1X/1.5X/2X Charge Pump White LED Driver for Main and Sub-Displays

Features

- ±1.5% LED Current Matching
- Powers Main and Sub-Display LEDs
- High Efficiency Up to 90% Over Li-ion Battery Discharge
- Output Current Up to 30mA per LED
- 2.7V to 5.5V Operating Voltage
- 1x/1.5x/2x Charge Pump Modes
- Low Shutdown Current: 2μA Maximum
- Low Input Ripple and EMI
- Internal Soft-Start Limits Inrush Current
- Short Circuit Current Limit
- Thermal Shutdown Protection
- Output Over-Voltage Protection
- 16-pin QFN Package
- Lead Free and Green Devices Available (RoHS Compliant)

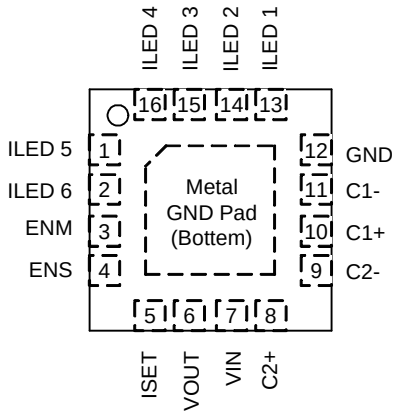
Applications

- Cellular Phone White LED Back Light
- Portable Device
- PDA, Handheld Computer
- DSC

General Description

The APW7001 is a high efficiency charge pump white LED driver; the device drives up to four white LEDs in the main display and up to two white LEDs in the sub-display with regulated constant current for uniform intensity. The supply voltage ranges from 2.7V to 5.5V and it is optimized for a Li-ion battery application. The APW7001 operates in 1x, 1.5x, and 2x charge pump modes and automatically switches the charge pump modes depend on the input voltage to maintain the required power for high power efficiency. The APW7001 provides up to 30mA per LED and allows several methods such as the PWM signals on the ENM pin for main-display dimming and on the ENS pin for sub-display dimming. The two control logic pins, ENM and ENS, allow disabling or enabling the main and sub-displays. The supply current is only 2mA in 2x mode, and the ENM and ENS are kept low for 20ms will allow the device to enter shutdown mode with 2μA quiescent current. The APW7001 features current limit and short circuit protection. The APW7001 switches at 1MHz frequency and only requires four 1μF ceramic capacitors and one resistor, and ensures low input current ripple and EMI. The APW7001 is available in a 16-pin QFN package.

Pin Configuration



APW7001
QFN4x4-16 Top View

ANPEC reserves the right to make changes to improve reliability or manufacturability without notice, and advise customers to obtain the latest version of relevant information to verify before placing orders.

Rev. A.4 - Oct., 2009

Ordering and Marking Information

APW7001 □□□-□□□ Assembly Material Handling Code Temperature Range Package Code	Package Code QA : QFN4x4-16 Operating Ambient Temperature Range I : -40 to 85 °C Handling Code TR : Tape & Reel Assembly Material G : Halogen and Lead Free Device
APW7001 QA : 	XXXXX - Date Code

Note: ANPEC lead-free products contain molding compounds/die attach materials and 100% matte tin plate termination finish; which are fully compliant with RoHS. ANPEC lead-free products meet or exceed the lead-free requirements of IPC/JEDEC J-STD-020D for MSL classification at lead-free peak reflow temperature. ANPEC defines "Green" to mean lead-free (RoHS compliant) and halogen free (Br or Cl does not exceed 900ppm by weight in homogeneous material and total of Br and Cl does not exceed 1500ppm by weight).

Absolute Maximum Ratings (Note 1)

Symbol	Parameter	Rating	Unit
V_{OUT}	VOUT to GND	-0.3 to +6	V
V_{IN}	VIN to GND	-0.3 to +6	V
V_{C1+}, V_{C1-}, V_{C2+}, V_{C2-}	C1+, C1-, C2+, C2- to GND	-0.3 to +6	V
$V_{ILED1-6}$	ILED1-6 to GND	-0.3 to +6	V
V_{ENM}, V_{ENS}	ENM, ENS to GND	-0.3 to +6	V
V_{ISET}	ISET to GND	-0.3 to 2	V
T_J	Maximum Junction Temperature	+150	°C
T_{STG}	Storage Temperature	-65 ~ 150	°C
T_{SDR}	Maximum Lead Soldering Temperature, 10 Seconds	260	°C

Note 1: Absolute Maximum Ratings are those values beyond which the life of a device may be impaired. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

Thermal Characteristics (Note 2)

Symbol	Parameter	Typical Value	Unit
θ_{JA}	Thermal Resistance -Junction to Ambient QFN4x4-16	40	°C/W

Note 2 : θ_{JA} is measured with the component mounted on a high effective thermal conductivity test board in free air.

Recommended Operating Conditions

Symbol	Parameter	Rating	Unit
V_{IN}	Input Voltage	2.8 to 4.5	V
V_{OUT}	Output Voltage	3 to 4	V
I_{LED}	LED Current	5 to 30	mA

Recommended Operating Conditions (Cont.)

Symbol	Parameter	Rating	Unit
I_{OUT}	Output Current, V_{IN}>3.5V, V_F=3.1V, 1x mode	180	mA
	Output Current, 3.5V<V_{IN}>3.1V, V_F=3.1V, 1.5x mode	120	
	Output Current, 3.1V<V_{IN}>2.8V, V_F=3.1V, 2X mode	90	
T_A	Ambient Temperature	-40 to 85	°C

Electrical Characteristics

V_{IN} = 2.85 to 5.5V, C_{IN} = C_{OUT} = C1 = C2 = 1µF (ESR = 0.03Ω), I_{LED} = 20mA, T_A = -40°C to +85°C, unless otherwise noted. Typical values are at T_A = +25°C.

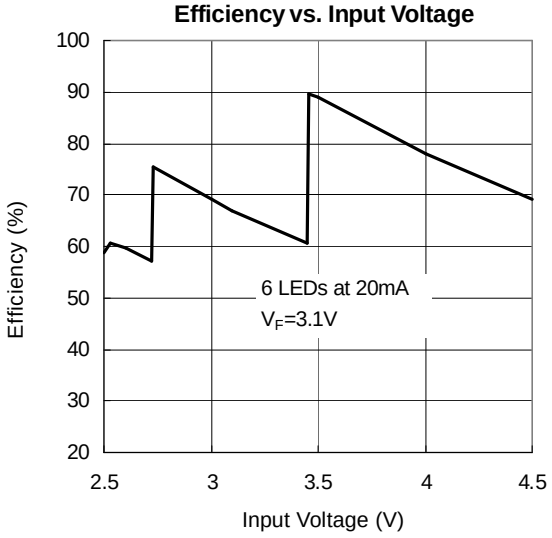
Symbol	Parameter	Test Conditions	APW7001			Unit
			Min.	Typ.	Max.	
V_{IN}	Input Voltage		2.7	-	5.5	V
V_{UVLO}	Under-voltage Lockout Threshold	V_{IN} falling	2.2	2.4	2.6	V
	Under-voltage Lockout Hysteresis		-	50	-	mV
I_Q	Quiescent Current	in 1.5x/2x mode	-	2	4	mA
		No switching in 1x mode	-	0.5	1	mA
		EN=0	-	0.1	2	µA
$I_{LED-ERR}$	LED Current Accuracy	5mA<I_{LED}<30mA (Note 3)	-	±2	±8	%
	Current Matching	5mA<I_{LED}<30mA (Note 4)	-	±1.5	±5	%
I_{ISET}	ISET Current		5	-	1000	µA
	ISET to LED Current Ratio	I_{LED} / (1.2V/R_{SET}) 5mA<I_{LED}<30mA, T_A= +25°C	370	400	420	
$V_{ILED-TH}$	ILED Threshold Voltage	V_{ILED} falling	-	100	-	mV
	1.5x mode to 1x mode Transition Hysteresis	V_{IN} rising, V_{IN}-V_{OUT}	-	300	-	mV
	2x mode to 1.5x mode Transition Hysteresis	V_{IN} rising, V_{OUT}-V_{IN}	-	300	-	mV
F_{OSC}	Switching Frequency		0.8	1	1.2	MHz
R_{OUT}	Open Loop VOUT Resistance	1x mode (V_{IN}-V_{OUT}) / I_{OUT}	-	1.6	3	Ω
		1.5x mode (1.5xV_{IN}-V_{OUT}) / I_{OUT}	-	7	12	
		2x mode (2xV_{IN}-V_{OUT}) / I_{OUT}	-	16	28	
I_{SHORT}	Short Circuit Current Limit	V_{OUT} < 1V	-	40	-	mA
V_{OVP}	Output Over Voltage Protection		5	5.5	6	V
V_{IH}	Logic Pins High Threshold		1.3	0.7	-	V
V_{IL}	Logic Pins Low Threshold		-	0.6	0.3	V
I_{IH}	Logic Pins High Current	V_{IH}=VIN	-	-	1	µA
I_{IL}	Logic Pins Low Current	V_{IL}=GND	-	-	1	µA
	Thermal Shutdown		-	150	-	°C
	Thermal Shutdown Hysteresis		-	20	-	°C

Note 3: LED current accuracy is defined as: ± ($I_{LED-MEASURED}$ - $I_{LED-SET}$) / $I_{LED-SET}$

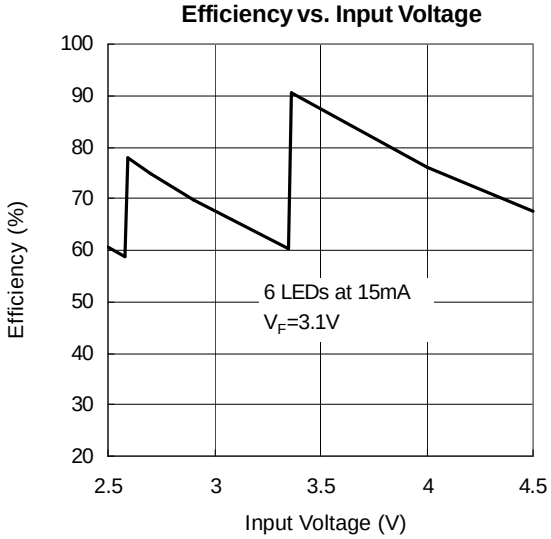
Note 4: LED current matching is defined as: ± ($I_{LED-MAX}$ - $I_{LED-MIN}$) / ($I_{LED-MAX}$ + $I_{LED-MIN}$)

Typical Operating Characteristics

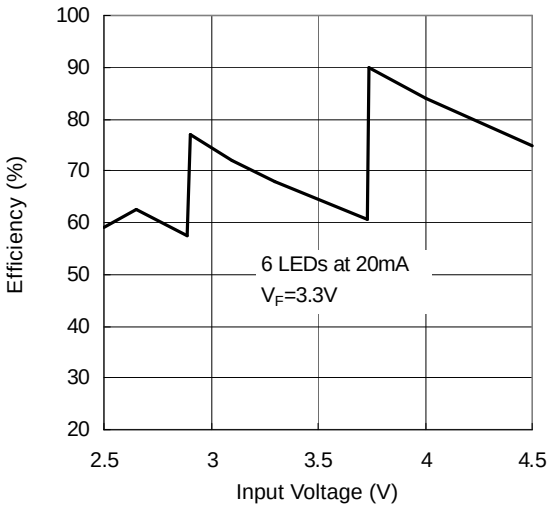
Efficiency vs. Input Voltage



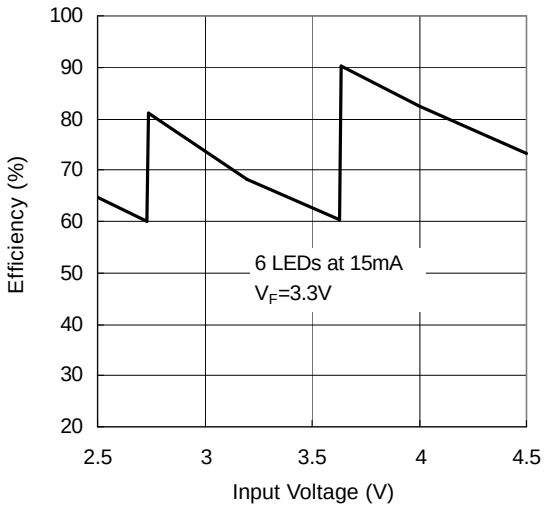
Efficiency vs. Input Voltage



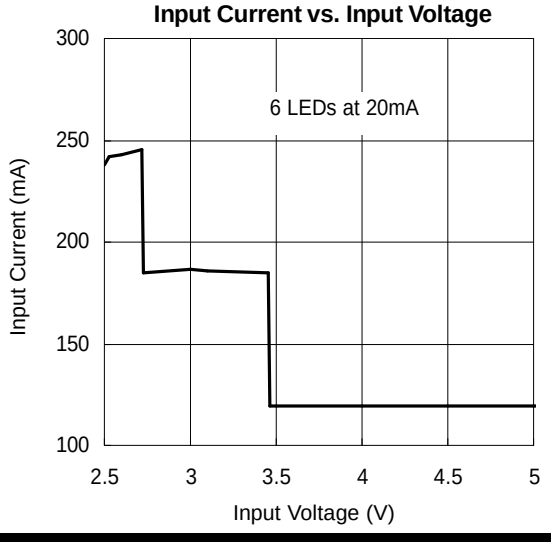
Efficiency vs. Input Voltage



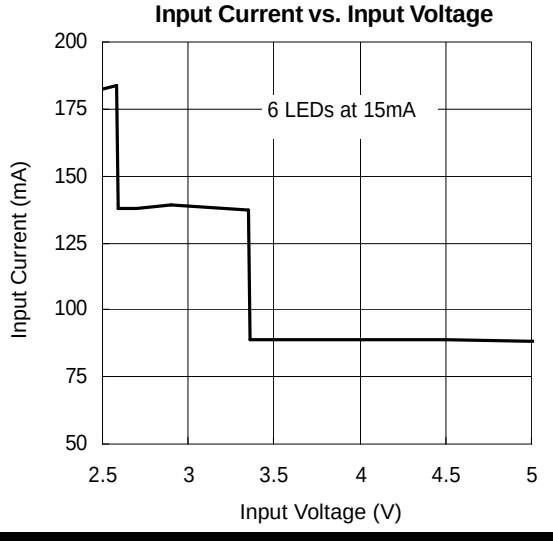
Efficiency vs. Input Voltage



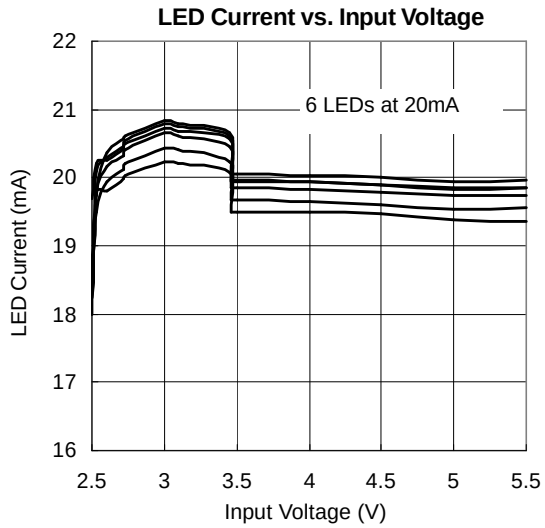
Input Current vs. Input Voltage

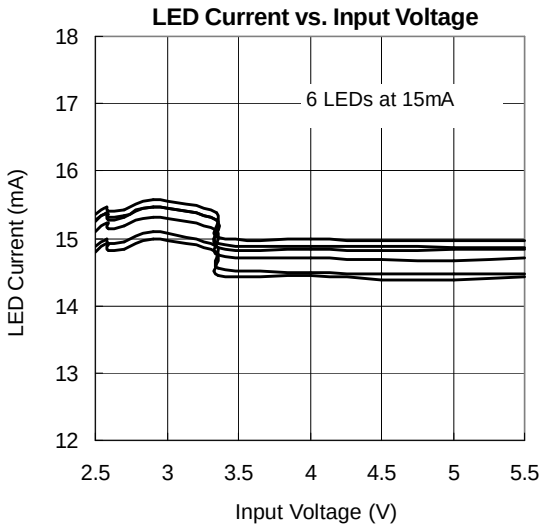


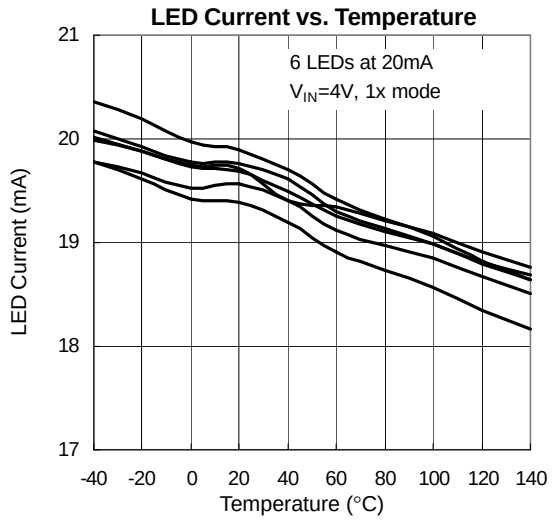
Input Current vs. Input Voltage

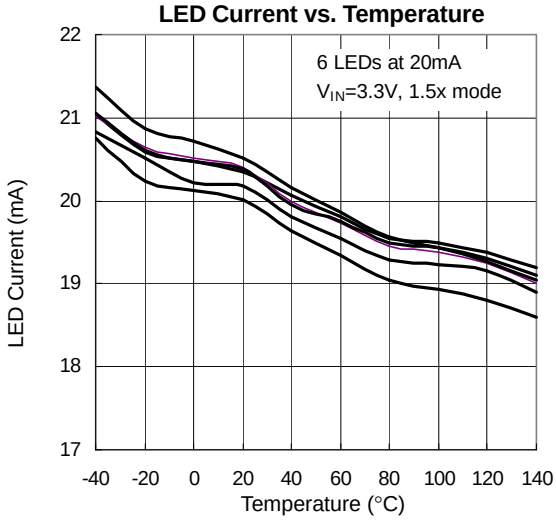


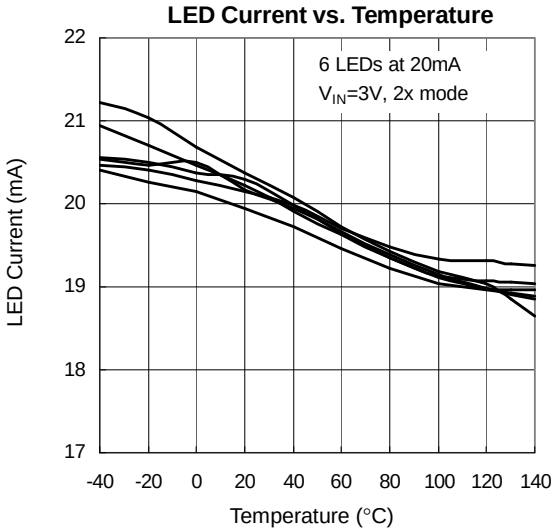
Typical Operating Characteristics (Cont.)

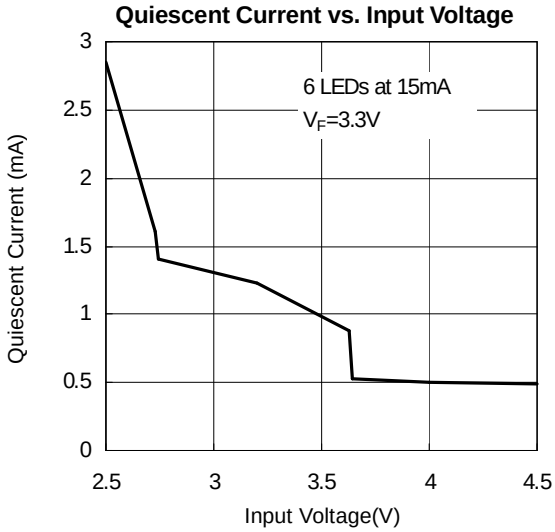






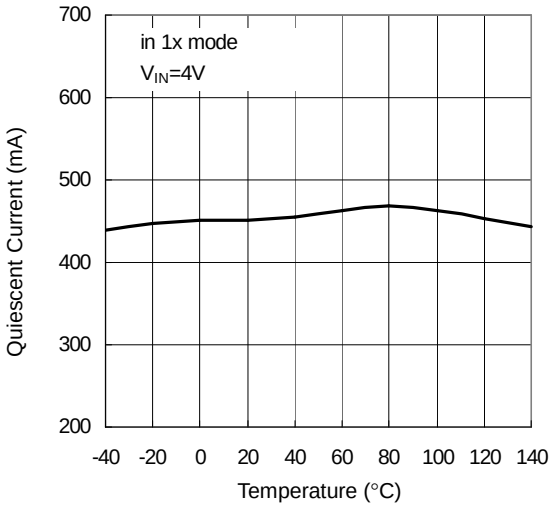




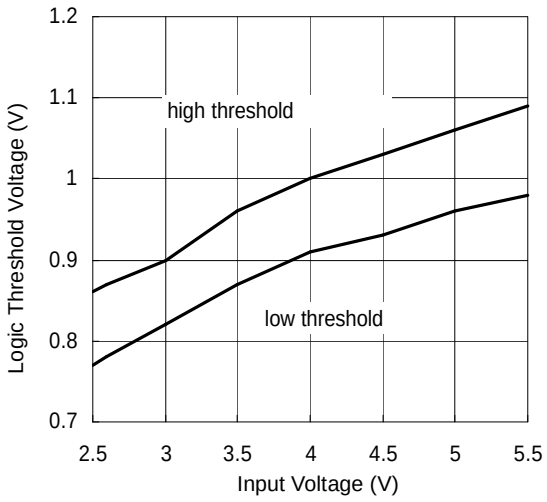


Typical Operating Characteristics (Cont.)

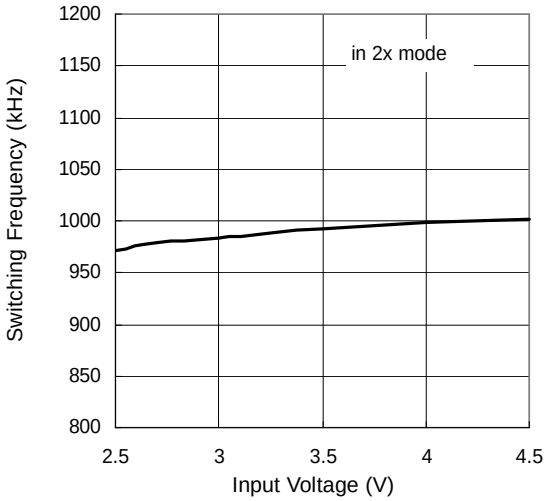
Quiescent Current vs. Temperature



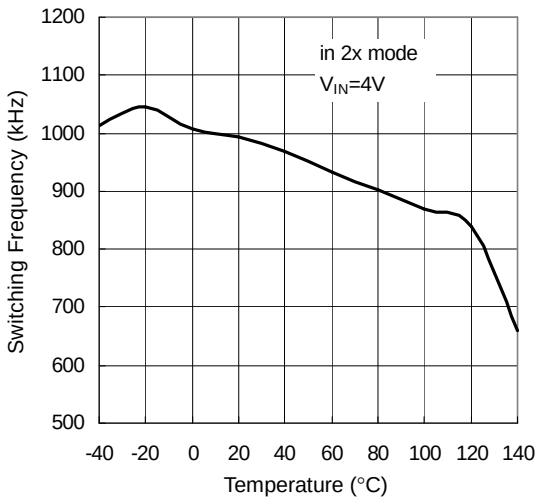
Logic Threshold Voltage vs. Input Voltage



Switching Frequency vs. Input Voltage

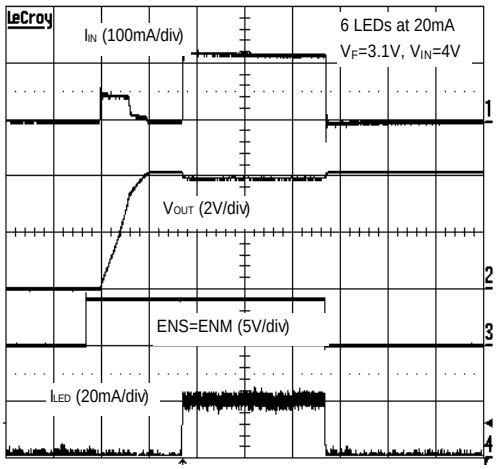


Switching Frequency vs. Temperature



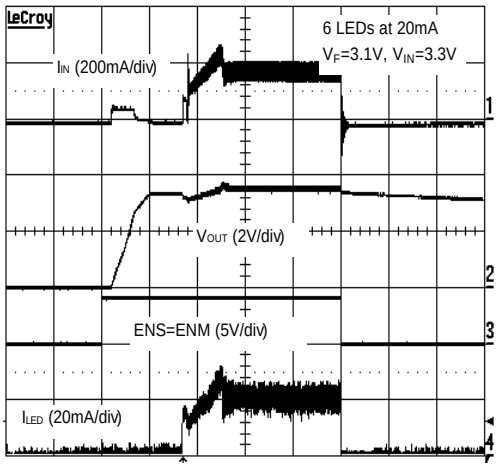
Typical Operating Characteristics (Cont.)

Start Up in 1x Mode



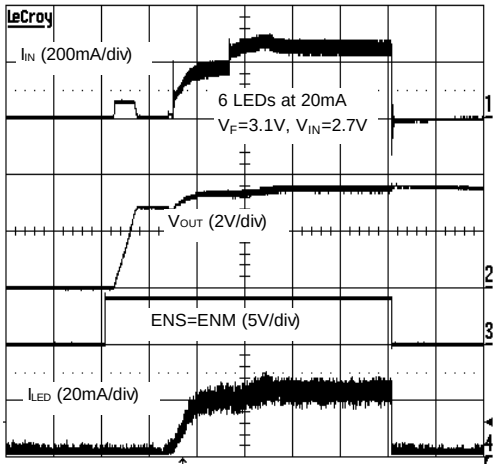
TIME (0.1ms/div)

Start Up in 1.5x Mode



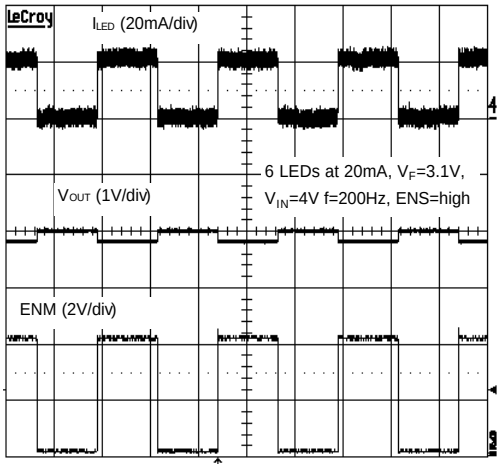
TIME (0.1ms/div)

Start Up in 2x Mode



TIME (0.1ms/div)

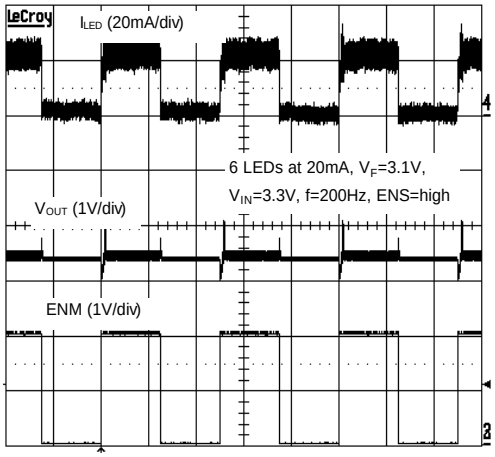
Dimming in 1x Mode



TIME (2ms/div)

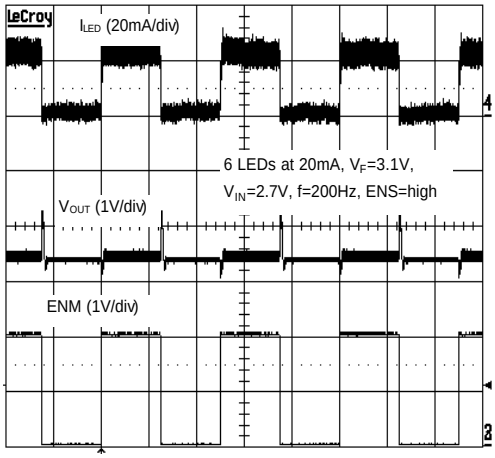
Typical Operating Characteristics (Cont.)

Dimming in 1.5x Mode



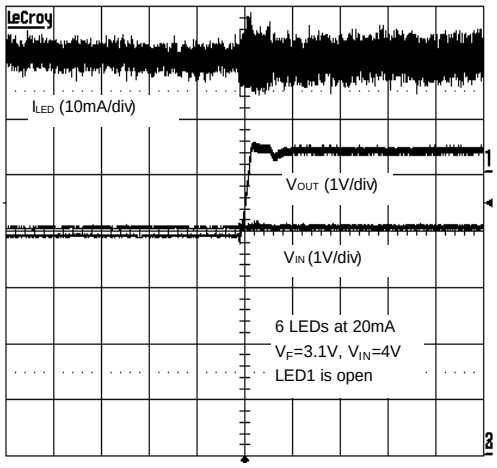
TIME (2ms/div)

Dimming in 2x Mode



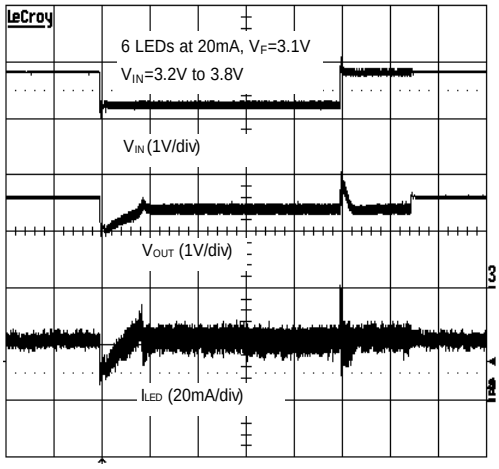
TIME (2ms/div)

OVP Even with LED Open Circuit



TIME (0.2ms/div)

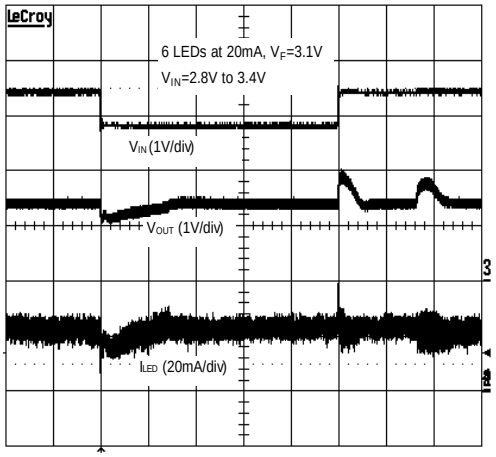
Line Transient Response in 1x to 1.5x Mode



TIME (0.1ms/div)

Typical Operating Characteristics (Cont.)

Line Transient Response in 1.5x to 2x Mode

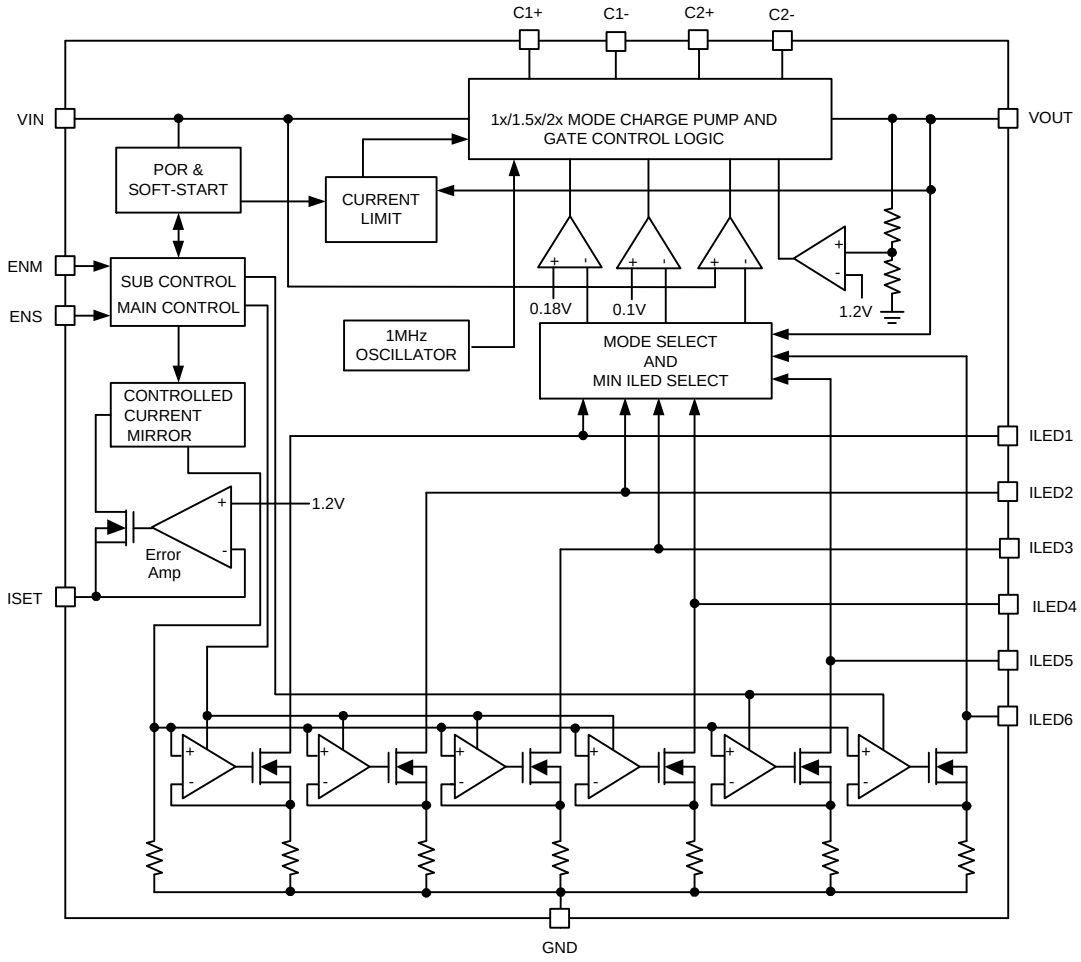


TIME (0.1ms/div)

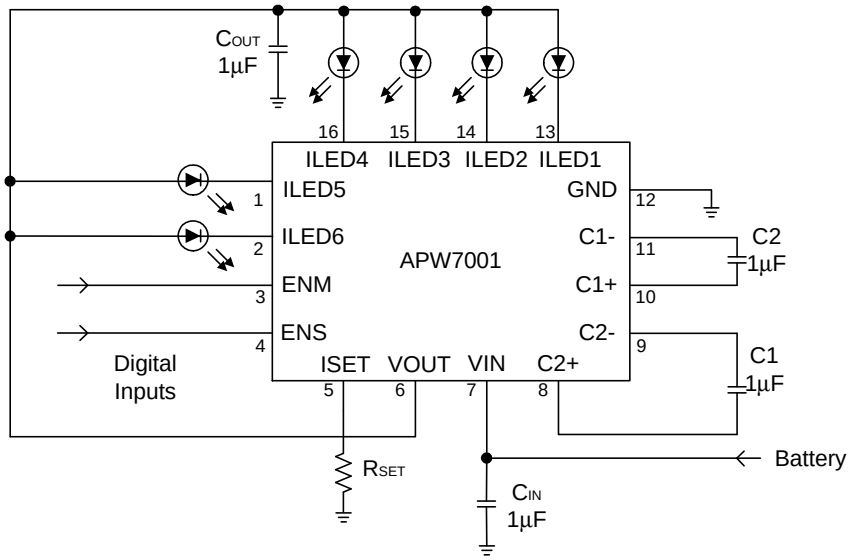
Pin Description

PIN		FUNCTION
NO.	NAME	
1	ILED5	Sub-Display LEDs Cathode Connection. The LED current flows from VOUT through LED into ILED_ pin. The charge pump regulates the lowest V_{ILED} to 180mV. Connect ILED_ pin to VOUT if the LED is not used.
2	ILED6	
3	ENM	On/Off and Dimming Control for LED1-4 (Main-Display).
4	ENS	On/Off and Dimming Control for LED5-6 (Sub-Display).
5	ISET	LED Current Set Input. Connect a resistor from ISET to GND to set the LED current. VISET is typically 1.2V.
6	VOUT	Output Voltage Pin. Connect VOUT to the LED anodes. Connect a 1µF capacitor from VOUT to GND.
7	VIN	Supply Voltage Input Pin. Connect a 1µF capacitor from VIN to GND.
8	C2+	Bucket Capacitor1 Positive Terminal. Connect a 1µF capacitor from C2+ to C2-.
9	C2-	Bucket Capacitor1 Negative Terminal. Connect a 1µF capacitor from C2+ to C2-.
10	C1+	Bucket Capacitor1 Positive Terminal. Connect a 1µF capacitor from C1+ to C1-.
11	C1-	Bucket Capacitor1 Negative Terminal. Connect a 1µF capacitor from C1+ to C1-.
12	GND	Device Ground Pin.
13	ILED1	Main-Display LEDs Cathode Connection. The LED current flows from VOUT through LED into ILED_ pin. The charge pump regulates the lowest V_{ILED} to 180mV. Connect ILED_ pin to VOUT if the LED is not used.
14	ILED2	
15	ILED3	
16	ILED4	

Block Diagram



Typical Application Circuit



Function Description

Soft-Start

The APW7001 provides the soft-start function to limit the inrush current during startup. When the input voltage is supplied to the device and exceeds the UVLO voltage, the output capacitor is charged directly from input with a limited current source. Approximate 100μs after the output voltage approaches the input voltage, the device starts to provide the programmed LED current and determines which of 1x, and 1.5x, or 2x mode is required. When the programmed LED current can be reached with 1x mode, the soft-start is completed and the device operates in 1x mode. When the programmed LED current cannot be reached, the charge pump goes into 1.5x mode. If the 1.5x mode charge pump cannot suffice for the LED current need, the charge pump will switch to 2x mode.

Mode Transition

The APW7001 operates in 1x, 1.5x, and 2x charge pump modes and automatically switches the charge pump modes depend on the input voltage to maintain the required power for high power efficiency. If the APW7001 operates in 1x mode, the VOUT is pulled up to V_{IN}. When V_{IN} decreases, the V_{ILED} will decease to maintain the regulated LED current. Until V_{ILED} is below 100mV, the device will switch to 1.5x mode. In 1.5x mode, the VILED is regulated to 0.18V, and the output voltage is VF+0.18V. If V_{IN} continues to decrease until V_{ILED} is below 100mV again, the device will switch to 2x mode. When the V_{IN} rises and reaches by approximately VOUT-300mV, the APW7001 switches back to 1.5x mode. If the V_{IN} continues to rise and reaches by approximately VOUT+300mV, the APW7001 switches back to 1x mode. The 2x charge pump is enough to suffice the White LED for a Li-ion battery application. The APW7001 ensures that in the 1x mode for as long as possible to increase the efficiency and extend the operating range by using the 2x mode. The transition voltages from 1x to 1.5x, and 1.5x to 2x are given by:

$$V_{TRANS1X} = V_F + 0.1V + (I_{OUT} \times R_{OUT1X})$$

$$V_{TRANS1.5X} = [V_F + 0.1V + (I_{OUT} \times R_{OUT1.5X})] / 1.5$$

where

V_F is the forward voltage of LED
I_{OUT} is the output current
R_{OUT1X} is the output impedance in 1x mode = 1.6Ω
$R_{OUT1.5X}$ is the output impedance in 1.5x mode = 7Ω

ENM/ENS Control Logic Pins

The APW7001 provides two logic input pins to enable or disable the main-display and sub-display. When the ENM or ENS is high, the VOUT is supplied and the respective LEDs are enabled. When ENM or ENS is low, the respective LEDs are disabled. If both logic pins are kept low for more than 20ms, the APW7001 enters shutdown mode. In shutdown mode, all internal control circuits are turned off and the quiescent current is below 2μA. When the device exits shutdown mode, the output has the soft-start function as the input voltage startup.

ENM	ENS	LED Status
0 (for more than 20ms)	0 (for more than 20ms)	IC enters shutdown
1	0	LED1, 2, 3, 4 are turned on / LED5, 6 are turned off
0	1	LED1, 2, 3, 4 are turned off / LED5, 6 are turned on
1	1	LED1, 2, 3, 4 are turned on / LED5, 6 are turned on

Table 1. The Truth Table of ENM and ENS

LED Current Setting

Connect a resistor from ISET pin to GND to set the LED current. The ISET voltage is 1.2V, and the LED current is typically 400 times the current through the ISET resistor. The LED current is given by:

$$R_{SET} = \frac{400 \times 1.2V}{I_{LED}}$$

The APW7001 provides up to 30mA of LED current per LED and the device has a max current matching of ±5% between any two LED currents and a max current accuracy of ±8%. If high accuracy is required, using a 1% precision surface mount resistor for the need.

ILED (mA)	RSET (kW)
5	92
10	47
15	32
20	24
30	16.5

Table 2. R_{SET} Value Selection

Function Description (Cont.)

LED Current Setting (Cont.)

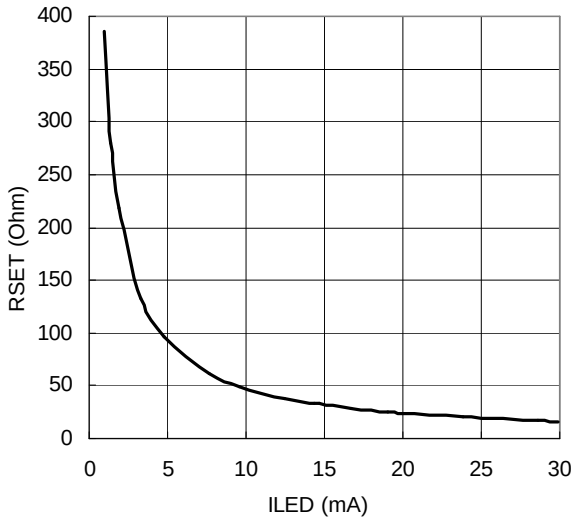


Figure 1. R_{SET} Value vs. LED Current

Over-Voltage Protection

If any of LEDs is failed or unused, LED channel is not connected to VOUT, the charge pump mode will go into 2x mode and the output voltage will be pumped to 2 times the input voltage. If the output voltage is over 5.5V, the over-voltage protection circuit will limit the output voltage to approximately 5.5V.

Application Information

Capacitor Selection

For lower input and output voltage ripples, both input and output capacitors should be larger values and lower ESR capacitors. However, the larger output capacitor values will increase the soft-start time. The lower charge pump flying capacitors values and ESR improve the efficiency, but lower capacitor values may limit the LED's currents at low input voltage.

It is recommended that the low ESR and low variation over temperature, such as the ceramic capacitors with X7R or X5R and the value is 1µF for the input capacitor, output capacitor, and the charge pump flying capacitors.

Brightness Control

1. PWM dimming using ENM, or/and EMS

The first method for dimming the LEDs is to apply a PWM signal into the ENM or/and ENS pins. Figure 2 shows the application circuit. The average LED current is proportional to the PWM signal duty cycle. Note that the frequency of PWM signal will affect the minimum dimming duty. Figure 3 shows the LED current vs. dimming frequency and dimming duty, the recommend dimming frequency is below 10kHz. The PWM signal can either be applied to ENM or ENS, or both inputs can be tied together and the PWM signal can be applied to both pins. Table 3 shows the truth table of ENM and ENS dimming control. The average LED current is calculated by the following equation:

$$I_{LED(avg)} = \frac{ton \times I_{LED(max)}}{ton + toff}$$

Where:

$I_{LED(max)}$ is programmed LED current by I_{SET} pin

toff is the off time of the PWM signal

ton is the on time of the PWM signal

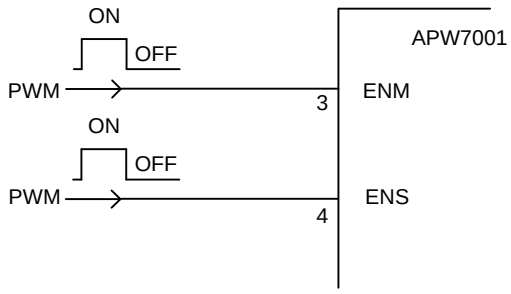


Figure 2. PWM Dimming Application Circuit

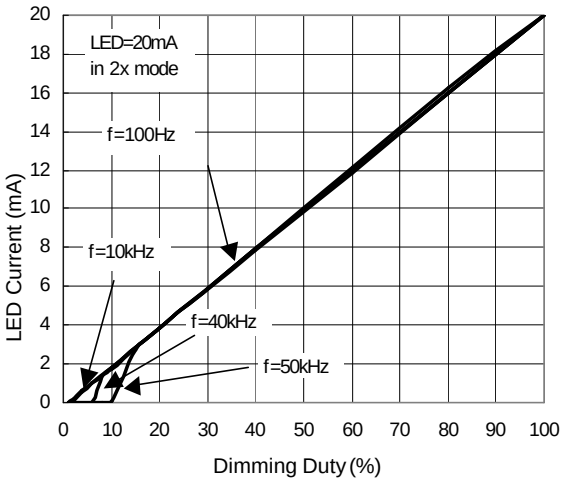


Figure 3. PWM Dimming Frequency vs. LED Current

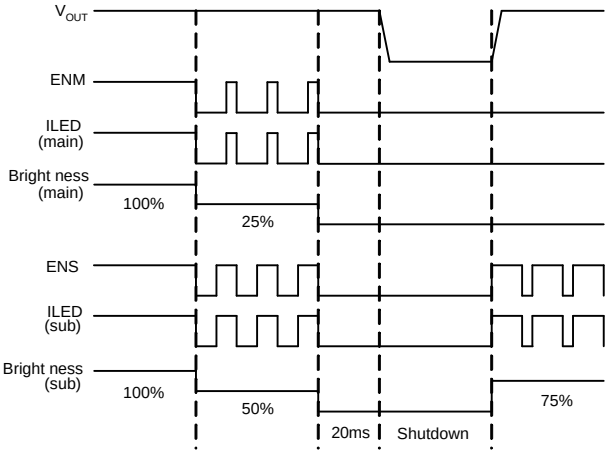


Figure 4. ENM/ENS Timing

ENM	ENS	LED Status
0	PWM	LED1, 2, 3, 4 are turned off LED5, 6 are PWM dimming
PWM	0	LED1, 2, 3, 4 are PWM dimming LED5, 6 are turned off
1	PWM	LED1, 2, 3, 4 are turned on LED5, 6 are PWM dimming
PWM	1	LED1, 2, 3, 4 are PWM dimming LED5, 6 are turned on
PWM	PWM	LED1, 2, 3, 4 are PWM dimming LED5, 6 are PWM dimming

Table 3. The Truth Table of ENM and ENS Dimming Control

Application Information (Cont.)

Brightness Control (Cont.)

2. Analog Dimming With Analog Voltage

The second method for dimming the LEDs is to apply a voltage through a resistor into the ISET pin. The variation of LED current is proportional to the variation of the analog voltage. If the resistor values are chosen correctly, the analog control voltage varies the output current from 0mA to full LED current. Figure 5 shows the application circuit, and the LED current is calculated by the following equation:

$$I_{LED} = 400 \times \left(\frac{1.2V - V_{ADJ}}{R2} + \frac{1.2V}{R1} \right)$$

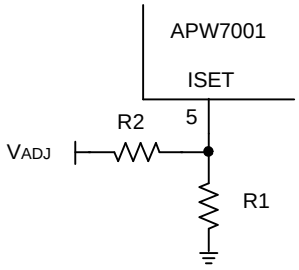


Figure 5. Analog Voltage Dimming Application Circuit

3. Digital dimming with external NMOS transistors

The third method for dimming the LEDs is to change the equivalent resistance for RSET with the external NMOS transistors. The equivalent resistance is the parallel combinations of the R1, R2, R3, and R4. R4 is always connected and selected for the minimum LED current. Figure 6 shows the application circuit.

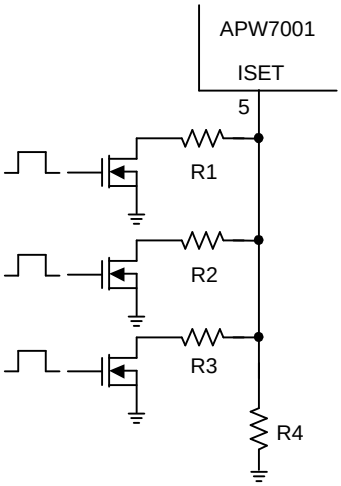


Figure 6. Digital Dimming Application Circuit

4. PWM dimming with EN pin

Another method for dimming the LEDs is to apply a PWM signal into the EN pin. The average LED current is proportional to the PWM signal duty cycle. Note that the frequency of PWM signal will affect the minimum dimming duty. The recommend dimming frequency is between 100Hz and 1kHz. The average LED current is calculated by the following equation:

$$I_{LED(avg)} = \frac{ton \times I_{LED(max)}}{ton + toff}$$

Where:

$I_{LED(max)}$ is programmed LED current by ISET pin

toff is the off time of the PWM signal

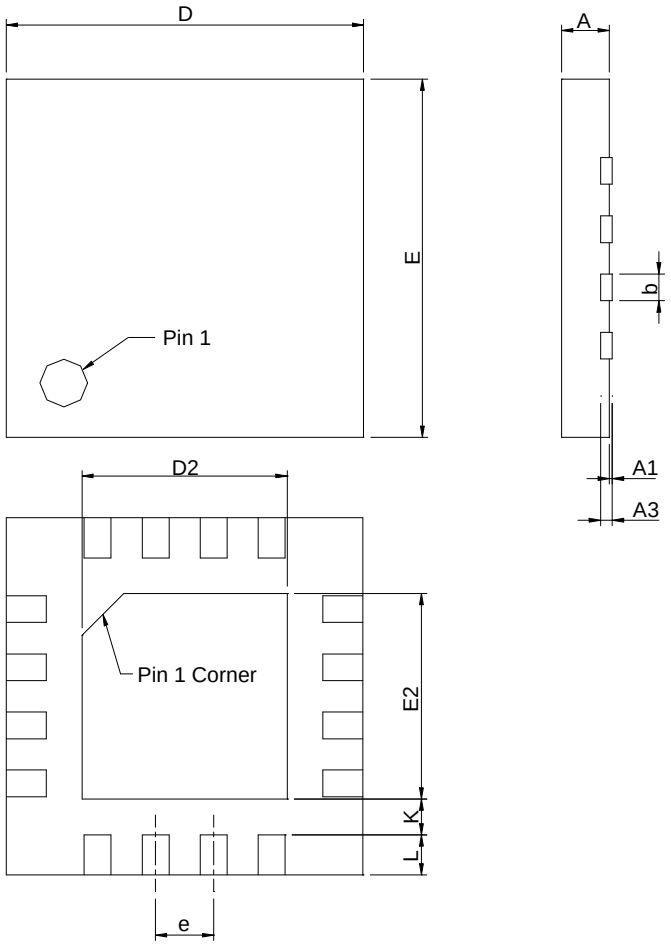
ton is the on time of the PWM signal

Layout Consideration

The APW7001 is a high frequency charge pump for white LED driver and requires some care when laying out the printed circuit board. The metal GND pad of the bottom of the package must be soldered to the PCB and connected to the GND plane on the backside through several thermal vias. Place the CIN, COUT, C1, and C2 as close to IC as possible for reducing the switching noise.

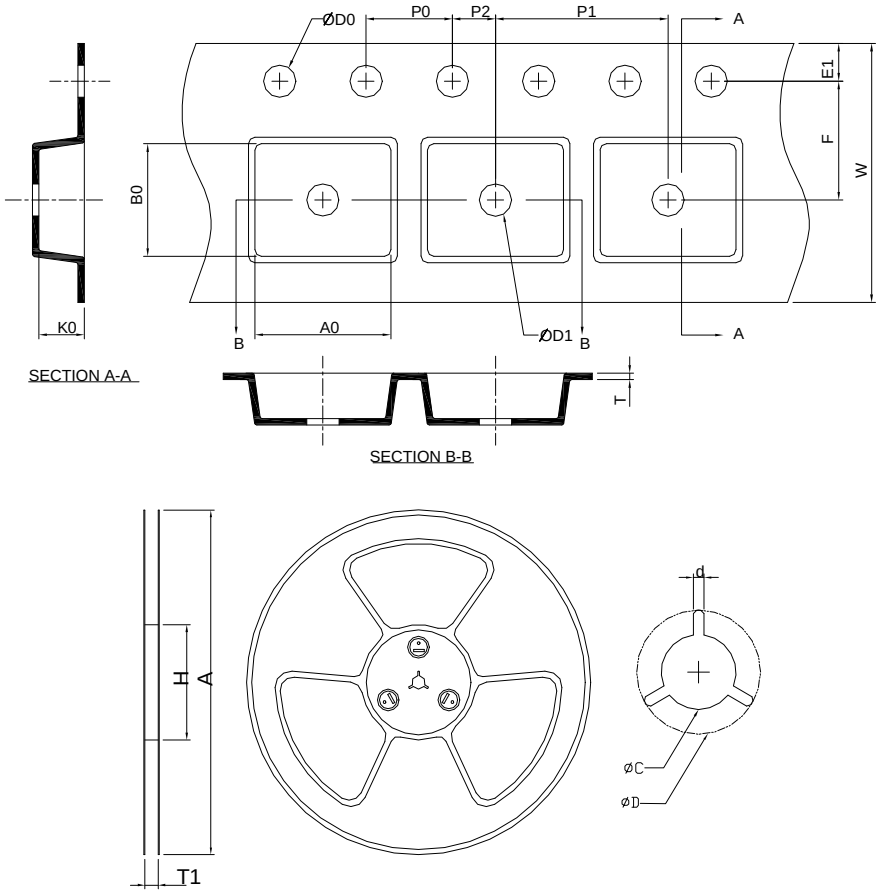
Package Information

QFN4x4-16



SYMBOL	QFN4x4-16			
	MILLIMETERS		INCHES	
	MIN.	MAX.	MIN.	MAX.
A	0.80	1.00	0.031	0.039
A1	0.00	0.05	0.000	0.002
A3	0.20 REF		0.008 REF	
b	0.25	0.35	0.010	0.014
D	3.90	4.10	0.154	0.161
D2	2.50	2.80	0.098	0.110
E	3.90	4.10	0.154	0.161
E2	2.50	2.80	0.098	0.110
e	0.65 BSC		0.026 BSC	
L	0.30	0.50	0.012	0.020
K	0.20		0.008	

Carrier Tape & Reel Dimensions



Application	A	H	T1	C	d	D	W	E1	F
QFN4x4-16	330.0±2.00	50 MIN.	12.4+2.00 -0.00	13.0+0.50 -0.20	1.5 MIN.	20.2 MIN.	12.0±0.30	1.75±0.10	5.5±0.05
	P0	**P1**	**P2**	**D0**	**D1**	**T**	**A0**	**B0**	**K0**
	4.0±0.10	8.0±0.10	2.0±0.05	1.5+0.10 -0.00	1.5 MIN.	0.6+0.00 -0.40	4.30±0.20	4.30±0.20	1.30±0.20

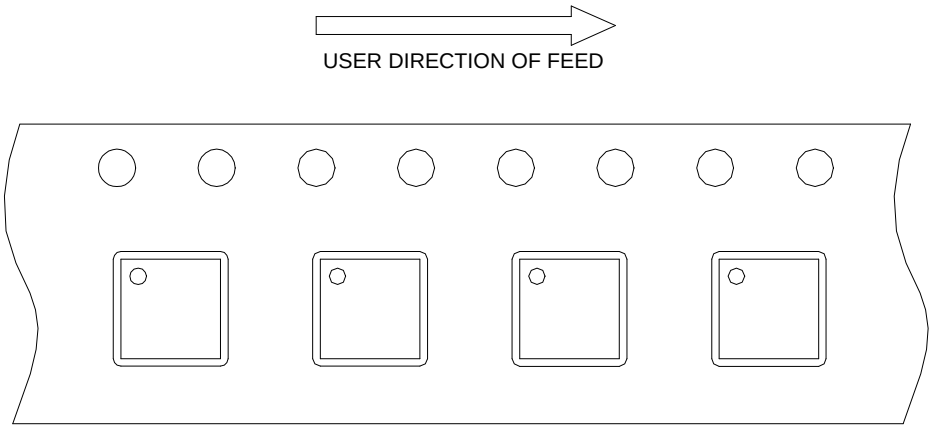
(mm)

Devices Per Unit

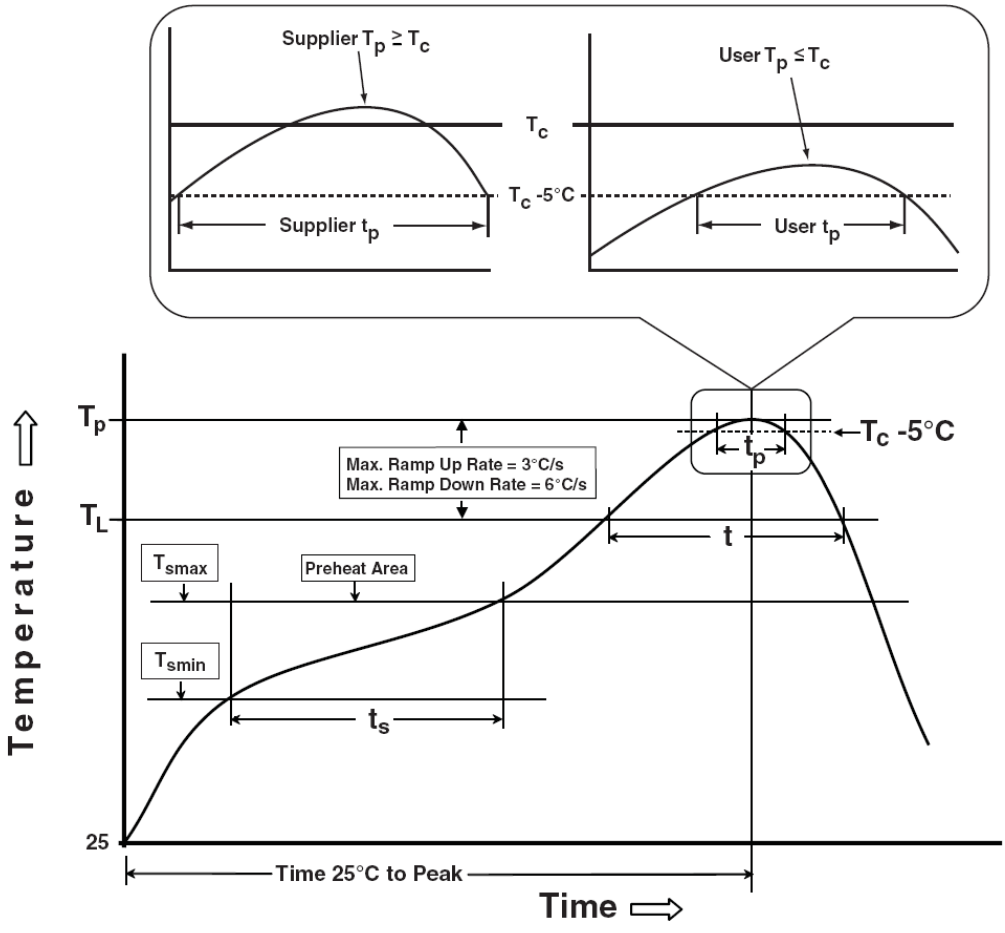
Package Type	Unit	Quantity
QFN4x4-16	Tape & Reel	3000

Taping Direction Information

QFN4x4-16



Classification Profile



Classification Reflow Profiles

Profile Feature	Sn-Pb Eutectic Assembly	Pb-Free Assembly
Preheat & Soak Temperature min (T_{smin}) Temperature max (T_{smax}) Time (T_{smin} to T_{smax}) (t_s)	 100 °C 150 °C 60-120 seconds	 150 °C 200 °C 60-120 seconds
Average ramp-up rate (T_{smax} to T_P)	3 °C/second max.	3°C/second max.
Liquidous temperature (T_L) Time at liquidous (t_L)	183 °C 60-150 seconds	217 °C 60-150 seconds
Peak package body Temperature (T_p)*	See Classification Temp in table 1	See Classification Temp in table 2
Time (t_P)** within 5°C of the specified classification temperature (T_c)	20** seconds	30** seconds
Average ramp-down rate (T_p to T_{smax})	6 °C/second max.	6 °C/second max.
Time 25°C to peak temperature	6 minutes max.	8 minutes max.
* Tolerance for peak profile Temperature (T_p) is defined as a supplier minimum and a user maximum. ** Tolerance for time at peak profile temperature (t_p) is defined as a supplier minimum and a user maximum.		

Table 1. SnPb Eutectic Process – Classification Temperatures (Tc)

Package Thickness	Volume mm^3 <350	Volume mm^3 3350
<2.5 mm	235 °C	220 °C
≥2.5 mm	220 °C	220 °C

Table 2. Pb-free Process – Classification Temperatures (Tc)

Package Thickness	Volume mm^3 <350	Volume mm^3 350-2000	Volume mm^3 >2000
<1.6 mm	260 °C	260 °C	260 °C
1.6 mm – 2.5 mm	260 °C	250 °C	245 °C
≥2.5 mm	250 °C	245 °C	245 °C

Reliability Test Program

Test item	Method	Description
SOLDERABILITY	JESD-22, B102	5 Sec, 245°C
HOLT	JESD-22, A108	1000 Hrs, Bias @ 125°C
PCT	JESD-22, A102	168 Hrs, 100%RH, 2atm, 121°C
TCT	JESD-22, A104	500 Cycles, -65°C~150°C
HBM	MIL-STD-883-3015.7	VHBM≧2KV
MM	JESD-22, A115	VMM≧200V
Latch-Up	JESD 78	10ms, 1_{tr}≧100mA

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