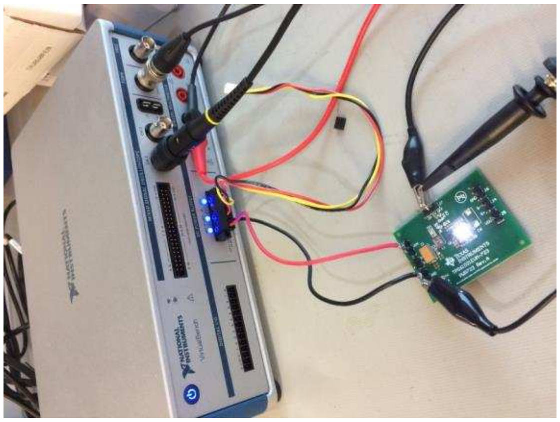
Green = LED Current Signal



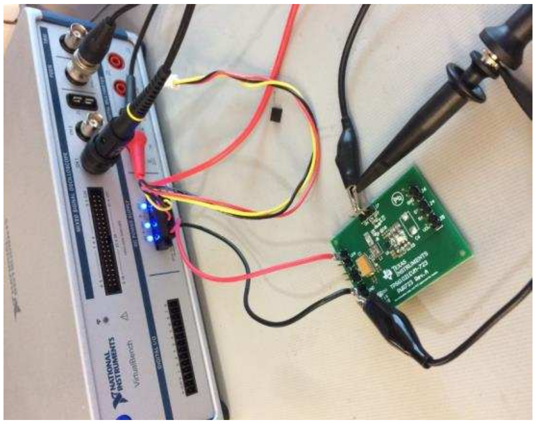
100% Duty Cycle



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 mA T = 25℃
	11	2.90	3.10		
	12	3.10	3.30		
	13	3.30	3.50		

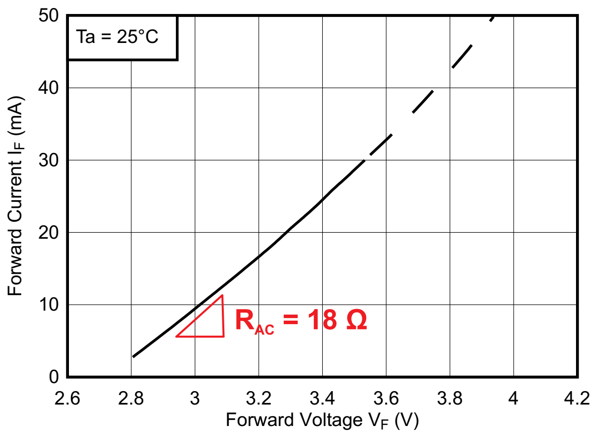


Figure 8. V_F versus I_F

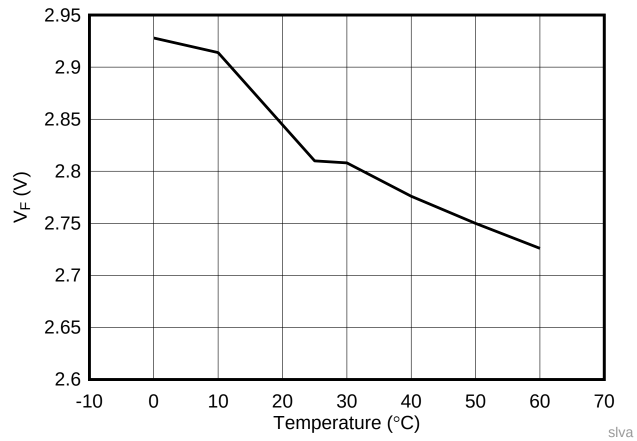


Figure 9. V_F versus Temperature

Consider all the possible V_F bins at the full temperature range from 0℃ to 60℃, as calculated in the following three equations.

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

$$\begin{aligned} 2.4\text{ V} = V_{I_F} &= 8\text{ mA at BIN}_{10_{min}}\text{ at 60℃} \\ &= V_{I_F} = 20\text{ mA at BIN}_{10_{min}}\text{ at \_25℃} - R_{AC}(20\text{ mA} - 8\text{ mA}) - K_T(60℃ - 25℃) \\ &= 2.7\text{ V} - 0.216 - 0.084 \end{aligned} \tag{2}$$

$$\begin{aligned} 3.4\text{ V} = V_{I_F} &= 8\text{ mA at BIN}_{13_{max}}\text{ at 0℃} \\ &= V_{I_F} = 20\text{ mA at BIN}_{13_{max}}\text{ at \_25℃} - R_{AC}(20\text{ mA} - 8\text{ mA}) + K_T(25℃ - 0℃) \\ &= 3.5\text{ V} - 0.216 + 0.118 \end{aligned} \tag{3}$$

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 typcial 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).

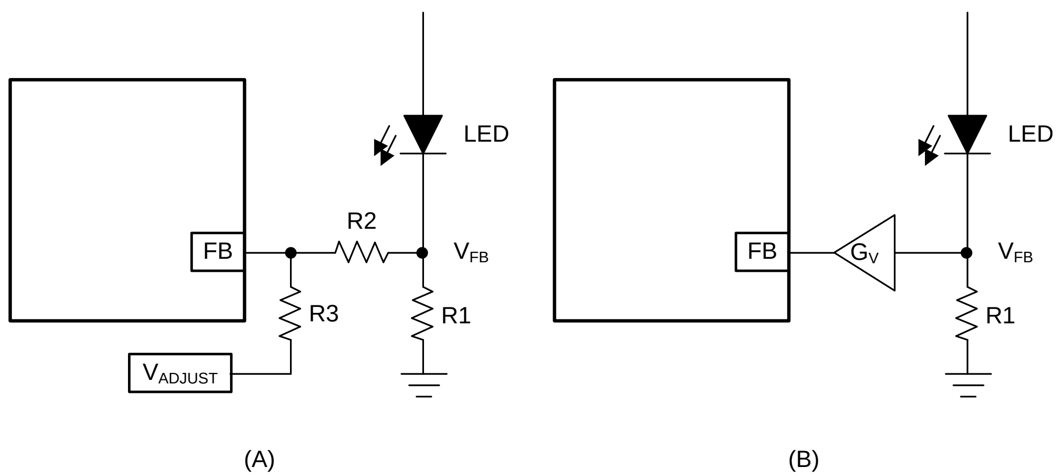


Figure 10. Using Voltage and Amplifier to Adjust V_{FB}

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}.

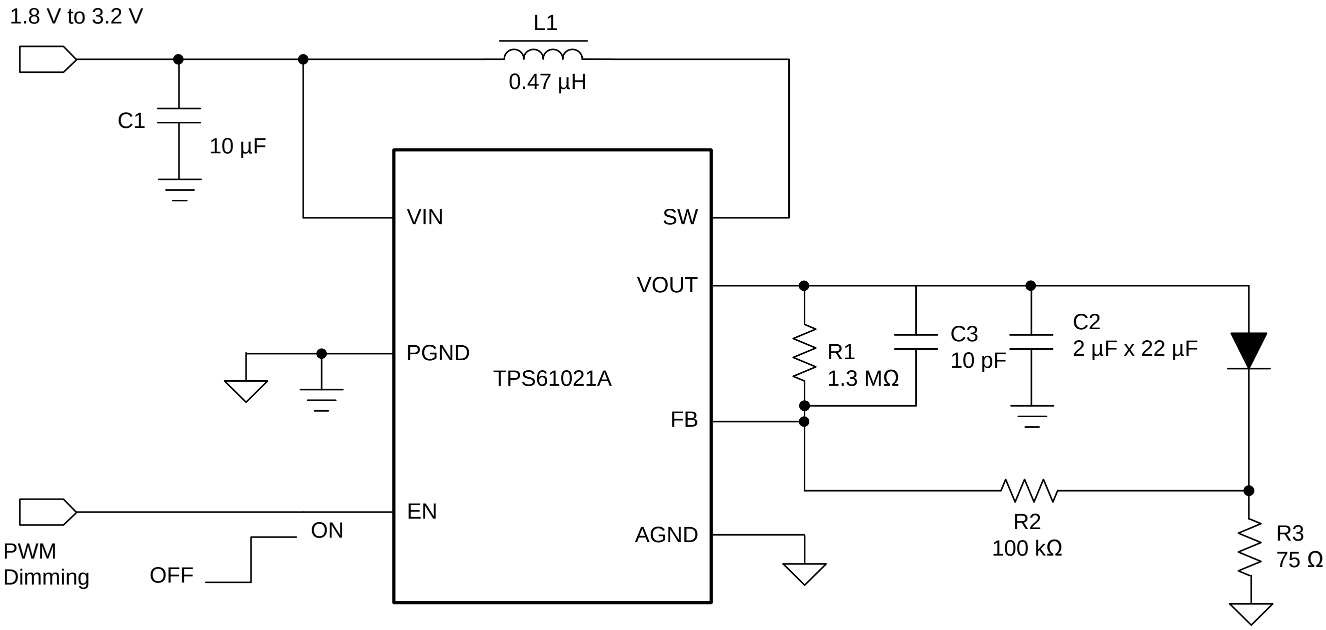


Figure 11. Using External Resistor Divider

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

$$V_{FB} = V_{FB} - \frac{\left(V_{ADJUST} - V_{FB}\right)R2}{R3} \; ; \; I_{LED} = \frac{V_{FB}}{R1} - \frac{\left(V_{ADJUST} - V_{FB}\right)R2}{R3R1} \tag{4}$$

2. Choose the values for R3 according to the V_{SET} and I_F values: R3 = 75 Ω for V_{SET} = 0.6 V and I_F = 8 mA.
3. Choose the values for R2 and R1 (see Equation 5):

$$V_{FB} = V_{FB} \; ; I_{LED} = \frac{V_{FB}}{GvR1}$$

Take R2 = 100 kΩ; R1 = 1.3 MΩ. (5)

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

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

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.

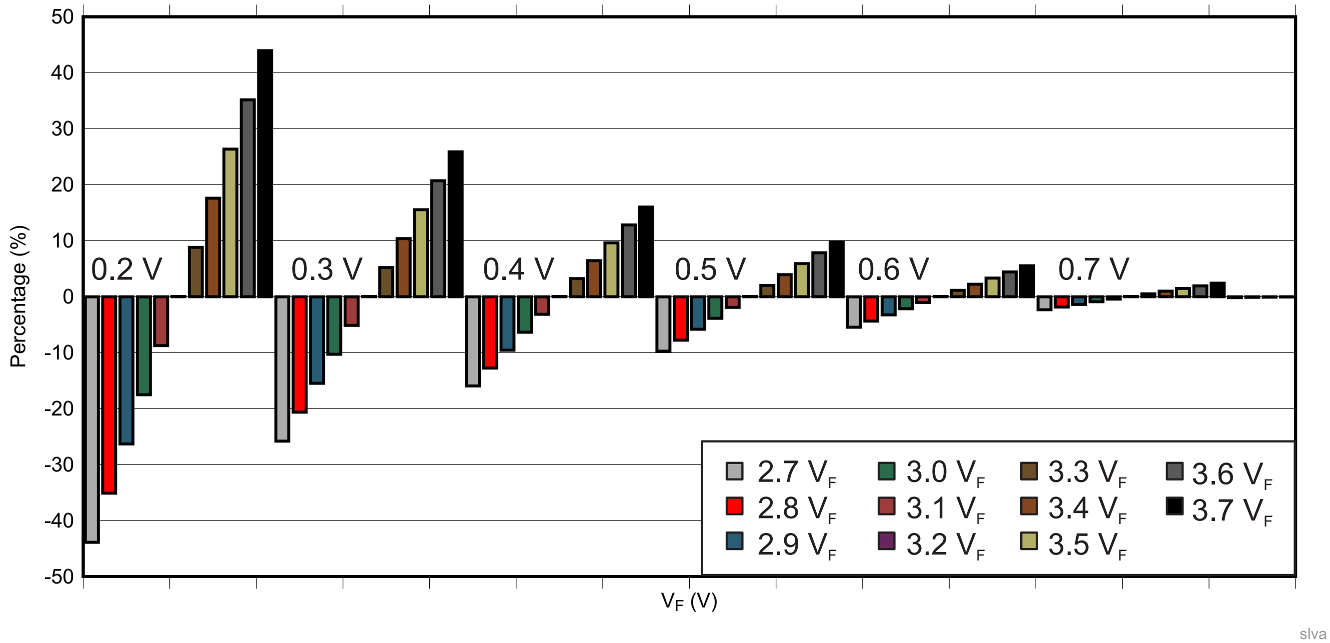


Figure 12. Error Trend With Lower V_{FB}

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)

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265