White LED Flash

Andreas Wacker, Texas Instruments

ABSTRACT

Today's generation of cellular telephones has included megapixel photographic capabilities. Often, the light available for taking a photograph is insufficient and the use of a flash unit as an additional light source is required. This lighting is crucial for yielding good photographic performance and needs careful consideration. This article presents a solution for flash illumination with high power white LED controlled by a single chip boost converter. Furthermore, the setup of a suitable application for a cell phone, smart phone or PDA with small form factor and optimized battery loading are presented.

I. INTRODUCTION

Two practical choices can be considered for flash illumination: Flash tubes and high power white LEDs. A short comparison is shown in Table I.

- Traditional flash units consist of a flash tube in which a flash is created by means of a gas discharge. Using a suitable circuit, the battery charges a capacitor to a level of a few hundred volts, this is then stepped up to a secondary voltage in the kV range by means of an ignition coil. This ignition voltage is released in the flash tube, causing the gas to ionize. The flash arises through recombination and lasts a few milliseconds. During this time, a few hundred Amperes of current flow. The light emitted from the flash tube exhibits a continuous spectrum similar to that of sunlight (a Planck emitter in the color temperature range of 5500°K to 6500° K).
- Recently introduced high power LEDs offer a smart solution for flash applications in small form factor portable equipment. Since the diodes are built in tiny packages and not requiring a high voltage, the complete flash solutions can be more cost and space effective. Just as well the same LED can be used for a torch function or a movie light, by just keeping them on continuously at less current.

TABLE 1: PERFORMANCE CHARACTERISTICS FOR LED- AND FLASH-LAMP-BASED ILLUMINATION

Performance Category	Flash Lamp	LED
Light output	High, typical 10 to 400 times higher than LEDs. Line source output makes even light distribution relatively simple.	Low, point source output makes even light distribution somewhat difficult
Illumination versus time	Pulsed, good for sharp and still picture.	Continuous, good for video.
Color temperature	5500° to 6000°K, very close to natural light. No color correction necessary.	7000°K, requires color correction
Solution size	Typically 3.5x8x4 mm for optical assembly; 27x6x 5 mm for circuitry dominated by flash capacitor (6.6 mm in diameter, may be remotely mounted)	Typically 3x3x2.4 mm for optical assembly; 8x8x1.5 mm for circuitry
Support-circuitry complexity	Moderate	Low
Charge time	1 to 5 sec, depending on flash energy	None, light always available
Operating voltage and currents	Kilovolts to trigger, 300V to flash. I_{SUPPLY} to charge is approximately 100 to 300 mA, depending on flash energy. Essentially zero standby current.	Typically 3.4 Vto 4.2V at 150 mA per LED continuous, 1000 mA peak. Essentially almost 0 standby current.
Battery power consumption	200 to 800 flashes per battery recharge, depending on flash energy.	Approximately 600 mW per LED (continuous light) and 4 W per LED (pulsed light)
Cost factor	High	Low

II. HEADING

A. LED Versus Flash Tube

Due to the increasing brightness of white LEDs, the flash tubes previously used in flash units can be replaced by these LEDs for use in mobile phones and digital cameras. In comparison to flash tubes, LEDs provide the following advantages:

- Higher mechanical stability
- Smaller dimensions
- Lower voltage required to create a flash
- No charging time–flash is immediately available
- RGB-LED
  - adjustable color temperature
  - adaptable spectrum
- Longer flash duration possible
- Longer life

A professional tube flash has much brighter light and is able to cover a longer distance to the object of interest. A build-in camera like in a cellular phone or PDA does not require such a bright light because of the different usage. The application for such a flash must be small in dimension and easy to use.

B. InGaN-Based White LED

Most blue and white LEDs use Indium Gallium Nitrite (InGaN) as active material. The wavelength of the generated light of these LEDs shows a strong dependency on the driving current. This special property of InGaN-based LEDs must be considered well in advance for new application solutions.

To obtain white light, a blue light-emitting die (wavelength 450 nm to 470 nm) is covered with a phosphorous based material that is stimulated by blue light and emits a yellow light. The human eye detects the mixture of blue and yellow light as white. This mixture cannot be described by a simple dominant wavelength but as spectrum. Fig. 1 shows this spectrum of a white LED in comparison to the standard eye response curve. As a consequence of this behavior, the image sensor must to correct this color error to obtain natural colored picture.

Another factor is the wavelength shift of an InGaN-based LED, caused by a change in the forward current. A color shift occurs in the following instances and must be considered as well.

- Dimming InGaN-based LEDs by varying the forward current
- Current balancing when driving multiple InGaN-based LEDs in parallel circuits

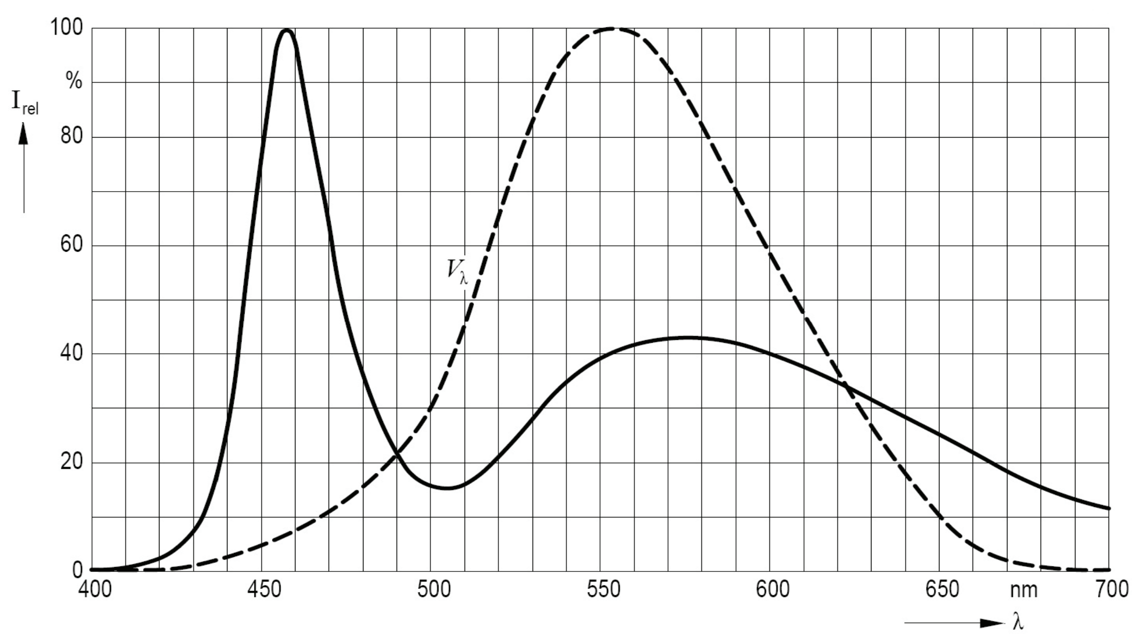

Fig. 1. Spectrum of a typical white LED. The dashed line represents the standard eye response.

The LED characteristics between diodes vary in manufacturing. The ratio of emitted light and LED forward current is one of the major parameters which change during production. Therefore, LEDs are generally preselected in different groups of similar current to light conversion ratio. However, even among these preselected groups of LEDs, the forward voltage still varies about ±0.8V of the nominal value.

Flash Devices for Mobile Phones

In order to build an appropriate flash application for a mobile phone, it is necessary to calculate how much light is needed for a proper picture. The minimal subject illuminance of approximately 5 lx is required, within a coverage range of up to three meters. This can be realized by using a high power white LED. Recently developed LEDs can provide 164 lx at a distance of 0.5 m and 700 mA forward current. Considering that the illuminance is inversely proportional to the square of the distance, the illuminance at a distance of 3 m is about 4.6 lx.

Using the LED as a light source to illuminate a scene for taking a picture requires generating light pulses at the same time the image sensor is active. To optimize the system regarding power consumption and heat dissipation, the LED on-time should be minimized. Synchronization with the image sensor is necessary. Typically, light pulses of 150ms or more are used, depending on the LED light emission capability and the way the image sensor and flash are operating together. So there are two things to solve. The LED current must be controlled and synchronization between the light pulse and the image sensor must be coordinated.

A bright white flash needs a high current and therefore a powerful battery. Today's portable applications are using Li-Ion or Li-Polymer Batteries, because of the high energy density and the small form factor. Cellular phones generally load the battery with high current pulses, mainly driven by the RF amplifier (PA current is about 1.5 A to 2 A). The use of a flash in such a camera adds extra current loading to the battery, which has influence on the discharging cycle time of the battery.

C. Li-Ion Batteries

Under nominal conditions Li-Ion batteries operate from 3.0 V to 4.2V (at 25°C). Much higher and lower temperatures change the behavior of the battery tremendously. High temperatures (>40°C) decrease the lifetime of the battery and lower temperatures increase the impedance of the battery.

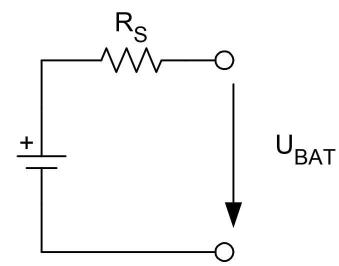

Fig. 2. Equivalent circuit of a battery.

The equivalent electrical circuit of a Li-ion battery consists of two components, an ideal battery and the serial resistor (R_S), representing the battery impedance. To a large extent the battery impedance determines the performance and runtime of a battery. The lower the resistance, the less restriction the battery encounters in delivering the needed power spikes. Even when the battery holds sufficient capacity, the voltage drop across a high serial resistor causes the battery to reach its cut-off voltage and the 'low battery' indicator is triggered. As a consequence, the equipment is reset and/or stops working so the remaining energy is undelivered. This battery behavior is extremely important when a high current LED flash is causing very high peak currents during flash.

The typical serial resistance of a new Li-Ion battery varies from 100 mΩ to 400 mΩ (including contact resistance). This resistance almost doubles after 100 cycles. The battery impedance increase significantly at low state of discharge, or at the end of discharge. It can increase 2-3 times compared with fully charged battery. The additional voltage drop over the serial resistor with an 800 mA current caused by the flash is about 250 mV. This should be taken into account when calculating the cut-off voltage for a cellular phone or PDA. Cellular phones are especially sensitive for high current pulses. Under normal conditions a cellular phone must handle a pulsed current of about 2.5 A which is a very heavy loading for the battery. Because of this, it is extremely important to have a high efficiency converter when high current LED flashes are used.

III. WHY USE A BUCK BOOST CONVERTER

The voltage supplied by typical Li-Ion batteries ranges from about 3 V when discharged up to 4.2 V when fully charged. However, the required forward voltage of a Flash LED can range from 3.2 V to 4.8 V under nominal conditions. During operation this range can extend in both directions. Assuming a minimum Junction Temperature of -40°C and a maximum of +120°C during operation, the required forward voltage ranges from 2.8 V to 5.1 V. Fig. 3. illustrates that the battery voltage does not completely cover the required LED voltage range.

To address these requirements, a regulator must be chosen that is able to cover both, buck and boost conversion.

Since LEDs are current driven devices and their light output is proportional to their forward current the regulating circuit must be a current source to drive the LED with a defined current.

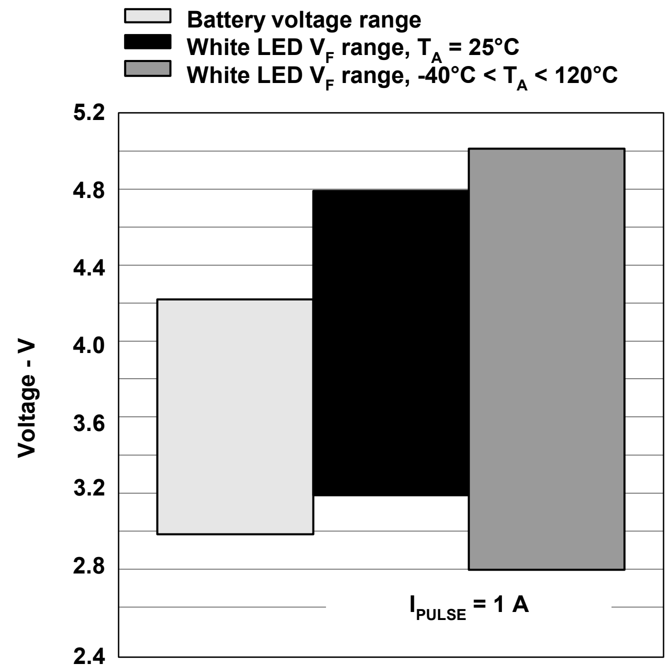

Fig 3. Battery Voltage vs. LED Forward Voltage

A. TPS61058/9: The Heart of the Solution

The TPS61058/9 devices are fixed frequency, synchronous boost DC/DC converters with an integrated down conversion mode (see Appendix). The devices are optimized for driving high power single cell white LEDs up to 800 mA LED forward current from a 2.7-V to 5.5-V input. External resistors program the LED current to different levels (e.g. torch, flash). The boost converter is based on a 650-kHz fixed frequency, pulse-width-modulation (PWM) controller with integrated power MOSFETs to obtain maximum efficiency. The maximum peak current in the boost switch is limited to 1000 mA (TPS61058) and 1500 mA (TPS61059).

To maximize battery life, the load is completely disconnected in the shutdown mode and the current consumption is reduced to less than 1 µA. Fig. 4. shows a standard circuit, using two current settings for torch- and flash mode.

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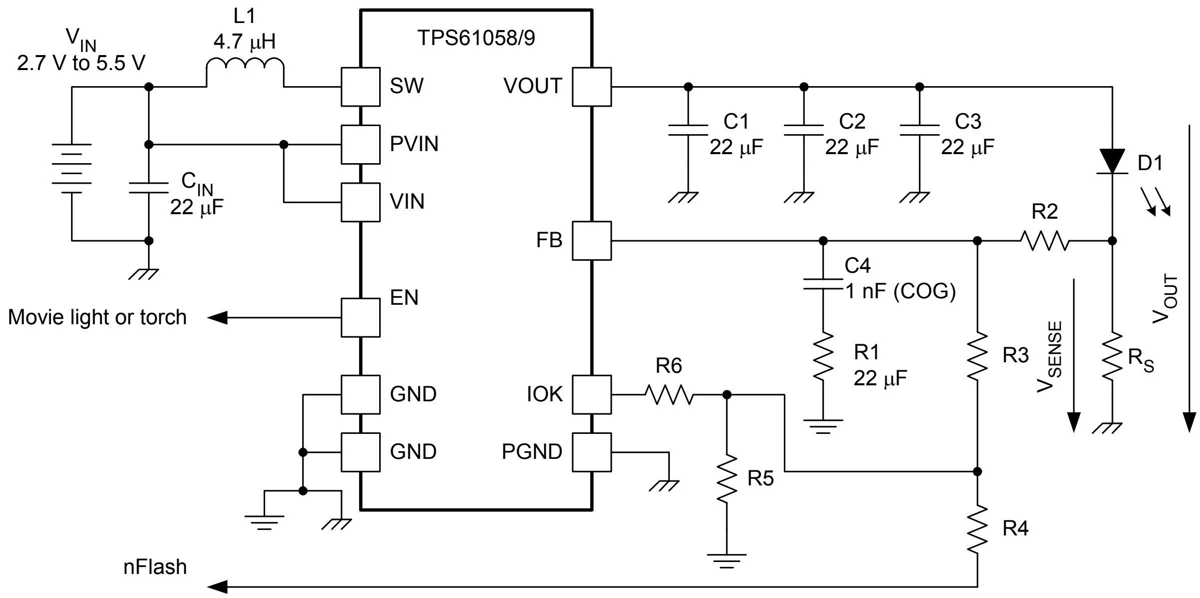


Fig. 4. Typical schematic for a two light mode application

The TPS6105x fulfills both attributes to be used as a flash driver. Fig 4. shows a typical schematic for using the LED in two current modes. In low current mode, when the enable pin and nFLASH is set to HIGH, it can be used as a torch or movie light. In a high current mode, nFLASH is LOW, it drives the LED for flash illuminationOne critical aspect of boost converters is the start-up phase. Since the load is permanently connected to the output, the converter must have a higher start-up current capability than the LED startup current.

B. *Secure Start-Up Due to Controlled Pre-Charge*

To avoid high inrush current during the start-up, special care is taken to control the inductor current in this phase. When the device is first enabled, the output capacitor is charged with a constant pre-charge current of 115 mA until either the output voltage is 0.1-V below the input voltage or the voltage at the feedback pin is 500 mV. The synchronous switch acts as a constant current source during the pre-charge phase. This also limits the output current under short circuit conditions at the output. The fixed pre-charge current during the start-up allows the device to charge the output capacitor without having a high current through the load.

Resistors R4 and R5 set the LED's startup current to 90 mA which ensures that the LED startup current is lower than the IC's pre-charge current. When the device has finished start-up and is ready for high current operation, the device connects IOK output to ground, starts switching and regulates the LED current to the desired value (e.g. torch or flash current level).

The accurate calculation of all external components is very important to get a stable working application within the wanted parameters.

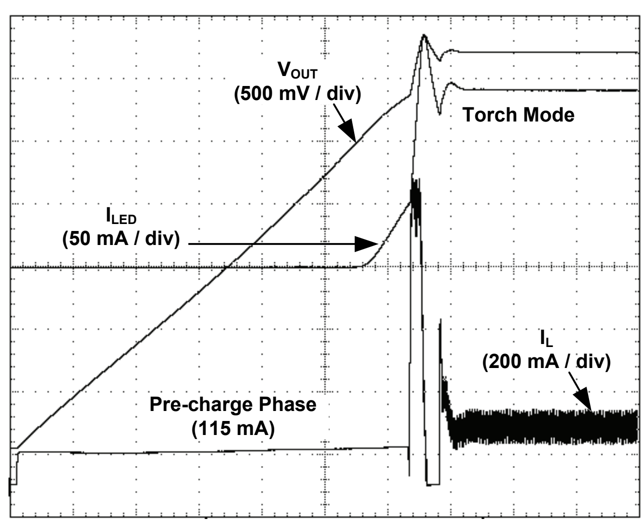


Fig. 5. Typical Startup of the TPS61058

III. Calculating the External Resistor Network

A. Sense Resistor, R_S

The voltage across the sense resistor should be set to 0.75 V at maximum LED current.

$$R_S = \frac{V_{SENSE}}{I_{LED}} \tag{1}$$

Check the power rating of the sense resistor ($P_D = R_S \bullet I_{LED}^2$).

B. LED Current Setting

Fig 6. shows an equivalent circuit for the feedback network. The regulation loop uses an external control voltage (nFLASH) to set the LED current. With the help of this voltage, the feedback bias current (I_{BIAS}) can be adjusted to control the LED current without changing any external components.

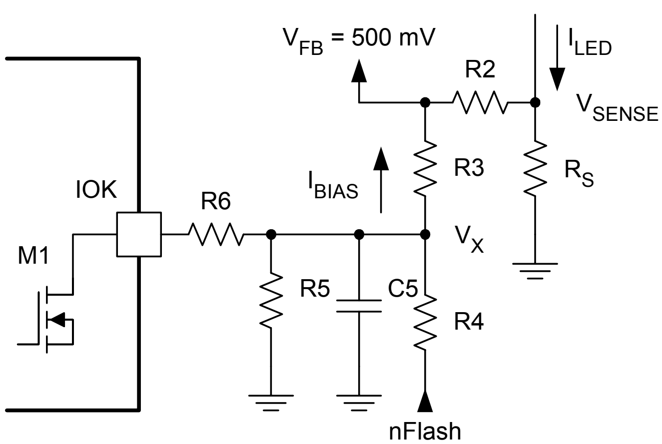


Fig 6. Feedback network equivalent circuit.

In practical applications, nFLASH can either be:

- A constant bias voltage (1.8 V for example) which in combination with IOK can be used to switch between two LED currents (off, flash).
- A logic signal generated by the imaging processor. This configuration permits three different LED currents: off, movie-light (nFLASH = High) and flash (nFLASH = Low).

The circuit operation can be split into different phases:

1. Pre-Charge Phase (IOK = Hi-Z)

During this phase IOK is kept high-impedance. For proper startup the external loop components must be chosen so that the regulation loop can settle for a maximum LED current of less than 80 mA. This is achieved by increasing the bias voltage (V_X) of the feedback network.

$$I_{LED} = \frac{0.5 - (R2 \bullet I_{BIAS})}{Rs} \tag{2}$$

$$I_{BIAS} \approx \frac{R5}{R3 \bullet (R4 + R5)} nFLASH - \frac{0.5}{R3}, \tag{3}$$

assuming R4||R5 is small compared to R3.

2. High-Current Operation (IOK = GND)

After the pre-charge phase, IOK is automatically pulled to ground. This modifies the feedback divider network changing the potential of the V_X node. As a consequence the LED current is adjusted accordingly.

$$I_{LED} = \frac{0.5 - (R2 \bullet I_{BIAS2})}{Rs} \approx \frac{1}{2 \bullet Rs} + \frac{R2}{2 \bullet R3 \bullet Rs} - \frac{R2}{R3 \bullet Rs} V_X \tag{4}$$

$$I_{BIAS2} \approx \frac{R5'}{R3 \bullet (R4 + R5')} nFLASH - \frac{0.5}{R3}, \tag{5}$$

with $R5' = \frac{R5 \bullet R6}{R5 + R6}$

For operation at maximum LED current (flash mode), nFLASH needs to be set to ground level.

$$I_{LED(FLASH)} \approx \frac{R2 + R3}{2 \bullet R3 \bullet Rs} \tag{6}$$

assuming R4||R5||R6 is small compared to R3.

For operation at other LED currents (movie-light or pre-charge), nFLASH applies a positive bias voltage (1.8 V for example) to the feedback divider network. The following equations show the relationship between LED current and bias voltage V_X.

$$V_X \approx \frac{1}{2} + \frac{R3}{2 \bullet R2} - I_{LED(MOVIE-LIGHT,PRE-CHARGE)} \frac{R3 \bullet Rs}{R2} \tag{7}$$

$$V_X \approx \frac{R5'}{R4 + R5'} nFLASH \text{, with } R5' = \frac{R5 \bullet R6}{R5 + R6} \tag{8}$$

For stable operation, R3 must be set in the range of 50 kΩ to 150 kΩ and R5 in the range of 3.3 kΩ to 10 kΩ. Best performance is obtained with a pre-charge current of 45 mA (typ)..

The following example is used to explain the procedure to size the external components for a given set of requirements:

- Movie-light mode: I_{LED} = 150 mA.
- Flash mode: I_{LED} = 500 mA.
- LED forward voltage: $V_{F\ (MAX)}$ = 4.5V @ 500 mA.
- nFLASH signal is 1.8-V logic compliant (0 V and 1.8 V ± 5%).
-

Step 1 – Current sense resistor calculation – R_S

$$R_s = \frac{V_{SENSE}}{I_{LED}} = \frac{0.75}{0.5} = 1.5\Omega \tag{9}$$

$V_{OUT(MAX)}$ $= V_{F\ (MAX)} + V_{SENSE}$
$= 4.5 + 0.75 = 5.25$V

Step 2 – Feedback divider resistor calculation – R2, R3

$$I_{LED(FLASH)} \approx \frac{R2 + R3}{2 \bullet R3 \bullet Rs} \tag{10}$$

R3 = 100 kΩ (recommended value)
R2 = 51 kΩ (calculated)

Step 3 – Bias resistor network calculation – R4, R5, R6

$$V_X \approx \frac{1}{2} + \frac{R3}{2 \bullet R2} - I_{LED} \frac{R3 \bullet Rs}{R2} \tag{11}$$

V_X = 1.05 V @ I_{LED} = 150 mA (movie-light)
V_X = 1.35 V @ I_{LED} = 45 mA (pre-load)

During the pre-charge phase, IOK is high impedance.

$$V_X \approx \frac{R5}{R4 + R5} nFLASH \tag{12}$$

$$\frac{R5}{R4 + R5} = 0.75 \tag{13}$$

R5 = 6.2 kΩ (Set between 3.3 kΩ and 10 kΩ)
R4 = 2.0 kΩ (calculated
In movie-light mode, IOK is grounded.

$$V_X \approx \frac{R5'}{R4 + R5'} nFLASH \tag{13}$$

$$\frac{R5'}{R4 + R5'} = 0.58, \tag{14}$$

$$R5' = 1.57 \bullet R4, \quad R5' = \frac{R5 \bullet R6}{R5 + R6} \tag{15}$$

R6 = 5.1 kΩ (calculated)

To make life easier, there is a calculation spread sheet available, which calculates all resistor values. This spread sheet allows the user to change the values for V_{SENSE} and the pre-charge current in order to fit all possible setups. The spread sheet can be found in the product folder on TI web.

Typical boost converter architectures need two main passive externals for storing the energy during conversion. These two components are an inductor and a storage capacitor at the output.

C. Inductor Selection

To select the boost inductor, keep the possible peak inductor current below the current limit threshold of the power switch in the chosen configuration. For example, the current limit threshold of the TPS61059 switch is 1700 mA at an output voltage of 5 V. The highest peak current through the inductor and the switch depends on the output load, the input voltage and the output voltage. Estimate the maximum average inductor current using the following equations.

$$I_L = I_{OUT} \bullet \frac{V_{OUT}}{V_{IN} \bullet 0.8} \tag{16}$$

$$V_{OUT} = V_{F(LED)} + R_S \bullet I_{LED} \tag{17}$$

The second parameter for choosing the inductor is the desired current ripple in the inductor. In order to optimize the solution size, an inductor current ripple as high as 40% of the average inductor current can be tolerated. The inductor current ripple is always a tradeoff between system performance and other aspects, like solution size or cost. The current ripple also influences the over all radiated noise of the system. A smaller ripple reduces the magnetic hysteresis losses in the inductor, as well as output voltage ripple and EMI. With those parameters, the value for the inductor can be calculated by using equation (18):

$$L = \frac{V_{IN} \bullet (V_{OUT} - V_{IN})}{\Delta I_L \bullet f_{Switch} \bullet V_{OUT}} \tag{18}$$

Parameter f_{Switch} is the switching frequency and ΔI_L is the ripple current in the inductor, i.e., 40% of I_L. The load transients and losses in the circuit can lead to higher currents as estimated in equation (19). Also, the losses in the inductor caused by magnetic hysteresis losses and copper losses are a major parameter for total circuit efficiency and described in the following chapter.

D. Capacitor Selection

Input Capacitor

For good input voltage filtering low ESR ceramic capacitors are strictly required. At least a 10-µF ceramic capacitor is recommended to improve the transient behavior of the regulator and EMI behavior of the total power supply circuit. The input capacitor must be placed as close as possible to the input pin of the converter.

Output Capacitor

The major parameter that defines the output capacitor is the maximum allowed output voltage ripple (ΔV) of the converter. This ripple is determined by two parameters of the capacitor, the capacitance and the ESR. It is possible to calculate the minimum effective capacitance needed for the defined ripple, supposing that the ESR is zero, by using Equation (19).

$$C_{MIN} = \frac{I_{OUT} \bullet (V_{OUT} - V_{IN})}{\Delta V \bullet f_{Switch} \bullet V_{OUT}} \tag{19}$$

To get the total output ripple, an additional component of ripple must be taken into account. This component is generated by the equivalent series resistance (ESR) of the capacitor and can be calculated in Equation (20).

$$\Delta V_{ESR} = I_{OUT} \bullet R_{ESR} \tag{20}$$

The total ripple voltage is the sum of the ripple caused by charging/discharging the capacitance and the ripple voltage caused by the ripple current flowing through the ESR of the capacitor. Additional ripple is caused by load transients. This means that the output capacitor must completely supply the load during the charging phase of the inductor. A reasonable value of the output capacitance depends on the speed of the load transients and the load current during the load change. For the high current white LED application, a minimum of 20 µF effective output capacitance is usually required when operating with 4.7-µH (typ.) inductors. For solution size reasons, this is usually one or more X5R/X7R ceramic capacitors.

Example

- Output current = 500 mA
- Output voltage = 4.5 V
- Switching frequency = 650 kHz
- Minimum input voltage = 3.3 V
- Inductor input ripple current = 40% of input current maximum
- Output ripple =15 mV (This value is depending on the application needs)
- ESR = 10 mΩ (This value depends on the type of capacitor)

$$I_L = 0.5A \bullet \frac{4.5V}{3.3V \bullet 0.8} \tag{21}$$

$\Rightarrow I_L = 0.85\text{A} \Rightarrow \Delta I_L = 0.34\text{A}$

$$L = \frac{3.3V \bullet (4.5 - 3.3)}{0.34A \bullet 650kHz \bullet 4.5V} \Rightarrow L = 4.0\ \mu H \quad (22)$$

$$\Delta V_{ESR} = 0.5A \bullet 0.01\Omega \Rightarrow \Delta V_{ESR} = 5\ mV \quad (23)$$

$$\Delta V = \Delta V_{total} - \Delta V_{ESR} \Rightarrow \Delta V = 10\ mV \quad (24)$$

$$C_{MIN} = \frac{0.5A \bullet (4.5V - 3.3V)}{0.01V \bullet 650kHz \bullet 4.5V} \quad (25)$$

$$\Rightarrow C_{MIN} = 20.5\ \mu F$$

The total output ripple is the addition of the estimated output ripple ΔV, which was used for the C_{MIN} calculation and the voltage drop ΔV_{ESR} over the output capacitor.

Total output ripple = 15 mV

The output voltage, under nominal temperature conditions, can vary from 3.75 V up to 5.15 V because of the forward voltage range of the LED. This has influence on the inductor as well as on the capacitor calculation. For this reason the chosen values of the inductor is 4.7 µH.

The choice of output capacitor must take into account the DC bias effects (see appendix) regarding the effective capacitance of ceramic capacitors (X5R/X7R) which decrease the capacitance drastically. This decrease can be more than 50% of the nominal capacitance. In addition to that there is also an aging effect, which reduces the capacitance over time.

There are three choices to reduce this DC bias effect:

- A capacitor with a higher rated voltage (>50%) than the output voltage of the regulator
- A capacitor with a bigger physical dimension. Larger physical size reduces the DC bias effect.
- Additional capacitors (1 or 2) of the same size and value in parallel.

Any of these choices increase circuit performance. The final decision must take the entire system into account. To keep the form factor small and the height as low as possible, the author chose three capacitors in parallel. Parallel capacitors also reduce the ESR of the overall output capacitance and therefore decrease the output ripple. In Fig. 7 the simulated output voltage of a boost converter using different capacitors can be seen. The upper graph shows a ceramic capacitor of 22 µF with a very low ESR of 5 mΩ. The curve below shows the graph of a capacitor with an ESR of 50 mΩ.

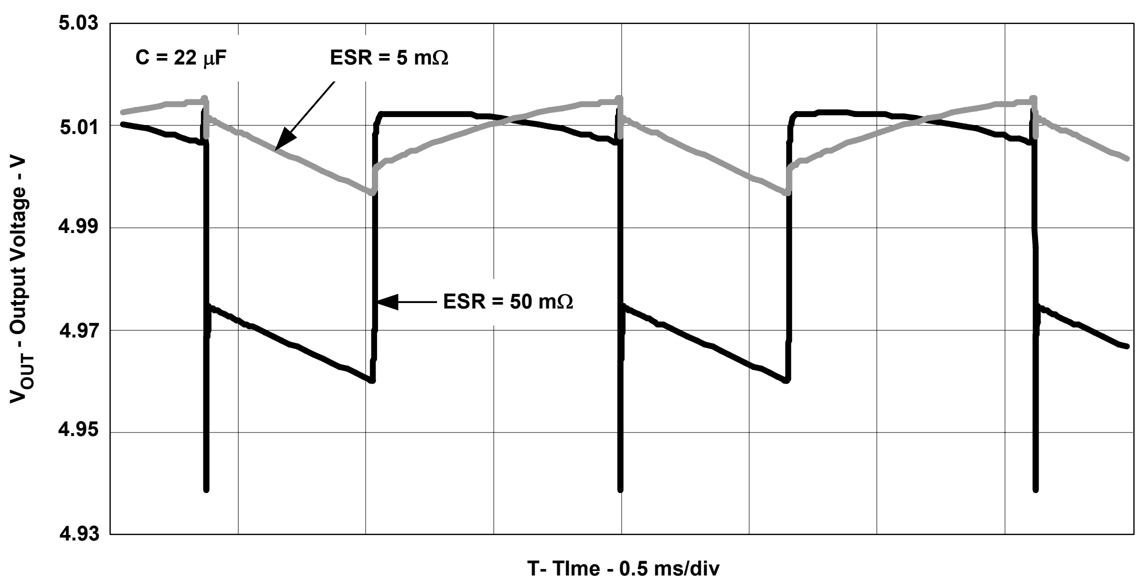


Fig. 7. ESR at different capacitance levels.

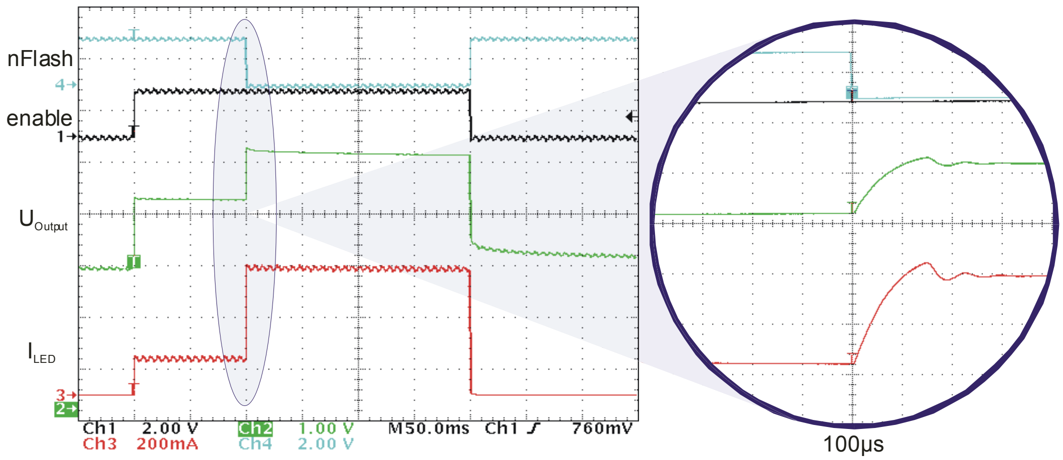


Fig. 8. Signal behavior when flash is activated.

E. Measurements

It is important that the flash can be synchronized with the image sensor therefore a short settling time for the output current and as well the output voltage is necessary. Fig. 8 shows the behavior of the TPS61058 regarding its control signals. The magnified view shows that the current through the LED has settled after less than 250 µs. Assuming that the typical exposure time is about 1/60s, the turn-on time is only 1.5% of the total flash time and therefore it is negligible.

The efficiency of a circuit like the introduced white LED flash is important for its use in mobile equipment. Higher the efficiency generates lower battery loading longer standby times.

The efficiency of the circuit is shown in Fig. 8. In the example shown here, the efficiency is mainly influenced by the current through the LED and especially through the sense resistor. Since the power dissipated in the sense resistor is rising with the current through the LED, the efficiency drops with higher currents. For example, when the LED is used as flash the power over the sense resistor is about 17.6% of the LED power, in torch mode it is only 5.9%.

After selection of all components, the PCB layout comes into focus. A well done layout is important especially in a cellular phone where the interference with other circuits must be minimized. Strong specifications compel mobile phone manufactures to keep the emission of unwanted electromagnetic radiation as small as possible. This radiation is known as electromagnetic interference (EMI) or as radio frequency interference (RFI).

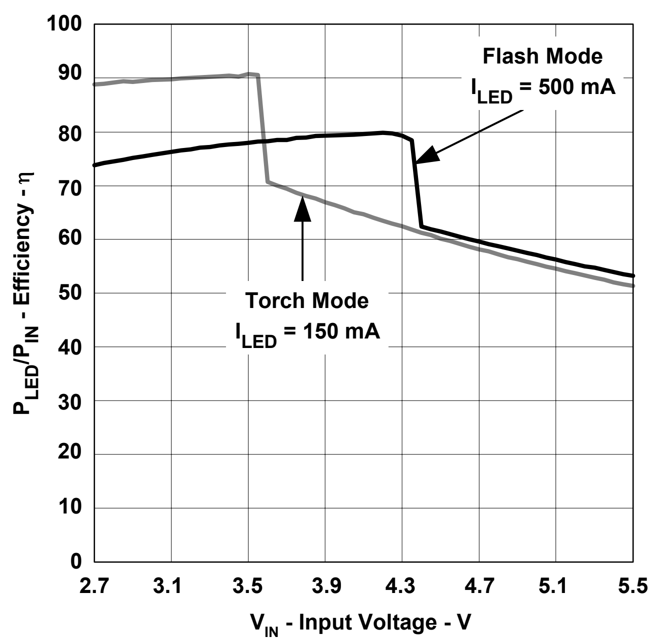


Fig. 9. Efficiency plot for flash and torch mode.

V. LAYOUT MADE EASY

To design a good power supply layout a different set of guidelines must be considered in comparison of those most digital and analog designs would use.

Experienced power-supply designers first consider the power-generating portions of the layout because these are mostly the source of noise and interference. Second, they consider sensitive nodes in the layout that are susceptible to interference.

An efficient power supply layout limits EMI and RFI by having small high-current loops, proper grounding of the control stage and well sized traces to handle peak currents. Small current loops achieve two things: They generate less radiation, and they produce less magnetic coupling between adjacent circuitry.

A. Power Stage: The First Place to Look

This portion of the layout features the highest circulating currents and is therefore one of the main sources of EMI. The primary guideline in power supply layout is to keep the loops in the power stage as short as possible.

In a boost power stage, the input current flows through the input capacitor, the inductor, and the power switch (see Fig. 10). In the second cycle, the accumulated energy in the inductor flows through the rectifier before splitting between the output capacitor and the LED. By placing the input capacitor, the inductor, the power IC and the output capacitors as close together as possible, the loop areas of these current flows are kept to a minimum and the circuit produces less EMI.

B. Feedback Network: A Noise Sensitive Node

The feedback network is high impedance and therefore very sensitive to pickup noise. Strategically placed ground connections can be critical to the performance of this stage. Any voltage difference between the grounds at the feedback network and the IC ground results in an error in the output voltage.

The feedback path from the low-impedance output through the sense resistor is not as critical as the path from the sense resistor to the high-impedance feedback (FB) input. The path from the sense resistor to the error amp should be as short as possible and routed away from any switching traces to reduce noise pickup.

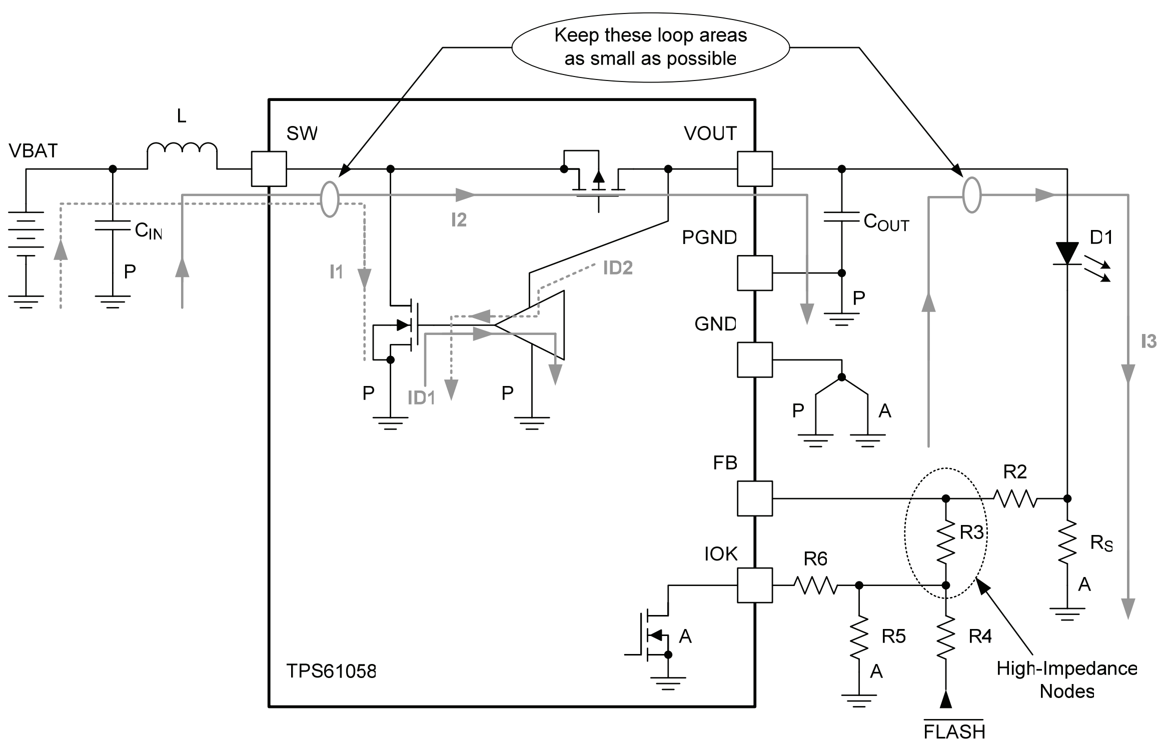


Fig. 10. Current path in the power stage.

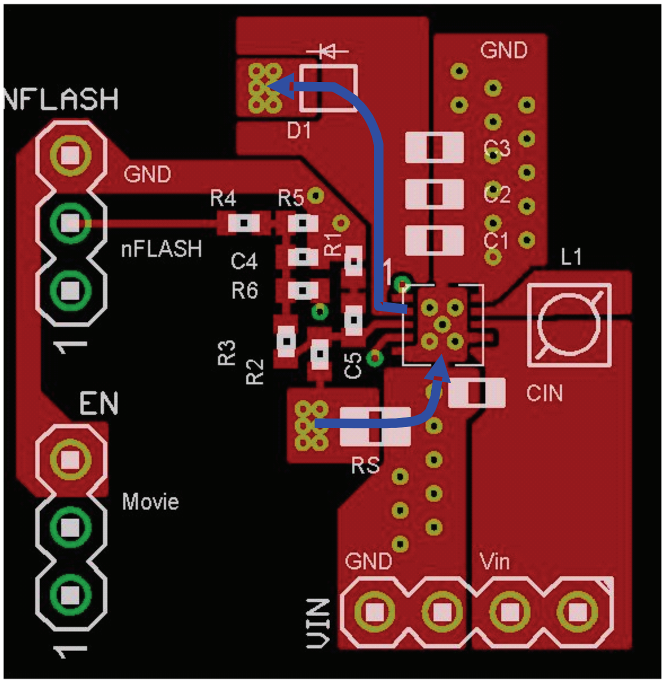


Fig. 11. Suggested layout (top side)

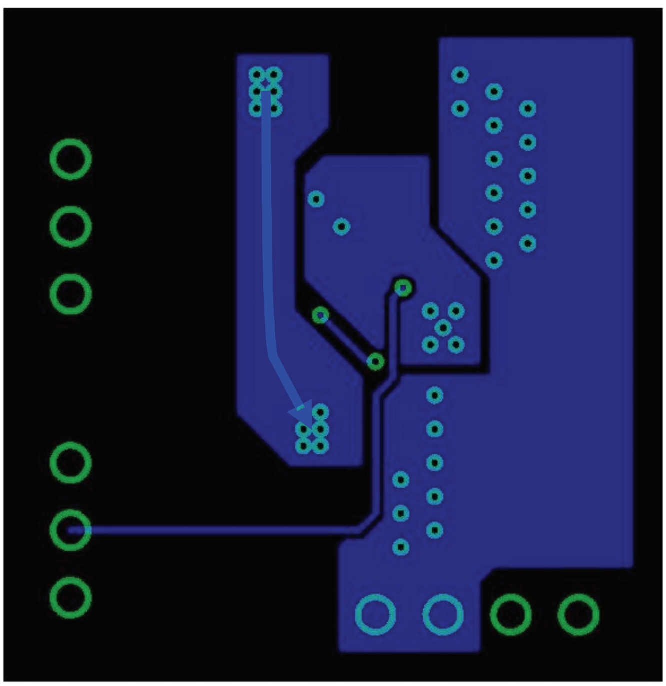


Fig. 12. Suggested layout (bottom side)

Designers should ground the converter's power stage to its output ground (PGND) and the feedback network including the sense resistor should be referenced to the converter signal ground (GND). Connect these ground nodes together in a star configuration at any place close the GND pin of the IC. Ideally this should be done close to pin 5 and the copper region underneath the IC PowerPAD™ can be used insure a low-impedance interconnection between GND and PGND (see Fig. 11)

VI. Conclusion

The introduced circuit has shown that it is possible to build flash solution for handheld equipment with a reasonable form factor and efficiency thus avoiding excessive battery loading preventing from unwanted system reset. The TPS61058/9 provides the flexibility to generate multiple flash modes required for camera flash application. By following the layout rules, EMI, noise and interference with the adjacent circuitry can be avoided.

VII. References

[1] Texas Instruments, TPS61058/9 Datasheet (SLVS572)

[2] Bill Johns, Application Note (SLVA199) *TPS6102x Boost Converter Down Conversion Mode*, Texas Instruments

[3] Monika Rose, Article: LEDs for Strobe Lights, Osram

I. DOWN CONVERSION MODE

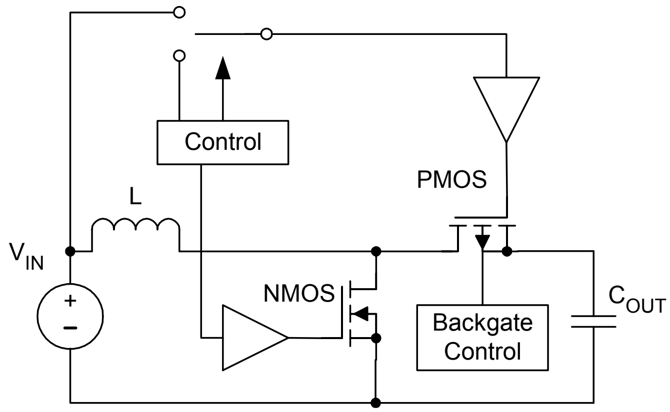


Fig. 13. Boost converter with Down Mode block diagram.

Down conversion mode is a combination of a boost converter and LDO regulator. When input voltage exceeds output voltage, the converter enters the down conversion mode. The synchronous rectification PMOS is reconfigured to act as a pass transistor similar to a LDO (see Fig. 13). The boost converter continues to switch and increase input voltage.

The PMOS gate is connected to V_{IN} which prevents the device from turning on when the NMOS transistor is on. In this configuration, the gate voltage is fixed at V_{IN} and the source voltage is adjusted to control conduction of the PMOS transistor by the boost converter.

The boost portion of the converter formed by the inductor and NMOS transistor continues to operate in the boost mode, increasing voltage at the PMOS transistor source (see Fig. 14). Voltage gate to source is increased only enough to place the PMOS transistor into a linear region to act as a pass transistor. This threshold voltage, V_T is about 1 V and increases as a function of output current, approximately 1 mV per 1 mA. In this configuration, the boost converter acts as a control element increasing inductor voltage, which in turn sets conduction of the PMOS transistor.

During NMOS transistor on-time (time D), the PMOS transistor is off and load current is supplied by the output capacitor, the same as occurs in boost mode. When the NMOS transistor is off (time 1-D), inductor voltage increases the PMOS transistor gate-to-source voltage to V_T, and it begins to conduct. Voltage drop across the PMOS transistor during this time is ($V_{IN} + V_T$).

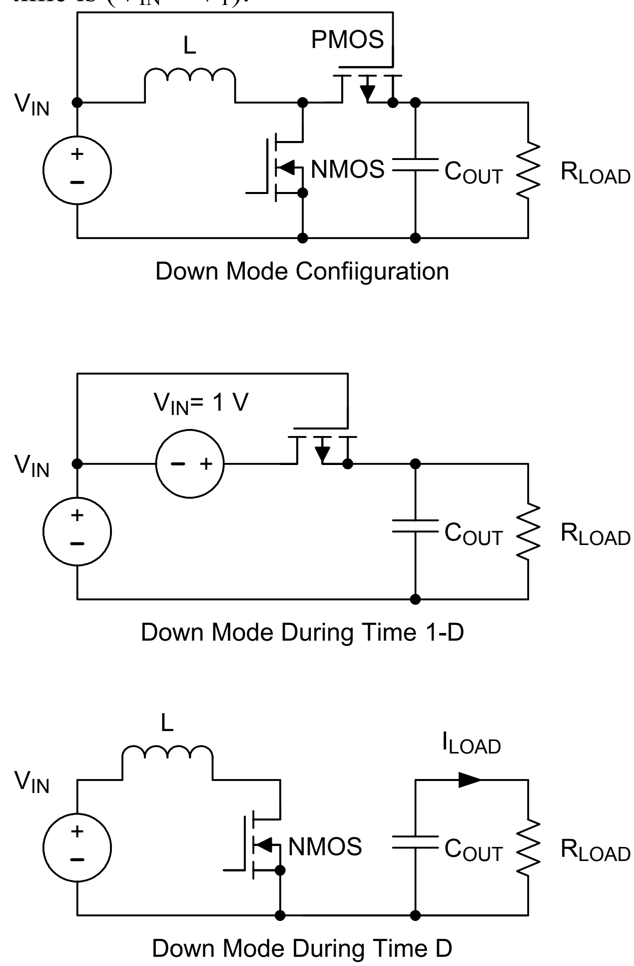


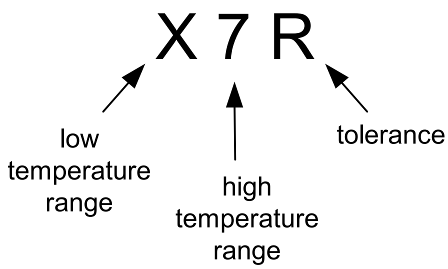
Fig. 13. Simplified Down Mode block diagrams.

For more information please review the application note *A Step-Down Conversion Concept for a PWM-Mode Boost Converter* written by C. Schimpfle and F. Kirchner from Texas Instruments (SLVA144).

A. Effective Capacitance of Class 2 Capacitors

There are two different kinds of ceramic capacitors, separated into class 1 (COG) and class 2 (X7R, X5R and Y5V). The main different between these two classes is the material and therefore the range of capacitance which is feasible. The capacitance available in class 1 ranges from picoFarads (pF) up to tens of nanoFarads (nF), which is quite not enough for applications we describe here. Only class 2 capacitors cover the range of capacitance that is needed for such circuits and therefore we must live with the limitations of these capacitors.

TABLE 2. CLASS II CAPACITOR DEFINITION.



Temperature (°C)		Tolerance (%)
Low	**High**	
X: -55	5: 85	R; ±15
Y: -30	6: 105	S; ±22
Z: 10	7: 125	U: +22/-56
	8: 155	V; +22/-82

B. Effective Capacitance Due to DC Bias Effect

Depending on the material, the form factor and the rated voltage versus the actual applied voltage of a capacitor, degradation on the effective capacitance can be observed. This loss of capacitance is related to the DC bias voltage applied. Some capacitor vendors are specifying this effect (see Fig. 15), but most of them are not. Therefore it is always recommended to check that in the circuit or in any other test setup a reliable and stable working power supply design is build.

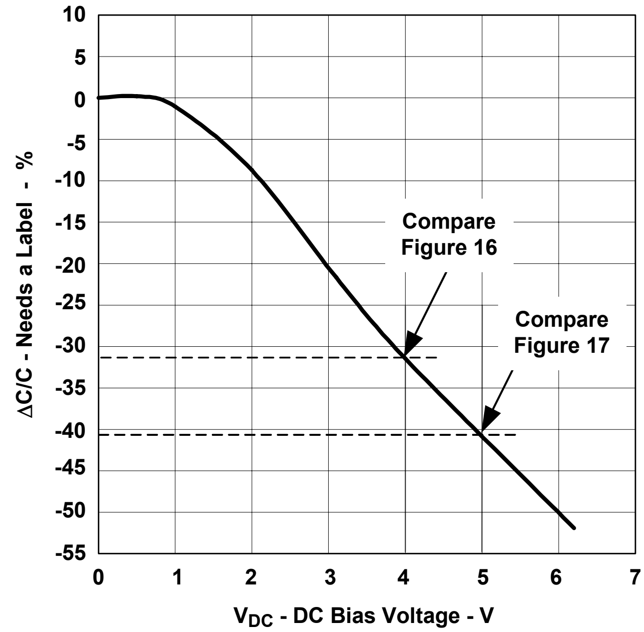


Fig.15: DC bias characteristics of a 22μF ceramic capacitor (X5R) with a rated voltage of 6.2V and a size of 2.0 mm x 1.25 mm.

A simple way to measure the effective output capacitance of a boost converter is to look at the output voltage ripple during the discharge phase of the output capacitor. This occurs when the main switch is turned on and the input current is charging the inductor. During the on time of the main switch the capacitor is discharging into the load and no other current is flowing. So the following equation can be used to determine the real value of the capacitor:

$$C = \frac{I \bullet \Delta t}{\Delta V} \qquad (26)$$

Fig. 16. shows the output voltage ripple of a boost converter with three 22-μF capacitors at the output. The rated voltage of these capacitors is quoted with 6.2 V. The output voltage is 4 V. According to Fig. 17, the effective capacitance should be less than 60% of the real value.

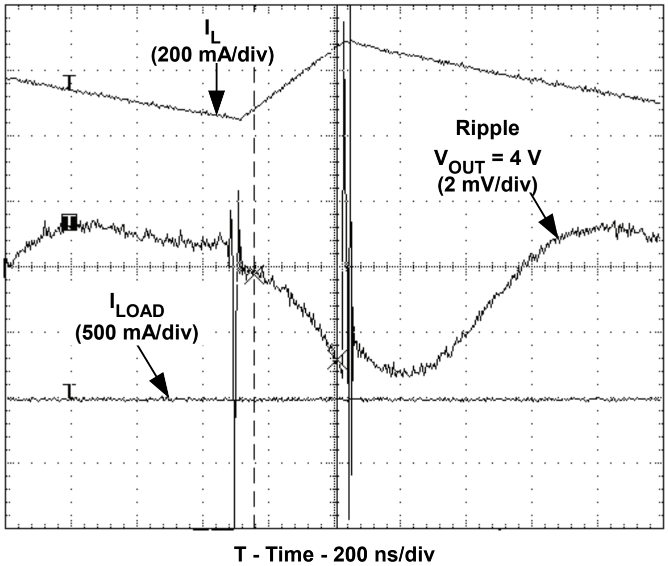


Fig. 16. Boost converter output voltage.

The calculation of the effective capacitance using the values measured with the scope is as follows:

$$C = \frac{252ns \bullet 488mA}{2.60mV} = 47.3\,\mu F \tag{27}$$

Fig. 17. shows output from the same circuit but with a higher output voltage. The output capacitors have not changed, only the margin between rated voltage and output voltage has decreased.

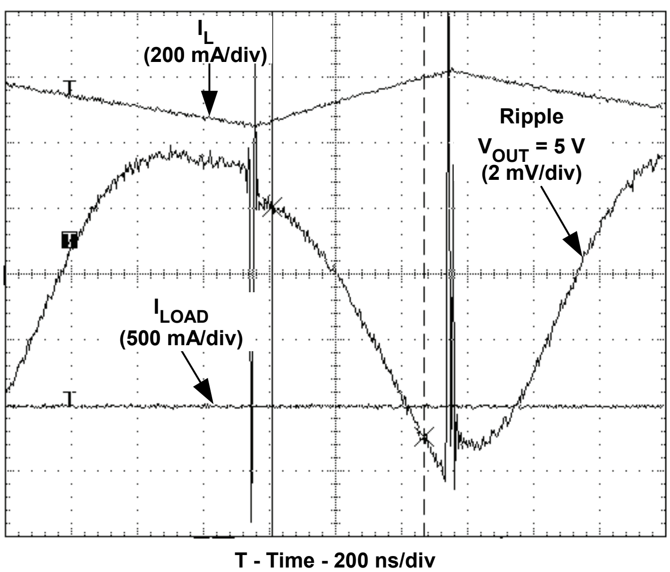


Fig. 17. Boost converter output voltage.

With the parameters taken from the oscilloscopes screen shot, the real value of the effective capacitance is calculated to be 32.4 µF. According to its datasheet, the capacitors should have an initial accuracy of ±20%. But obviously an error of almost 50% is observed here.

TABLE 3: COMPARISON OF DATA SHEET VALUES AND MEASURED VALUES.

Datasheet Capacitance (µF)			Measured for DC Bias Voltage	
Min	**Typ**	**Max**	**4 V**	**5 V**
17.6	22	26.4	15.8	10.8

The measurement results show a fairly high change in capacitor value versus applied DC voltage. Therefore it is important to select a capacitor with a higher voltage rating than the nominal operation voltage to minimize the DC bias effect on capacitance value. This is especially important when using output capacitors smaller 1206 size.

In addition to the above described effect there are two other effects which you have to taken into account. There is degrading over time (aging) and temperature.

Degrading over Time

Aging refers to the natural process, that class 2 ceramic capacitors exhibit a change in capacitance after their temperature is raised above the Curie-point for their particular formation. This can happen during soldering or temperature cycling tests. When the capacitor is heated above the Curie-point (approximately 120°C), a change in the crystal structure occurs and the capacitance increases. This increase in capacitance is called "de-aging". As the temperature is later reduced below the Curie-point, the capacitance gradually returns to its previous values. The decline in capacitance is called "aging" and occurs at a rate that decreases roughly linearly with the log of time.

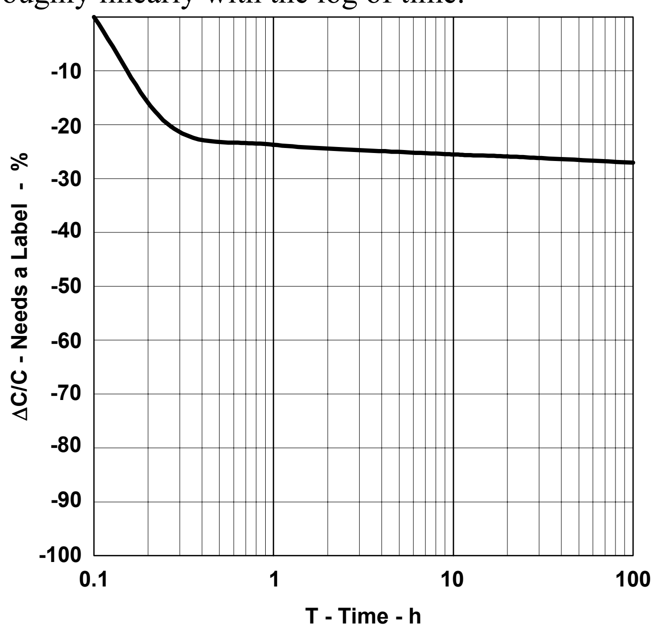


Fig. 18. Typical class 2 MLCC capacitor aging.

The disadvantage of this effect is that, when you have recognized that the capacitance is getting worse over time and you want to cross-check your measurement with a component tester, you have to de-solder the capacitor before measuring it. While de-soldering the capacitor the temperature of the capacitor is rising above the Curie-point and this resets the capacitance back to its original value.

The capacitance changes over temperature are coupled to the used material and described in the capacitors datasheet. Keep in mind that the value of the selected component changes in the range of ±10% over temperature (-30°C to +85°C)