

## GENERAL DESCRIPTION

The SP7686/SP7686A are current regulated charge pumps ideal for powering high power, high brightness LEDs for camera FLASH applications of up to 500mA.

The charge pump automatically switches between step-up and step-down modes ensuring that the LED current does not depend on the forward voltage. A low current sense reference voltage (60mV to 360mV) allows the use of small 0603 current sensing resistors. The SP7686 has a DAC programmable feedback reference voltage allowing the user to precisely set FLASH and TORCH output current levels, while the fixed version SP7686A has set levels of FLASH and TORCH reference voltage. Both parts have over-voltage, over-current, over-temperature and FLASH time-out protection features.

The SP7686 and SP7686A are offered in a RoHS compliant "green"/halogen free space saving 8-pin 2x3mm DFN package.

## APPLICATIONS

- Cell Phone Flash
- Cell Phone Torch
- General LED applications

## FEATURES

- Output current up to 500mA
- Up to 94% efficiency
- Single Wire serial interface
- 2.4MHz switching frequency
- FB Reference voltage adjusts in 10mV steps from 60mV to 360mV
- 10nA Shutdown
- PWM brightness control for DAC
- Fast turn-on (<150µs)
- 3.5s Timeout function
- Thermal shutdown protection
- Built-in over-voltage and over-current protection
- Fixed output SP7686A
- Automatic soft start limits in-rush current
- RoHS Compliant, "Green"/Halogen Free 8-pin 2x3mm DFN

## TYPICAL APPLICATION DIAGRAM

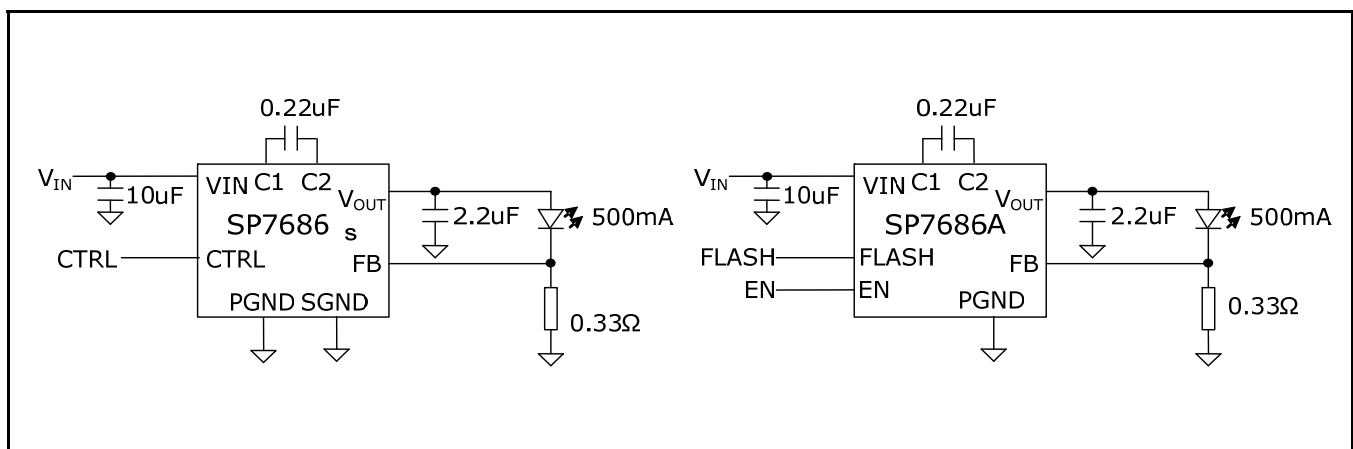


Fig. 1: SP7686 and SP7686A Application Diagrams



**ABSOLUTE MAXIMUM RATINGS**

These are stress ratings only and functional operation of the device at these ratings or any other above those indicated in the operation sections of the specifications below is not implied. Exposure to absolute maximum rating conditions for extended periods of time may affect reliability.

V<sub>IN</sub>..... -0.6V to 6.0V  
 C1, C2, EN, CTRL, FB, V<sub>OUT</sub> ..... -0.6 to V<sub>IN</sub>+0.3V  
 Storage Temperature ..... -65°C to 150°C  
 Power Dissipation ..... Internally Limited<sup>1</sup>  
 Lead Temperature (Soldering, 10 sec) ..... 260°C  
 ESD Rating (HBM - Human Body Model) ..... 2kV  
 ESD Rating (HBM) EN ..... 1.2kV

**OPERATING RATINGS**

Input Voltage Range V<sub>IN</sub>.....2.7V to 5.5V  
 Ambient Temperature Range ..... -40°C to 85°C  
 Thermal Resistance  $\theta_{JA}$  ..... 59°C/W

**ELECTRICAL SPECIFICATIONS**

Specifications with standard type are for an Operating Temperature of T<sub>A</sub> = 25°C only; limits applying over the full Operating Temperature range are denoted by a “•”. Minimum and Maximum limits are guaranteed through test, design, or statistical correlation. Typical values represent the most likely parametric norm at T<sub>A</sub> = 25°C, and are provided for reference purposes only. Unless otherwise indicated, V<sub>IN</sub> = 3.6V, C<sub>IN</sub>=10µF, C<sub>OUT</sub>=2.2µF, C<sub>FLY</sub>=0.22µF, T<sub>A</sub>= -40°C to 85°C.

Parameter	Min.	Typ.	Max.	Units	Conditions
Operating V <sub>IN</sub> Range	2.7		5.5	V	• Condition 1
Operating Input Current		2	3	mA	V <sub>IN</sub> = 2.7 – 5.5V, FLASH = 0V, I <sub>load</sub> = 100uA
Shutdown Supply Current		0.01	1	µA	V <sub>CTRL</sub> < 0.4V for > 350µsec, V <sub>EN</sub> < 0.4V (SP7686A)
Quiescent Current		300		µA	V <sub>FB</sub> = 0mV, DAC=00000
FB Voltage for DAC=00000		0		mV	•
FB Voltage for DAC=00001		58		mV	Open loop comparator trip voltage
FB Voltage for DAC=11111		350		mV	Open loop comparator trip voltage
FB DAC LSB		9.7		mV	
FB Voltage Accuracy	-14		14	%	• Variation from specified V <sub>FB</sub>
FB voltage (SP7686A, Torch)	54	60	66	mV	• Flash = LOW, Open loop comparator trip voltage
FB Voltage (SP7686A, Flash)	147	160	173	mV	• Flash = HIGH, Open loop comparator trip voltage
FB Pin Current			0.5	µA	• V <sub>FB</sub> =0.3V
Switching Frequency	2.0	2.4	2.8	MHz	•
Equivalent Resistance, 1x mode		0.6	1.4	Ω	•
Equivalent Resistance, 2x mode		8		Ω	
Thermal Regulation			0.01	%/°C	V <sub>FB</sub> = 60mV
Thermal Shutdown Die Temperature		140		°C	Driver turns off
Thermal Shutdown Hysteresis		15		°C	Driver turns on again
Settle time (TS) after last count		15	50	µs	
Ctrl Input Data Rate	0.5	1		µs	CTRL minimum pulse width
Wake-up time (TPOR) from Vin off			600	µs	• V <sub>IN</sub> pin low to high, 1 CTRL pulse, V <sub>FB</sub> =0mV
Wake-up time (TON) from shutdown			200	µs	• 1 CTRL pulse or (EN pin low to high SP7686A)
Delay time (TDELAY) from 1st to 2nd pulse		25	75	µs	1 <sup>st</sup> to 2nd CTRL pulse time delay – guaranteed by design
Turn-off time (TOFF) into shutdown			50	µs	EN pin high to low (SP7686A)
Turn-off time (TOFFC) into shutdown		200	350	µs	• CTRL pin high to low
Time Duration before shutdown	2.8	3.5	4.2	s	• V <sub>FB</sub> >120mV (SP7686, 11 CTRL pulses), FLASH= high (SP7686A)
Logic low voltage			0.4	V	• Driver shutdown

Parameter	Min.	Typ.	Max.	Units	Conditions
Logic high voltage	1.4			V	• Driver enabled
CTRL, EN pin current			0.5	μA	• (EN pin is SP7686A only)

Note 1: Guaranteed maximum allowable power dissipation depends on the ambient temperature

### BLOCK DIAGRAM: SP7686

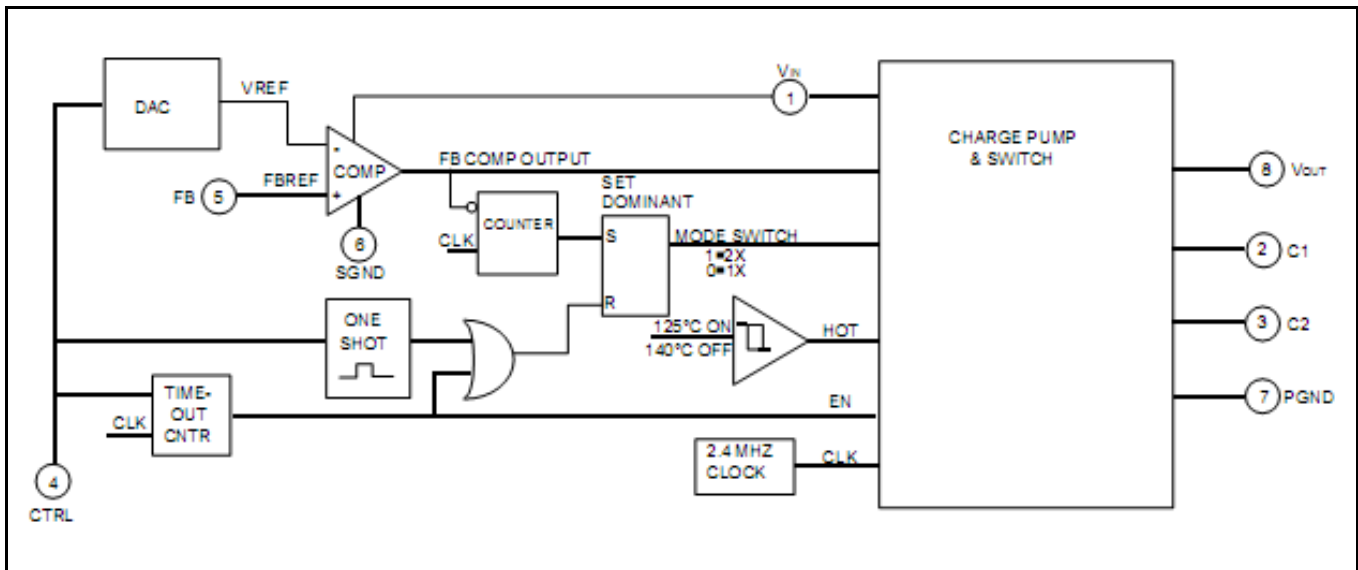


Fig. 2: SP7686 Block Diagram

### BLOCK DIAGRAM: SP7686A

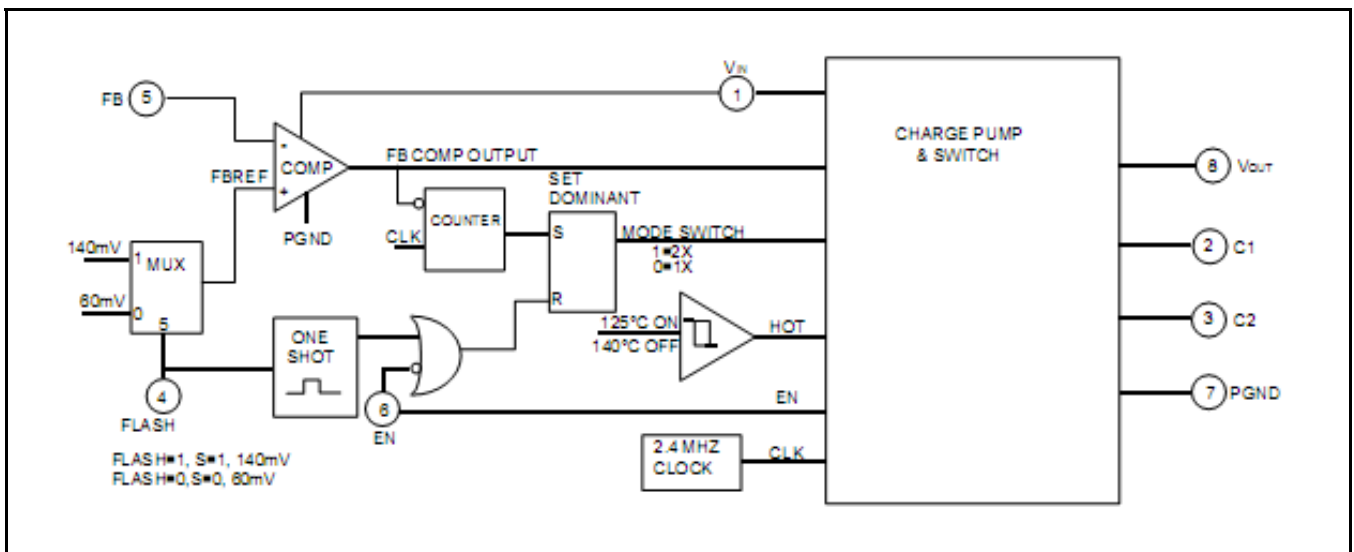


Fig. 3: SP7686A Block Diagram

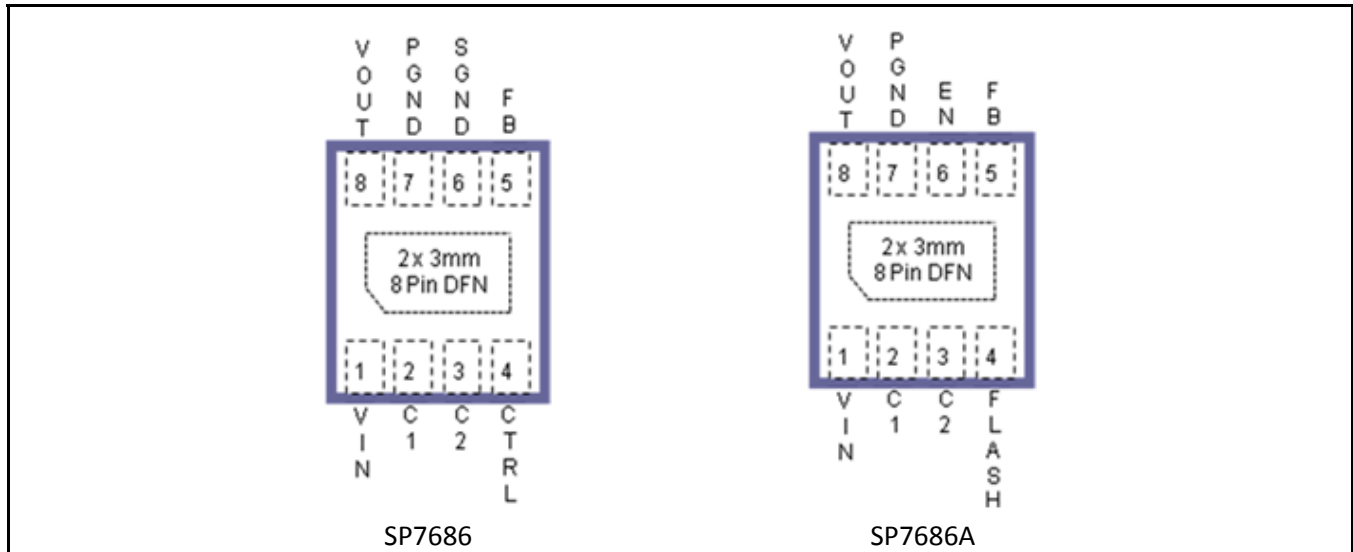
**PIN ASSIGNMENT**


Fig. 4: SP7686 and SP7686A Pin Assignment

**PIN DESCRIPTION: SP7686**

Name	Pin Number	Description
1	V <sub>IN</sub>	Power supply input. Place a 10μF decoupling capacitor next to this pin.
2, 3	C1, C2	Connect an external 0.22μF flying capacitor between these pins
4	CTRL	This pin is used to control LED current. Once enabled the adjustable driver counts positive going edges at this pin and sequentially increases FB voltage with 10mV steps to a maximum 31 steps or 360mV. When this pin is held LOW for longer than 200μs the SP7686 enters shutdown. The part can be enabled using this pin. The first positive edge resets the part. A second positive edge sets the part to VFB=0. A third positive going edge will increase FB voltage to 60mV and subsequent positive edges increment VFB in 10mV steps. The voltage level can increase only and must be reset to zero by the 200μs shutdown timer in order to go to a lower current value. The part will be limited to a 3.5s on time when FB voltage is set to 120mV and above. This pin cannot be left open.
5	FB	Current feedback input. Place an external current sense resistor from this pin to ground. Voltage at this pin will be internally compared to the DAC output (60mV - 360mV).
6	SGND	Ground pin for SP7686 bias and reference (low current).
7	PGND	Ground pin for power (high current).
8	V <sub>OUT</sub>	Output voltage of the internal charge pump. Connect the LED between this pin and the current sense resistor. Voltage at this pin will be regulated in order to maintain constant LED current. Place a 2.2μF ceramic capacitor next to this pin.



**PIN DESCRIPTION: SP7686A**

Name	Pin Number	Description
1	V <sub>IN</sub>	Power supply input. Place a 10µF decoupling capacitor next to this pin.
2, 3	C1, C2	Connect an external 0.22µF flying capacitor between these pins
4	FLASH	The SP7686A uses the flash pin to switch between two internally preset voltage levels, for Flash and Torch mode. The part is enabled and disabled by the separate ENABLE pin. The part has a 3.5s maximum on time in Flash mode. After a 3.5s timeout occurs the part shuts down and can be enabled by the FLASH or ENABLE pins. This pin cannot be left open.
5	FB	Current feedback input. Place an external current sense resistor from this pin to ground. Voltage at this pin will be internally compared to 60mV or 160mV depending on the logic level of the FLASH pin.
6	EN	The SP7686A has this enable/shutdown pin. (Logic high = enable, logic low = shutdown). Used to immediately disable the driver and PWM brightness control. There is an internal pull down on this pin.
7	PGND	Ground pin for power (high current).
8	V <sub>OUT</sub>	Output voltage of the internal charge pump. Connect the LED between this pin and the current sense resistor. Voltage at this pin will be regulated in order to maintain constant LED current. Place a 2.2µF ceramic capacitor next to this pin.

**ORDERING INFORMATION**

Part Number	Temperature Range	Marking	Package	Packing Quantity	Note 1	Note 2
SP7686AER-L	-40°C ≤ T <sub>A</sub> ≤ +85°C	SP7686A YYWWX	2x3mm DFN8	Bulk	Lead Free and Halogen Free	MSL L1@250°C
SP7686AER-L/TR	-40°C ≤ T <sub>A</sub> ≤ +85°C	SP7686A YYWWX	2x3mm DFN8	3K/Tape & Reel	Lead Free and Halogen Free	MSL L1@250°C
SP7686ER-L	-40°C ≤ T <sub>A</sub> ≤ +85°C	SP7686 YYWWX	2x3mm DFN8	Bulk	Lead Free and Halogen Free	MSL L1@250°C
SP7686ER-L/TR	-40°C ≤ T <sub>A</sub> ≤ +85°C	SP7686 YYWWX	2x3mm DFN8	3K/Tape & Reel	Lead Free and Halogen Free	MSL L1@250°C
SP7686EB	SP7686EB					

“YY” = Year – “WW” = Work Week – “X” = Lot Number



**TYPICAL PERFORMANCE CHARACTERISTICS**

All data taken at  $V_{IN} = 3.6V$ ,  $T_J = T_A = 25^\circ C$ , unless otherwise specified, Typical Application Circuit, D1 = Luxeon LXCL-PWF3.

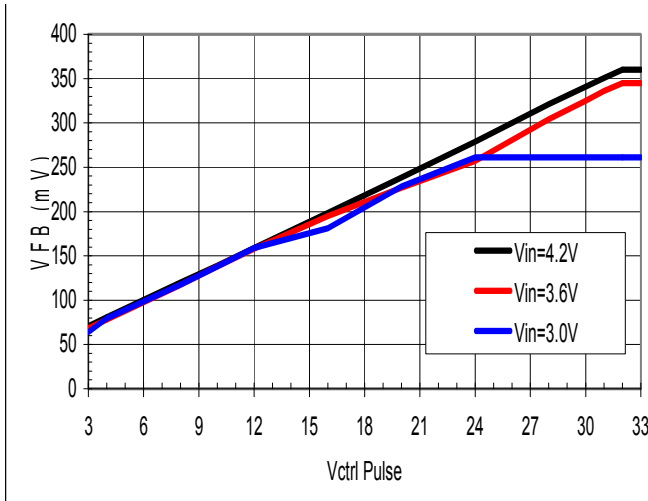


Fig. 3: SP7686 VFB vs CTRL Pulses

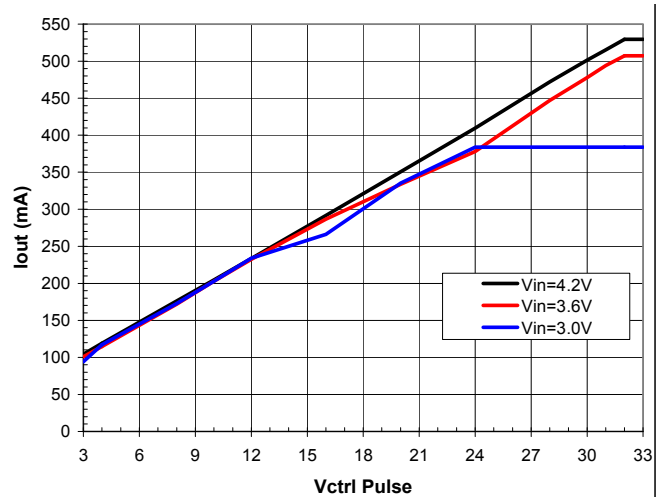


Fig. 4: SP7686  $I_{OUT}$  vs CTRL Pulses

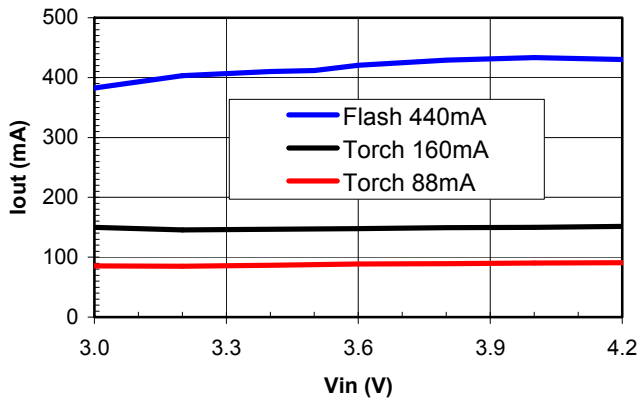


Fig. 5: SP7686 Output Current vs Input Voltage

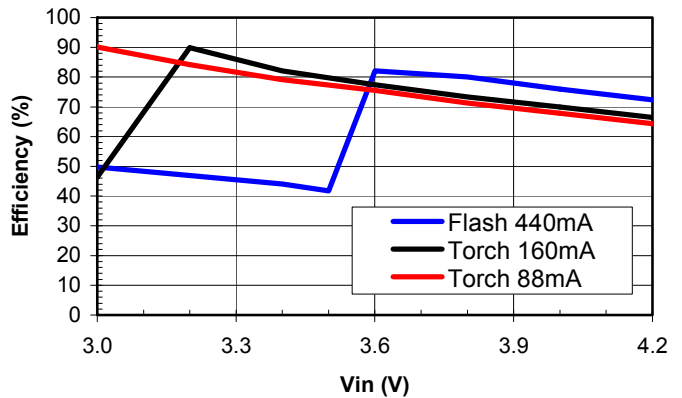


Fig. 6: SP7686 Efficiency

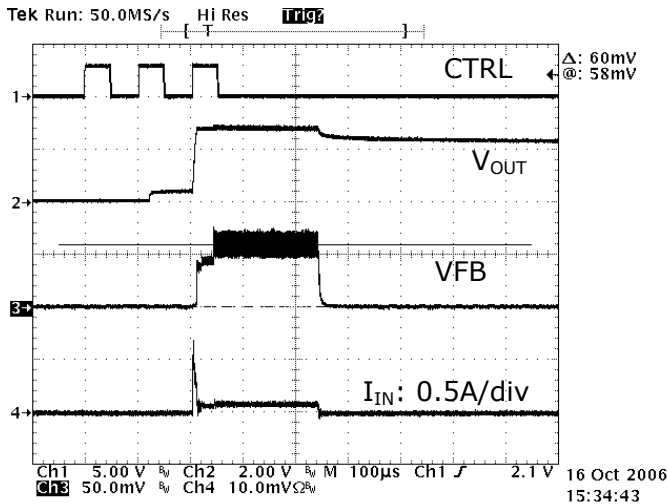


Fig. 7: SP7686 Startup with 3 CTRL Pulses,  $V_{IN}=4.2V$

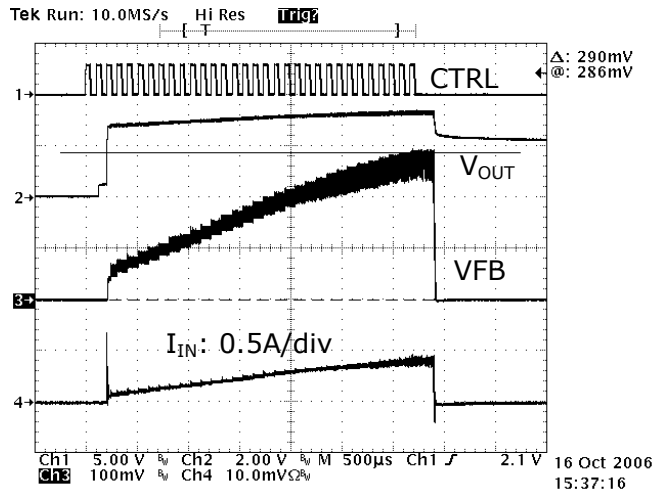


Fig. 8: SP7686 Startup with 32 CTRL Pulses,  $V_{IN}=4.2V$

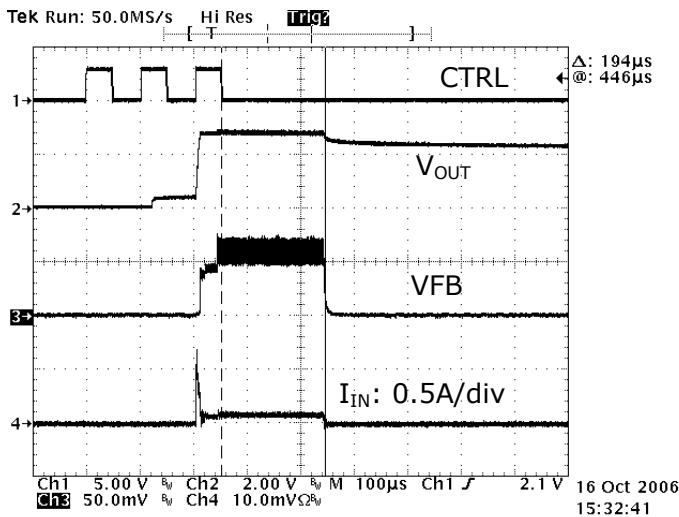


Fig. 9: SP7686 Turn-off time into SHDN

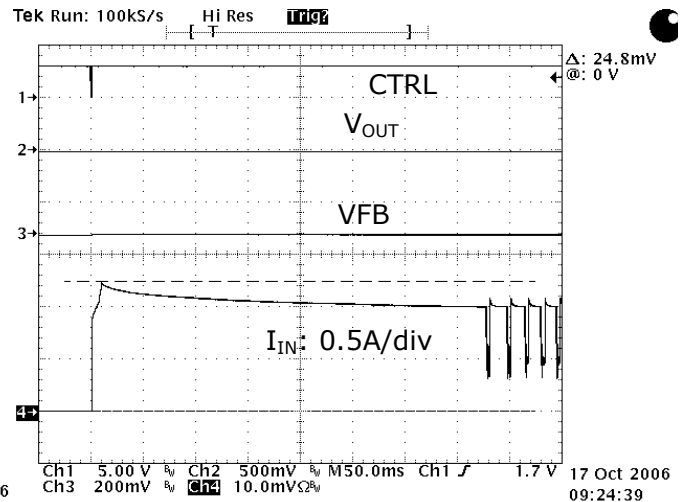


Fig. 10: SP7686 Vout Shorted to GND,  $V_{IN} = 5.5V$

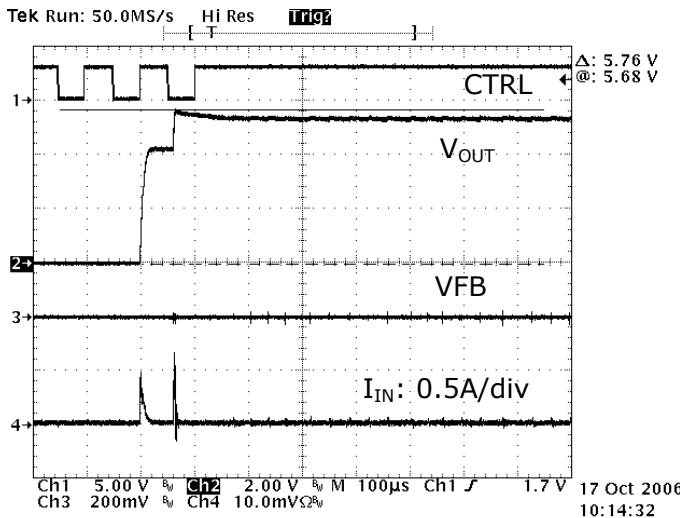


Fig. 11: SP7686 LED Open,  $V_{IN} = 4.2V$

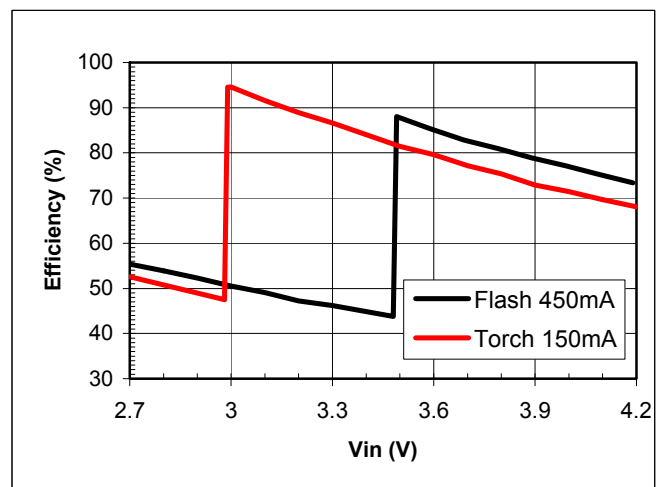


Fig. 12: SP7686A Efficiency

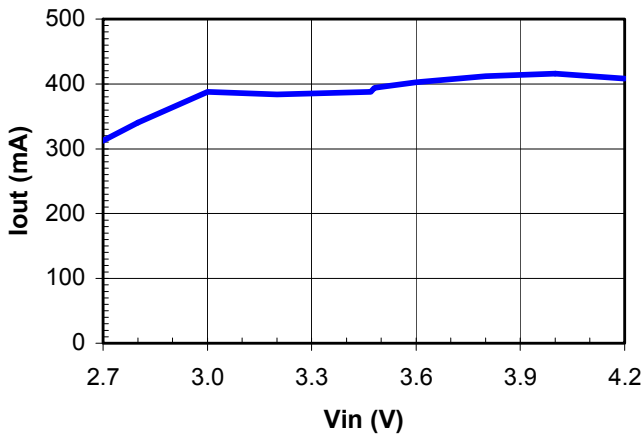


Fig. 13: SP7686A Flash Mode Output Current

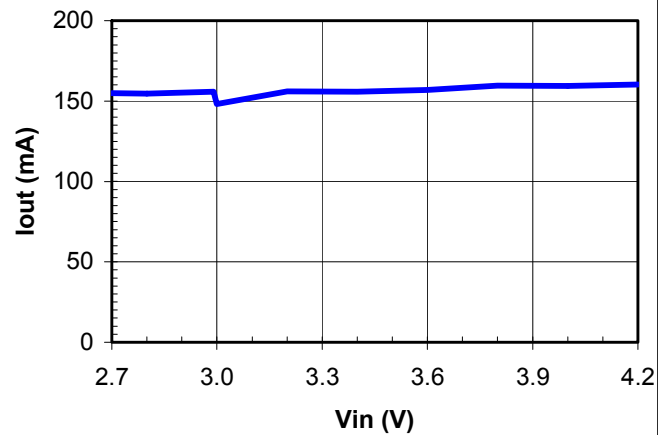
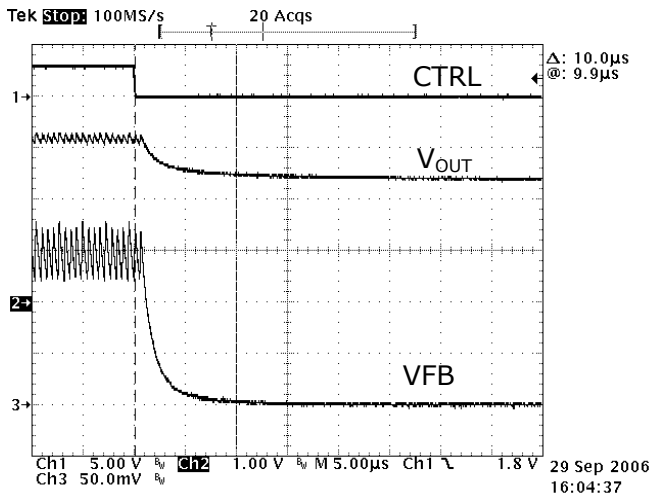
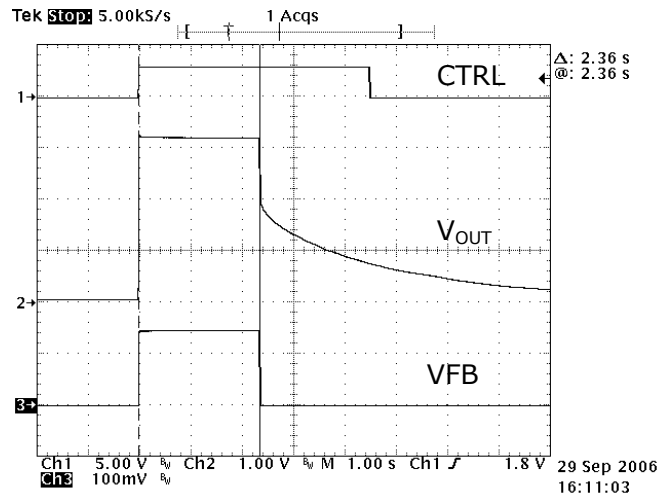


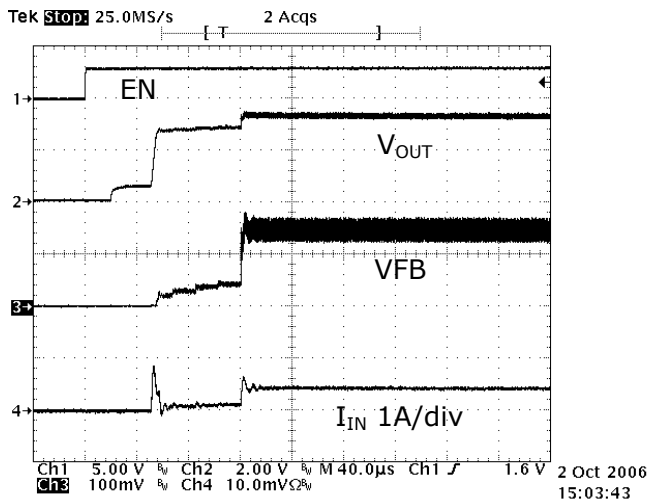
Fig. 14: SP7686A Torch Mode Output Current



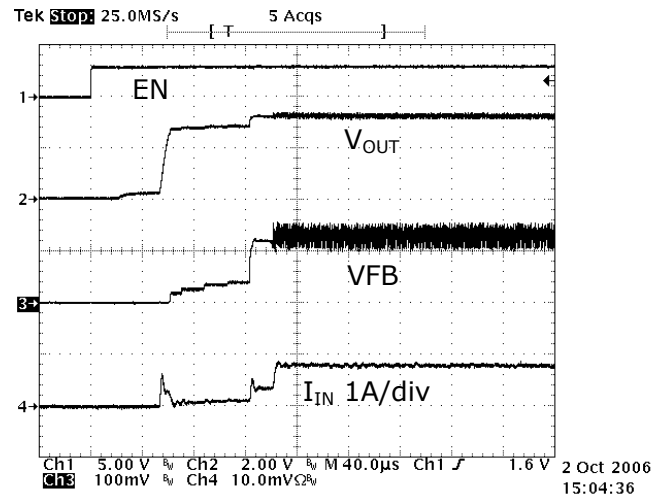
SP7686A Turn-off to Shutdown,  $V_{IN}=4.2V$



SP7686A Time-out Flash to Shutdown,  $V_{IN}=4.2V$

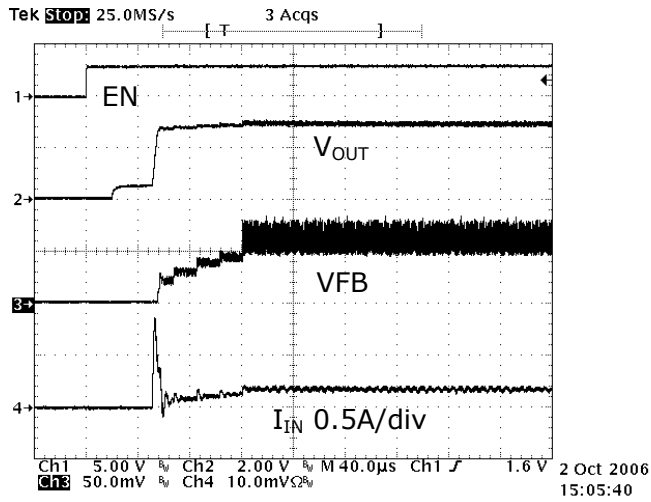


SP7686A Flash Mode 1X,  $V_{IN}=4.2V$

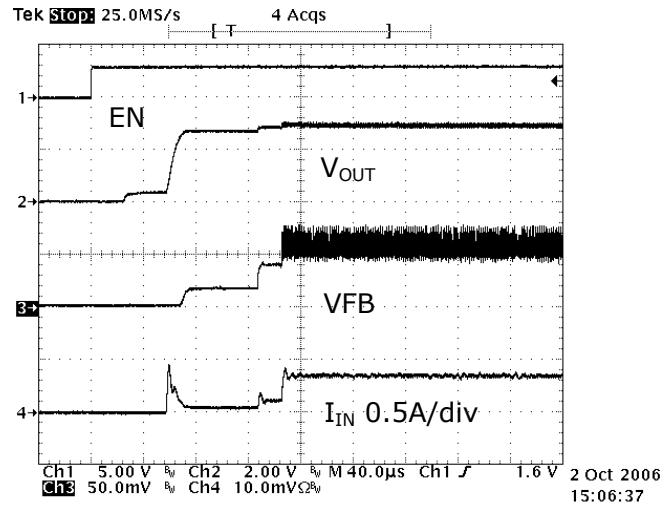


SP7686A Flash Mode 2X,  $V_{IN}=3.4V$

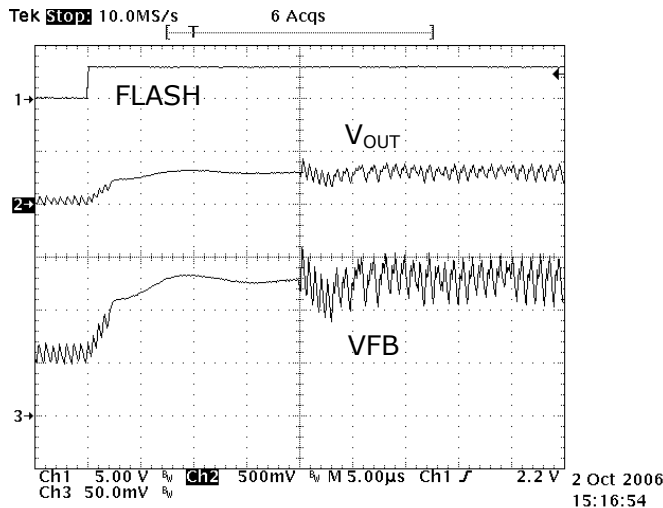




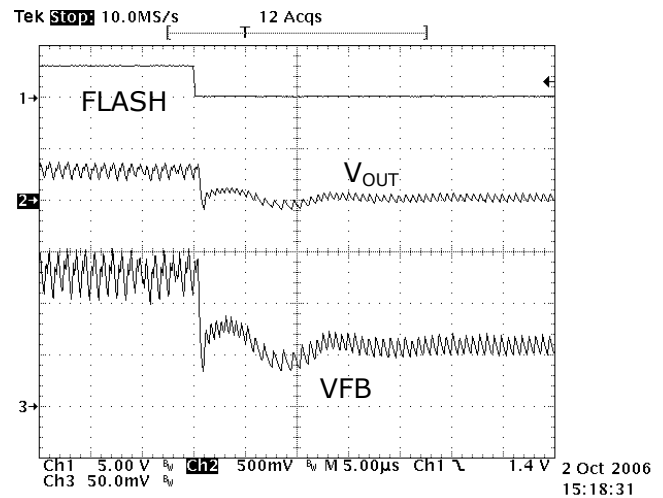
SP7686A Torch Mode 1X, VIN=4.2V



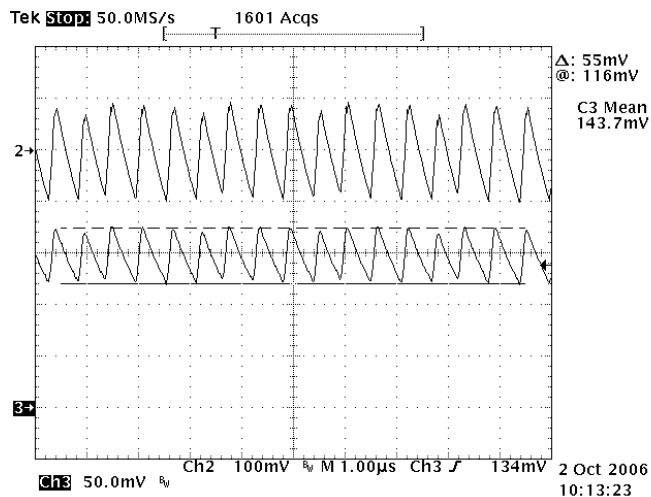
SP7686A Torch Mode 2X, VIN=2.9V



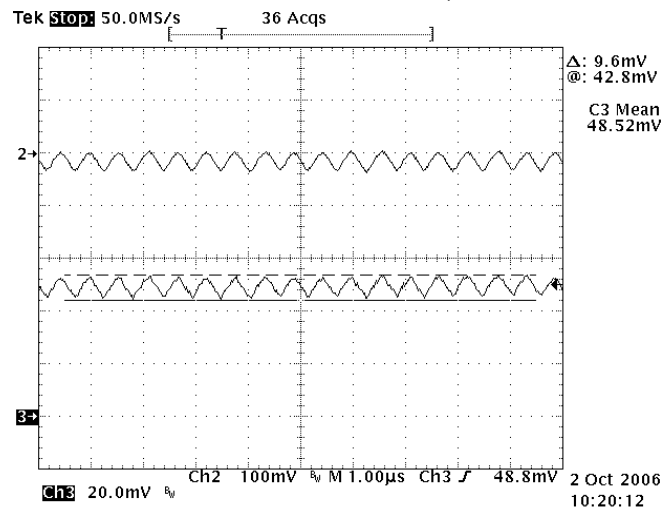
SP7686A 1X Torch to 2X Flash, VIN=3.3V



SP7686A 2X Flash to 1X Torch, VIN=3.3V



SP7686A Flash 1X Ripple, VIN=4.2V



SP7686A Torch 1X Ripple, VIN=3.0V



## THEORY OF OPERATION

### OVERVIEW

The SP7686 is a charge pump regulator designed for converting a Li-Ion battery voltage of 2.7V to 4.2V to drive a white LED used in digital still camera Flash and Torch applications. The SP7686 has two modes of operation which are pin selectable for either Flash or Torch. Flash mode is usually used with a pulse of about 200 to 300 milliseconds to generate a high intensity Flash. Torch can be used continuously at a lower output current than Flash and is often used for several seconds in a digital still camera "movie" mode. The SP7686 also has two modes of operation to control the output current: the 1X mode and 2X mode. Operation begins after the enable pin EN receives a logic high, the bandgap reference wakes up after 200µsec, and then SP7686 goes through a softstart mode designed to reduce inrush current. The SP7686 starts in the 1X mode, which acts like a linear regulator to control the output current by continuously monitoring the feedback pin FB. In 1X mode, if the SP7686 auto detects a dropout condition, which is when the FB pin is below the regulation point for more than 32 cycles of the internal clock, the SP7686 automatically switches to the 2X mode. The SP7686 remains in the 2X mode until one of four things happens: 1) the enable pin EN has been toggled, 2) the Flash pin has changed from high to low, 3) VIN is cycled or, 4) a thermal fault occurs. The 2X mode is the charge pump mode where the output can be pumped as high as two times the input voltage, provided the output does not exceed the maximum voltage for the SP7686, which is internally limited to about 5.5V. In the 2X mode, as in the 1X mode, the output current is regulated by the voltage at the FB pin.

### SP7686A

The fixed current driver (SP7686A) uses the flash pin to switch between two internally preset voltage levels, for Flash and Torch mode. The part is enabled and disabled by the separate ENABLE pin. The part has a 3.5s maximum on time in Flash mode. After a 3.5s timeout occurs the part shuts down and can be enabled by the FLASH or ENABLE pins. This

pin cannot be left open. When in Flash mode, (Flash = VIN), the FB regulation voltage is set to 160mV. When in Torch mode, (Flash = GND), the FB regulation voltage is set to 60mV. The output current is then set in either Flash or Torch mode by the equation:

$$I_{OUT} = V_{FB} / R_{SENSE}$$

### SP7686

The digital controlled current driver (SP7686) uses the CTRL pin as a serial data input to a DAC to set the FB voltage. The CTRL pin is used to control LED current. Once enabled the adjustable driver counts positive going edges at this pin and sequentially increases the FB voltage from 60mV with 10mV steps to a maximum 31 steps or 360mV. When this pin is held LOW for longer than 200µs the SP7686 enters shutdown. The part can be enabled using this pin. The first positive edge resets the part. A second positive edge sets the part to VFB=0. A third positive going edge will increase FB voltage to 58mV and subsequent positive edges increment VFB in 9.7mV steps. The voltage level can increase only and must be reset to zero by the 200µs shutdown timer in order to go to a lower current value. The part will be limited to a 3.5s on time when FB voltage is set to 120mV and above. The CTRL pin cannot be left open.

### FLASH TIMEOUT PROTECTION

Due to the high currents typically available in Flash mode, it is necessary to protect the white LED from damage if left on too long. The SP7686 has a timeout in Flash mode of approximately 3.5 seconds after which it will shutdown operation. Operation will not begin again in Flash mode until the Enable pin has been set Low and then High again.

### OVER TEMPERATURE PROTECTION

When the temperature of the SP7686 Rises above 140 degrees Celsius, the over temperature protection circuitry turns off the output switches to prevent damage to the device. If the temperature drops back down below 125 degrees Celsius, the part automatically recovers and executes a soft start cycle.

**OVERVOLTAGE PROTECTION**

The SP7686 has over voltage protection. If the output voltage rises above the 5.5V threshold, the over voltage protection shuts off all of the output switches to prevent the output voltage from rising further. When the output decreases below 5.5V, the device resumes normal operation.

**OVERCURRENT PROTECTION**

The overcurrent protection circuitry monitors the average current out of the VOUT pin. If the average output current exceeds approximately 1.5Amp, then the overcurrent protection circuitry shuts off the output switches to protect the chip.

**APPLICATIONS INFORMATION**

The SP7686 can be used with multiple LEDs in parallel as shown below. For best performance, the LEDs should be in a single package, preferably from a single die to have better matching for forward voltage VF for a given forward current IF. In practice, if the VF of one LED is higher than the others, it will consume a larger IF, which will raise its temperature which will then cause its VF to reduce, correcting the imbalance. The overall current will be the sum of the individual currents, for example  $I_{TOTAL} = 4 \cdot I_{LED}$ .

Figure 24.

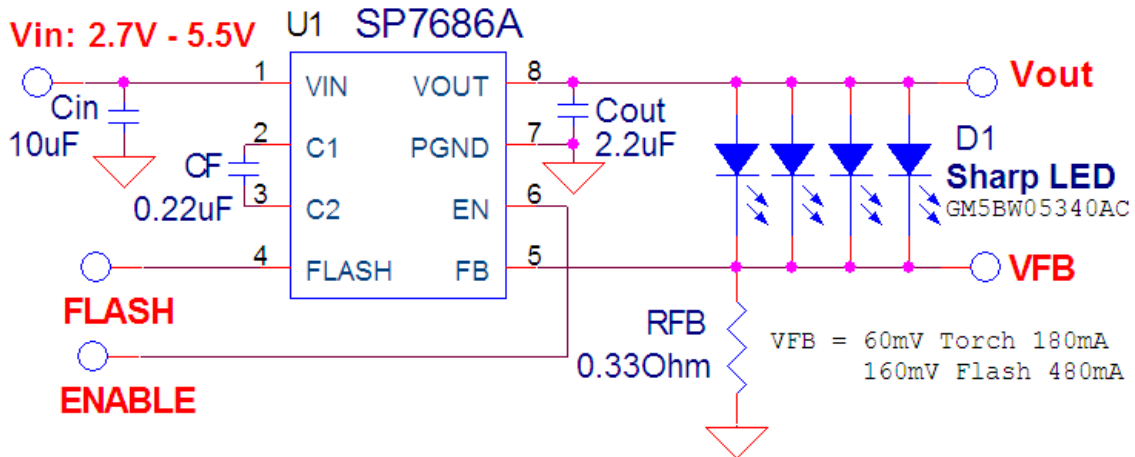


Fig. 1: SP7686 with 4 LEDs in parallel

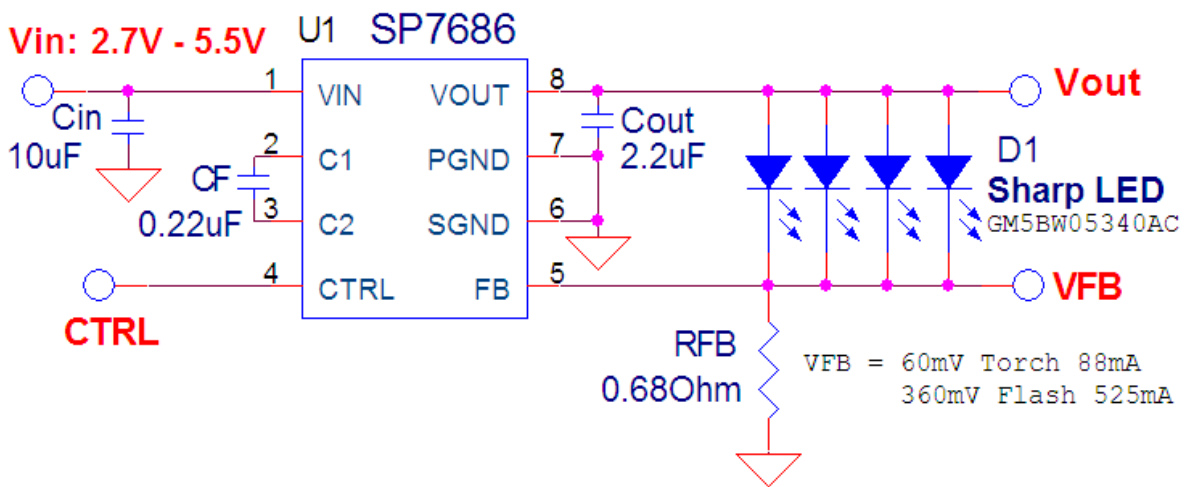


Fig. 2: SP7686A with 4 LEDs in parallel



**APPLICATIONS INFORMATION  
CONT'D**

The SP7686 charge pump circuit requires 3 capacitors: 10µF input, 2.2µF output and 0.22µF fly capacitor are typically recommended. For the input capacitor, a value of 10µF will help reduce input voltage ripple for applications sensitive to ripple on the battery voltage. All the capacitors should be surface mount ceramic for low lead inductance necessary at the 2.4MHz switching frequency of the SP7686 and to obtain low ESR, which improves bypassing on the input and output and improves output voltage drive by reducing output resistance. Ceramic capacitors with X5R or X7R temperature grade are recommended for most applications. A selection of recommended capacitors is included in Table 1 below.

The input and output capacitors should be located as close to the V<sub>IN</sub> and V<sub>OUT</sub> pins as possible to obtain best bypassing, and the returns should be connected directly to the PGND pin or to the thermal pad ground located under the SP7686. The fly capacitor should be located as close to the C1 and C2 pins as possible. See the RECOMMENDED LAYOUT section for details on the recommended layout.

To obtain low output ripple, a value of 2.2µF is recommended for C<sub>OUT</sub>. For all output currents the value for C<sub>FLY</sub> of 0.22µF is recommended. For best regulation and low input current ripple the input capacitor value of 10µF is recommended. A smaller 4.7µF for C<sub>in</sub> will

work but input voltage ripple will increase and may effect regulation.

**RESISTOR SELECTION FOR THE SP7686A**

The 7686A part has fixed FB voltages in Torch and Flash modes so the sense resistor R<sub>SENSE</sub> is determined by the value needed in the Torch or Flash mode for the desired output current by the equation:

$$R_{SENSE} = V_{FB} / I_{OUT} \text{ where } V_{FB} = 60\text{mV (Torch Mode)}$$

$$R_{SENSE} = V_{FB} / I_{OUT} \text{ where } V_{FB} = 160\text{mV (Flash Mode)}$$

Once the R<sub>SENSE</sub> resistor has been selected for one mode, the I<sub>OUT</sub> can be selected for the other mode using the following equation:

$$I_{OUT} = V_{FB} / R_{SENSE}$$

Using an example of Torch current of 180mA and Flash current of 450mA, calculated R<sub>SENSE</sub> for Torch is 0.06 / 0.180 = 0.333 Ohms. Use a standard value of 0.33 Ohms. I<sub>OUT</sub> for Flash mode is 0.16 / 0.33 = 480mA

The power obtained in the Flash mode would be:

$$P_{FLASH} = V_{FB} * I_{OUT} = 160\text{mV} * 480\text{mA} \sim 77\text{mW.}$$

The typical 0603 surface mount resistor is rated 1/10 Watt continuous power and 1/5 Watt pulsed power, more than enough for this application. For other applications, the P<sub>FLASH</sub> power can be calculated and resistor size selected. The R<sub>SENSE</sub> resistor is recommended to be size 0603 for most applications. The range of typical resistor values and sizes are shown here in Table 2.

Manufacturers/ Website	Part Number	Capacitance/ Voltage	Capacitor Size/Type/Thickness	ESR at 100kHz
TDK/www.tdk.com	C1005X5R0J224K	0.22uF/6.3V	0402/X5R/0.55mm	0.05
TDK/www.tdk.com	C1005X5R0J105K	1uF/6.3V	0402/X5R/0.55mm	0.03
TDK/www.tdk.com	C1608X5R0J225K	2.2uF/6.3V	0603/X5R/0.9mm	0.03
TDK/www.tdk.com	C1608X5R0J475K	4.7uF/6.3V	0603/X5R/0.9mm	0.02
TDK/www.tdk.com	C1608X5R0J107M	10uF/6.3V	0603/X5R/0.9mm	0.02
Murata/www.murata.com	GRM155R60J224KE19D	0.22uF/6.3V	0402/X5R/0.55mm	0.05
Murata/www.murata.com	GRM155R60J105KE19D	1uF/6.3V	0402/X5R/0.55mm	0.03
Murata/www.murata.com	GRM188R60J225KE19D	2.2uF/6.3V	0603/X5R/0.8mm	0.03
Murata/www.murata.com	GRM188R60J475KE19D	4.7uF/6.3V	0603/X5R/0.8mm	0.02
Murata/www.murata.com	GRM188R60J106ME19D	10uF/6.3V	0603/X5R/0.9mm	0.02

Table 1: Capacitor Selection



Part Reference	Value	Tolerance	Size	Manufacturers
RSENSE	0.22ohms	1% or 5%	0603	Panasonic or Vishay
RSENSE	0.27ohms	1% or 5%	0603	Panasonic or Vishay
RSENSE	0.33ohms	1% or 5%	0603	Panasonic or Vishay
RSENSE	0.39ohms	1% or 5%	0603	Panasonic or Vishay
RSENSE	0.47ohms	1% or 5%	0603	Panasonic or Vishay
RSENSE	0.56ohms	1% or 5%	0603	Panasonic or Vishay
RSENSE	0.68ohms	1% or 5%	0603	Panasonic or Vishay

Table 2: Resistor Selection

**RESISTOR SELECTION FOR SP7686**

The SP7686 part uses an internal 5 bit DAC to set the LED current. The DAC input is at the CTRL pin. The user inputs a pulse train of up to 1MHz to set the LED current. The DAC sets the feedback voltage point from 58mV to 350mV in 9.7mV steps. The LED current is determined by the equation:

$$I_{LED} = V_{FB}/R_{SENSE}$$

The curves below show the feedback and LED currents for the CTRL pin pulse count and standard R<sub>SENSE</sub> resistor values.

After the desired count is reached the CTRL input must remain high to hold the count. If

the CTRL pin goes low for more than 200µs the part will shutdown. See the timing diagrams in the Typical Performance Characteristics. The first pulse turns on the SP7686. The first pulse needs to occur at least 600µsec after V<sub>IN</sub> is applied in order to activate after the power on reset (POR). The second pulse resets the DAC to 0. The timing between the first and second pulse needs to be 25µsec typical to as long as 75µsec. After the second pulse the feedback voltage remains at ground. The third pulse sets the feedback voltage to 58mV. Subsequent pulses set the feedback voltage in 9.7mV steps as shown previously in the Typical Performance Characteristics.

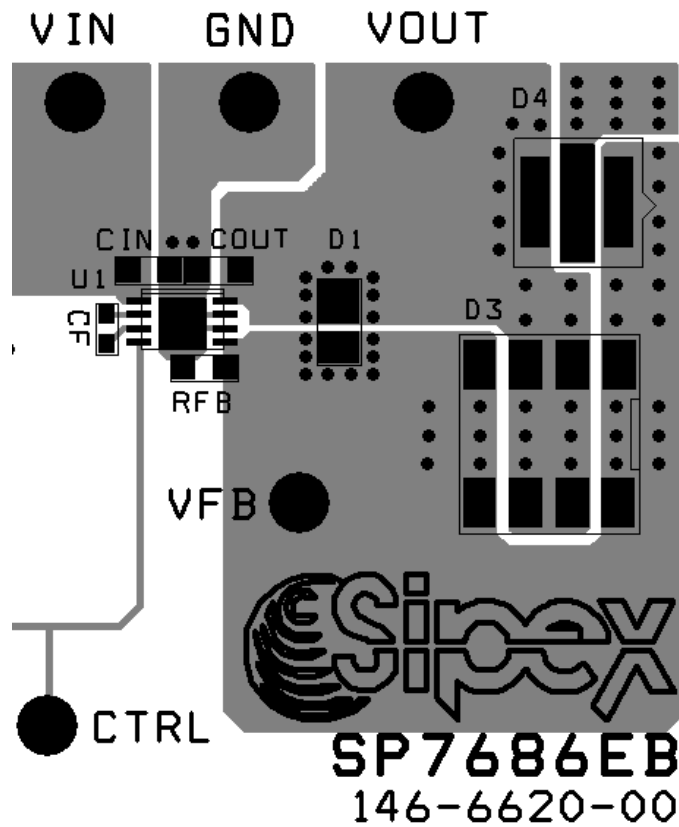


Fig. xx: Example Board Layout

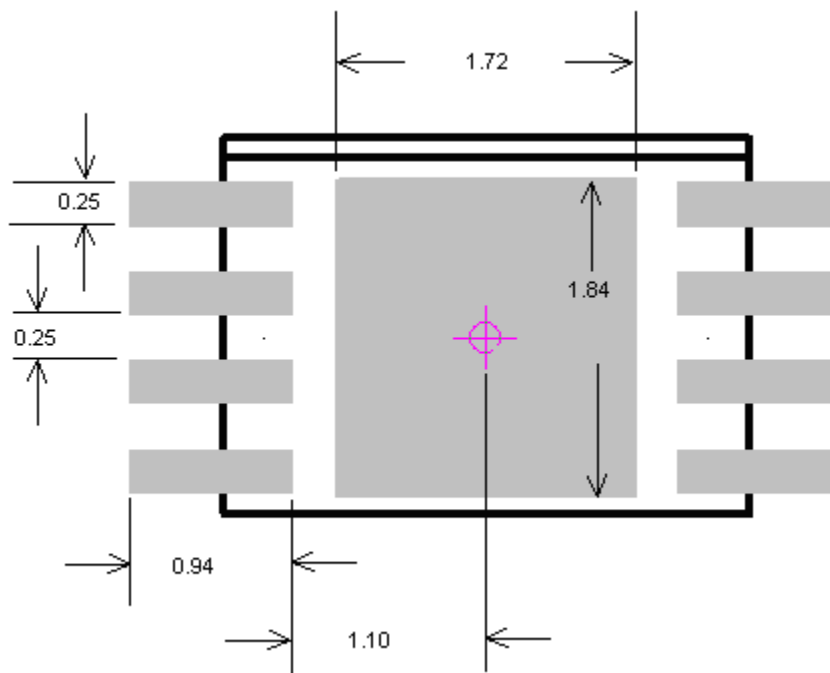
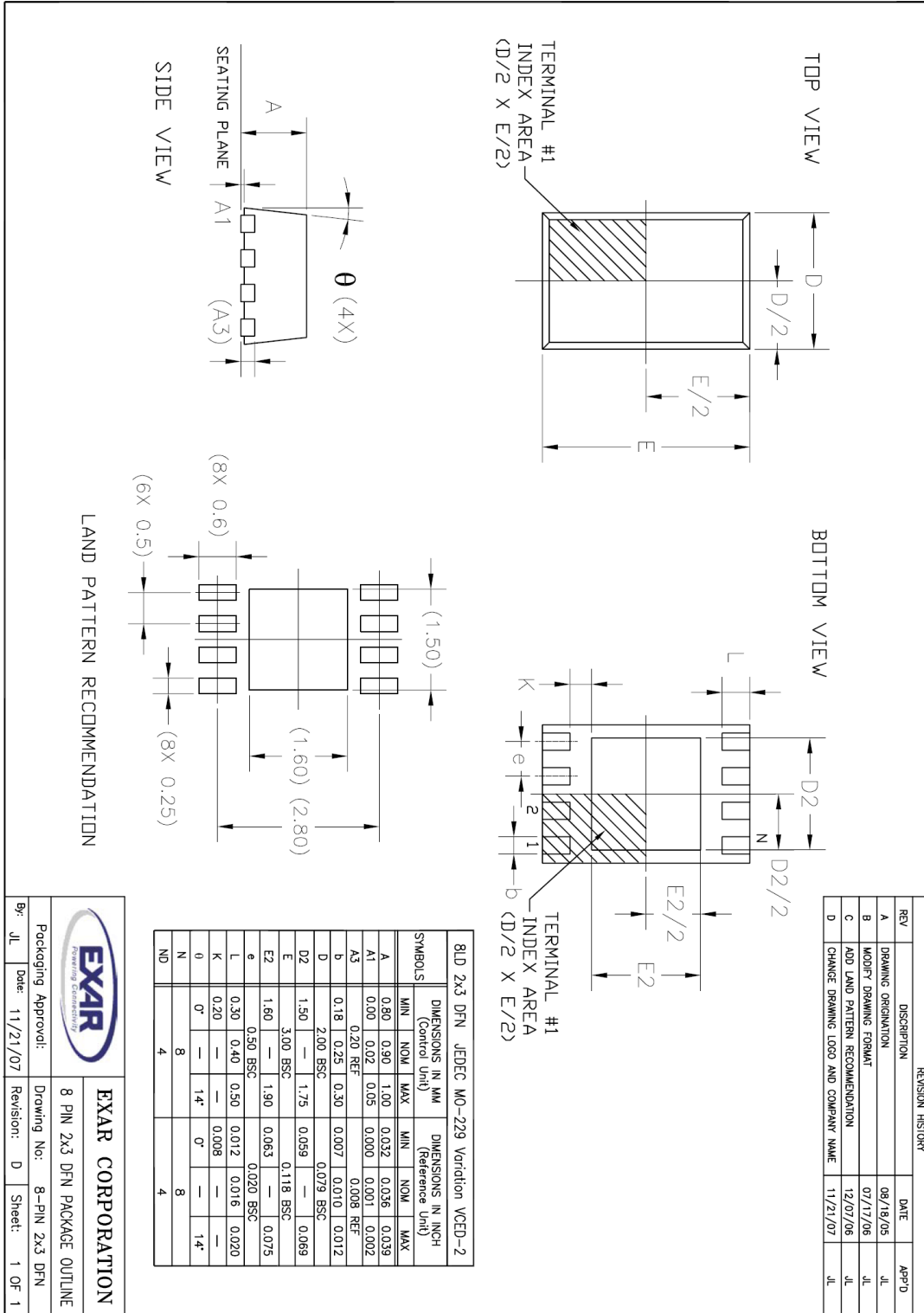


Fig. xx: PCB Footprint for 2x3mm 8pin DFN Package (JEDEC MO-229) All Dimensions in millimeters



PACKAGE SPECIFICATION

2x3MM DFN







**REVISION HISTORY**

<b>Revision</b>	<b>Date</b>	<b>Description</b>
2.0.0	02/20/2010	Datasheet re-write into new format. Previous Revision was P under Sipex logo. Added changes reflected in PCN#10-0201-01
2.1.0	02/26/2010	Fixed resistor values in figure 1 (typical application diagrams) Swapped labels on figures 13 and 14

**FOR FURTHER ASSISTANCE**

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Exar Technical Documentation: <http://www.exar.com/TechDoc/default.aspx?>

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