November 2005

FAN5616
High-Efficiency, Constant-Current LED Driver with Adaptive Charge Pump

Features

- 3-Channel Parallel LED Driver for a Large Range of Forward Voltages
- Adaptive V_{OUT} Adjustment to the Highest Diode Forward Voltage
- Internally Matched LED Current Sources
- Matched LED Currents with Matched or Unmatched LEDs
- Built-in Charge Pump with Three Modes of Operation: 1x, 1.5x, and 2x
- Up to 90% Efficiency
- Up to 50kHz PWM Dimming Frequency
- Low EMI, Low Ripple
- Up to 120mA Output Current
- Drives up to 3 LEDs at 40mA each
- External Resistor to Set Maximum (100%) LED Current
- Built-in 2-bit DAC to Control LED Current in Digital Mode
- 2.5V to 5.5V Input Voltage Range
- I_{CC} < 1µA in Shutdown Mode
- 1MHz Operating Frequency
- Shutdown Isolates Output from Input
- Smart Soft-Start Limits In-Rush Current
- Short Circuit Protection
- Minimal External Components Needed
- Available in a 3x3mm 16-lead MLP Package

Applications

- Cell Phones
- PDAs, DSCs, and MP3 Players

Description

The FAN5616 generates a regulated output current from a battery with an input voltage between 2.7V to 5.5V. Switch reconfiguration and fractional switching techniques are utilized to achieve high efficiency over the entire input voltage range. The adaptive nature of the built-in charge pump eliminates the need for LED preselection (matching) and ensures operation with high efficiency. The driver's built-in, proprietary, auto-sense circuitry ensures the same high efficiency regardless of the number of LEDs. When the input voltage is sufficiently high to sustain the LED's programmed current level, the FAN5616 reconfigures itself to operate as a linear regulator, and the charge pump is turned off.

The FAN5616 supports both digital and PWM LED brightness control methods. The built-in 2-bit DAC offers a selection of four LED current levels, each level is a percentage of the maximum LED current set by the external R_{SET} resistor.

The FAN5616 includes built-in shutdown, short circuit and thermal protection circuitry. A built-in smart soft-start circuitry prevents excessive current draw during power on while allowing for an increased PWM frequency for dimming.

Minimal external components are required. Only two 0.1µF to 1µF bucket capacitors, a 4.7µF input capacitor and a 1µF output capacitor are needed for proper operation.

The FAN5616 is available in a 3x3mm 16-lead MLP package.

Ordering Information

Product Number	Package Type	Order Code
FAN5616	3x3mm 16-Lead MLP	FAN5616MPX

Typical Application

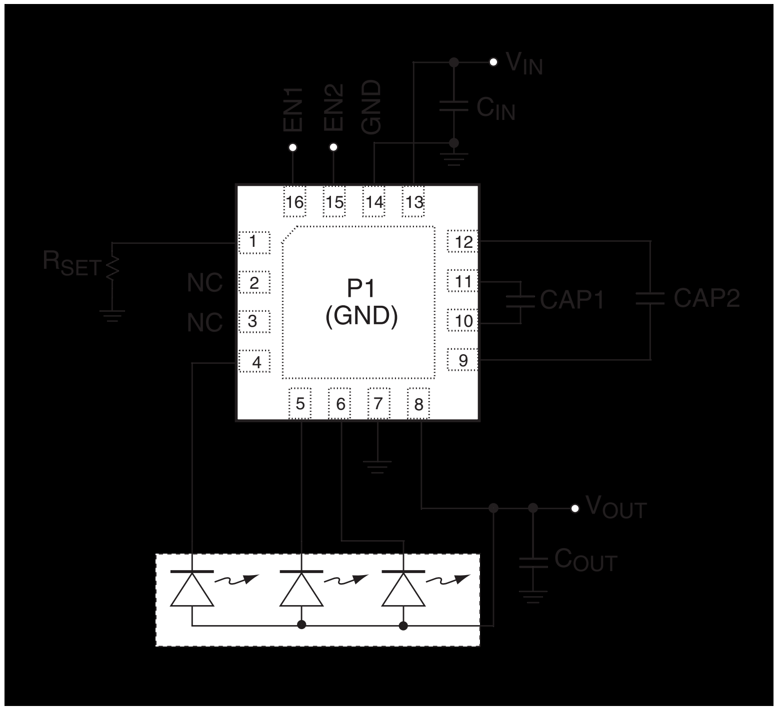
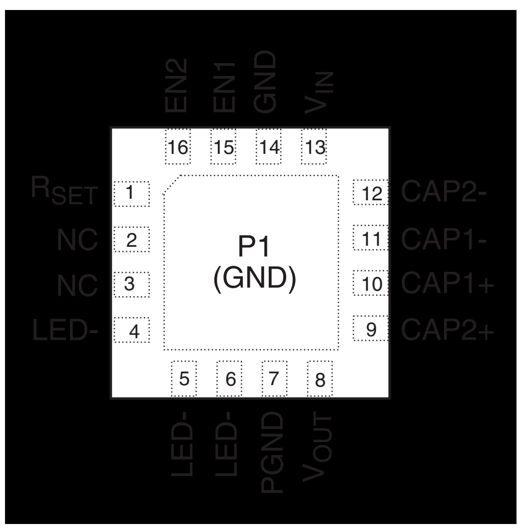


Figure 1. Typical Application

Pin Assignment

Top View



3x3mm 16-Lead MLP

Figure 2. Pin Assignment

Pin Description

Pin No.	Pin Name	Pin Description
P1	GND	**Ground.** P1 must be soldered to the PCB ground.
1	R_{SET}	**R_{SET} Pin.** Connect this pin to the resistor used to set the maximum LED current.
2	NC	**No Connection.**
3	NC	**No Connection.**
4	LED-	**1st LED Cathode.** Connect this pin to the LED's cathode.
5	LED-	**2nd LED Cathode.** Connect this pin to the LED's cathode.
6	LED-	**3rd LED Cathode.** Connect this pin to the LED's cathode.
7	PGND	**Power Ground.**
8	V_{OUT}	**Output Voltage.** Connect this pin to all of the LED's anodes.
9	CAP2+	**Bucket Capacitor 2.** Connect this pin to the positive terminal of the bucket capacitor.
10	CAP1+	**Bucket Capacitor 1.** Connect this pin to the positive terminal of the bucket capacitor.
11	CAP1-	**Bucket Capacitor 1.** Connect this pin to the negative terminal of the bucket capacitor.
12	CAP2-	**Bucket Capacitor 2.** Connect this pin to the negative terminal of the bucket capacitor.
13	V_{IN}	**Supply Voltage Input.**
14	GND	**Ground.**
15	EN1	**Enable Input.**
16	EN2	**Enable Input.**

Absolute Maximum Ratings (Note1)

Parameter		Min	Max	Unit
V_{IN}, V_{OUT}, EN1, EN2, GND		-0.3	6	V
Voltage On All Other Pins		GND – 0.3	V_{IN} + 0.3	V
CAP+, CAP- to GND		-0.3	V_{IN} + 0.3	V
Thermal Resistance – Junction to Tab (θ_{JC}) (Note 2)			8	°C/W
Lead Soldering Temperature (10 seconds)			260	°C
Junction Temperature			150	°C
Storage Temperature		-65	150	°C
Electrostatic Discharge Protection (ESD) Level (Note 3)	HBM	2.5		kV
	CDM	1.5		

Recommended Operating Conditions

Parameter	Min	Max	Unit
Supply Voltage Range	2.5	5.5	V
LED Forward Voltage		4	V
Current Through Each LED	2	40	mA
PWM Dimming Signal Frequency	0.2	50	kHz
Operating Ambient Temperature	-40	+85	°C
Operating Junction Temperature	-40	+125	°C

Notes:

1. Stresses above those listed under “Absolute Maximum Ratings” may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operational section of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability. Absolute maximum ratings apply individually only, not in combination. Unless otherwise specified all other voltages are referenced to GND.
2. Junction to ambient thermal resistance, θ_{JA}, is a strong function of PCB material, board thickness, thickness and number of via used, diameter of via used, available copper surface, and attached heat sink characteristics. A reasonable estimated value for θ_{JA} for zero air flow at 0.5W is 60°C/W.
3. Using Mil Std. 883E, method 3015.7(Human Body Model) and EIA/JESD22C101-A (Charge Device Model).

Electrical Characteristics

Unless otherwise noted, V_{IN} = 2.7V to 5.5V, I_{LED} = 2mA to 20mA, EN1 = EN2 = HIGH, T_A = -40°C to +85°C. Typical values are at 25°C.

Parameter	Conditions	Min	Typ	Max	Unit
Input Under-Voltage Lockout	V_{IN} falling			1.6	V
	V_{IN} rising	2.3			
I_{LED}/I_{SET} Ratio	V_{IN} = 3.6V, I_{OUT} = 15mA	240	255	270	
I_{LED}/I_{SET} Ratio	I_{LED} = 2 to 20mA	230	260	280	
I_{LED}/I_{SET} Ratio	EN1 = HIGH, EN2 = LOW		86		
	EN1 = LOW, EN2 = HIGH		173		
Current Matching with Unmatched LEDs (Note 1)	2mA ≤ I_{LED} ≤ 15mA 2.8V ≤ LED V_F <4V		0.6	+3	%
Reference Voltage for Current Set		588	600	612	mV
Start Up time	C_{OUT} = 1µF, V_{IN} = 3.6V, I_{LED} = 15mA	200	270	500	µS
Minimum Cathode Voltage	I_{LED} = 15mA		170	250	mV
Quiescent Current	V_{IN} = 5.5V, I_{OUT} = 5mA		250		µA
Shutdown Supply Current	EN1 = EN2 = Logic "L"		0.1	1	µA
Output Short Circuit Current	V_{IN} = 5.5V, V_{OUT} = 0V		65	80	mA
V_{OUT} Over-voltage Protection				6	V
V_{IN} at Mode Transition from 1x to 1.5x	LED V_f = 3.5V, I_{LED} = 3 x 20mA		3.9		V
V_{IN} at Mode Transition from 1.5x to 2x	LED V_f = 3.5V, I_{LED} = 3 x 20mA		2.9		V
Peak Efficiency (Note 2)	V_{IN} = 3.75V, LED V_f = 3.4V, I_{LED} = 18mA		90		%
Oscillator Frequency		0.8	1	1.2	MHz
Thermal Shutdown Threshold			150		°C
Thermal Shutdown Hysteresis			15		°C
"EN1" Logic Input Low Voltage				0.4	V
"EN1" Logic Input High Voltage		1.6			V
"EN2" Logic Input Low Voltage				0.4	V
"EN2" Logic Input High Voltage		1.6			V

Notes:

1. Current Matching refers to the absolute value of the difference in the current between the two LED branches.

   [redacted]

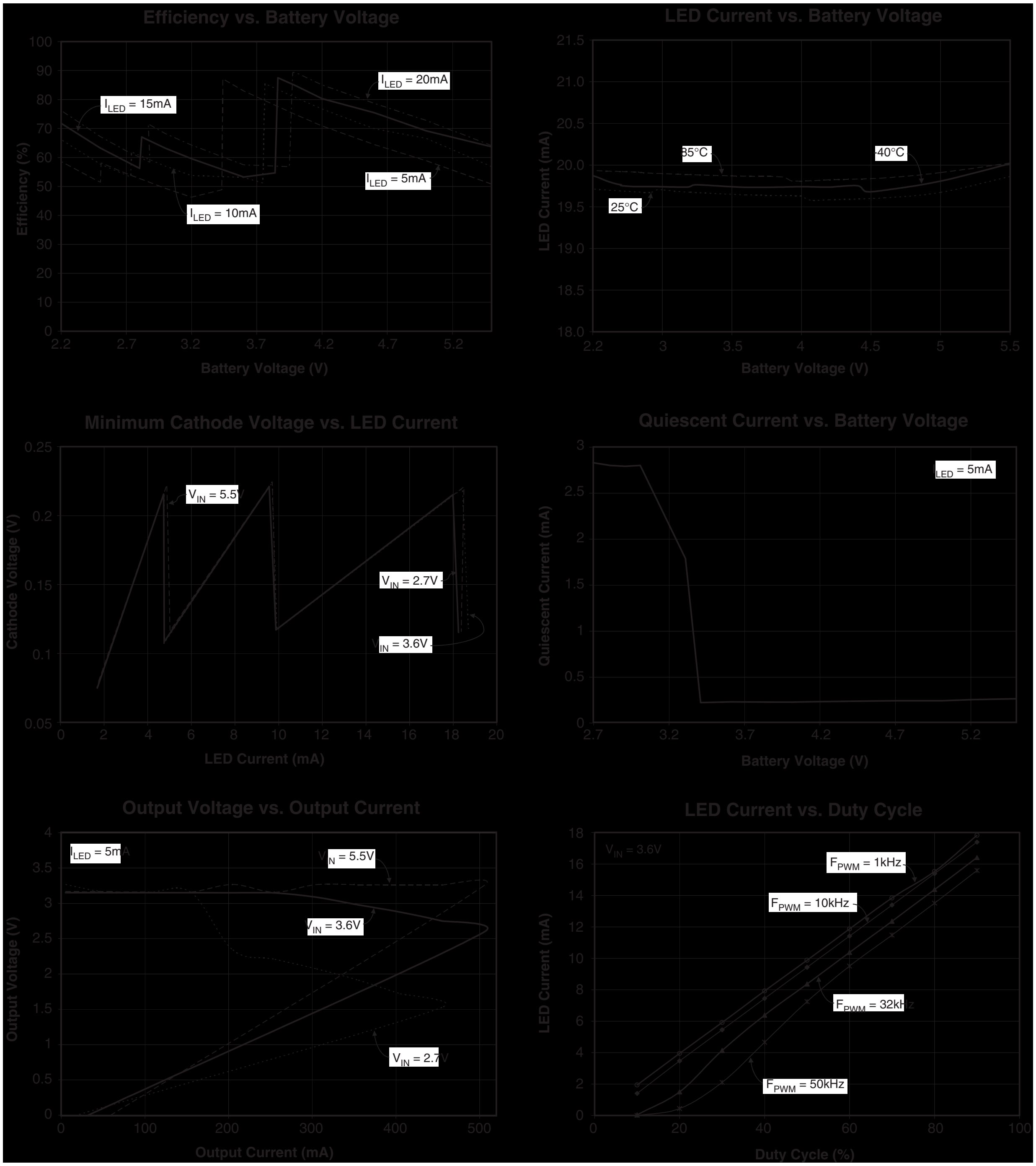
2. Efficiency is expressed as a ratio between the electrical power into the LEDs and the total power consumed from the input power supply.

   [redacted]

   Some competitors calculate the efficiency as a function of V_{OUT} instead of LED V_F. Their method does not account for the power lost due to the cathode voltage not being equal to zero. This method allows them to provide an "improved" efficiency up to 5%.

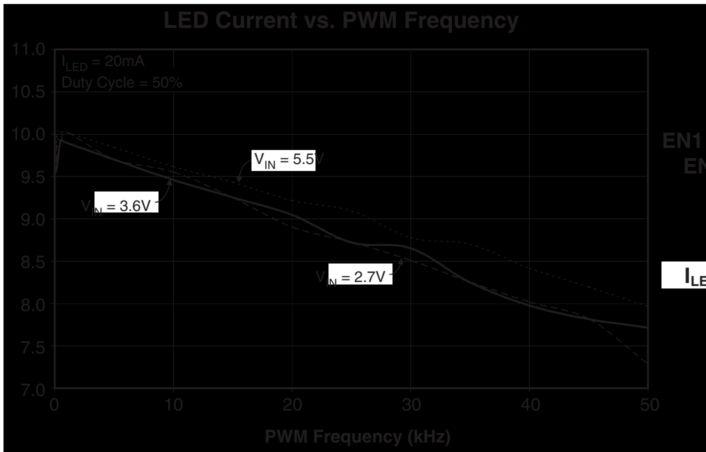
Typical Performance Characteristics

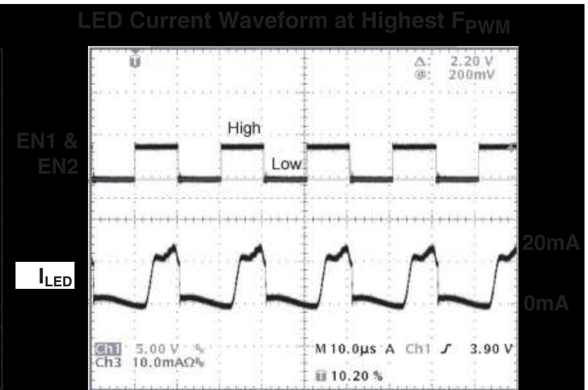
Unless otherwise noted, V_{IN} = 3.6V, T_A = 25°C, C_{IN} = 4.7µF, C_{OUT} = 1µF, CAP1 = CAP2 = 0.1µF, FAN5616 driving three LEDs with V_F = 3.5V at 20mA.

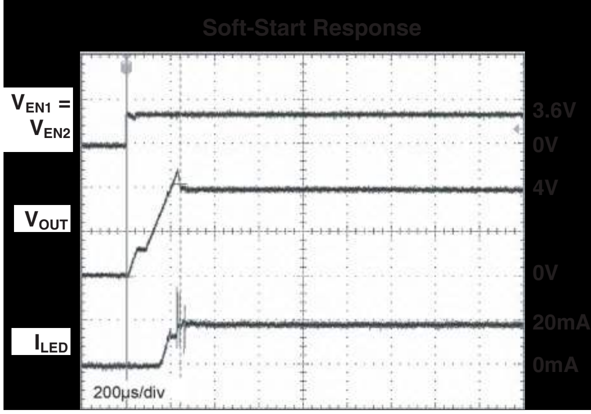


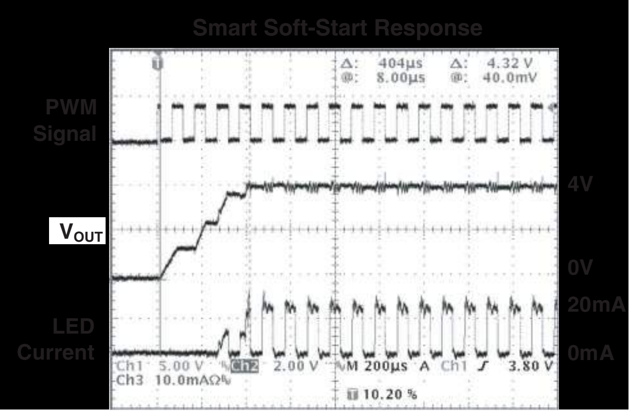
Typical Performance Characteristics (Continued)

Unless otherwise noted, V_{IN} = 3.6V, T_A = 25°C, C_{IN} = 4.7µF, C_{OUT} = 1µF, CAP1 = CAP2 = 0.1µF, FAN5616 driving three LEDs with V_F = 3.5V at 20mA.









Block Diagram

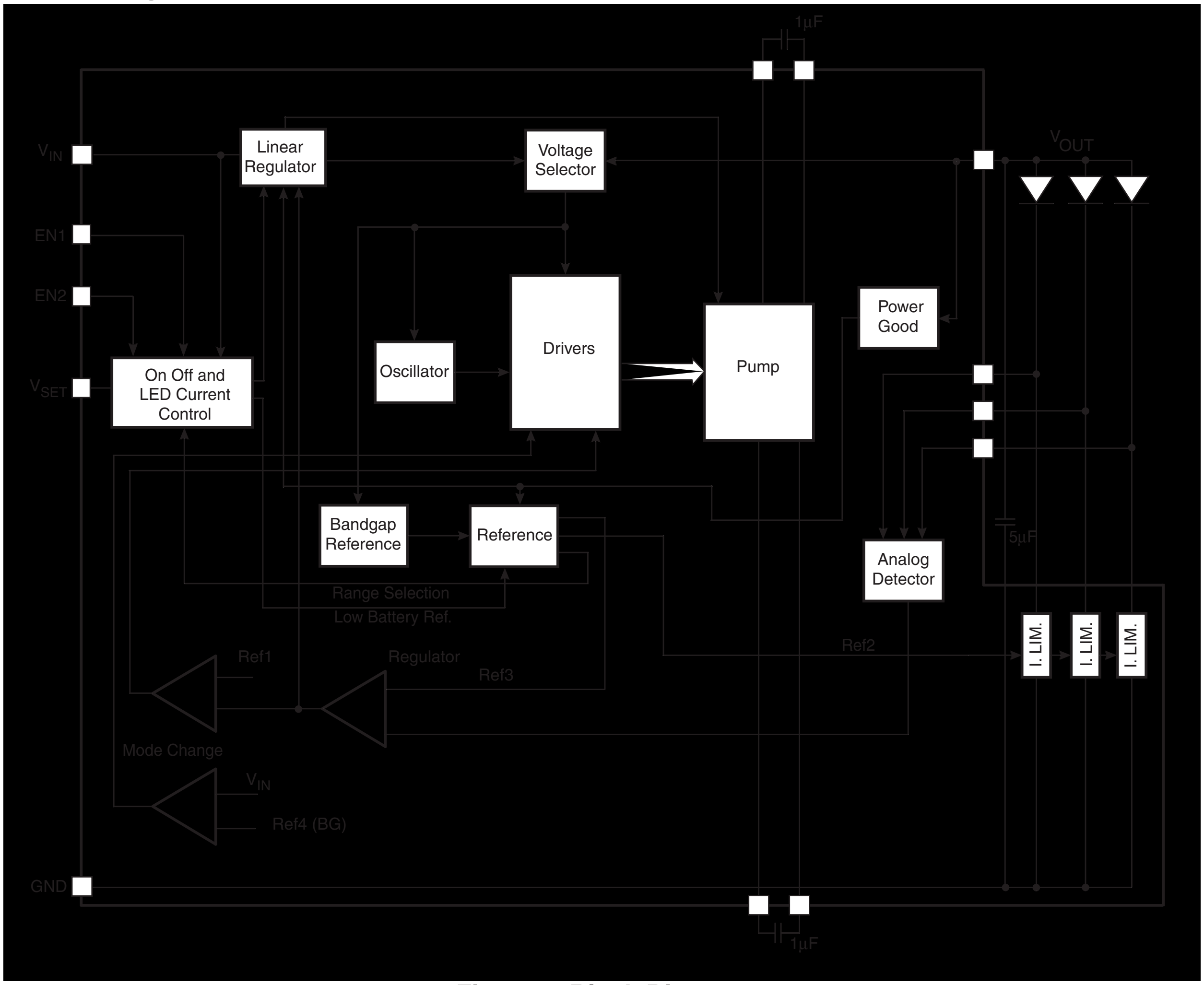


Figure 3. Block Diagram

Circuit Description

As shown in Figure 4, the FAN5616's switch capacitor DC/DC converter automatically configures its internal switches to achieve high efficiency and to provide tightly-regulated output currents for the LEDs. An analog detector determines which diode requires the highest voltage in order to sustain the pre-set current levels, and adjusts the pump regulator accordingly. Every diode has its own linear current regulator. In addition, a voltage regulator controls the output voltage when the battery voltage is within a range where linear regulation can provide maximum possible efficiency. If the battery voltage is too low to sustain the diode current in linear mode, a fractional 3:2 charge pump is enabled. When the battery voltage drops and the mode is no longer sufficient to sustain proper operation, the pump is automatically reconfigured to operate in 2:1 mode. As the battery discharges and the voltage decays, the FAN5616 switches between modes to maintain a constant current through the LEDs throughout the battery life. This transition has hysteresis to prevent toggling.

The internal supply voltage of the device is automatically selected from the V_{IN} or V_{OUT} pins, whichever has a higher voltage.

The FAN5616 enters shutdown mode to reduce overall current consumption when both DAC inputs (EN1 and EN2) are low.

Short Circuit and Thermal Protection

In the event of an output voltage short circuit, the output current will be limited to a typical value of 65mA.

In addition, when the die temperature exceeds 150°C, a reset occurs and remains in effect until the die cools to 135°C. At which time the circuit will restart and resume normal operation.

[redacted]

enabling the device the output voltage (V_{OUT}) is increased linearly until it reaches its nominal level. When a logic "Low" is applied to EN1/EN2 for more than 5mS, the device is placed in a low power mode and the output voltage is turned off. The LED current is controlled by applying a PWM signal to the EN1/EN2 pin. To avoid interference between the PWM signal and the soft-start circuit, the PWM signal applied must be faster than 200Hz but not greater than 50kHz. The soft-start circuit will be reactivated with each low to high transition on the EN1/EN2 pin. As shown in Figure 5, the PWM signal, ideally, should be controlled so that the initial logic "High"

The following formula explains the relationship between duty cycle (D) and soft-start V_{OUT} ramp time (T_{STR}),

[redacted]

For example, a PWM signal with a 50% duty ratio (D=0.5) generates a 500µS soft-start V_{OUT} ramp.

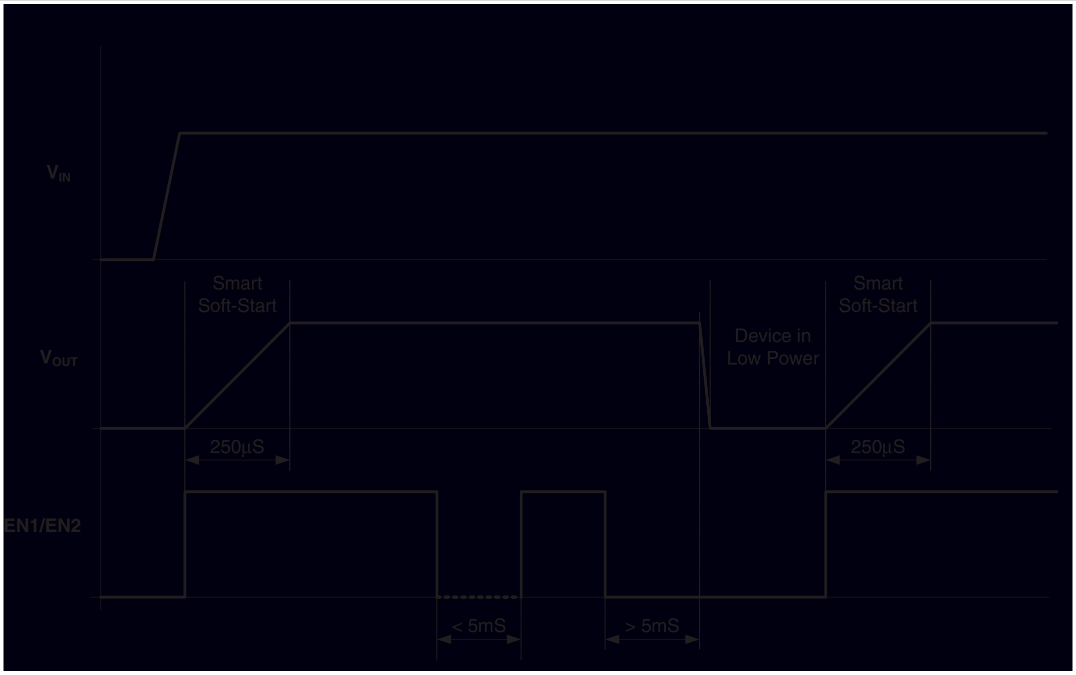


Figure 5. Smart Soft-Start Timing

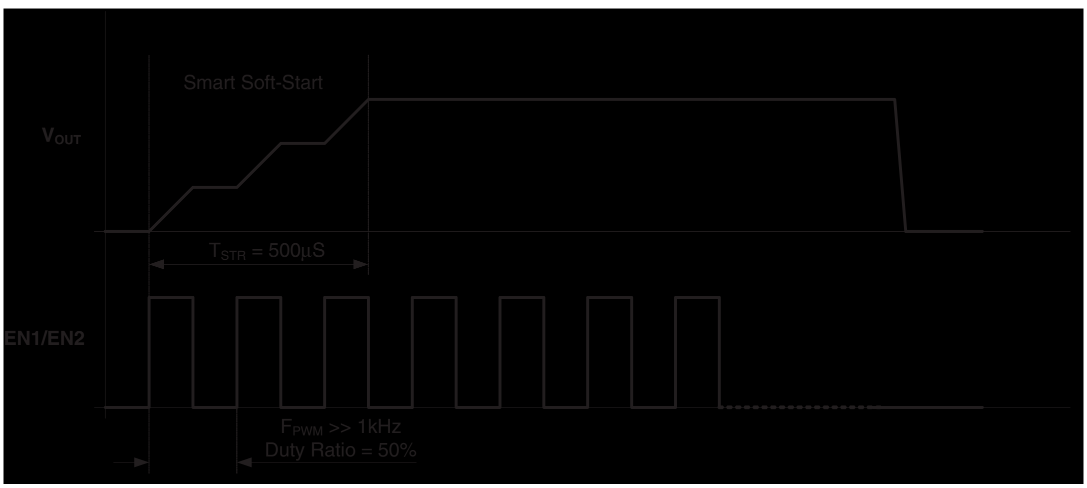


Figure 6. Smart Soft-Start Timing with 50% PWM

Application Information

LED Brightness Control Methods

1. External R_{SET} Resistor

The external R_{SET} resistor sets the maximum LED current for LED brightness control.

Table 1. Max. I_{LED} (EN1=EN2 = Logic "High")

R_{SET} (kΩ)	7.8	15.6	31.2	62.4
$I_{LED-MAX}$ (mA)	20	10	5	2.5

The resistor value establishes the reference current needed for a constant LED current. To calculate different R_{SET} values, use the formula below:

$$R_{SET} = \frac{156}{I_{LED}}$$

2. Digital Control

A built-in 2-bit DAC is used to digitally control the LED's brightness through the EN1 and EN2 inputs. Once the desired maximum LED current is set by the external R_{SET} resistor, the percentage of the maximum LED current is selected, as described in Table 2, to perform the dimming operation.

Table 2. LED Dimming with Internal 2-bit DAC

EN2	EN1	LED Current % of Maximum
0	0	0%
0	1	33.3% (1/3)
1	0	66.7% (2/3)
1	1	100% (3/3)

3. PWM Control

In addition to the digital LED brightness control, the FAN5616 features a PWM control. The LED current varies according to the width of the PWM signal applied to the EN1/EN2 input pins. Once the desired maximum LED current ($I_{LED-MAX}$) is set by the external R_{SET} resistor, the percentage of $I_{LED-MAX}$ to perform the dimming operation depends on the configuration of the PWM signal with respect to the 2-bit DAC inputs (EN1 and EN2) as described in Table 2.

For example, if R_{SET} = 7.8kΩ then $I_{LED-MAX}$ = 20mA. If EN1 and EN2 are tied together and a PWM signal is applied, the LED current will vary between 0% and 100% (0mA and 20mA) of the maximum LED current according to the duty cycle of the PWM signal.

The PWM signal can be applied to either enable input pins (EN1/EN2) or to both tied together. Depending upon the configuration, the average LED current can be adjusted within any range limited by 0, 1/3, 2/3, 3/3 of the maximum LED current as described in Table 3. The PWM duty cycle is assumed to be between 10% and 90%.

Table 3. Average LED Dimming Range

Enable Input Pins		Average I_{LED} Adjustment Range
EN2	EN1	
LOW	TOGGLE	3% to 30% of $I_{LED-MAX}$
HIGH	TOGGLE	70% to 97% of $I_{LED-MAX}$
TOGGLE	LOW	6% to 60% of $I_{LED-MAX}$
TOGGLE	HIGH	39% to 93% of $I_{LED-MAX}$
TOGGLE	TOGGLE	10% to 90% of $I_{LED-MAX}$

The recommended PWM frequency range is 200Hz to 50kHz for an acceptable linear response. At higher frequencies, the current waveform can no longer follow the PWM signal waveform, resulting in a significant difference between the value of the average I_{LED} and the theoretical calculation.

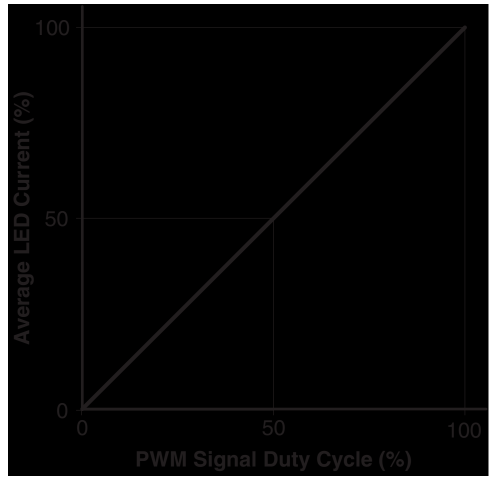


Figure 7. Ideal PWM Dimming Response

4. Dimming with DC Voltage

The brightness control using a variable DC voltage is shown in Figure 8. If R1 = 78kΩ, R2 = 7.8kΩ, adjusting V_{EXT} in the 0V to 0.6V range results in dimming the LED current from 22mA to 2mA.

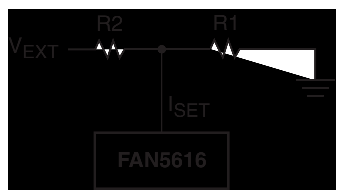


Figure 8. DC Voltage Control

The FAN5616's internal circuit maintains a constant V_{SET} = 0.6V. Adjusting V_{EXT} changes the I_{SET} and I_{LED} accordingly.

By selecting different values for R1, R2 and V_{EXT}, the I_{LED} variation range can be changed according to the following equation:

$$I_{LED} = \left[\frac{156}{R1} + \frac{(156 - 260 \times V_{EXT})}{R2}\right] mA$$

Where, 0V < V_{EXT} < 0.6V (1+R2/R1) and R1 and R2 are in kΩ.

Selecting Capacitors

It is important to select the appropriate capacitor types and the values for use with the FAN5616. In order to reduce battery ripple, both C_{IN} and C_{OUT} should be low-ESR capacitors. If necessary, the ripple can be further reduced by powering the FAN5616 through an RC input filter, as shown in Figure 9.

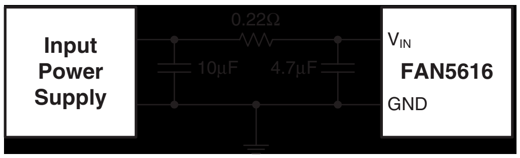


Figure 9. Battery Ripple Reduction

Two MLCC bucket capacitors of 0.1µF to 1µF should be used for best efficiency in boost mode. For better I_{LED} regulation, 1µF bucket capacitors are recommended particularly when I_{LED} > 25mA and the battery discharges below 3V.

PCB Layout Considerations

For best performance, a solid ground plane is recommended on the back side of the PCB. All capacitors should be placed as close to the FAN5616 as possible and connected with reasonably thick traces to minimize the ESL and ESR parasitics.

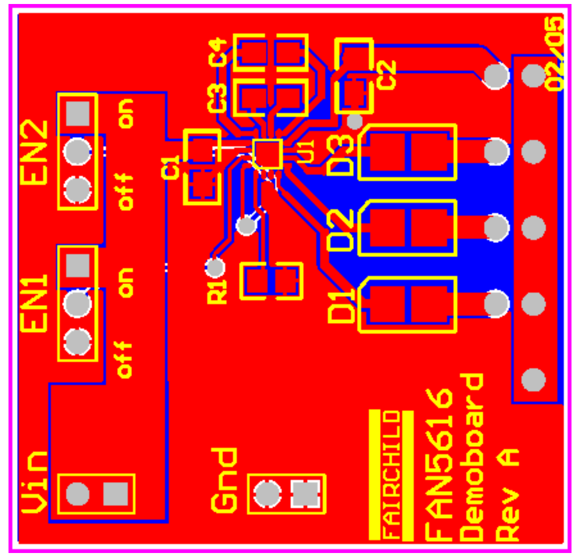
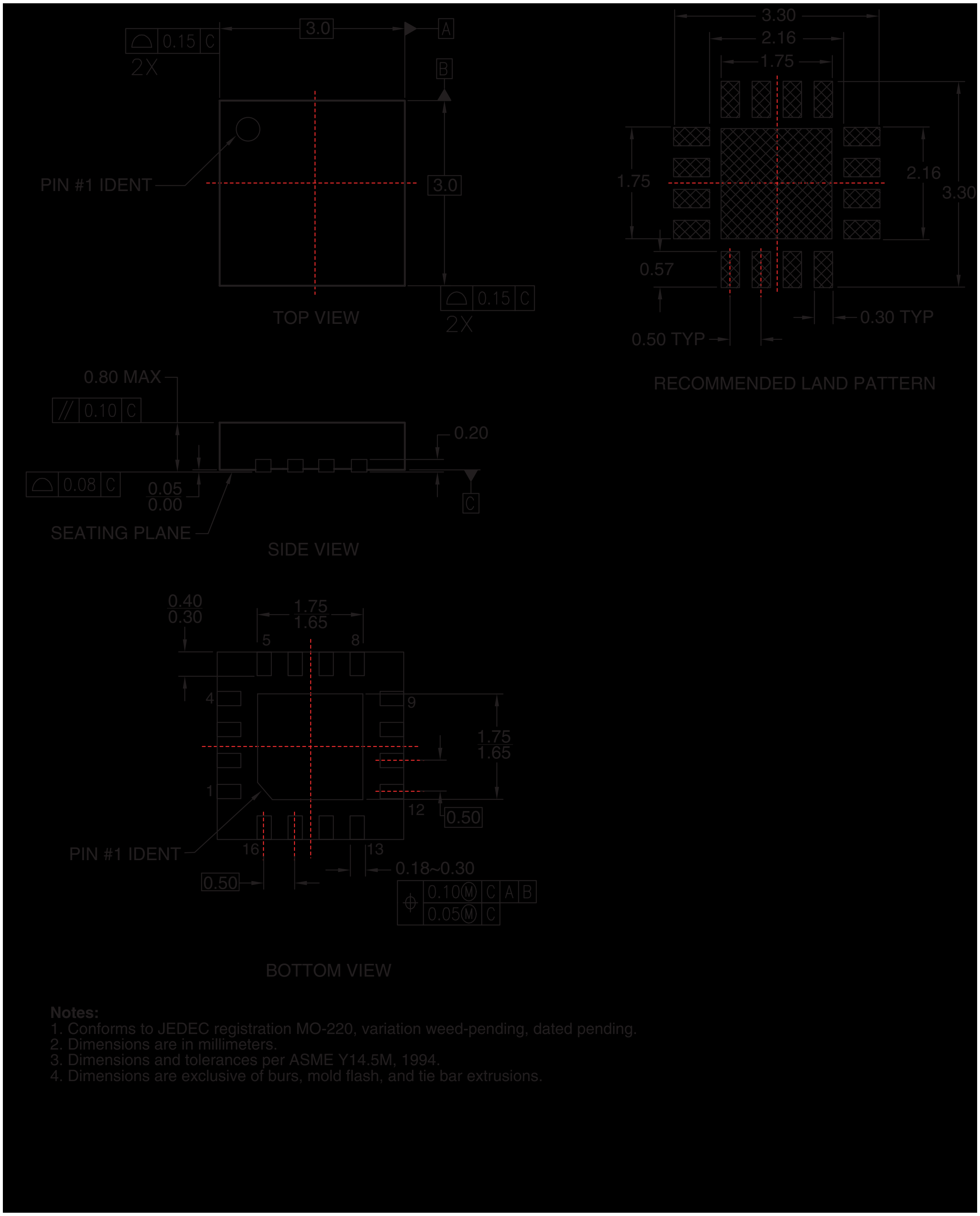


Figure 10. Recommended PCB Layout

Mechanical Dimensions

3x3mm 16-Lead MLP



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