LC5220 Series Off-Line LED Driver IC

General Description

The LC5220 series is the power IC for non-isolated LED driver applications with commercial power supply. It provides constant output current control for driving LEDs. The buck or buck-boost topology is selectable by peripheral circuit structure.

The product incorporates a power MOSFET and a controller IC in a single industry-standard package. It includes various functions, and this design allows the achievement of highly cost-effective LED lighting power supply systems by reducing external component count and minimizing PCB area.

Figure 1. The LC5220D series package is a fully molded DIP8 with pin 7 removed for greater isolation, and the LC5220S series package is an SOP8.

Features and Benefits

- Buck and buck-boost topology; selectable by peripheral circuit structure
- Built-in fixed reference voltage limiting constant current control; high precision regulator improves current precision and simplifies setting of current level
- Sleep function, with latch mode; input high, 3 V or more, on REF pin turns off IC output to LEDs
- Enable function; input low on REF pin toggles IC output to LEDs
- High input voltage; up to 250 V or 450 V, depending on product
- Built-in constant current control; PWM method, output current adjustable by the voltage input on the REF pin
- External adjustable PWM dimming control
- Protection features:
  - ▫Open protection (OPP) with latched shutdown; protects IC when a free-wheeling diode is open
  - ▫Undervoltage lockout (UVLO)
  - ▫Overcurrent protection (OCP) with latched shutdown; variable OCP threshold linked to REF pin voltage
  - ▫Thermal shutdown (TSD) with auto restart

Applications

- LED lighting fixtures
- LED light bulbs

The product lineups for the LC5220 series provide the following options:

Part Number	Input Voltage		Output Current (A)	Package
	Absolute Maximum (V)	Recommended Operating Range* (V)		
LC5222D	250	25 to 200	0.5	DIP8
LC5223D	250	25 to 200	1.0	
LC5225D	450	25 to 400	0.5	
LC5226D	450	25 to 400	1.0	
LC5222S	250	25 to 200	0.5	SOP8
LC5225S	450	25 to 400	0.5	

*Minimum input voltage of recommended range depends on LED output voltage and converter topology.

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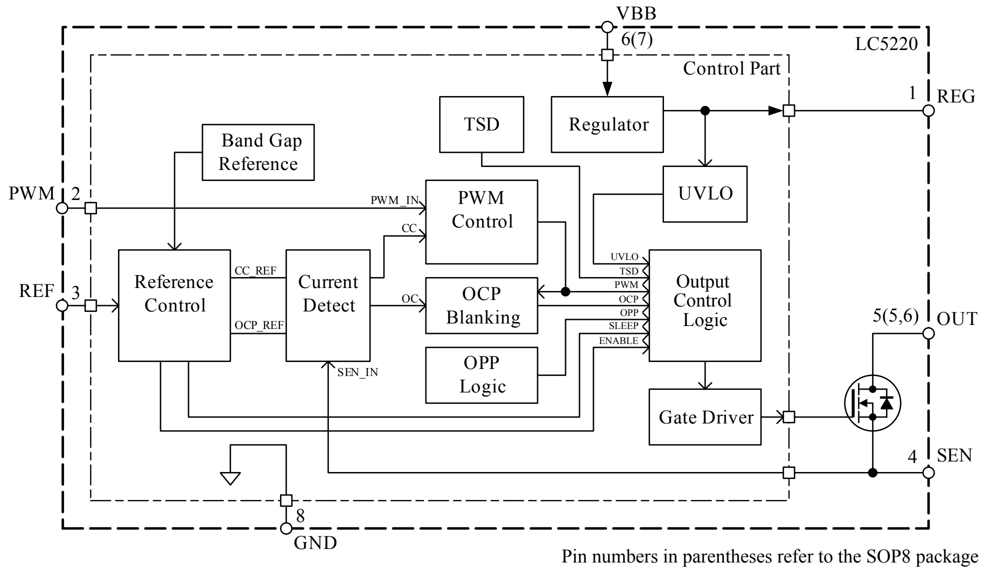
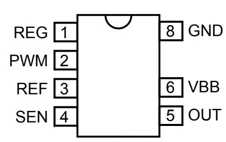
Functional Block Diagram

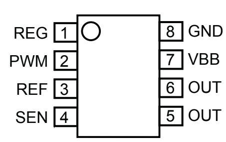


Pin numbers in parentheses refer to the SOP8 package

Pin-out Diagrams



DIP8
(LC5220D series)



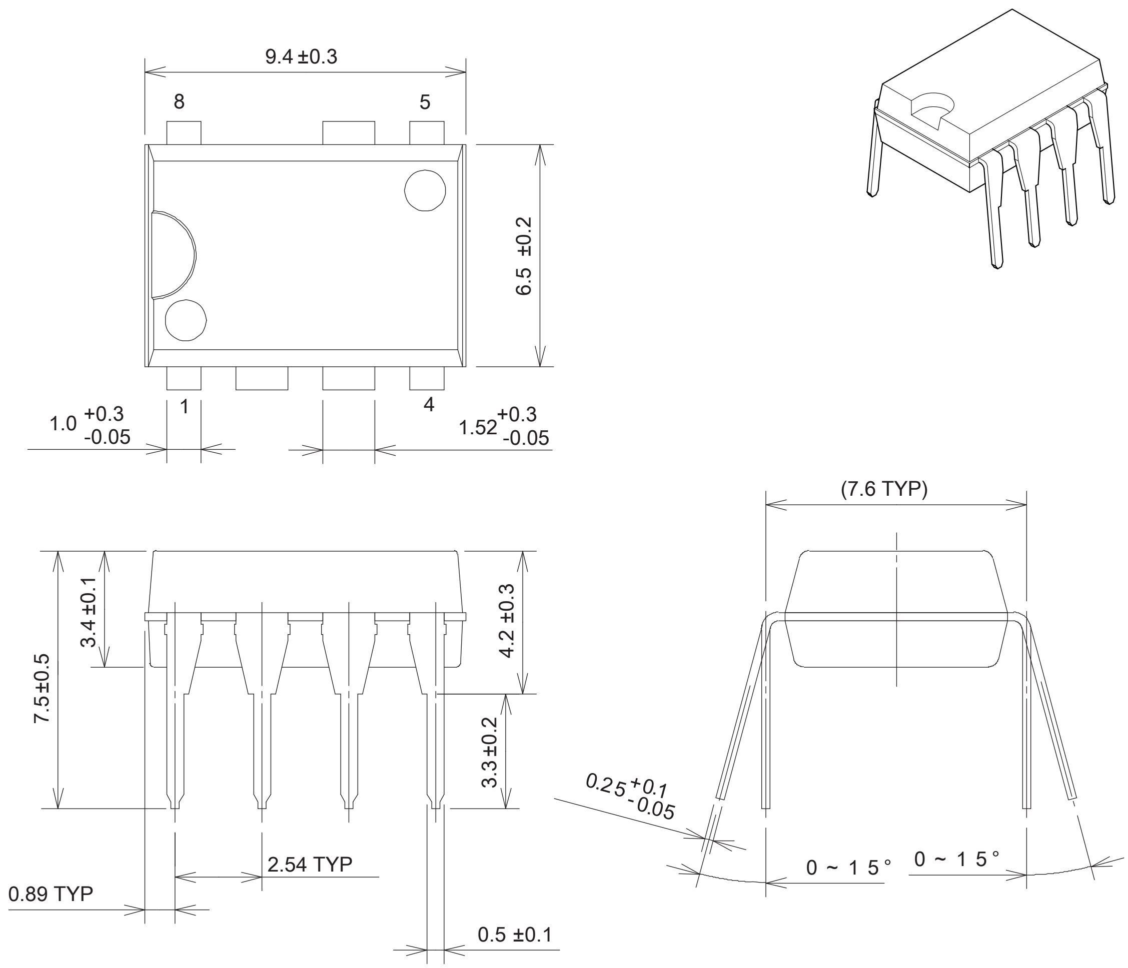
SOP8
(LC5220S series)

Pin List Table

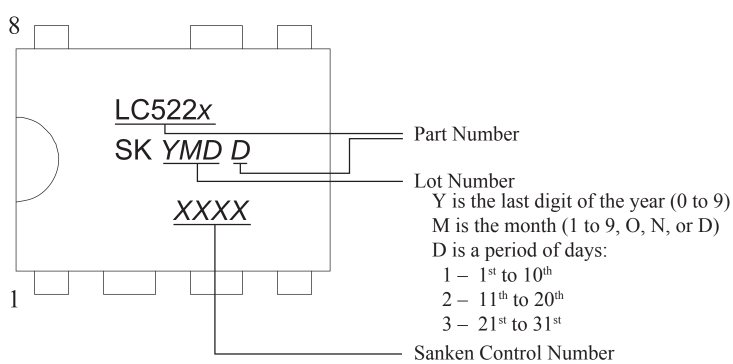
Name	Number		Function
	DIP8	SOP8	
REG	1	1	Internal regulator supply, provides current to internal and external circuits; connect a 0.1 μF bypass capacitor between this pin and GND.
PWM	2	2	Input for PWM control: to use internal PWM, connect a capacitor for setting off-time; to use external PWM, connect to PWM signal source.
REF	3	3	Reference voltage input: sets peak output current of OUT pin (internal power MOSFET) for internal PWM control, enables toggling output of OUT pin (Enable function), and enables latched shutdown of output (Sleep function)
SEN	4	4	Output current detection: detects peak output current for internal PWM control, and detects overcurrent for OCP; connect to current detection resistor.
OUT	5	5, 6	Drain of internal power MOSFET.
VBB	6	7	Supply voltage, provides power to internal circuits through internal regulator.
GND	8	8	Ground pin.
—	7	—	LC5220D DIP8 pin removed to increase creepage distance between high voltage pin and low voltage pin. Note: Apply user’s criteria for creepage distance when using LC5220S SOP8.

Package Diagram

DIP8 package

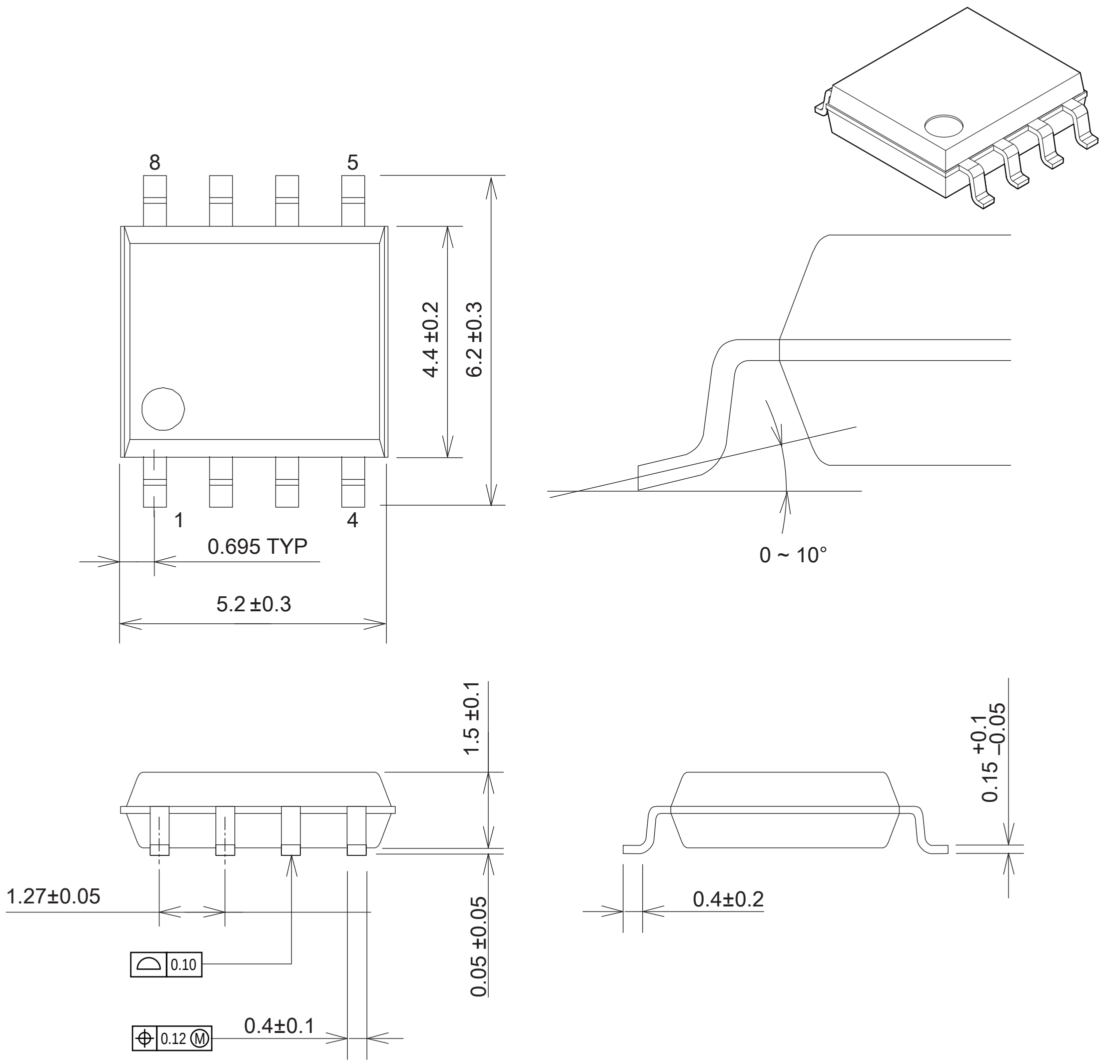


Unit: mm

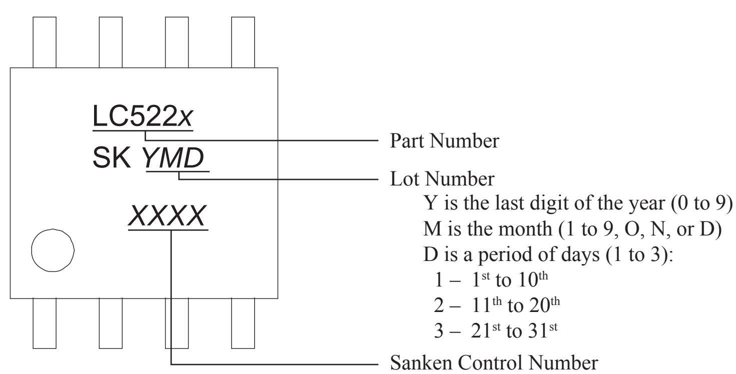


Pb-free. Device composition compliant with the RoHS directive.

Package Diagram
SOP8 package



Unit: mm



Pb-free. Device composition compliant with the RoHS directive.

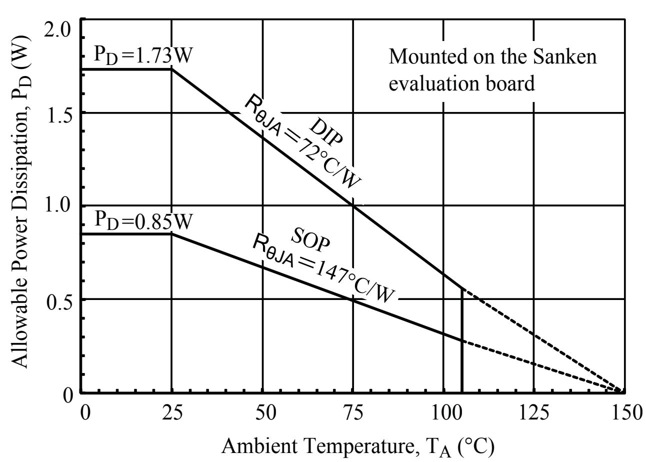
Electrical Characteristics

• For additional details, refer to the datasheet of each product.
• The polarity value for current specifies a sink as "+ ," and a source as “−,” referencing the IC.
• When pin numbers of the SOP8 differ from those of the DIP8, they are indicated in parentheses for the SOP8.

Absolute Maximum Ratings Unless specifically noted, T_A is 25°C

Characteristic	Symbol	Notes		Pins	Rating	Unit
Main Power Supply Voltage	V_{BB}	LC5222 LC5223		6 – 8 (7 – 8)	250	V
		LC5225 LC5226			450	V
Output Breakdown Voltage	$V_{O(BR)}$	LC5222 LC5223		5 – 4 (5,6 – 4)	250	V
		LC5225 LC5226			450	V
Output Current[1]	I_O	LC5222 LC5225	Pulse width ≥ 1 μs	5 – 4 (5,6 – 4)	0.5	A
		LC5223 LC5226			1.0	A
PWM Pin Voltage[2]	V_{PWM}			2 – 8	−0.3 to V_Z	V
REF Pin Voltage[2]	V_{REF}			3 – 8	−0.3 to V_Z	V
SEN Pin Voltage	V_{SEN}	Pulse width ≥ 1 μs		4 – 8	−0.3 to 4.0	V
Allowable Power Dissipation[3,4]	P_D	Mounted on Sanken evaluation board for SOP8		–	0.85	W
		Mounted on Sanken evaluation board for DIP8		–	1.73	W
Operating Temperature Range	T_A			–	−40 to 105	°C
Storage Temperature Range	T_{stg}			–	−40 to 150	°C
Junction Temperature	T_J			–	150	°C

[1]Output current rating may be limited by duty cycle, ambient temperature, and heat sinking. Under any set of conditions, do not exceed the specified junction temperature, T_J.
[2]V_Z here is the breakdown voltage of the Zener diode that is internally connected between the PWM and REF pins and GND; V_Z = 6.3 V (typ). Maximum input current is 1 mA.
[3]Allowable Power Dissipation, P_D, depends on PWB pattern layout.
[4]Refer T_A versus P_D curve.



Recommended Operating Conditions*

Characteristic	Symbol	Notes		Pins	Min.	Max.	Unit
Power Supply Voltage	V_{BB}	LC5222 LC5223	Minimum input voltage depends on LED output voltage and converter topology.	6 – 8 (7 – 8)	25	200	V
		LC5225 LC5226			25	400	V
Average Output Current	$I_{O(AVG)}$	LC5222 LC5225		5 – 4 (5,6 – 4)	–	0.4	A
		LC5223 LC5226			–	0.8	A
REF Pin Input Voltage	V_{REF}	Normal operation		3 – 8	0.2	2.5	V
Case Temperature	T_C	Center of branded side, $T_J \leq 150°C$.		–	–	105	°C

*Recommended operating conditions means the operation conditions maintained normal function shown in electrical characteristics.

Electrical Characteristics Unless specifically noted, T_A is 25°C, V_{BB} is 140 V

Characteristic	Symbol	Test Conditions		Pins	Min.	Typ.	Max.	Unit
Power Supply Current	I_{BBs}	Output off		6 – 8 (7 – 8)	–	1	1.5	mA
	I_{BB}	Normal operation			–	2.5	4.0	mA
Output MOSFET Breakdown Voltage	$V_{(BR)DSS}$	LC5222 LC5223	I_D = 1 mA	5 – 4 (5,6 – 4)	250	–	–	V
		LC5225 LC5226	I_D = 1 mA		450	–	–	V
Output MOSFET ON Resistance	$R_{DS(ON)}$	LC5222	I_D = 0.5 A	5 – 4 (5,6 – 4)	–	1.2	2.2	Ω
		LC5223	I_D = 1.0 A		–	0.7	1.3	Ω
		LC5225	I_D = 0.5 A		–	3.5	6	Ω
		LC5226	I_D = 1.0 A		–	1.7	3	Ω
Body Diode Forward Voltage	V_F	LC5222	I_F = 0.5 A	4 – 5 (4 – 5,6)	–	0.8	1.0	V
		LC5223	I_F = 1.0 A		–	0.75	1.2	V
		LC5225	I_F = 0.5 A		–	0.8	0.9	V
		LC5226	I_F = 1.0 A		–	0.88	1.0	V
UVLO Threshold (Turn on)	$V_{UVLO(ON)}$	VBB pin		6 – 8 (7 – 8)	–	14	–	V
UVLO Threshold (Turn off)	$V_{UVLO(OFF)}$	VBB pin			–	12	–	V
REG Output Voltage	V_{REG}	I_{REG} = 0 mA		1 – 8	9.6	10	10.4	V
REG Output Current	I_{REG}	V_{REG} = 9 V		1 – 8	−2	–	–	mA
Enable Output Threshold Voltage	V_{ENB}	REF pin		3 – 8	–	0.15	0.19	V
Sleep Mode Threshold Voltage	V_{SLP}	REF pin		3 – 8	2.85	3.0	–	V
REF Pin Input Current	I_{REF}			3 – 8	−10	–	10	μA
Current Control Detection Voltage	V_{SEN}	V_{REF} = 0.2 to 2.0 V		4 – 8	$0.4 \times V_{REF} - 0.3$	$0.4 \times V_{REF}$	$0.4 \times V_{REF} + 0.3$	V
		V_{REF} = 2.0 to 3.0 V			0.77	0.8	0.83	V
OCP Detection Voltage	V_{OCP}	V_{REF} = 0.2 to 2.0 V		4 – 8	–	$0.4 \times V_{REF} + 0.7$	–	V
		V_{REF} = 2.0 to 3.0 V			–	1.5	–	V
SEN Pin Input Current	I_{SEN}			4 – 8	−10	–	10	μA
PWM Pin Low Voltage	$V_{PWM(L)}$			2 – 8	–	2	–	V
PWM Pin High Voltage	$V_{PWM(H)}$			2 – 8	–	3	–	V
PWM Pin Output Current	I_{PWM}			2 – 8	–	−20	–	μA
PWM Blanking Time	$t_{BLK(P)}$			–	–	0.3	–	μs
OCP Blanking Time	$t_{BLK(O)}$			–	–	0.2	–	μs
Operation Frequency	f_{PWM}	Duty cycle = 50%		2 – 8	–	–	200	kHz
PWM Off-Time	t_{OFF}	C_{PWM} = 100 pF		–	–	17	–	μs
Output MOSFET Rise Time	t_r	I_O = 0.4 A		5 – 4 (5,6 – 4)	–	25	–	ns
Output MOSFET Fall Time	t_f	I_O = 0.4 A		5 – 4 (5,6 – 4)	–	50	–	ns
Thermal Shutdown Threshold	T_{TSD}	Temperature of Control Part		–	–	150	–	°C
Thermal Shutdown Hysteresis	$T_{TSD(HYS)}$	Temperature of Control Part		–	–	55	–	°C

Typical Application Circuit

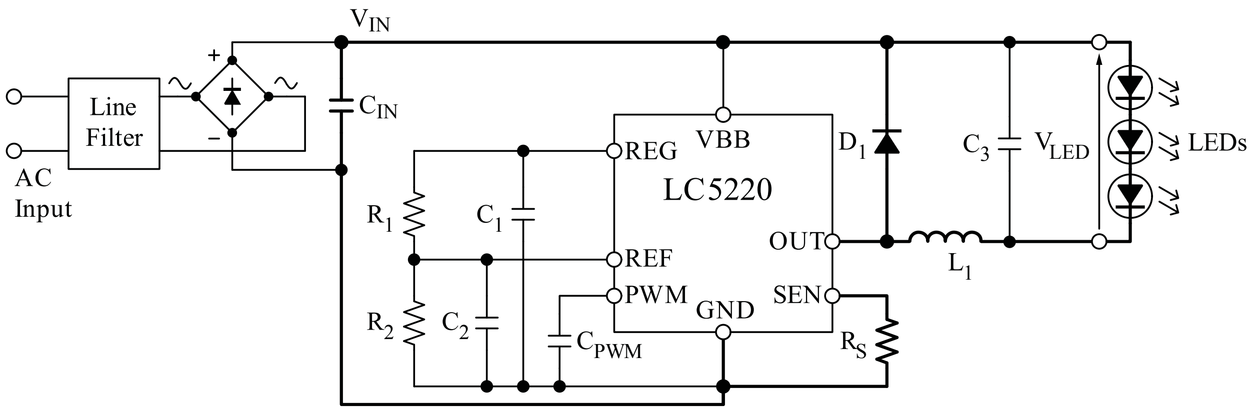


Figure 2. Typical application circuit example for a buck configuration; for component values, see Application Information section

Functional Description

Internal Circuit Descriptions

This section describes the functions displayed in the Functional Block diagram.

Regulator
This regulator steps-down from the supply voltage, V_{BB}, to 10 V, and provides power to internal circuits and external devices. A ceramic capacitor of 0.1 µF should be connected at the REG pin to stabilize operation because some pulse currents flow through the gate capacitor when charging the internal power MOSFET.

Band Gap Reference
This is a high precision voltage source, which generates a reference voltage that is not susceptible to fluctuations of the power supply voltage and/or temperature, and is used as a reference voltage for internal current control.

Reference Control
This function controls an internal reference voltage and the on/off switching of the internal power MOSFET in response to the input voltage at the REF pin.

There are two reference voltages generated by this function. One is CC_REF for peak current control when using internal PWM control, and the other is OCP_REF for overcurrent protection (OCP).

In addition, the SLP (Sleep mode) comparator, with a reference voltage of 3 V, and the ENB (Enable) comparator with a reference voltage 0.15 V are provided. These are used to generate the SLEEP signal and ENABLE control signals respectively.

Current Detect
This detects the output current of the IC by the voltage of the detection resistor, R_S, connected to SEN pin.

Two comparators compare SEN_IN voltage with internal reference voltages: CC_REF, the reference voltage of the CC comparator for peak current control of internal PWM; and OCP_REF, the reference voltage of the OCP comparator for overcurrent protection (OCP) (see figure 3).

PWM Control
This is PWM control circuit for the internal power MOSFET, which includes the constant current control by internal PWM, and the external PWM by external PWM signal. It has a 20 µA current source for setting the fixed off-time (see figure 4).

OCP (Overcurrent Protection) Blanking
When an overcurrent fault condition is indicated by the OC signal from the Current Detect circuit, this function outputs the OCP signal. In this circuit, the OCP Blanking Time, $t_{BLK(O)}$, is built-in to prevent malfunctions caused by surge voltages generated by turning off the internal power MOSFET.

OPP (Open Protection) Logic
This function detects open conditions on the free-wheeling diode line and prevents resulting circuit failure. When the free-wheeling diode line opens during operation of the IC without the OPP function, the recirculation path for energy stored in the inductor is cut off. Thus, the internal power MOSFET can be damaged if it applies this energy. This function is also available for the protection of a buck-boost configuration, when LEDs open.

UVLO (Undervoltage Lock Out)
This continually monitors whether the output voltage from the Regulator function is normal, and prevents abnormal operation resulting from low input voltage. When the VBB pin voltage is

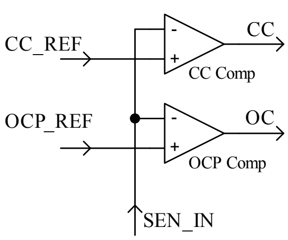


Figure 3. Current Detect circuit

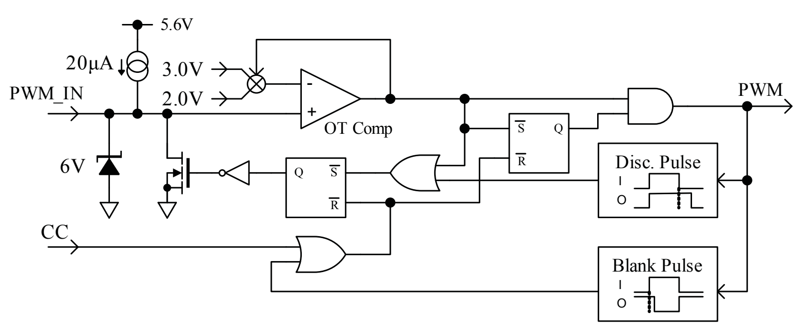


Figure 4. PWM Control circuit

lower than the UVLO threshold (turn-off), the IC reverts to the state before startup. In addition, this function is available during power-on reset, for releasing latched shutdowns resulting from operation of protection functions.

TSD (Thermal Shutdown)

This continually monitors the chip temperature of the Control Part. When the temperature increases to T_{TSD} or higher, the output of OUT pin turns off to prevent damage from abnormally high temperature.

After TSD operation, when the temperature decreases to T_{TSD} minus $T_{TSD(HYS)}$ or lower, or after cycling power to the IC (that is, the VBB pin voltage falling down to $V_{UVLO(OFF)}$ and then rising to $V_{UVLO(ON)}$), the IC returns to normal operation. Because this circuit is in the Control Part, there is a delay before temperature increases in the internal power MOSFET are conducted to the Control Part. If the temperature of power MOSFET increases rapidly, the power MOSFET may be damaged before TSD is activated. Therefore, it is necessary design the application well to protect against this.

Output Control Logic

This controls the enabling and disabling of the output of the OUT pin according to signals from PWM control circuit and the various protection circuits. The resulting logic operation is set to non-latch mode or latch mode by the input signal as shown in table 1.

The output is enabled only when all input signals indicate the output can be turned on safely. To release latch mode, cycling power to the IC is required.

Gate Driver

Gate driver for internal power MOSFET.

Internal Power MOSFET

An internal power MOSFET for LED driving is incorporated in the IC series, according to the individual product ratings for current and voltage.

PMW Current Control

• The polarity value for current specifies a sink as "+ ," and a source as “–,” referencing the IC.

• All of the parameter values used in these descriptions are typical values, unless they are specified as minimum or maximum.

• The basic current control of internal PWM is shown in the following with a buck configuration circuit.

PWM On-Time Period

At startup, or during normal operation before the output current through the LED string reaches the target current level, the internal power MOSFET turns on and the output current flows through the I_{ON} path shown in figure 5.

Turning-Off Period

The output current through the LED string is equivalent to the current through the detection resistor, R_S, and thus the LED current is detected at the SEN pin as a voltage. When the SEN pin voltage, V_{SEN}, is equal to the internal PWM reference voltage, V_{CCR}, the internal power MOSFET turns off.

PWM Off-Time Period

• When the internal power MOSFET turns off, the current recirculation diode, D_1, is forward biased by the back electromotive force (BEMF) in the inductor, L_1, and D_1 turns on. Then the energy stored in L_1 during PWM on-time flows through the recirculation path shown as I_{OFF} in figure 5.

Table 1. Control Logic States

Input Signal	Latch Mode	Conditions for Output Disable (Power MOSFET Off)
UVLO	Non-latched	When REG pin voltage decreases
TSD	Non-latched	When the Control Part overheats
PWM	Non-latched	When PWM control outputs the off signal
OCP	Latched	When OCP is detected
OPP	Latched	When free-wheeling diode line open
SLEEP	Latched	When REF pin voltage increases to 3 V or higher
ENABLE	Non-latched	When REG pin voltage decreases to less than 0.15 V

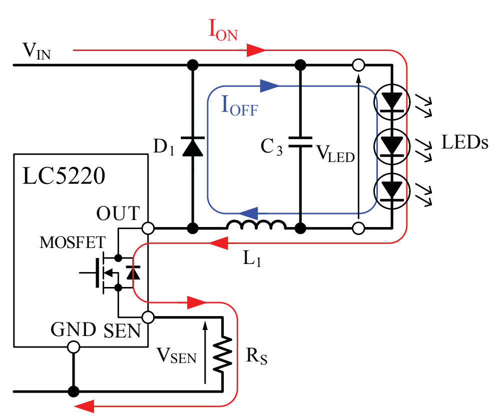


Figure 5. Output current flow in a buck configuration during PWM on-time and off-time periods

Turning-On Period

After the fixed off-time, t_{OFF}, the internal power MOSFET turns on again, and the PWM on-time period repeats. The cycle is shown in figure 6.

Internal PWM Control Circuit

The internal PWM control circuit is shown in figure 7, and the operation timing diagram is shown in figure 8.

When the internal power MOSFET turns on, the load current increases, and the SEN pin voltage, V_{SEN}, also increases. This voltage is compared to the internal PWM reference voltage, V_{CCR}, in the Current Detect comparator, CC Comp, which is connected to the SEN pin. When V_{SEN} is more than V_{CCR}, CC Comp inverts, as shown at point A in figure 8. After this signal is received, the output Q of the RS flip-flop is reset, and a turn-off signal is transmitted from the AND gate to the gate control logic, to the Gate Driver, and to the internal power MOSFET. After that, the internal power MOSFET turns off. At the same time, a MOS switch for discharging C_{PWM}, connected to the PWM pin, turns on, and C_{PWM} is discharged.

When V_{PWM} decreases to less than 2 V, the Off-Time comparator, OT Comp, inverts and the the Q of RS flip-flop is set. Then the MOS switch for discharging C_{PWM} turns off, and C_{PWM} is again charged by the 20 μA internal constant current source.

When V_{PWM} increases to more than 3 V, the fixed off-time period expires and then the internal power MOSFET turns on. After

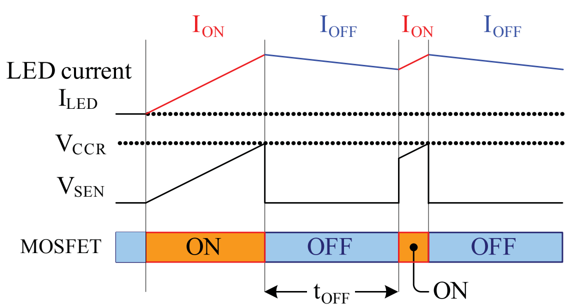


Figure 6. Constant current control operation in a buck configuration

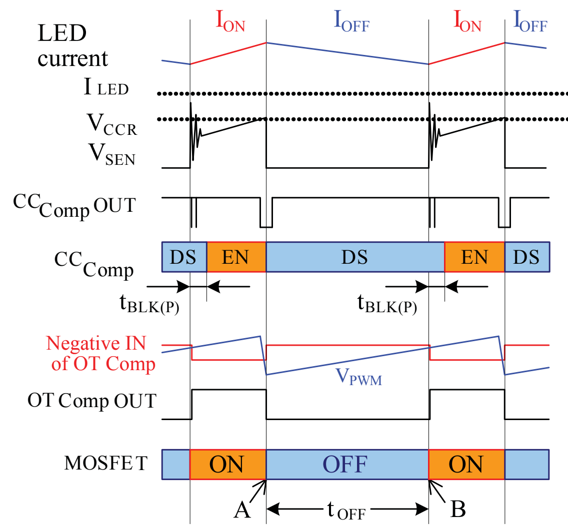


Figure 8. Constant current control circuit operation

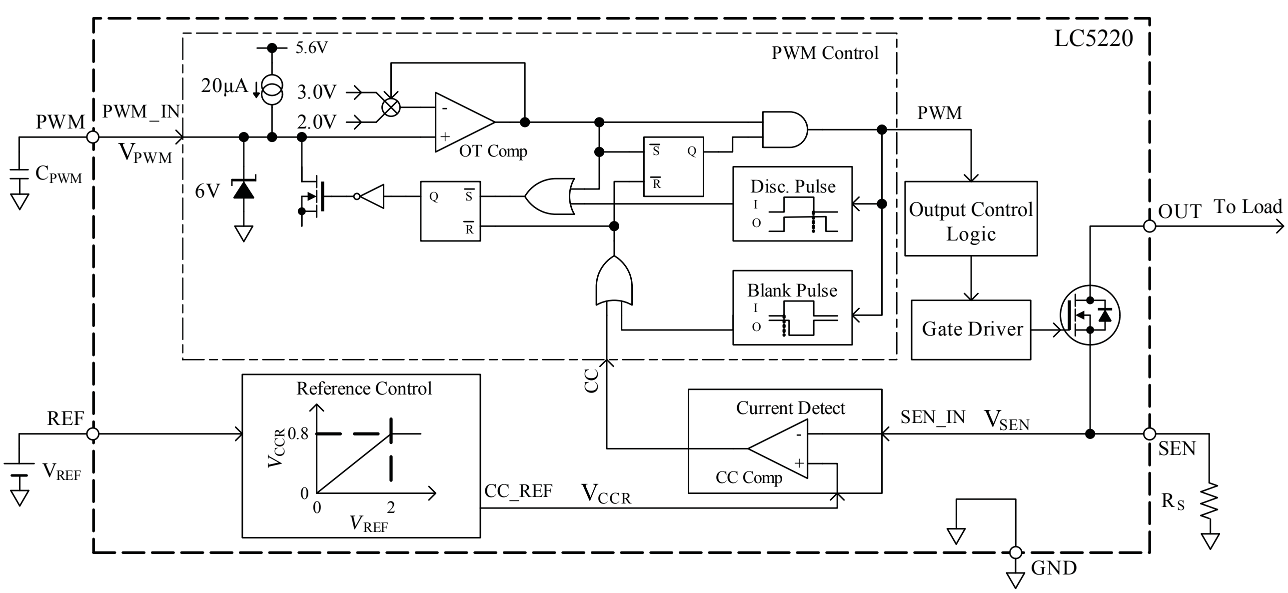


Figure 7. Current control circuit

that, the operation reverts to the initial state, as shown at point B of figure 8. The V_{SEN} voltage is detected in the on-time period except during the PWM blanking time, $t_{BLK(P)}$, to prevent malfunction.

REF Pin Input Operation

The REF pin input voltage is used by the Reference Control function to generate two internal reference voltages and two logic signals: the reference voltages are V_{CCR} and V_{OCP}, and the logic signals are OFF(Disable) and Latched Shutdown(Sleep). These operate as follows.

Internal PWM Reference Voltage, V_{CCR}

The CC_REF signal voltage, V_{CCR}, is used for the internal PWM Control function. The SEN pin voltage, V_{SEN}, which occurs at the external current detection resistor, R_S, is controlled so that the peak voltage of V_{SEN} is equal to V_{CCR}.

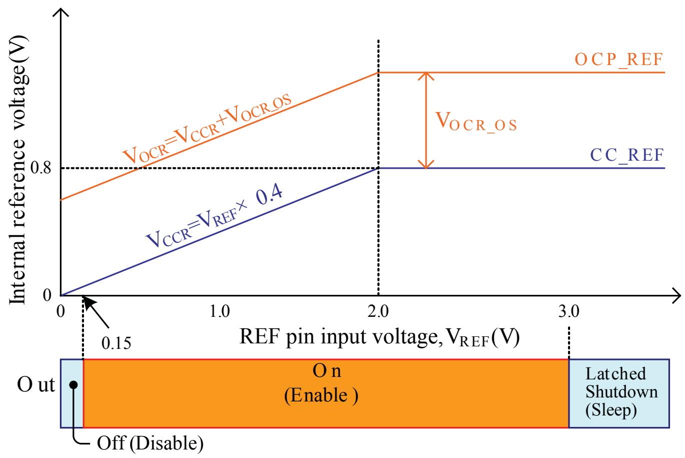


Figure 9. Input−output characteristic of the Reference Control function

As shown in figure 9, the CC_REF signal transitions between variable and constant slope at the REF pin input voltage, V_{REF}, of 2 V:

- Case of $V_{REF} < 2$ V

$$V_{CCR} = 0.4 \times V_{REF} \quad (1)$$

$$I_{PEAK} = 0.4 \times V_{REF} / R_S \quad (2)$$

According to equation 1, V_{CCR} is proportional to V_{REF}. Thus the peak output current, I_{PEAK}, is proportional to V_{REF} in this range. Therefore, an external DC voltage on the REF pin can control the output current.

- Case of $V_{REF} > 2$ V

$$V_{CCR} = 0.8 \text{ (V)} \quad (3)$$

$$I_{PEAK} = 0.8 \text{ (V)} / R_S \quad (4)$$

In equation 3, V_{CCR} is not set relative to V_{REF}, and is fixed. Because this voltage is generated from the internal stabilized reference voltage, it is not affected by the precision of V_{REF} in this range. The external current detection resistor, R_S, sets the peak output current.

OCP Reference Voltage, V_{OCR}

The OCP_REF signal voltage, V_{OCR}, is used for the OCP function. As shown in figure 9, this voltage is offset from V_{CCR} by V_{OCP_OS}. When V_{SEN} increases to more than V_{OCR}, the internal power MOSFET is shut down in latch mode. To release latch mode, cycling power to the IC (that is, the VBB pin voltage falling down to $V_{UVLO(OFF)}$ and then rising to $V_{UVLO(ON)}$) is required. V_{OCP_OS} is 0.7 V, and is reduced by increasing temperature. Therefore, this characteristic makes OCP activation quicker at higher temperatures, at which withstand voltages are lower.

ENABLE Signal

When the REF pin input voltage, V_{REF}, exceeds the Enable voltage, $V_{ENB} = 0.15$ V, the ENABLE (enable output) signal is output to the Output Control Logic circuit. Conversely, when V_{REF} is

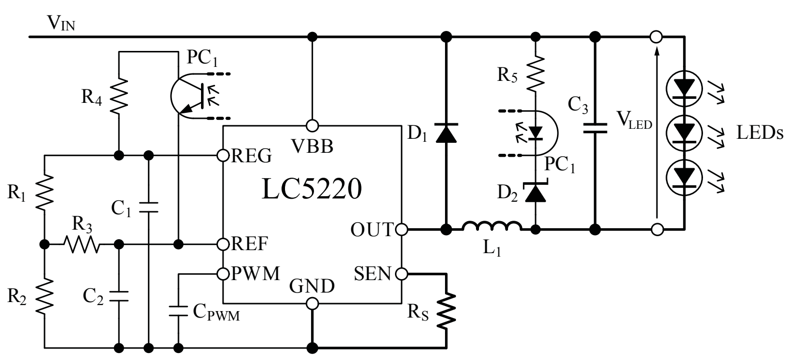


Figure 10. Sleep mode application circuit example implementing external protection (OVP)

less than V_{ENB}, the output is kept off regardless of other signals. This signal is not latched, and is available to turn-off LEDs by connecting the REF pin to GND.

SLEEP Signal

When the REF pin input voltage, V_{REF}, exceeds the Sleep voltage, V_{SLP} = 3.0 V, the SLEEP signal is output to the Output Control Logic circuit, and the internal power MOSFET is shut down in latch mode. To release latch mode, cycling power to the IC (that is, the VBB pin voltage falling down to $V_{UVLO(OFF)}$ and then rising to $V_{UVLO(ON)}$) is required. This function allows an external protection circuit, such as overvoltage protection (see figure 10), to turn-off the internal power MOSFET in response to an load open, or other fault condition.

Unless a protection circuit (for example, the circuit in figure 10) is used, the withstand voltage of C_3 could be exceeded in a fault condition. In a buck configuration without the protection, when an LED is open, the C_3 voltage would be charged to approximately V_{IN}.

Again referring to figure 10, when an overvoltage occurs, it is detected by the network of R_5, PC_1 (source side), and D_2, and the REF pin voltage is increased to 3 V or higher by the pullup R_4 and PC_1 (detector side). The IC enters latched Sleep mode, turning-off the internal power MOSFET to prevent excessive output voltage. Latched Sleep mode can be used not only for OVP for an open LED, but also for other protections with appropriate application circuits.

Buck-Boost Operation

Buck-Boost Circuit Features

Figure 5 shows the typical application circuit for buck converter operation. In order for that circuit to operate, the following condition must be fulfilled:

$$V_{IN} \text{ (input voltage)} > V_{LED} \text{ (output voltage)}$$

When the input voltage is low or the total voltage across the LEDs in series is high, some limitations occur.

In the LC5220 series, it is possible to use a buck-boost converter by changing the way of connecting the load. The operation range of buck-boost converter is:

$$V_{IN} + V_{LED} < V_O(\text{max}) \text{ (maximum output voltage)}$$

However, as compared to the input voltage, the output voltage fluctuation and the ripple current on the LEDs may be worse than those with a buck converter configuration. It is necessary to take that into consideration.

Buck-Boost Circuit Operation

In the buck-boost converter configuration, the internal PWM current control operates as follows:

PWM On-Time Period

At startup, or during normal operation before the output current through the LED string reaches the target current level, the internal power MOSFET turns on and the output current flows through the I'_{ON} path shown in figure 11. During the on-time, an inductor, L_1, stores energy, and no current flows through the LED string. If it is not acceptable to intermittently flow the current through the LED string, add a capacitor in parallel to the LED string.

Turning-Off Period

The current through an inductor, L_1, is equivalent to the current through the detection resistor, R_S, and thus the L_1 current is detected at the SEN pin as a voltage. When the SEN pin voltage, V_{SEN}, is equal to the internal PWM reference voltage, V_{CCR}, the internal power MOSFET turns off.

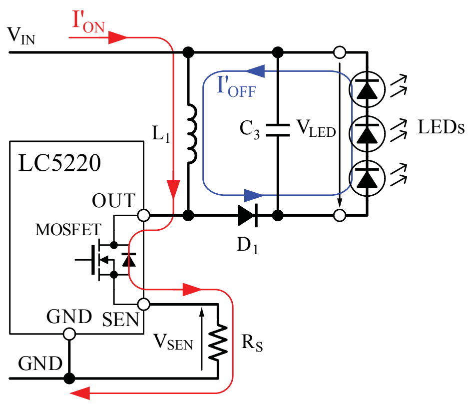


Figure 11. Output current flow in buck-boost configuration during PWM on-time and off-time periods

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PWM Off-Time Period

When the internal power MOSFET turns off, the current recirculation diode, D_1, is forward biased by the back electromotive force (BEMF) in the inductor, L_1, and D_1 turns on. Then the energy stored in L_1 during PWM on-time flows through the recirculation path shown as I'_{OFF} in figure 11, turning on the LEDs.

PWM On-Time Period

After the fixed off-time, t_{OFF}, the internal power MOSFET turns on again, and the PWM on-time period repeats. The cycle is shown in figure 12.

Note: In a buck-boost topology, if the LED load is open, the recirculation path for energy stored in an inductor is cut off, so when the internal power MOSFET applies the energy, it would fail. The LC5220 series prevents such a failure because it has an additional function for protection against open loads.

Overcurrent Protection Function (OCP)

Figure 13 shows the OCP circuit, and figure 14 shows the OCP operation timing diagram. The OCP comparator, OCP Comp, is connected to SEN pin, and compares the V_{SEN} voltage detected by R_S with the OCP reference voltage, V_{OCR}.

When V_{SEN} is greater than V_{OCR}, OCP Comp inverts, and an OCP condition is detected. When the OCP signal is received, the internal power MOSFET is shut down in latch mode by the latch function of the Output Control Logic circuit. To release latch mode, cycling power to the IC (that is, the VBB pin voltage falling down to $V_{UVLO(OFF)}$ and then rising to $V_{UVLO(ON)}$) is required.

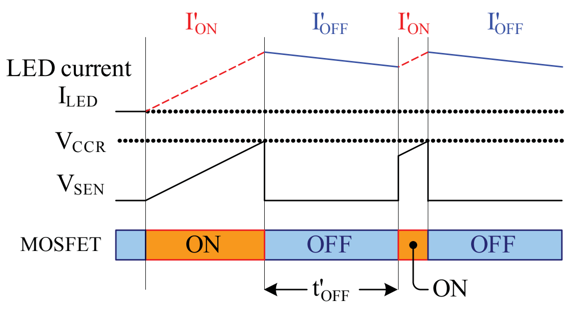


Figure 12. Constant current control operation in buck-boost configuration

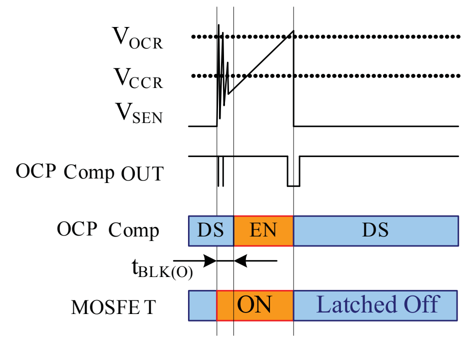


Figure 14. Overcurrent protection (OCP) operation

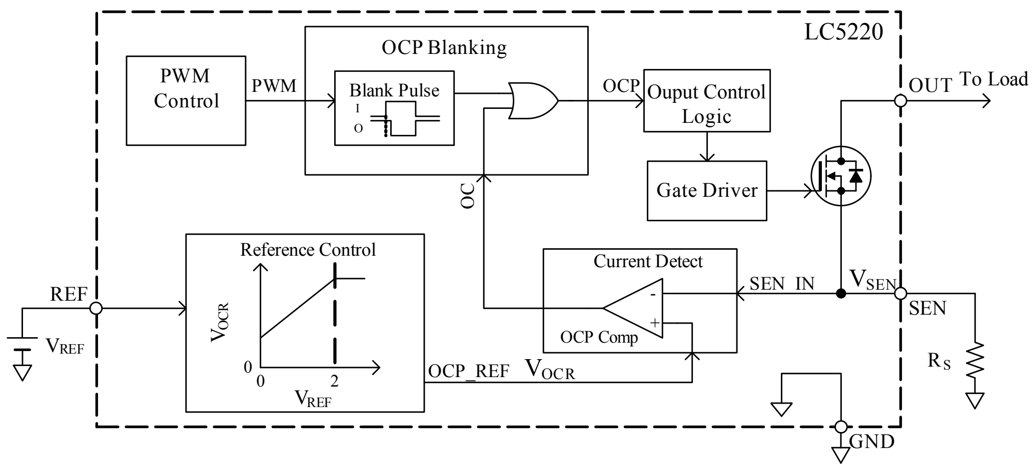


Figure 13. Overcurrent protection (OCP) circuit

The OCP detection is in the on-time period, except for the OCP Blanking Time, $t_{BLK(O)}$, to prevent malfunction.

Note: The OCP function is activated only when the SEN pin voltage, V_{SEN}, reaches V_{OCR} by excessive output current flowing to R_S. Therefore if the output current is restricted to less than its target value, for example by current limitations of the inductor, even though the LEDs are shorted, OCP would not be activated.

Current Value Setting for Dimming Control

The LC5220 series allows constant current control using the internal PWM control, an external PWM signal, or a combination of both of them.

Using Internal PWM Dimming

The LC5220 series has a built-in PWM constant current control circuit, and thus can achieve a constant current drive system for the LED string using few external components. The peak output current, I_{PEAK}, for driving the LED string is calculated as follows:

$$I_{PEAK} = V_{CCR} / R_S$$

where V_{CCR} is as described in the REF Pin Input Operation section. The LC5220 series allows external adjustment of the current flowing through the LED string, using either of the following methods:

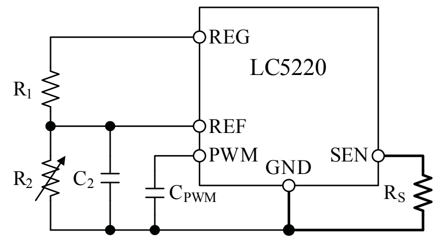
- Adjust the analog voltage on the REF pin (figure 15A)
- Input the analog voltage integrated PWM signal through a low pass filter, LPF, to the REF pin (figure 15B)

Using External PWM Dimming

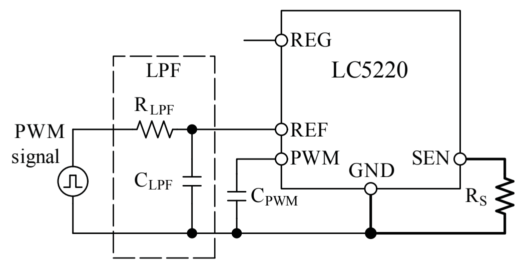
Using an external PWM signal allows applying the LC5220 series as a high voltage power switch. In this configuration, the output of the OUT pin turns on and off according to a logic signal input to the PWM pin. Because this control is not activated by the internal PWM current control circuit, an external current control circuit is needed. The frequency of the input PWM signal is recommended to be in the range 20 to 200 kHz.

As shown in figure 16, there is no C_{PWM} on the PWM pin, allowing the PWM signal to be input to the PWM pin through an open drain device. Do not use the device with CMOS output because its output is shorted when the internal power MOSFET for discharging C_{PWM} turns on. The range of the REF pin voltage, V_{REF}, should be 0.15 to 3 V, and the SEN pin should be connected to GND.

Note: Both OCP and OPP protection are invalid when using this configuration.

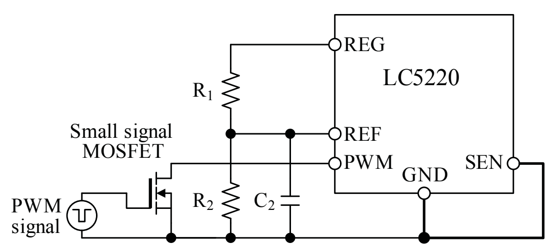


(A) Analog input



(B) Integrated PWM analog input

Figure 15. Dimming application circuit with internal PWM



Truth Table for External PWM

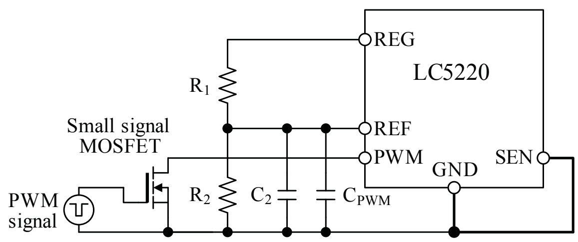
PWM Signal	OUT Pin
Low	On
High	Off

Figure 16. Dimming application circuit with external PWM

Using Internal and External PWM Dimming

This configuration combines the two configurations described above: the internal PWM control circuit determines the limitation of the peak output current flowing through the LED string, and the external PWM circuit controls the average current. This configuration is effective for a low frequency external PWM range, 200 to 500 Hz. This circuit is shown in figure 17.

The narrower the duty cycle of the external PWM signal is, the bigger the average LED output current is. At 100% duty cycle, the LED output current is 0 A. The timing diagram is shown in figure 18.



Truth Table for Combined Internal and External PWM

PWM Signal	LED Current Control
Low	Internal PWM current control
High	LED current off

Figure 17. Dimming application circuit with combined internal and external PWM

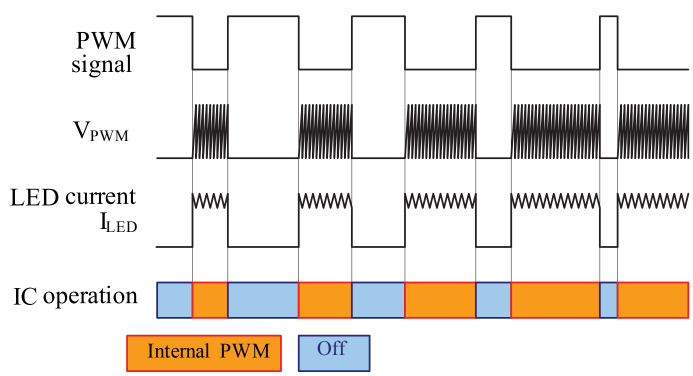


Figure 18. Combined internal and external PWM operation

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Application Information

Typical Application Components

The typical application circuit for a buck configuration in figure 2 is an example for a basic peripheral circuit. Table 2 provides an listing of parts in figure 2, as examples for the sole purpose of reference for the initial use of the IC. These are typical values, but do not take into the application usage conditions such as PCB layout, LED types, or circuit noise. It is necessary to take account of such factors fully while designing and components should be validated by operation in the actual application.

External Component Selection

The following recommendations should be observed when selecting components for use with the LC5220 series.

• ***LEDs*** The relation between the LED ratings and the output current ratings of the IC should be considered.

In buck configuration, the total forward voltage drop, V_{LED}, of LEDs in series should be less than the input voltage, V_{IN}, because the LEDs would be turned off if V_{LED} were more than V_{IN}. Normally, a V_{LED} of 9 to 60 V is assumed.

With a buck-boost topology, the IC is capable of turning on LEDs on the condition that V_{LED} is more than V_{IN}. Refer to the Buck-Boost Circuit Operation section.

• ***L_1*** This is an inductor for smoothing output current. When the value of L_1 is higher, the LED ripple current is lower, and thus the current stability is improved.

Normally, an L_1 value of 0.5 to 10 mH is assumed. In actual operation, it should be rated so that the inductor is not saturated by the peak of the ripple current. If the inductor becomes saturated by an unexpectedly high surge current flow, the LEDs and the IC could be damaged.

• ***D_1*** This is a free-wheeling diode for recirculation of the output current. The energy stored during the PWM on-time period is provided to LEDs through this diode during the off-time period.

The withstand voltage and recovery time, t_{RR}, should be considered. If a diode with a long recovery time, t_{RR}, is selected, surge current may flow into the OUT pin when the internal power MOSFET turns on. As a result, it would cause increased noise, potentially malfunction due to the noise, and decreased efficiency. Thus, it is recommended to select a diode equivalent to the diode recommended in table 2, which has a t_{RR} of approximately 30 ns, or a diode with a lower t_{RR}.

• ***C_{IN}*** This is an input smoothing capacitor. When the value of C_{IN} is high, the input and output ripple voltages are small. In addition, given a certain capacitance level, the greater the output power is, the greater the ripple voltages are. Thus it is necessary to select the value according to the output power.

The IC is capable of operation in V_{IN} full-wave rectification with an input capacitor rated as low as approximately 1000 pF, instead of an electrolytic capacitor. Therefore the configuration without electrolytic capacitor enhances the power supply system operation life, and reduces system size and cost.

Note: If the lower peak of the ripple voltage of the VBB pin is allowed to fall below the UVLO threshold (turn off) or the output voltage is less than V_{LED} in a buck configuration, the LEDs are turned off. Thus it is necessary to take account of the value of C_{IN}.

• ***C_1*** This is a capacitor for stabilizing the internal regulator. It is required to provide the charge current for charging the gate of the internal power MOSFET, and to maintain a stable voltage.

Table 2. Reference Specification of a Buck Configuration Circuit

Input voltage: 100 VAC, LED output voltage: 15 V, LED peak output current: 0.3 A

Symbol	Part Type	Values and Ratings	Description
LED	LED	—	User-defined
L_1	Inductor	1 mH / 1 A	Choke coil for smoothing current
D_1	Fast recovery rectifier diode	RD2A	Free-wheeling diode for recirculation
C_{IN}	Capacitor	Up to 4.7 µF / 450 V	Main supply source filtering capacitor; 1 nF or higher can be used
C_1	Capacitor	0.1 µF / 25 V	Internal regulator stabilizing capacitor
C_2	Capacitor	1000 pF (to 0.1 µF) / 25 V	REF pin voltage stabilizing capacitor
C_3	Capacitor	0.1 µF / 250 V	Smoothing capacitor for reducing LED ripple current (Optional)
C_{PWM}	Capacitor	100 pF / 25 V	PWM off-time setting capacitor (internal PMW control)
R_1	Resistor	620 kΩ / $^1/_8$ W	Resistor for setting peak output current on OUT pin
R_2	Resistor	51 kΩ / $^1/_8$ W	Resistor for setting peak output current on OUT pin
R_S	Resistor	1.0 Ω / 1 W	Resistor for output current detection

Normally, a ceramic capacitor of 0.1 µF is used. A too-low value of this capacitor causes decreased switching speed, and malfunctions. Conversely, a too-high value causes a longer startup time because a long charging time for this capacitor delays startup of the power supply. These factors should be carefully evaluated.

The capacitor should be placed as close to the IC as possible.

• ***REF pin capacitor C_2*** C_2 is a capacitor which prevents noise at the REF pin. Because the OCP detection voltage, V_{OCP}, is dependent on the REF pin voltage, according to the REF pin voltage, V_{OCP} rises during startup. For this reason, when the capacity of C_2 is large, the V_{OCP} value during startup rises slowly.

When the output capacitor, C_3, is connected, if the capacity of both C_2 and C_3 is large, OCP may operate during startup. Then, the REF pin voltage (the voltage which determines V_{OCP}) and the SEN pin voltage during startup need to be checked, and a C_2 capacity at which the OCP does not operate is to be selected.

• ***Output capacitor C_3 (Optional)*** As a measure against LED current ripple on the LEDs, the output capacitor, C_3, is connected in parallel to the LEDs if needed.

C_3 is in an electric discharge state at the time of power activation. If a power supply is switched on during this state, it is as if the load is in short circuit state, the inductor current increases during startup, and the OCP may operate. Then, the REF pin voltage (the voltage which determines V_{OCP}) and the SEN pin voltage during startup need to be checked, and a C_3 capacity in which the OCP does not operate is to be selected.

• ***R_1, R_2, and R_S*** These resistors determine the peak output current, I_{PEAK}, flowing to the LEDs. There are two methods for setting the reference current values, internal or external.

To input the reference voltage externally, the range of the REF pin voltage, V_{REF}, is set to be 0.2 to 2 V.

The peak output current is calculated as follows:

$$I_{PEAK} = 0.4 \times V_{REF} / R_S \tag{5}$$

$$V_{REF} = V_{REG} \times R_2 / (R_1 + R_2) \tag{6}$$

For example, to set I_{PEAK} to 0.3 A, when an R_1 of 620 kΩ, an R_2 of 51 kΩ, and an R_S of 1 Ω are chosen:

$$I_{PEAK} \approx \frac{0.4 \times 10\,(V) \times 51\,(k\Omega)}{1\,(\Omega) \times (620\,(k\Omega) + 51\,(k\Omega))} \approx 0.3\ A$$

The variation of I_{PEAK} results from that of the REG output voltage, R_1, R_2, and R_S.

To use the internal reference voltage, the range of the REF pin voltage, V_{REF}, is set to be 2 to 3 V.

For example, to set V_{REF} to 2.4 V, when an R_1 of 510 kΩ and an R_2 of 160 kΩ are chosen:

$$V_{REF} \approx \frac{10\,(V) \times 160\,(k\Omega)}{510\,(k\Omega) + 160\,(k\Omega)} \approx 2.4\ V$$

The peak output current is calculated as follows:

$$I_{PEAK} = 0.8\ (V) / R_S$$

For example, to set I_{PEAK} to 0.3 A, when an R_S of 2.7 Ω is chosen:

$$I_{PEAK} \approx 0.8\ (V) / 2.7\ (\Omega) \approx 0.3\ A$$

The variation of I_{PEAK} results from that of the internal reference voltage and R_S.

In actual operation, the current value is higher than that calculated by the above equations because there is some propagation delay in internal circuit. Especially when the input voltage is high and the inductance value is low, the di/dt slope of the current is high, and the actual current value is much higher than the calculated current value.

The current flowing to R_1 and R_2 affects the losses in the internal regulator directly. Therefore it is recommended to select R_1 and R_2, such that 500 kΩ < $R_1 + R_2$, in order to restrict current as much as possible.

It is recommended that the detection resistor, R_S, have an allowable power dissipation that is twice to three times as much as the loss in R_S as margin, because the output current flows to it when the internal power MOSFET turns on, and the loss may be comparatively big.

• ***C_{PWM}*** This determines the fixed off-time when using internal PWM control. The recommended value is 100 pF, however the proper value is changeable according to the load conditions of the user-selected LEDs. When the C_{PWM} value is small, the off-time is short, and thus the operation frequency increases.

The following equation shows the relation between C_{PWM} and off-time:

$$t_{OFF}\ (\mu s) = 0.15 \times C_{PWM}\ (pF) + 2 \tag{7}$$

When the recommended C_{PWM} value, 100 pF, is used, t_{OFF} is calculated as follows:

$$t_{OFF} = 0.15 \times 100\ (pF) + 2 \approx 17\ \mu s$$

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