![Texas Instruments]

Programmable LED Driver with Single-Wire Interface

General Description

The LP5560 is a programmable LED driver that can generate a variety of blinking sequences with up to three pulses of different length per sequence. Blinking sequences can be programmed through a single-wire interface. Programmable parameters include on and off times as well as rise and fall times. A default sequence is programmed into LP5560 to enable use of the device in simple systems without programming capabilities.

Very low headroom voltage eliminates the need for a boost converter. Indicator LEDs can be driven directly from the battery. Small package size, combined with zero external components, minimizes the solution size.

The LP5560 is available in a tiny 4-bump micro SMD package with 0.4 mm pitch.

Features

- Programmable blinking sequence with current rise and fall time control
- Default blinking sequence for simple systems without programming capabilities
- Single-wire interface
- Constant current high side output driver
- Ultra-small solution size
  - No external components
  - 0.891 mm (max.) x 0.891 mm (max.) x 0.6 mm micro SMD package with 0.4 mm pitch
- Very low headroom voltage (40 mV typ.)
- Adjustable output current from 2.8 mA to 19.5 mA
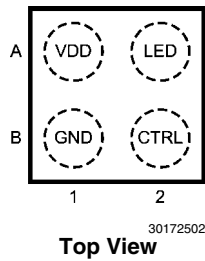- Wide input-voltage range: 2.7V to 5.5V

Applications

- Indicator LEDs in cell phones and other portable devices

Typical Application Circuit

30172501
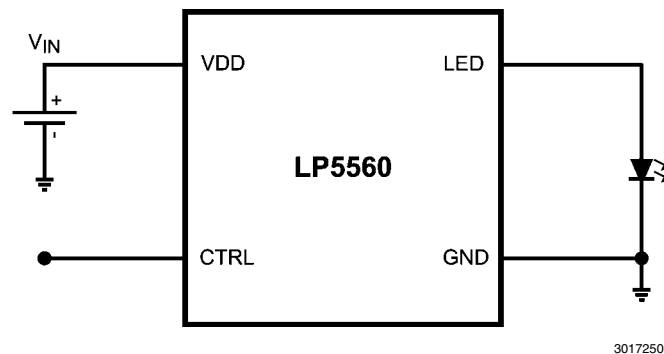
Connection Diagrams and Package Mark Information

Connection Diagram

Top View

ORDERING INFORMATION

Order Number	Package Marking	Supplied As
LP5560TME	I	250 units, Tape and Reel
LP5560TMX		3000 units, Tape and Reel

PIN DESCRIPTIONS

Pin	Name	Type	Description
A1	VDD	P	Power supply pin
A2	LED	A	Current source output
B1	GND	G	Ground
B2	CTRL	DI	Single-wire interface input

A: Analog Pin D: Digital Pin G: Ground Pin P: Power Pin I: Input Pin

Absolute Maximum Ratings (*Note 1*, *Note 2*)

If Military/Aerospace specified devices are required, please contact the Texas Instruments Sales Office/ Distributors for availability and specifications.

Voltage on VDD pin	−0.3V to +6.0V
Voltage on other pins (CTRL, LED)	−0.3V to VDD +0.3V with 6.0V max
Continuous Power Dissipation (*Note 3*)	Internally Limited
Junction Temperature (T_{J-MAX})	125°C
Storage Temperature Range	−65°C to +150°C
Maximum Lead Temperature (Reflow soldering, 3 times) (*Note 4*)	260°C
ESD Rating (*Note 5*)	
Human Body Model	2.0kV
Charged Device Model	1000V

Operating Ratings (*Note 1*, *Note 2*)

Voltage on power pin (VDD)	2.7V to 5.5V
Junction Temperature (T_J) Range	−30°C to +125°C
Ambient Temperature (T_A) Range (*Note 7*)	−30°C to +85°C

Thermal Properties

Junction-to-Ambient Thermal Resistance (θ_{JA}), TMD04 Package (*Note 8*)	120°C/W

Electrical Characteristics (*Note 2*, *Note 9*)

Limits in standard typeface are for T_A = 25°C. Limits in **boldface** type apply over the operating ambient temperature range (−30°C < T_A < +85°C). Unless otherwise specified: V_{IN} = 3.6V, CTRL = 3.6V, V_{LED} = 3.1V.

Symbol	Parameter	Condition	Min	Typ	Max	Units
I_{SD}	Shutdown Supply Current	CTRL = 0V		0.4	**0.75**	μA
I_Q	Quiescent Supply Current	I_{LED} = 0 mA		25	**30**	
I_{LED}	LED Output current	ISET = 0	**2.26**	2.8	**3.34**	mA
		ISET = 1 (default)	**4.61**	5.3	**5.99**	
		ISET = 2	**6.78**	7.8	**8.82**	
		ISET = 3	**8.87**	10.2	**11.53**	
		ISET = 4	**10.96**	12.6	**14.24**	
		ISET = 5	**13.50**	15.0	**16.50**	
		ISET = 6	**15.05**	17.3	**19.55**	
		ISET = 7	**16.96**	19.5	**22.04**	
$\Delta I_{LED}\%/\Delta V_{IN}$	Line regulation	2.7V ≤ V_{IN} ≤ 4.5V, I_{DX} = 5.3 mA, Vf = 2.5V	**−3%**		**3%**	%/1V
$\Delta I_{LED}\%/\Delta V_{LED}$ (*Note 11*)	Load regulation	1.7V ≤ V_{LED} ≤ 3.4V, I_{LED} = 5.3 mA		0.6		
V_{HR}	Headroom Voltage(*Note 12*)	I_{LED} = 5.3 mA		40	**100**	mV
		I_{LED} = 19.5 mA		40		
V_{IH}	Logic Input High level	V_{IN} = 2.7V to 5.5V	**1.1**			V
V_{IL}	Logic Input Low level	V_{IN} = 2.7V to 5.5V			**0.6**	V
I_{CTRL}	CTRL pin leakage current	CTRL = 1.8V			**400**	nA

Symbol	Parameter	Condition	Min	Typ	Max	Units
T_cycle_H	LED On time	adjustable (*Note 10*)	13.2		3009.6	ms
T_cycle_L	LED OFF time	adjustable (*Note 10*)	26.4		6019.2	
T rise	LED current rise time (*Note 13*)	adjustable (*Note 10*)	0		1584	
T fall	LED current fall time (*Note 13*)	adjustable (*Note 10*)	0		1584	
Fade resolution	Rise/fall time resolution	(*Note 10*)		105.6		

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the component may occur. Operating Ratings are conditions under which operation of the device is guaranteed. Operating Ratings do not imply guaranteed performance limits. For guaranteed performance limits and associated test conditions, see the Electrical Characteristics tables.

Note 2: All voltages are with respect to the potential at the GND pins.

Note 3: Internal thermal shutdown circuitry protects the device from permanent damage. Thermal shutdown engages at $T_J=160°C$ (typ.) and disengages at $T_J=140°C$ (typ.).

Note 4: For detailed soldering specifications and information, please refer to *Texas Instruments Application Note AN1112 : Micro SMD Wafer Level Chip Scale Package.*

Note 5: The Human body model is a 100 pF capacitor discharged through a 1.5 kΩ resistor into each pin. MIL-STD-883 3015.7

Note 6: Under-voltage lockout (UVLO) shuts down the LED driver with V_{IN} drops to 2.3V (typ.). Power-on reset (POR) trips at V_{IN} = 2.0V (typ.).

Note 7: In applications where high power dissipation and/or poor package thermal resistance is present, the maximum ambient temperature may have to be derated. Maximum ambient temperature (T_{A-MAX}) is dependent on the maximum operating junction temperature ($T_{J-MAX-OP}$ = 125°C), the maximum power dissipation of the device in the application (P_{D-MAX}), and the junction-to ambient thermal resistance of the part/package in the application (θ_{JA}), as given by the following equation: $T_{A-MAX} = T_{J-MAX-OP} - (\theta_{JA} \times P_{D-MAX})$.

Note 8: Junction-to-ambient thermal resistance is highly application and board-layout dependent. In applications where high maximum power dissipation exists, special care must be paid to thermal dissipation issues in board design.

Note 9: Min and Max limits are guaranteed by design, test, or statistical analysis. Typical numbers are not guaranteed, but do represent the most likely norm.

Note 10: Guaranteed by design.

Note 11: I_{LED} = LED output current, V_{LED} = LED forward voltage.

Note 12: For LED output pin, headroom voltage is defined as the voltage across the internal current source when the LED current has dropped 10% from the value measured at VIN – 0.5V. If headroom voltage requirement is not met, LED current regulation will be compromised.

Note 13: LED current ramp up and ramp down uses a combined PWM / current adjustment.

Single-Wire Interface Timing Characteristics (*Note 9*)

Symbol	Parameter	Condition	Min	Typ	Max	Units
T_{C_ON}	Command pulse on time	(*Note 10*)	15			µs
T_{C_OFF}	Command pulse off time	(*Note 10*)	30			
T_{T_ON}	Minimum training pulse on time (*Note 14*)	(*Note 10*)	200			
T_{T_OFF}	Minimum training pulse off time (*Note 15*)	(*Note 10*)	200			
T_{CAL}	Calibration pulse length	(*Note 10*)	0.35		8	ms
T_{ENTER}	Command entering period	(*Note 10*)	500			µs
$T_{ENTER}+T_{BLANK}$	Command entering period + Blank period	(*Note 10*)			1500	

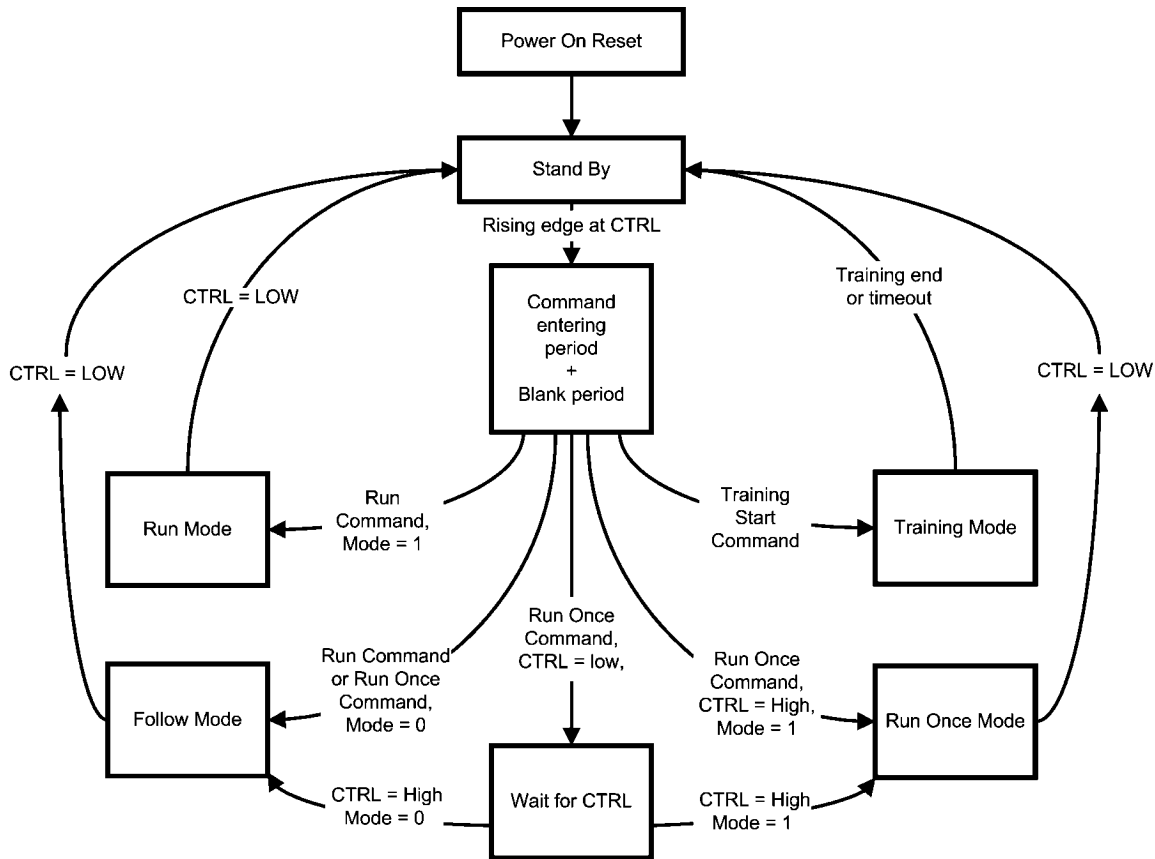**Note 14:** All CTRL signal high times between calibration pulse and training end are considered as training pulse on times.

Note 15: All CTRL signal low times between calibration pulse and training end are considered as training pulse off times.
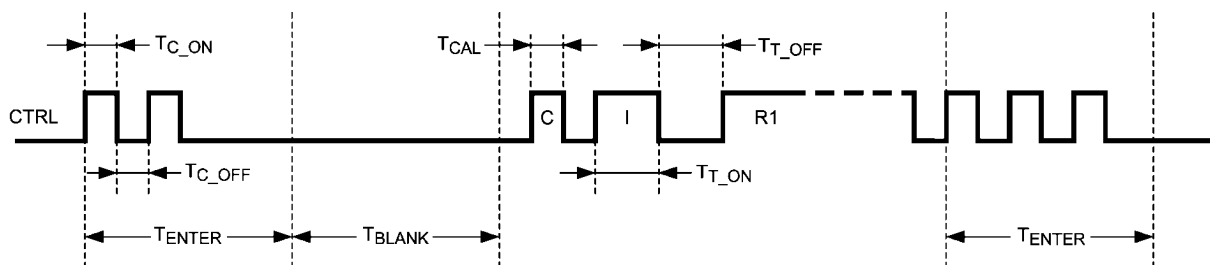
FIGURE 1. Interface Timing

Operating Modes

30172504

POWER-ON RESET	When input voltage is applied to VDD pin device goes through Power On Reset (POR). During POR defaults are set into control registers.
STANDBY:	After POR device goes to standby. This is the low-power mode when all the internal blocks are shut down.
COMMAND ENTERING PERIOD + BLANK PERIOD:	Rising edge of the CTRL signal activates the circuit and starts a command entering period. During the command entering period all rising edges are counted. After command entering period there is a blank period when no rising edges are allowed.
RUN:	If mode bit is "1" (run mode), and run command has been detected, device goes into run mode. In run mode the LP5560 generates the programmed blinking sequence.
FOLLOW MODE:	If mode bit is "0" (follow mode), and run command or run once command has been detected, the LP5560 goes into follow mode. In follow mode LED stays on as long as CTRL pin is held high.
RUN ONCE MODE:	If run once command has been detected, and mode bit is "1" (run mode), the device goes into run once mode. In run once mode the LP5560 generates the programmed blinking sequence once. CTRL must be high as long as blinking sequence is running.
TRAINING:	If training start command has been detected device goes into training mode. In training mode a new blinking sequence can be programmed into the device.

TEXAS
INSTRUMENTS

Typical Performance Characteristics

T_J = 25°C. Unless otherwise noted, typical performance characteristics apply to the LP5560 Typical Application Circuit with: V_{IN} = 3.6V, R_{ISET} = 24 kΩ, C_{IN} = 100 nF.
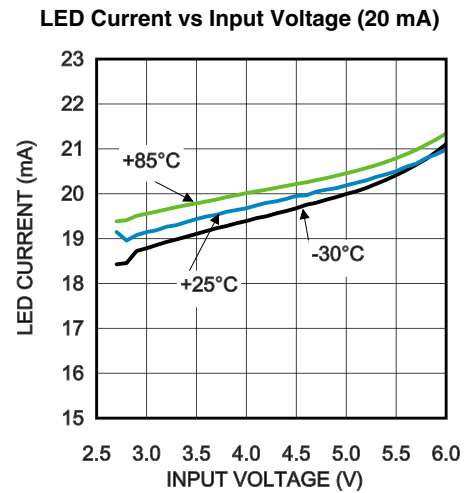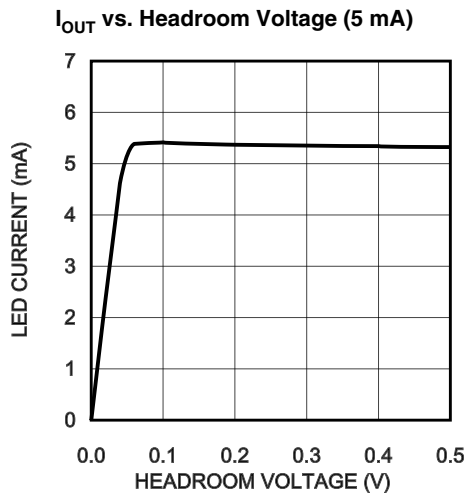
Standby Current vs V_{IN}

30172521

Quiescent Current vs V_{IN}

30172522

LED Current vs Input Voltage (5 mA)

30172523

LED Current vs Input Voltage (20 mA)

30172524

I$_{OUT}$ vs. Headroom Voltage (5 mA)

30172525

I$_{OUT}$ vs. Headroom Voltage (20 mA)
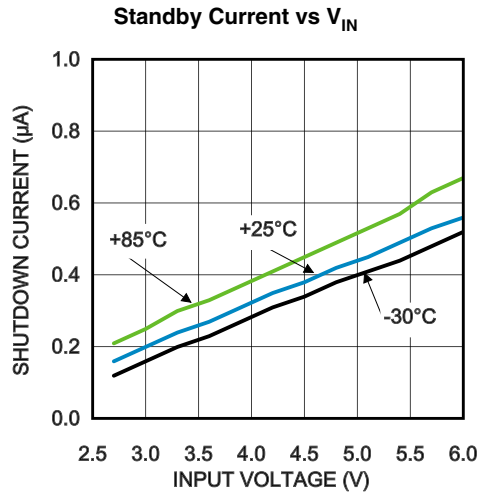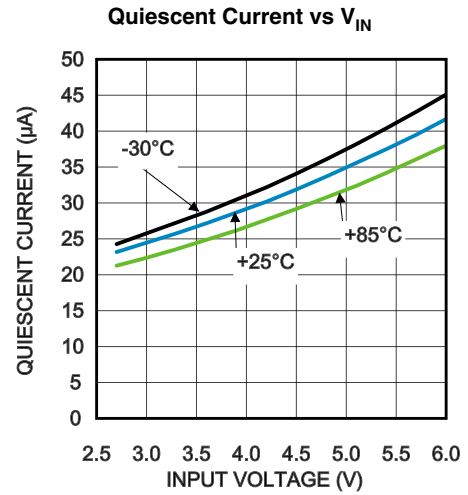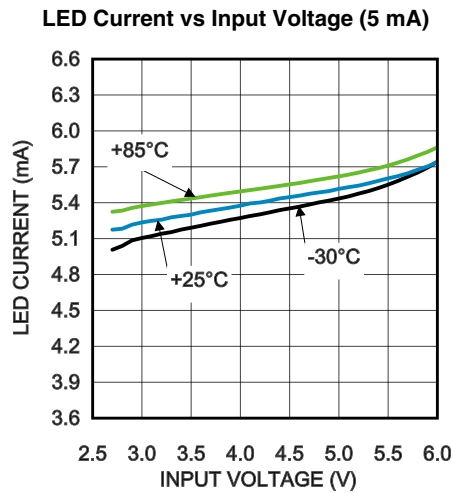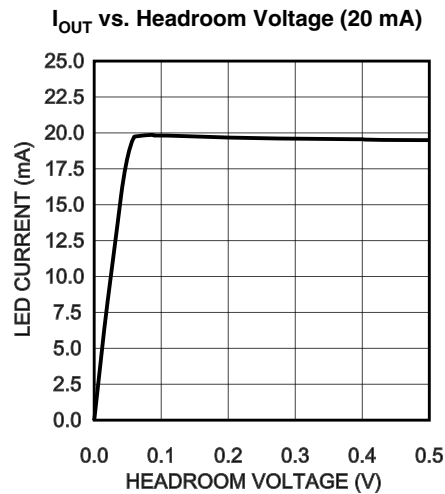
30172526

Application Information

The LP5560is a programmable LED driver with a single-wire interface. It is designed to drive a single indicator LED with different blinking sequences. Up to three pulses with different on and off times can be programmed into the device. LED current rise and fall times can also be independently controlled. Blinking sequence is stored into volatile memory, thus removing input voltage V$_{IN}$ resets the memory into default state.

High-side LED driver has a very low headroom voltage requirement and can drive most indicator LEDs directly from battery voltage. A single CTRL pin is used to control the device on and off and to change settings of the device. A default blinking sequence is programmed into the device to enable use of the devices in simply applications without programming capabilities.

LED DRIVER HEADROOM VOLTAGE

Current source is connected internally between the VDD and LED output pins. The voltage across the current source, (V$_{VDD}$ − V$_{LED}$), is referred to as headroom voltage (V$_{HR}$). The current source requires a sufficient amount of headroom voltage to be present across it in order to regulate the output current properly. LP5560's headroom voltage requirement is 40 mV (typ.) and does not depend on the current setting.

SINGLE-WIRE INTERFACE

The LP5560 has one digital control input (CTRL). Threshold levels of CTRL input are fixed to support control from low-voltage controller. The CTRL signal is used to control the mode of the circuit. Rising edge of the CTRL signal activates the circuit and starts a command entering period. During the command entering period all rising edges are counted. After command entering period there is a blank period when no rising edges are allowed. If there are any rising edges during the blank period, they are not detected. User must take care not to start the training sequence before the blank period has elapsed, or the training sequence will be corrupted.

If CTRL is left high after command entering period, the consequent command is performed right after the blank period. In case of run once command, CTRL pin can be set low after the command entering period, and execution of the command starts once CTRL pin is pulled high after blank period.
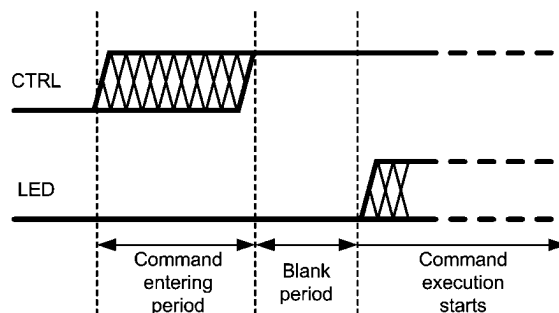

30172505

FIGURE 2. Single-Wire Interface Command

The LP5560 has four different commands. Each command depends on the number of rising edges during command entering period. If there are more than 4 rising edges during command entering period, the command is ignored. Note that even in this case the blank period needs to elapse before next command can be given.

Command	Number of Rising Edges During Command Entering Period
Run	1
Training start	2
Training end	3
Run once	4

Run Command

One rising edge of CTRL signal within the command entering period is interpreted as Run command. The CTRL pin must be kept high during blank period. If the CTRL pin is pulled low during the command entering period or the blank period, the device goes to Standby. In run mode (mode bit = 1) a blinking sequence is started right after the blank period, and it is repeated as long as the CTRL signal is kept high. When the CTRL signal is set low the device goes into Standby mode (*Figure 3*).

30172506
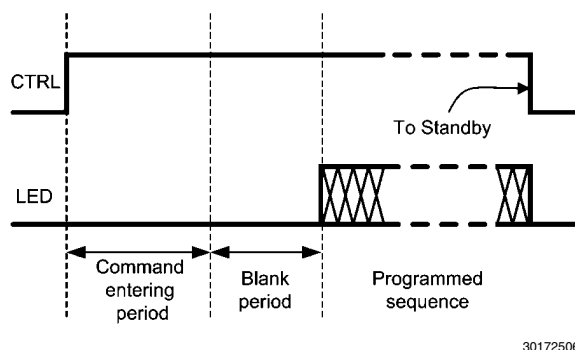
FIGURE 3. Run Mode

In Follow mode (mode bit = 0) LED is turned on right after the Blank period, and it stays on as long as CTRL is kept high. When the CTRL signal is set low, LED is turned off, and the device goes into Standby mode (*Figure 4*).

30172507
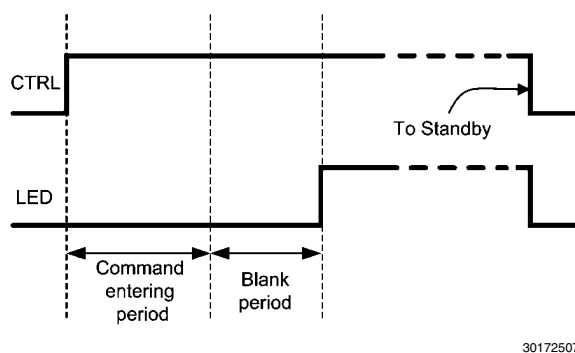
FIGURE 4. Follow Mode

Training Start Command

Two rising edges of the CTRL signal within the command entering period is interpreted as a Training Start command. The Training Start command starts the training sequence. Different blinking sequences can be trained into the device in Training mode. Training mode is described in more details in *TRAINING MODE*.

Training End Command

Three rising edges of CTRL signal within the command entering period is interpreted as a Training End command. Training End is used to stop the training sequence.

Run Once Command

Four rising edges of CTRL signal within the command entering period is interpreted as a Run Once command. A programmed blinking sequence is performed once after the Run Once command. If CTRL is kept high after the command entering period, the programmed blinking sequence starts right after the blank period has elapsed (*Figure 5*). The CTRL signal must stay high as long
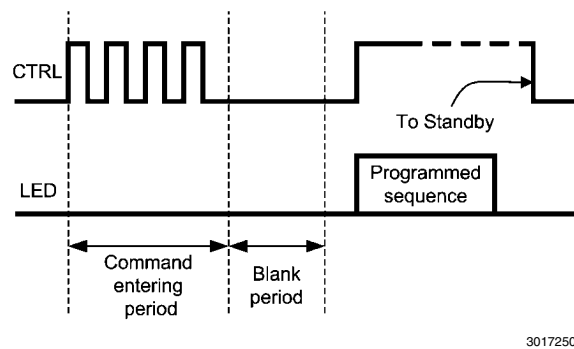
as the programmed blinking sequence is executed. If CTRL is set low during execution of the blinking sequence, the device goes to standby, and execution of the blinking sequence is stopped.
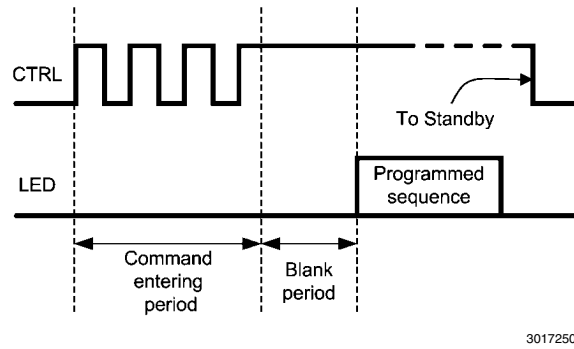
FIGURE 5. Run Once Command

If the CTRL signal is low after the command entering period, a blinking sequence is executed once the CTRL is set high (*Figure 6*).

FIGURE 6. Delayed Run Once Command

If the device is in Follow mode (mode bit is "0"), the run once command turns LED on, and it is kept on as long as CTRL is held high.

TRAINING MODE

Figure 11 shows an example of the full training sequence with 3 pulses. Training mode starts with a training start command. The training start command is followed by blank time during which no rising edges are allowed. Blank time is followed by calibration pulse. Calibration pulse length (T_{CAL}) defines the speed of the training sequence and can vary from 300 µs to 10 ms. During parameter settings register values are incremented at a speed defined by T_{CAL}. For example, if calibration pulse length is 1 ms and current setting pulse length is 3.3 ms, the current setting value is 3 (current set register is incremented 3 times). If parameter setting pulse is shorter than calibration, the pulse setting is 0.

The next rising edge after the calibration pulse starts the LED driver current setting (I). The LED driver current is recorded once CTRL is pulled low. Note that there are "empty" low times before and after current setting pulse. For the following pulses both CTRL high and CTRL low times are used to set the parameters. Next , CTRL high time defines LED current rise time setting for pulse 1 (R1). When R1 setting is started, Mode bit is set to "0". This sets the LP5560 into Follow mode. Mode bit is set to "1" after the first off time has been saved into the register. This means that at least one full pulse needs to be trained into memory to set the device into Run mode.

CTRL low time after R1 defines the LED on time for pulse 1 (ON1). CTRL high time after ON1 sets the LED current fall time (F1). CTRL low time after F1 sets pulse 1 off time (OFF1). Once the rising edge of CTRL is detected after first off-time setting, mode bit is set to "1" (Run mode), and number of pulses register (NOP[1:0]) is set to 1. This indicates that one full pulse has been trained into memory.

Rise-, on-, fall- and off-times for pulses 2 and 3 are set the same way as for pulse 1. Note that NOP register is always incremented after OFFx time setting. This means that all pulse parameters (rise-, on-, fall- and off-time) need to be trained for each pulse make it valid. The training sequence ends with the Training End command.
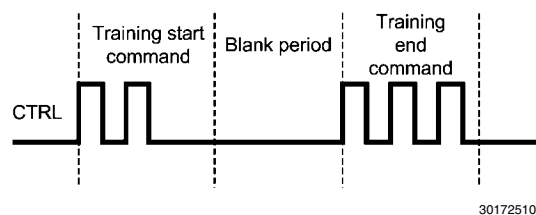
Ending the Training Sequence

The training end command can be given at any time of the training sequence except during blank time. Outcome of the training sequence depends on the place of the Training End command. If the Training End command is given after any of the off-time setting (OFF1, OFF2 or OFF3), mode bits are set to "1", and corresponding number of pulses are stored into memory. If the Training End

command is given after any of the other pulse parameters (Rx, ONx or Fx), that pulse is ignored. For example, if the Taining End command is given after ON2, pulse 2 is ignored, and the blinking sequence will include only pulse 1.

Reset to Default

If the Training End command is given right after the Training Start command, the LP5560 is reset back to factory defaults (*Figure 7*). In this case the mode bit is set to "1" (Run mode) with the factory-set default blinking sequence.

FIGURE 7. Reset to Default

Changing LED Current

The LP5560 allows the LED output current to be changed without the need to reprogram the previously programmed blinking sequence. This is done by giving the Training End command after current setting (*Figure 8*). In this case only the current setting changes. If a blinking sequence was programmed into the LP5560, it remains unchanged. If mode bit was "0" (Follow mode) before the training sequence, it remains "0".
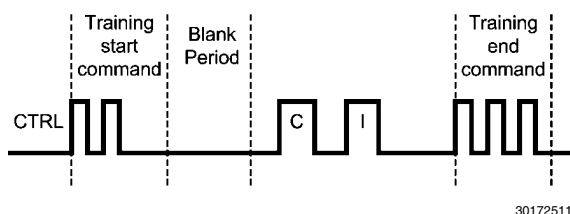
FIGURE 8. Current Programming Sequence

Entering Follow Mode

The Mode bit can be set to "0" (Follow mode) in two ways. If the Training end command is given after calibration, the pulse mode bit is set to "0" (Follow mode), and the previously set LED output current setting remains unchanged (*Figure 9*).
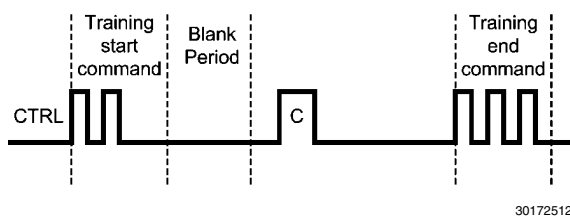
FIGURE 9. Entering Follow Mode

If the Training End command is given after R1, ON1 or F1 modes, bits are set to "0" (follow mode), and new current setting is stored to the current register (*Figure 10*). If the Training End command is given after F1, CTRL low time before training end command needs to be less than Minimum training pulse off time (200 μs). Otherwise off-time OFF1 will be set to minimum value, and pulse 1 will be stored into memory.
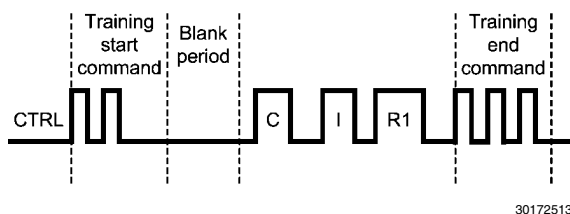
FIGURE 10. Entering Follow Mode with New Current Setting

Timeout

If during training CTRL stays constant for more than 127 * T_{CAL} time, this is interpreted as timeout. For example, if calibration pulse length T_{CAL} is 1ms, timeout time is 127 ms. Timeout ends the training sequence. Timeout is considered as a "false" training, and it is a good practice to always give a complete training sequence after timeout to ensure correct data is stored into memory.

30172514
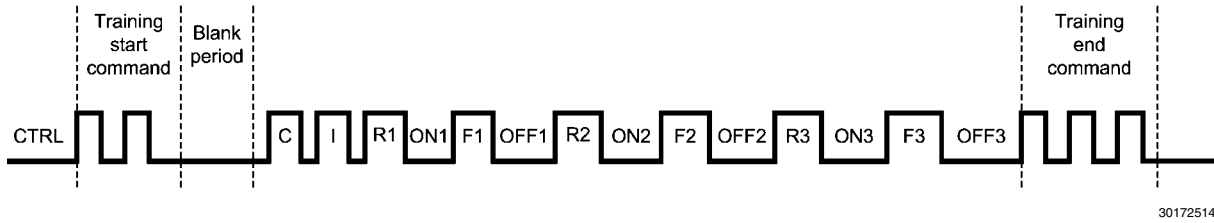
FIGURE 11. Full Training Sequence

LED OUTPUT CURRENT SETTING

The LED output current can be set from 2.8 mA to 19.5 mA in 7 steps. Duration of the current setting pulse (I) defines the current setting.

Current Setting	LED Current (mA)
0	2.8
1	5.3 default
2	7.8
3	10.2
4	12.6
5	15.0
6	17.3
7	19.5

RISE/FALL TIME SETTING

Rise and fall times of each pulse can be programmed independently. Rise and fall times can be set from 0 to 1584 ms with 105.6 ms steps. Rise and fall times are generated using a combined PWM and current control. Ramp has 32 PWM steps. For the first 8 steps LED current is decreased to 12.5%. For the remaining steps current is set to 100%. Each step is 3.3 ms long. This result in a minimum ramp time of 3.3 ms * 32 = 105.6 ms. When ramp time is increased, each PWM step is done multiple times. When setting rise and fall times, they are always rounded down. For example, if calibration pulse length is 1 ms, and rise time setting pulse is 2.9 ms, rise time is set to 2 which is 211.2 ms. Rise and fall times can be set to zero by giving a pulse that is shorter than a calibration pulse.

Ramp setting	Ramp time (ms)
0	0
1	105.6
2	211.2
3	316.8
4	422.4
5	528 default
6	633.6
7	739.2
8	844.8
9	950.4
10	1056
11	1161.6
12	1267.2
13	1372.8
14	1478.4
15	1584

LED ON-TIME SETTING

LED on-time has a 5-bit control. On-time can be controlled from 13.2 ms to 3009.6 ms in 31 steps. Step size is not constant to increase resolution on shorter ON times. With longer on-times the step size is increased as well. The table below shows the available on-times:

Setting	LED On time (ms)
0	13.2
1	26.4
2	52.8
3	105.6
4	158.4
5	211.2
6	264
7	316.8
8	369.6
9	435.6
10	501.6 default
11	594
12	699.6
13	805.2
14	910.8
15	1016.4
16	1122
17	1227.6
18	1353
19	1478.4
20	1603.8
21	1729.2
22	1854.6
23	1980
24	2105.4
25	2230.8
26	2356.2
27	2481.6
28	2613.6
29	2745.6
30	2877.6
31	3009.6

LED OFF-TIME SETTING

LED off-time has also a 5-bit control. Off-time can be controlled from 26.4 ms to 6019.2 ms in 31 steps. Off-time is always twice as long as on-time with the same setting.

Setting	LED Off time (ms)
0	26.4
1	52.8
2	105.6
3	211.2
4	316.8
5	422.4
6	528
7	633.6
8	739.2

Setting	LED Off time (ms)
9	871.2
10	1003.2
11	1188
12	1399.2
13	1610.4 default
14	1821.6
15	2032.8
16	2244
17	2455.2
18	2706
19	2956.8
20	3207.6
21	3458.4
22	3709.2
23	3960
24	4210.8
25	4461.6
26	4712.4
27	4963.2
28	5227.2
29	5491.2
30	5755.2
31	6019.2

DEFAULT SEQUENCE

A default blinking sequence is programmed into the LP5560 to enable the use of the device in simple systems without programming capabilities. Default sequence has a single pulse with following parameters:

I = 5.3 mA
R1 = 528 ms
ON1 = 501.6 ms
F1 = 528 ms
OFF1 = 1610.4 ms

CONTROL REGISTERS

Control registers are shown only for reference. There is no direct way to write or read these registers. Register values are set in the Training mode as described earlier in the document.

7	6	5	4	3	2	1	0
F1[3:0]				R1[3:0]			
MODE	NOP[1:0]		ON1[4:0]				
I_LED[2:0]			OFF1[4:0]				
F2[3:0]				R2[3:0]			
n/a			ON2[4:0]				
n/a			OFF2[4:0]				
F3[3:0]				R3[3:0]			
n/a			ON3[4:0]				
n/a			OFF3[4:0]				

Physical Dimensions inches (millimeters) unless otherwise noted

PKG SYMM

PKG SYMM

(0.4)

(0.4)

4X $\emptyset^{0.24}_{0.21}$

DIMENSIONS ARE IN MILLIMETERS
DIMENSIONS IN ( ) FOR REFERENCE ONLY

LAND PATTERN RECOMMENDATION

TOP SIDE COATING

BUMP A1 CORNER

$\begin{array}{c}0.125\\0.050\end{array}$

X3

BUMP

SILICON

$\begin{array}{c}0.205\\0.165\end{array}$

4X $\emptyset^{0.28}_{0.25}$

$\oplus$ | 0.005 Ⓢ | C | A Ⓢ | B Ⓢ |

B

X2

SYMM

SYMM

X1

0.4

0.4

B   A

A

2

1

TMD04XXX (Rev A)
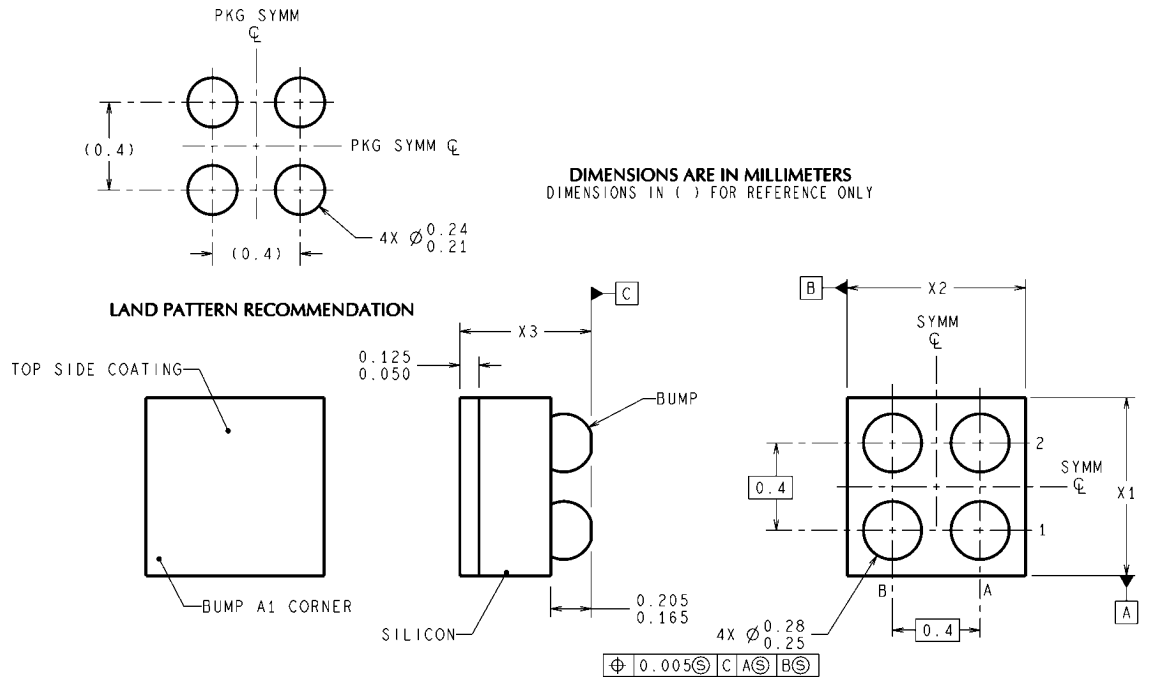
NS Package Number TMD04DDA
4-bump micro SMD
The dimension for X1, X2 and X3 are as given:
X1 = 0.891 mm ±0.03 mm
X2 = 0.891mm ±0.03 mm
X3 = 0.60 mm ±0.075 mm

See Texas Instruments Application Note 1112 Micro SMD Wafer Level Chip Scale Package for PCB design and assembly instructions.

Notes

Notes

IMPORTANT NOTICE

Products		Applications	
Audio	www.ti.com/audio	Automotive and Transportation	www.ti.com/automotive
Amplifiers	amplifier.ti.com	Communications and Telecom	www.ti.com/communications
Data Converters	dataconverter.ti.com	Computers and Peripherals	www.ti.com/computers
DLP® Products	www.dlp.com	Consumer Electronics	www.ti.com/consumer-apps
DSP	dsp.ti.com	Energy and Lighting	www.ti.com/energy
Clocks and Timers	www.ti.com/clocks	Industrial	www.ti.com/industrial
Interface	interface.ti.com	Medical	www.ti.com/medical
Logic	logic.ti.com	Security	www.ti.com/security
Power Mgmt	power.ti.com	Space, Avionics and Defense	www.ti.com/space-avionics-defense
Microcontrollers	microcontroller.ti.com	Video and Imaging	www.ti.com/video
RFID	www.ti-rfid.com		
OMAP Mobile Processors	www.ti.com/omap	**TI E2E Community**	e2e.ti.com
Wireless Connectivity	www.ti.com/wirelessconnectivity		