

## 集成灵活的一线数字调光和 PWM 调光的串联 WLED 驱动器

### 特性

- 2.7V 至 5.5V 的输入电压范围
- 38V 过压保护 (OVP) 电压支持最多 10 颗串联 LED
- 采用创新的 CDC(Classification Drive Control)输出驱动技术, 显著提升 EMI 性能
- 200mV 反馈电压
- 集成灵活的一线数字调光和 PWM 调光
- 支持 EMI 性能一线/PWM 模式下可调
- PWM 调光频率范围 10k~100kHz, 调光最小占空比: 1%
- 600kHz 开关频率
- 内置过流保护和过温保护功能
- 内置软启动功能, 限制启动时的浪涌电流
- 纤小的 TDFN2x2-6L 封装

### 应用

- 移动电话
- 便携式多媒体播放器
- PDA
- GPS 接收器

### 典型应用图

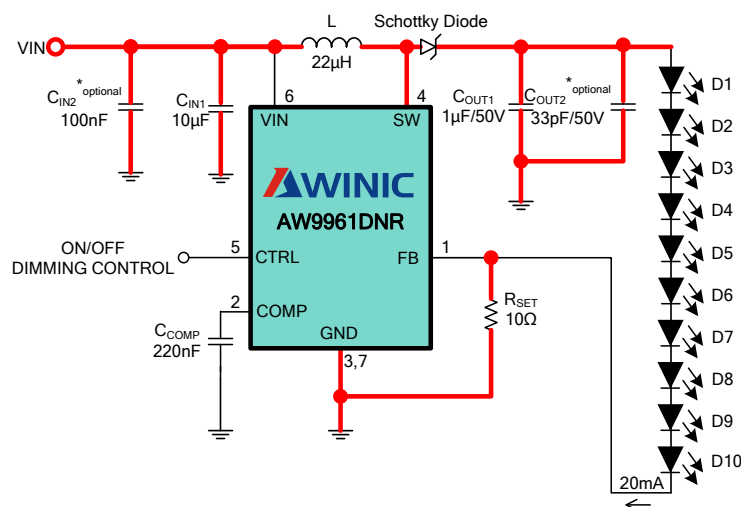


图 1 AW9961 典型应用图

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### 概要

AW9961 是一款高效率的电感升压型白光 LED 驱动器。AW9961 内部集成了 40V 的功率开关, 可支持单串最多 10 颗 LED 应用。AW9961 的 600kHz 固定工作频率减小了输出电压纹波, 提高了转换效率, 而且允许使用封装更小的外围器件。

AW9961 的反馈电压为 200mV, 如典型应用图所示, LED 的电流通过外置设定电阻确定。AW9961 同时支持两种调光方式, LED 的电流可通过 CTRL 引脚的一线数字接口控制, 也可通过加在 CTRL 引脚的 PWM 调光信号的占空比来控制。无论采用哪种调光方式, AW9961 都尽可能降低输出电压及电流的纹波, 避免产生人耳可听见的噪声。

AW9961 内置 EMI 配置寄存器, 可在一线或 PWM 模式下进行配置。

AW9961 内置软启动功能, 最大限度地减小电源的浪涌电流。AW9961 还内置过流保护、LED 开路过压保护 (OVP) 及过温保护, 防止芯片进入异常工作状态。

# White LED Driver with Flexible Digital and PWM Brightness Control in Small Package

## FEATURES

- 2.7 to 5.5V Input Voltage Range
- 38V Over-voltage Protection for up to 10 LEDs in Series
- **Innovative CDC Output Drive Technology, Significantly Improve EMI Performance**
- 200mV Reference Voltage
- **Flexible Digital and PWM White LED Brightness Control**
- **Support EMI performance programmable under 1-wire/PWM mode**
- PWM Dimming Frequency Range: 10kHz ~ 100kHz, Minimum Duty Cycle:1%
- 600kHz Switching Frequency
- Over-current and Over-temperature Protection
- Built-in Soft-start Limits Inrush Current
- **Ultra Small 2mm\*2mm TDFN-6L package**

## APPLICATIONS

- Mobile Phones
- Portable Media Players
- GPS Receivers

## TYPICAL APPLICATION CIRCUIT

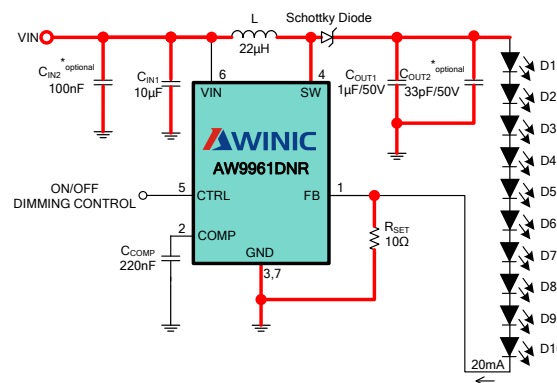


Figure 1 Typical Application Circuit of AW9961

## GENERAL DESCRIPTION

The AW9961 is a white LED driver with integrated boost converter. With an internal 40V switch FET, the AW9961 drives up a string of up to 10 LEDs in series. The boost converter runs at 600kHz fixed switching frequency to reduce output ripple, improve conversion efficiency, and allows for the use of small external components.

The default white LED current is set with the external sense resistor  $R_{SET}$ , and the feedback voltage is regulated to 200mV, as shown in the typical application. During the operation, the LED current can be controlled by using the 1-wire digital interface through the CTRL pin. Alternately, a pulse width modulation (PWM) signal can be applied to the CTRL pin through which the duty cycle determines the feedback reference voltage. In either digital or PWM mode, the AW9961 does not generate audible noises on the output capacitor. For maximum protection, the device features integrated open LED over-voltage protection that disables the AW9961 to prevent the output from exceeding the absolute maximum ratings during open LED conditions.

AW9961 sets a built-in EMI performance register, which can be configured under either 1-wire or PWM mode.

## PIN CONFIGURATION AND TOP MARK

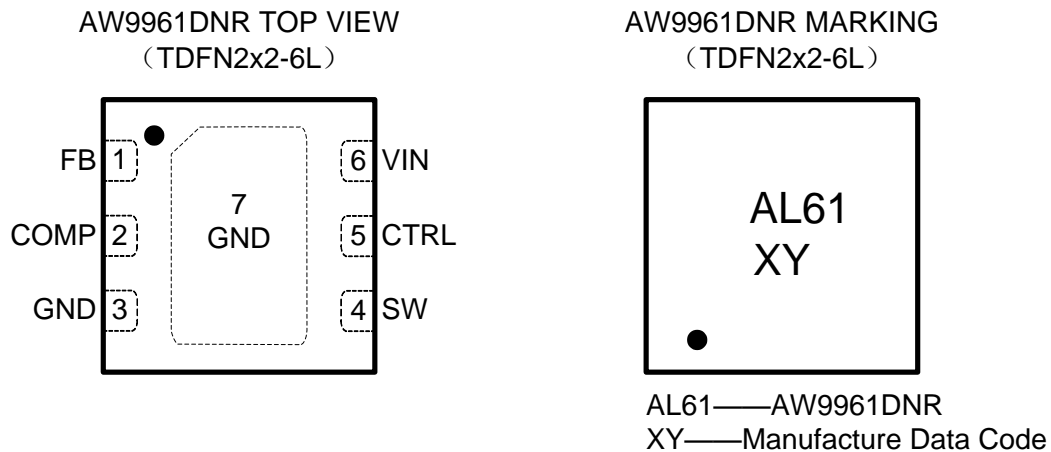
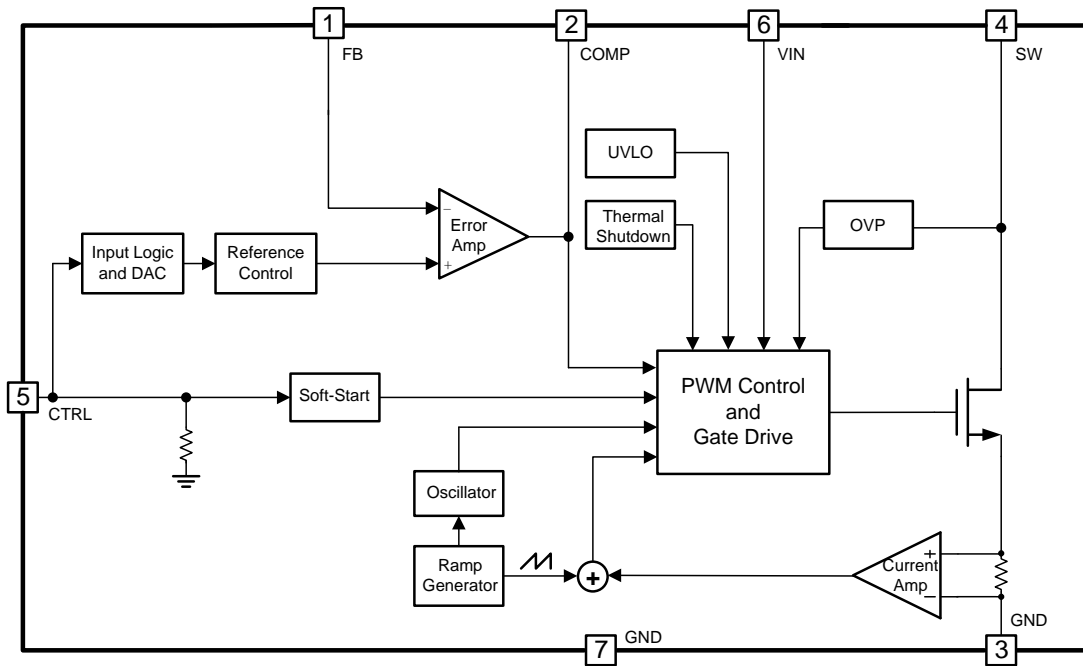


Figure 2 Pin Configuration and Top Mark

## PIN DEFINITION

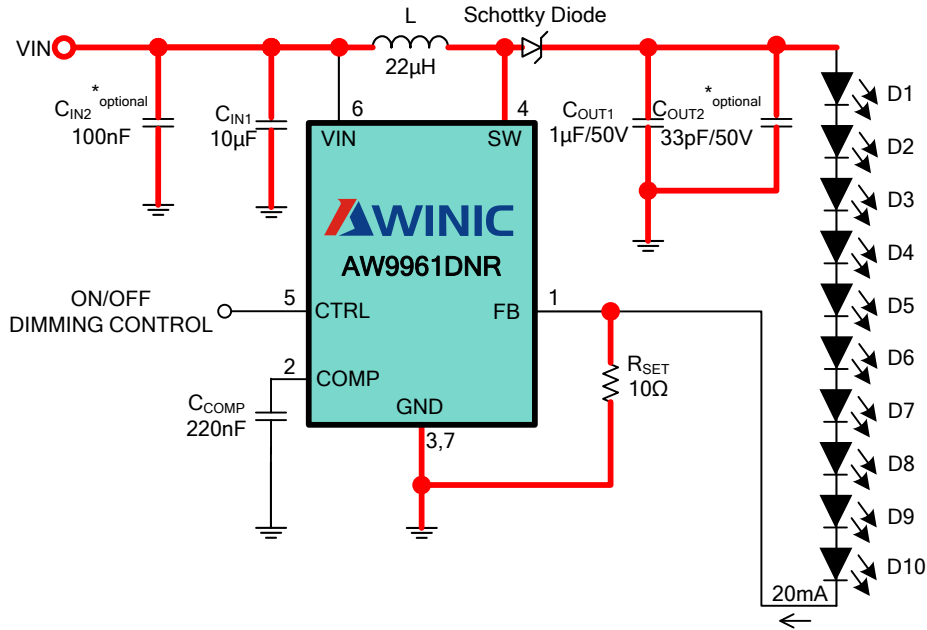
No.	NAME	DESCRIPTION
1	FB	Feedback pin for current. Connect the sense resistor from FB to GND.
2	COMP	Output of the transconductance error amplifier. Connect an external capacitor to this pin to compensate the regulator.
3	GND	Ground.
4	SW	This is the switching node of the IC. Connect the inductor between the VIN and SW pin. This pin is also used to sense the output voltage for open LED protection.
5	CTRL	Control pin of the boost regulator. It is a multi-functional pin which can be used for enable control, PWM and digital dimming.
6	VIN	The input supply pin for the IC. Connect VIN to a supply voltage between 2.7 and 5.5V.
7	GND	Exposed pad should be soldered to PCB board and Connected to GND.

**FUNCTIONAL BLOCK DIAGRAM**

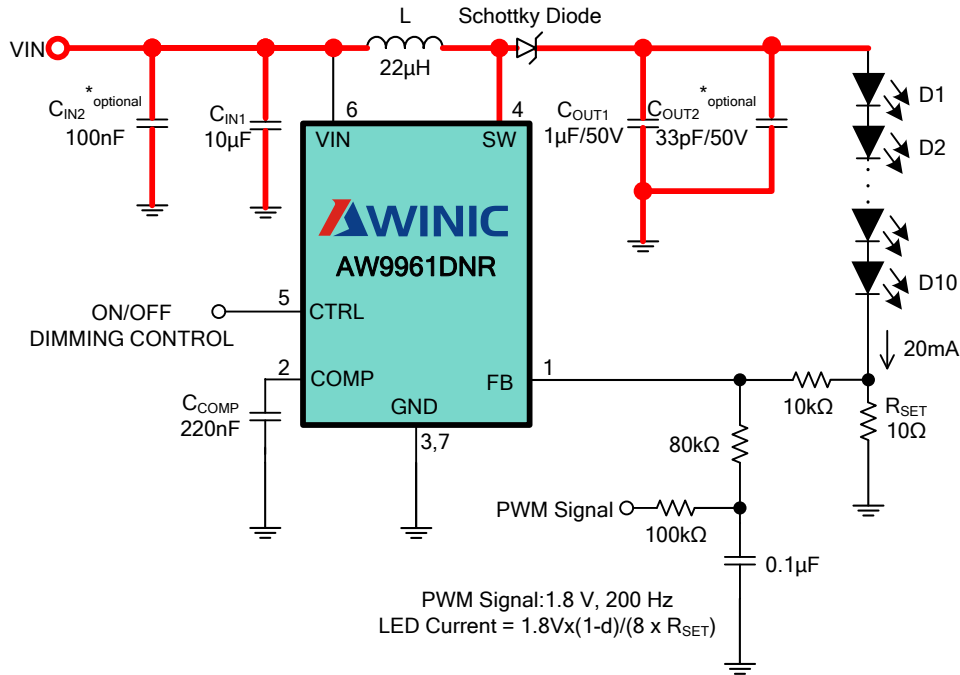


**Figure 3 FUNCTIONAL BLOCK DIAGRAM**

**TYPICAL APPLICATION CIRCUITS**



**Figure 4 Typical Application of AW9961**



**Figure 5 Additional Typical Application for 10 LEDs with External PWM Dimming Network**

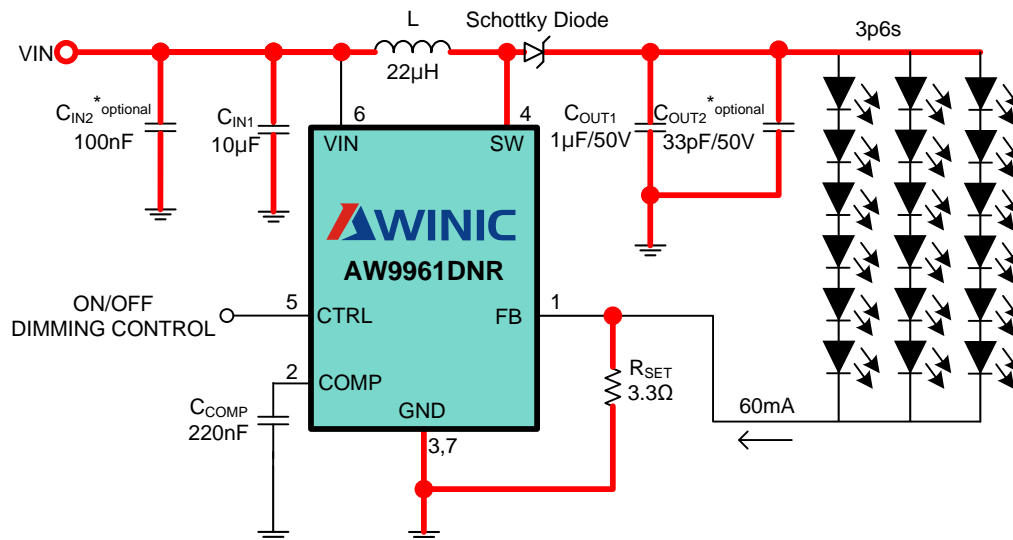


Figure 6 Drive 18 White LEDs for Big Screen Display

**Notice for Typical Application Circuits:**

1: Recommended device for AW9961:

L: TDK VLCF5020T-220MR75-1

C<sub>IN1</sub>: Murata GRM188R61C106MA73

C<sub>IN2</sub>: Murata GRM155R61C104K

C<sub>OUT1</sub>: Murata GRM21BR71H105KA

C<sub>OUT2</sub>: Murata GRM1555C1H330GA

Schottky Diode: ONsemi MBR0540T1

2: C<sub>IN2</sub> and C<sub>OUT2</sub> are recommended to use in parallel with the input capacitor and output capacitor to suppress high frequency noise.

3: Red lines are high current paths, reference to the section APPLICATION INFORMATION.

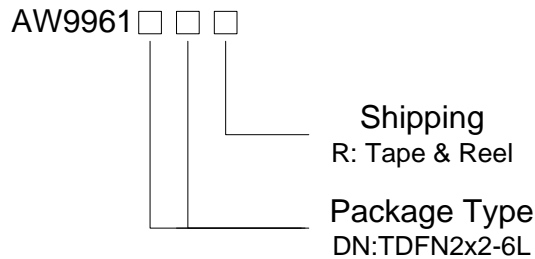
4: The capacitors (C<sub>IN1</sub>, C<sub>IN2</sub>, C<sub>OUT1</sub>, C<sub>OUT2</sub> and C<sub>COMP</sub>) should be placed as close to the pins of the IC as possible.

5: Minimize trace lengths between the IC and the inductor, the Schottky diode and the output capacitor, keep these traces short, direct, and wide.

6: Minimize the length and area of all traces connected to the SW pin and always use a ground plane under the switching regulator to minimize inter-plane coupling.

## ORDERING INFORMATION

Part Number	Temperature	Package	Marking	Delivery Form
AW9961DNR	-40°C~85°C	TDFN2x2-6L	AL61	3000 units/ Tape and Reel



## ABSOLUTE MAXIMUM RATINGS<sup>(NOTE1)</sup>

PARAMETERS	RANGE
Supply voltage range $V_{IN}$ <sup>(NOTE 2)</sup>	-0.3V to 6V
Voltage on FB,CTRL and COMP <sup>(NOTE 2)</sup>	-0.3V to 6V
Voltage on SW <sup>(NOTE 2)</sup>	-0.3V to 40V
Junction-to-ambient thermal resistance $\theta_{JA}$	65°C/W
Operating free-air temperature range	-40°C to 85°C
Maximum Junction temperature $T_{JMAX}$	160°C
Storage temperature $T_{STG}$	-65°C to 150°C
Lead Temperature (Soldering 10 Seconds)	260°C
ESD <sup>(NOTE 3)</sup>	
ALL PINS HBM (human body model) <sup>(NOTE 4)</sup>	±6000V
ALL PINS CDM (charge device model) <sup>(NOTE 5)</sup>	±2500V
ALL PINS MM (machine model) <sup>(NOTE 6)</sup>	±300V
Latch-up <sup>(NOTE 7)</sup>	
Latch-up current maximum rating per JEDEC standard	+IT: 250mA -IT: -250mA

**NOTE1:** Conditions out of those ranges listed in "absolute maximum ratings" may cause permanent damages to the device. In spite of the limits above, functional operation conditions of the device should within the ranges listed in "recommended operating conditions". Exposure to absolute-maximum-rated conditions for prolonged periods may affect device reliability.

**NOTE2:** All voltage values are with respect to network ground terminal.

**NOTE3:** This integrated circuit can be damaged by ESD if you don't pay attention to ESD protection. AWINIC recommends that all integrated circuits be handled with appropriate precautions. Failure to observe proper handling and installation procedures can cause damage. ESD damage can range from subtle performance

*degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.*

*NOTE4: The human body model is a 100pF capacitor discharged through a 1.5kΩ resistor into each pin. Test method: MIL-STD-883H Method 3015.8.*

*NOTE5: Test Condition: JEDEC EIA/JESD22-C101E.*

*NOTE6: Test Condition: JEDEC EIA/JESD22-A115.*

*NOTE7: Test Condition: JEDEC STANDARD NO.78D NOVEMBER 2011.*



## ELECTRICAL CHARACTERISTICS

 Test Condition:  $T_A = 25^\circ\text{C}$ ,  $V_{IN} = 3.6\text{V}$ ,  $V_{CTRL} = V_{IN}$  (Unless otherwise specified).

PARAMETER	TEST CONDITION	MIN	TYP	MAX	UNIT	
<b>SUPPLY VOLTAGE AND CURRENT</b>						
$V_{IN}$	Input voltage range	2.7		5.5	V	
$I_Q$	Operating quiescent current	$V_{FB} = 1\text{V}$	0.9	1.4	mA	
$I_{SD}$	Shutdown current	$V_{CTRL} = \text{GND},$ $V_{IN}=4.2\text{V}$	0.1	1	$\mu\text{A}$	
UVLO	Under-voltage lockout threshold	$V_{IN}$ falling	2.45	2.75	V	
$V_{hys}$	Under-voltage lockout hysteresis		250		mV	
<b>ENABLE AND REFERENCE CONTROL</b>						
$V_{(CTRLh)}$	CTRL logic high voltage	$V_{IN} = 2.7\text{V to } 5.5\text{V}$	1.5		V	
$V_{(CTRLl)}$	CTRL logic low voltage	$V_{IN} = 2.7\text{V to } 5.5\text{V}$		0.3	V	
$R_{(CTRL)}$	CTRL pull down resistor		600		k $\Omega$	
$t_{off}$	CTRL pulse width to shutdown	CTRL high to low	2.5		ms	
$t_{1w\_det}$	Digital 1-wire brightness detection time <sup>(NOTE 1)</sup>	CTRL pin low	260		$\mu\text{s}$	
$t_{1w\_delay}$	Digital 1-wire brightness detection delay		100		$\mu\text{s}$	
$t_{1w\_win}$	Digital 1-wire brightness detection window time	Measured from CTRL pin	1		ms	
<b>VOLTAGE AND CURRENT CONTROL</b>						
$V_{REF}$	Voltage feedback regulation voltage		195	200	205	mV
$V_{(REF\_PWM)}$	Voltage feedback regulation voltage under brightness control	$f_{PWM} = 10\text{ kHz},$ duty cycle = 25%	46	50	54	mV
		$f_{PWM} = 10\text{ kHz},$ duty cycle = 10%	16	20	24	mV
$I_{FB}$	Voltage feedback input bias current		0.1	1	$\mu\text{A}$	
$f_s$	Oscillator frequency		500	600	700	kHz
$D_{max}$	Maximum duty cycle		90%	95%		
<b>POWER SWITCH</b>						
$R_{DS(on)}$	N-channel MOSFET on-resistance	$V_{IN} = 3.6\text{V}$		0.36	0.65	$\Omega$
		$V_{IN} = 3.0\text{V}$			0.7	$\Omega$
$I_{LN\_NFET}$	N-channel leakage current	$V_{SW} = 35\text{V}, T_A = 25^\circ\text{C}$		1	$\mu\text{A}$	

PARAMETER	TEST CONDITION	MIN	TYP	MAX	UNIT		
<b>OCP AND OVP</b>							
$I_{LIM}$	N-channel MOSFET current limit	0.6	1.1	1.7	A		
$V_{OVP}$	Open LED overvoltage protection threshold	Measured on the SW pin		36	38	40	V
$t_{REF}$	VREF filter time constant		480		$\mu$ s		
<b>DIGITAL 1-WIRE COMMAND TIMING</b>							
$t_{start}$	Start time of program stream	2			$\mu$ s		
$t_{EOS}$	End time of program stream	2		360	$\mu$ s		
$t_{H\_LB}$	High time low bit	Logic 0	2	180	$\mu$ s		
$t_{L\_LB}$	Low time low bit	Logic 0	$2 \times t_{H\_LB}$	360	$\mu$ s		
$t_{H\_HB}$	High time high bit	Logic 1	$2 \times t_{L\_HB}$	360	$\mu$ s		
$t_{L\_HB}$	Low time high bit	Logic 1	2	180	$\mu$ s		
$V_{ACKNL}$	Acknowledge output voltage low	Open drain, $R_{pullup} = 15k\Omega$ to VIN		0.1	V		
$t_{valACKN}$	Acknowledge valid time	See <sup>(NOTE 2)</sup>		2	$\mu$ s		
$t_{ACKN}$	Duration of acknowledge condition	See <sup>(NOTE 2)</sup>		512	$\mu$ s		
<b>PWM DIMMING TIMING</b>							
$f_{PWM}$	Frequency of PWM dimming	10		100	kHz		
$t_{H\_PWM}$	High time of PWM dimming signal	$f_{PWM}=10kHz$	1		$\mu$ s		
		$f_{PWM}=100kHz$	100		ns		
<b>THERMAL SHUTDOWN</b>							
$T_{OTP}$	Thermal shutdown threshold		165		$^{\circ}$ C		
$T_{hys}$	Thermal shutdown threshold hysteresis		16		$^{\circ}$ C		

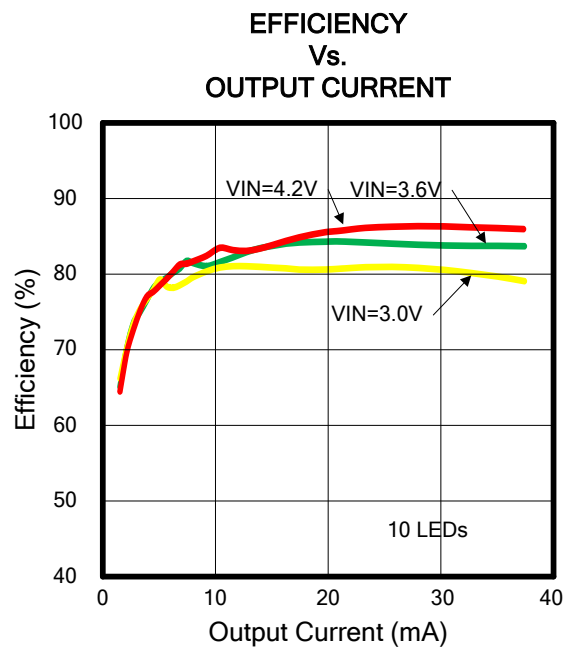
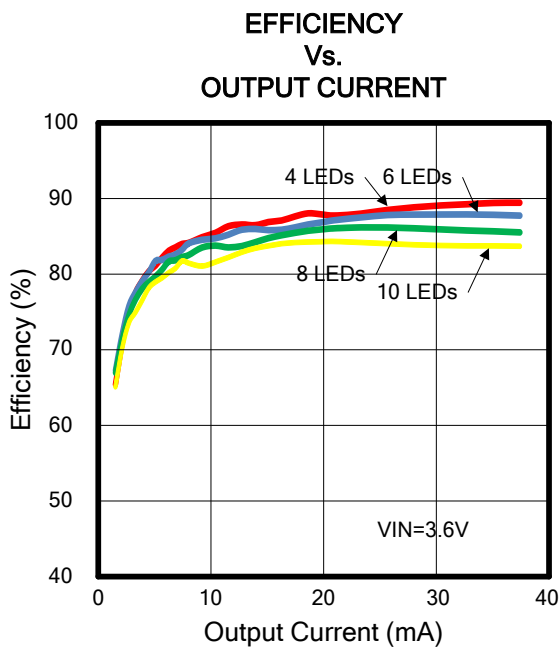
NOTE1: To select 1-wire digital interface mode, the CTRL pin has to be low for more than  $t_{1w\_det}$  during  $t_{1w\_win}$ .

NOTE2: Acknowledge condition active 0, this condition will only be applied in case the RFA bit is set. Open drain output, line needs to be pulled high by the host with resistor load.

## TYPICAL CHARACTERISTICS

**Table 1 TABLE OF FIGURES**

INDEX		FIGURE No.
Efficiency 1	VIN=3.6V; 4,6,8,10 LEDs; L=22μH	<a href="#">FIGURE 7</a>
Efficiency 2	VIN=4.2/3.6/3.0V; 10 LEDs, L=22μH	<a href="#">FIGURE 8</a>
Efficiency 3	VIN=2.5~5.5V; 1P10S, 2P8S,3P8S LEDs, L=22μH	<a href="#">FIGURE 9</a>
Switching frequency	VIN=2.5~5.5V, 10 LEDs, L=22μH	<a href="#">FIGURE 10</a>
1-wire dimming step		<a href="#">FIGURE 11</a>
PWM dimming linearity	PWM Freq = 20 kHz	<a href="#">FIGURE 12</a>
Feedback voltage line regulation	VIN=2.5~5.5V	<a href="#">FIGURE 13</a>
Soft-start waveform	VIN=3.8V, 10 LEDs, L=22μH	<a href="#">FIGURE 14</a>
Switching waveform	VIN=3.8V, 10 LEDs, L=10μH	<a href="#">FIGURE 15</a>
Open LED protection	VIN=3.6V, 10 LEDs, L=22μH	<a href="#">FIGURE 16</a>



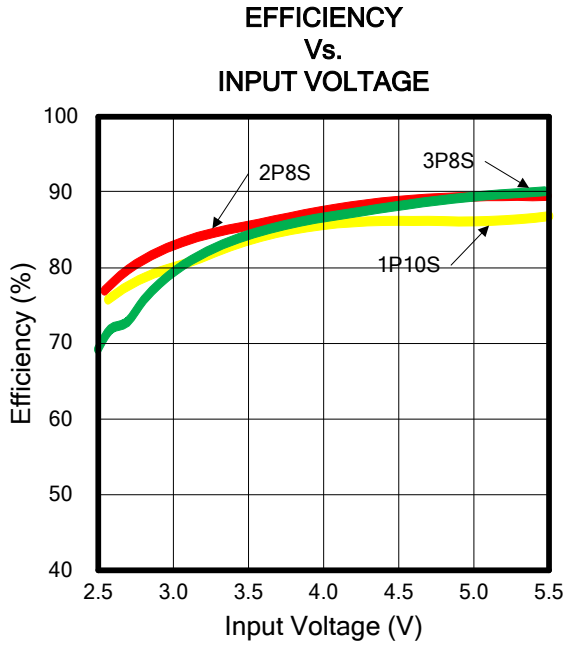


Figure 9.

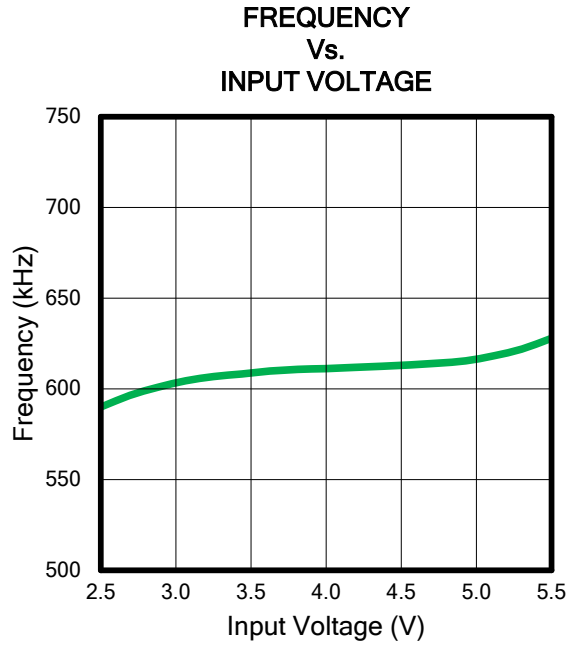


Figure 10.

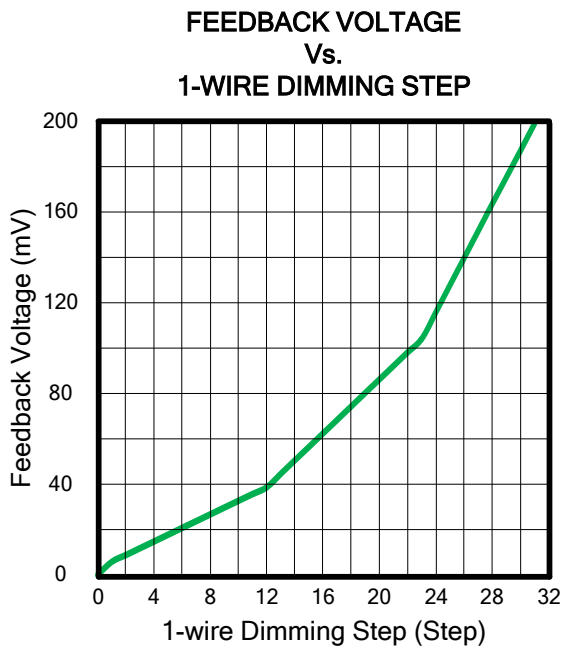


Figure 11.

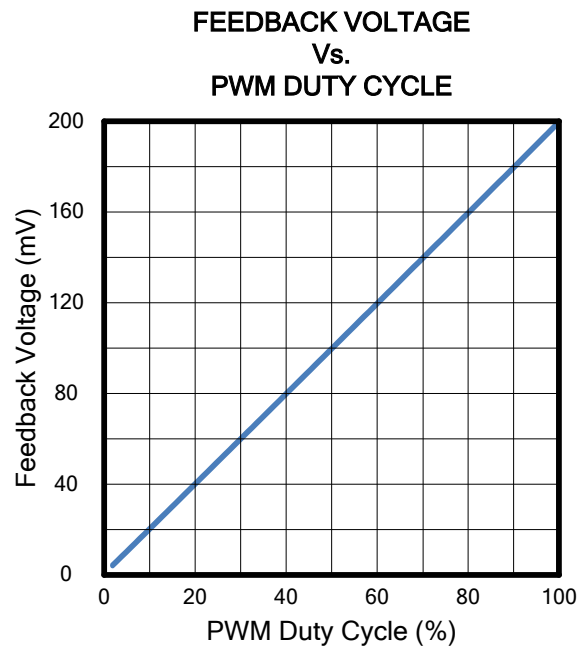
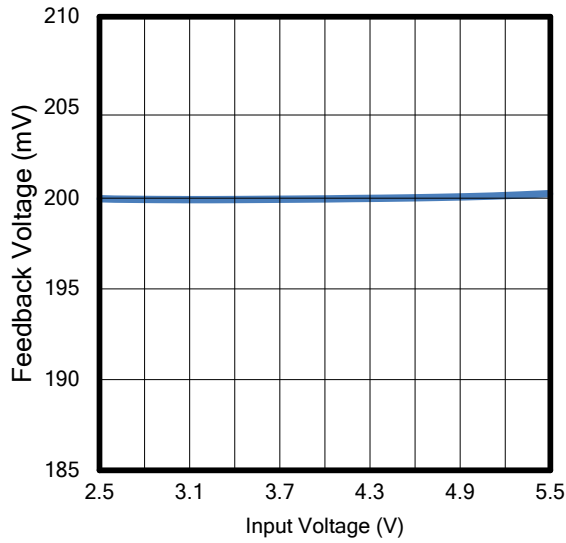


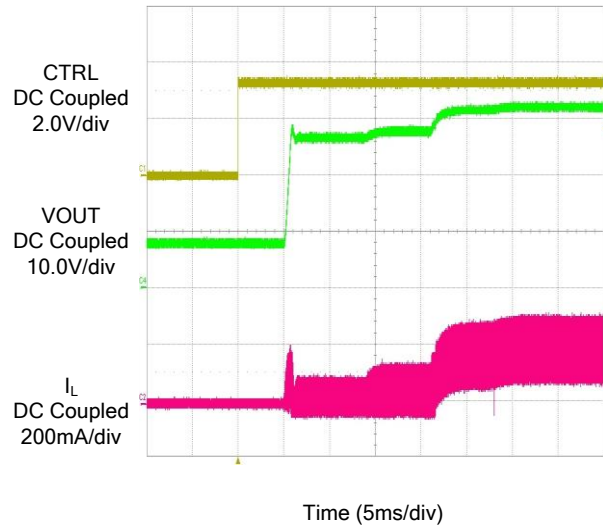
Figure 12.

**FEEDBACK VOLTAGE  
Vs.  
INPUT VOLTAGE**



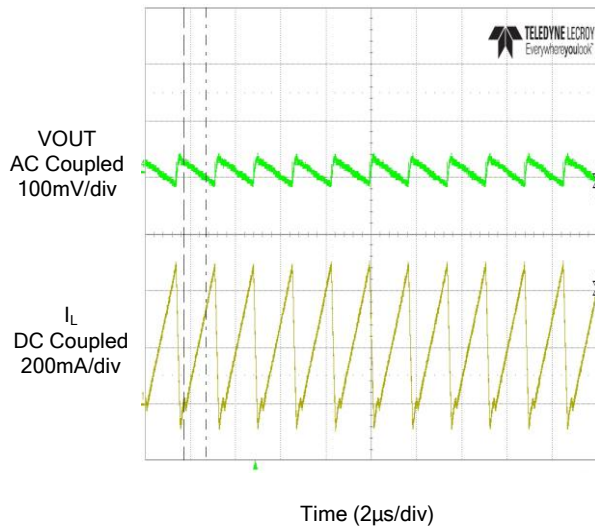
**Figure 13.**

**SOFT-START  
WAVEFORM**



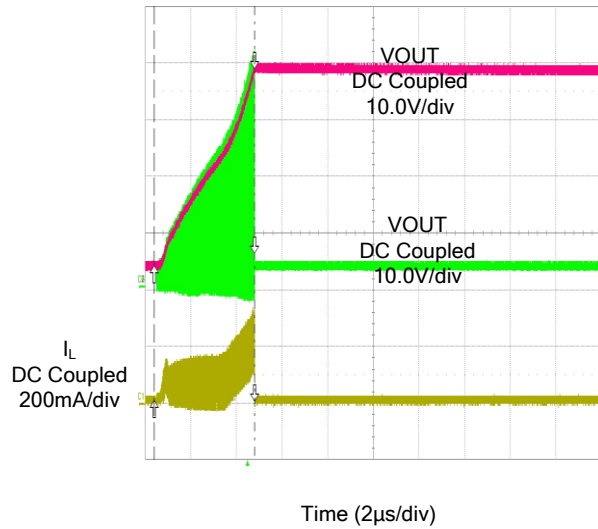
**Figure 14.**

**SWITCHING  
WAVEFORM**



**Figure 15.**

**OPEN LED  
PROTECTION**



**Figure 16.**

## DETAILED FUNCTIONAL DESCRIPTION

The AW9961 is a high efficiency, high output voltage boost converter in small package size. The device is ideal for driving up to 10 white LED in series. The serial LED connection provides even illumination by sourcing the same output current through all LEDs, eliminating the need for expensive factory calibration. The device integrates 40V/1.0A switch FET and operates in pulse width modulation (PWM) with 600kHz fixed switching frequency. For operation see the block diagram. The duty cycle of the converter is set by the error amplifier output and the current signal applied to the PWM control comparator. The control architecture is based on traditional current-mode control. Therefore, slope compensation is added to the current signal to allow stable operation for duty cycle larger than 50%. The feedback loop regulates the FB pin to a low reference voltage (200mV typical), reducing the power dissipation in the current sense resistor.

### SOFT START-UP

Soft-start circuitry is integrated into the IC to avoid a high inrush current during start-up. After the device is enabled, the voltage at FB pin ramps up to the reference voltage. This ensures that the output voltage rises slowly to reduce the input current. See the start-up waveform of a typical example.

### OPEN LED OVER-VOLTAGE PROTECTION

Open LED over-voltage protection circuitry prevents IC damage as the result of white LED disconnection. The AW9961 monitors the voltage at the SW pin during each switching cycle. The circuitry turns off the switch FET as soon as the SW voltage exceeds the  $V_{OVP}$  threshold for 8 clock cycles. The switch will switch after about 50ms. When the above condition is met, the protection circuitry will work again.

### SHUTDOWN

The CTRL input is used to enable or disable the AW9961. Pulling the CTRL pin higher than 1.5V will enable the device. The AW9961 has an internal shutdown delay circuitry, when the CTRL pin is held low for an amount of time longer than 3.0ms, the AW9961 will enter shutdown mode and the input supply current for the device is less than 1 $\mu$ A. Although the internal FET does not switch in shutdown, there is still a DC current path between the input and the LEDs through the inductor and Schottky diode. The minimum forward voltage of the LED array must exceed the maximum input voltage to ensure that the LEDs remain off in shutdown. However, in the typical application with two or more LEDs, the forward voltage is large enough to reverse bias the Schottky and keep leakage current low.

### UNDER-VOLTAGE LOCKOUT

An under-voltage lockout prevents operation of the device at input voltage below typical 2.45V. When the input voltage is below the under-voltage threshold, the device is shutdown and the internal switch FET is turned off. If the input voltage rises by under-voltage lockout hysteresis, the IC restarts.

### CURRENT PROGRAM

The FB voltage is regulated by a low 200mV reference voltage. The LED current is programmed externally using a current sense resistor in series with the LED string. The value of the RSET can be calculated by the following equation:

$$I_{LED} = \frac{V_{FB}}{R_{SET}} \quad (1)$$

Where:

$I_{LED}$  = output current of LEDs

$V_{FB}$  = regulated voltage of FB

$R_{SET}$  = current sense resistor

## LED BRIGHTNESS DIMMING MODE SELECTION

The CTRL pin is used for the control input for both dimming modes, PWM dimming and the 1-wire dimming. The dimming mode for the AW9961 is selected each time the device is enabled. The default dimming mode is PWM dimming. To enter 1-wire mode, the following digital pattern on the CTRL pin must be recognized by the IC every time that the IC starts from the shutdown mode.

1. Pull the CTRL pin high to enable the AW9961, and to start the 1-wire detection window.
2. After the digital 1-wire brightness detection delay ( $t_{1w\_dealy}$ , 100 $\mu$ s) expires, drive the CTRL pin low for more than the digital 1-wire brightness detection time ( $t_{1w\_det}$ , 260 $\mu$ s).
3. The CTRL pin has to be low for more than digital 1-wire brightness detection time before the digital 1-wire brightness detection window ( $t_{1w\_win}$ , 1ms) expires. Digital 1-wire brightness detection window starts from the first CTRL pin low to high transition.

The IC immediately enters 1-wire mode once the above three conditions are met. The 1-wire mode communication can start before the detection window expires. Once the dimming mode is programmed, it cannot be changed without another start up. This means the IC needs to be shut down by pulling the CTRL pin low for 2.5ms and restarts. See the *Dimming Mode Detection and Soft-start* (See [FIGURE 17](#)) for a graphical explanation.

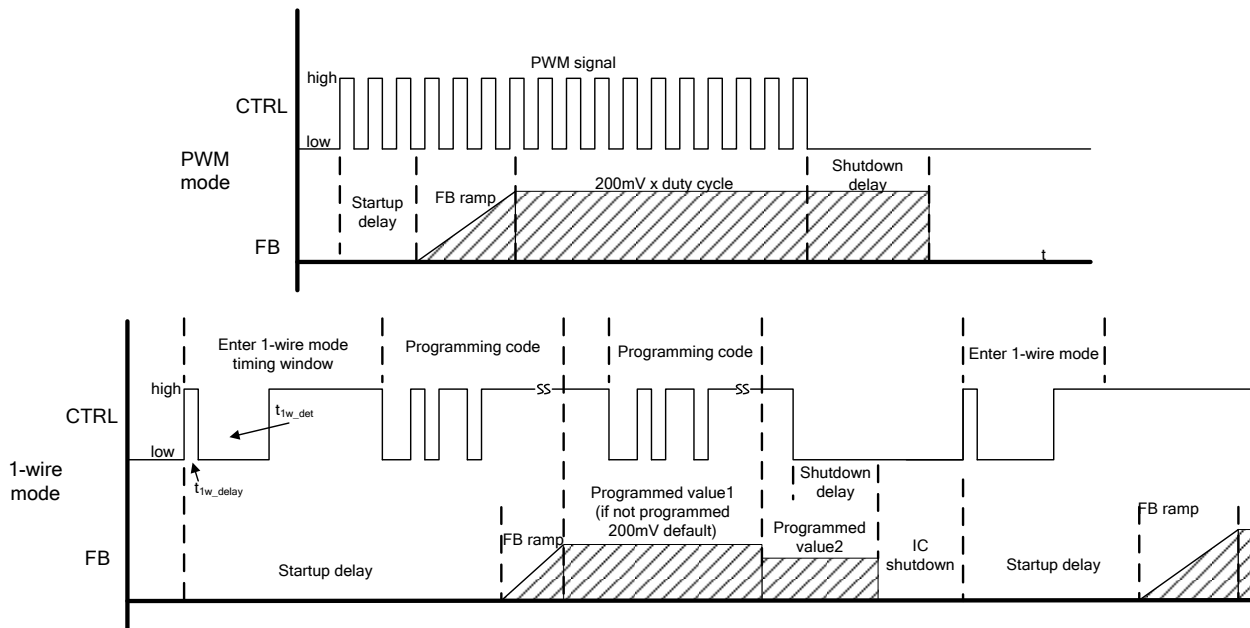


Figure 17 Dimming Mode Detection and Soft Start PWM Brightness Dimming

## PWM BRIGHTNESS DIMMING

When the CTRL pin is constantly high, the FB voltage is regulated to 200mV typically. However, the CTRL pin allows a PWM signal to reduce this regulation voltage, it achieves LED brightness dimming. The relationship between the duty cycle and the FB voltage is given by the following equation:

$$V_{FB} = \text{Duty} \times 200\text{mV} \quad (2)$$

Where:

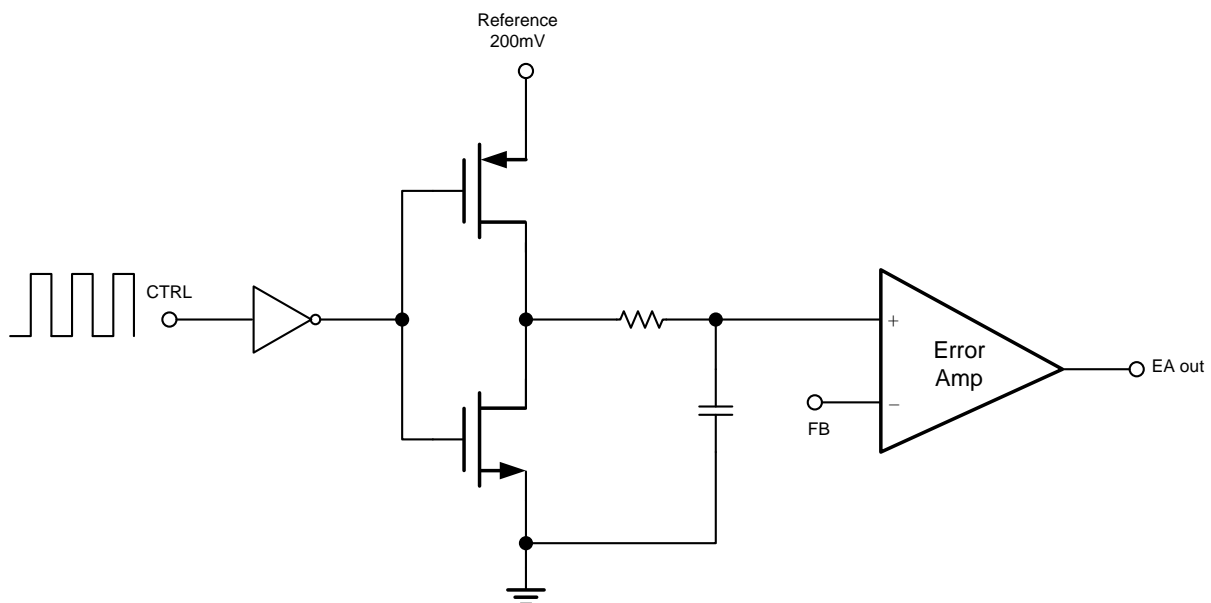
Duty = duty cycle of the PWM signal

200mV = internal reference voltage

As shown in the [FIGURE 18](#), the IC chops up the internal 200mV reference voltage at the duty cycle of the PWM signal. The pulse signal is then filtered by an internal low pass filter. The output of the filter is connected to the error amplifier as the reference voltage for the FB pin regulation. Therefore, although a PWM signal is used for brightness dimming, only the WLED DC current is modulated, which is often referred as analog dimming. This eliminates the audible noise which often occurs when the LED current is pulsed in replica of the frequency and duty cycle of PWM control. Unlike other scheme which filters the PWM signal for analog dimming, AW9661 regulation voltage is independent of the PWM logic voltage level which often has large variations.

For optimum performance, use the PWM dimming frequency in the range of 10kHz to 100kHz. The requirement of minimum dimming frequency comes from the digital 1-wire brightness detection delay and detection time specification in the dimming mode selection. Since the CTRL pin is logic only pin, adding external RC filter applied to the pin does not work.

To use lower PWM dimming, add an external RC network connected to the FB pin as shown in the additional typical application, [FIGURE 5](#).



**Figure 18 Block Diagram of Programmable FB Voltage Using PWM Signal**

## DIGITAL 1-WIRE BRIGHTNESS DIMMING

The CTRL pin features a simple digital interface to allow digital brightness control. The digital dimming can save the processor power and battery life as it does not require a PWM signal all the time, and the processor can enter idle mode if available.

The AW9961 adopts the 1-wire digital interface for the digital dimming, which can program the FB voltage to any of the 32 steps with single command. The step increment increases with the voltage to produce pseudo logarithmic curve for the brightness step. See [TABLE 2](#) for the FB pin voltage steps. The default step is full scale when the device is first enabled ( $V_{FB} = 200\text{mV}$ ). The programmed reference voltage is stored in an internal register. The shutdown mode clears the register value and reset it to default.

1-wire digital interface is a simple but flexible single pin interface to configure the FB voltage. The interface is based on a master-slave structure, where the master is typically a microcontroller or application processor.



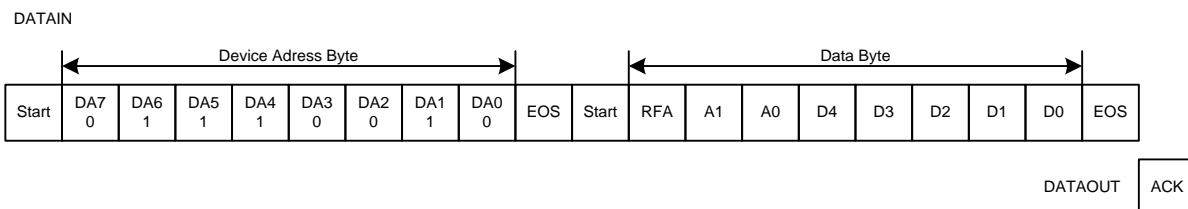
TABLE 3 and FIGURE 19 give an overview of the protocol. The protocol consists of a device specific address byte and a data byte. The device specific address byte is fixed to 72H. The data byte consists of five bits for information, two address bits, and the RFA bit. The RFA bit set to high indicates the “Request for Acknowledge” condition. The Acknowledge condition is only applied if the protocol was received correctly. The advantage of 1-wire digital interface compared with other single pin interface is that its bit detection is in a large extent independent from the bit transmission rate.

**Table 2 Selectable FB Voltage**

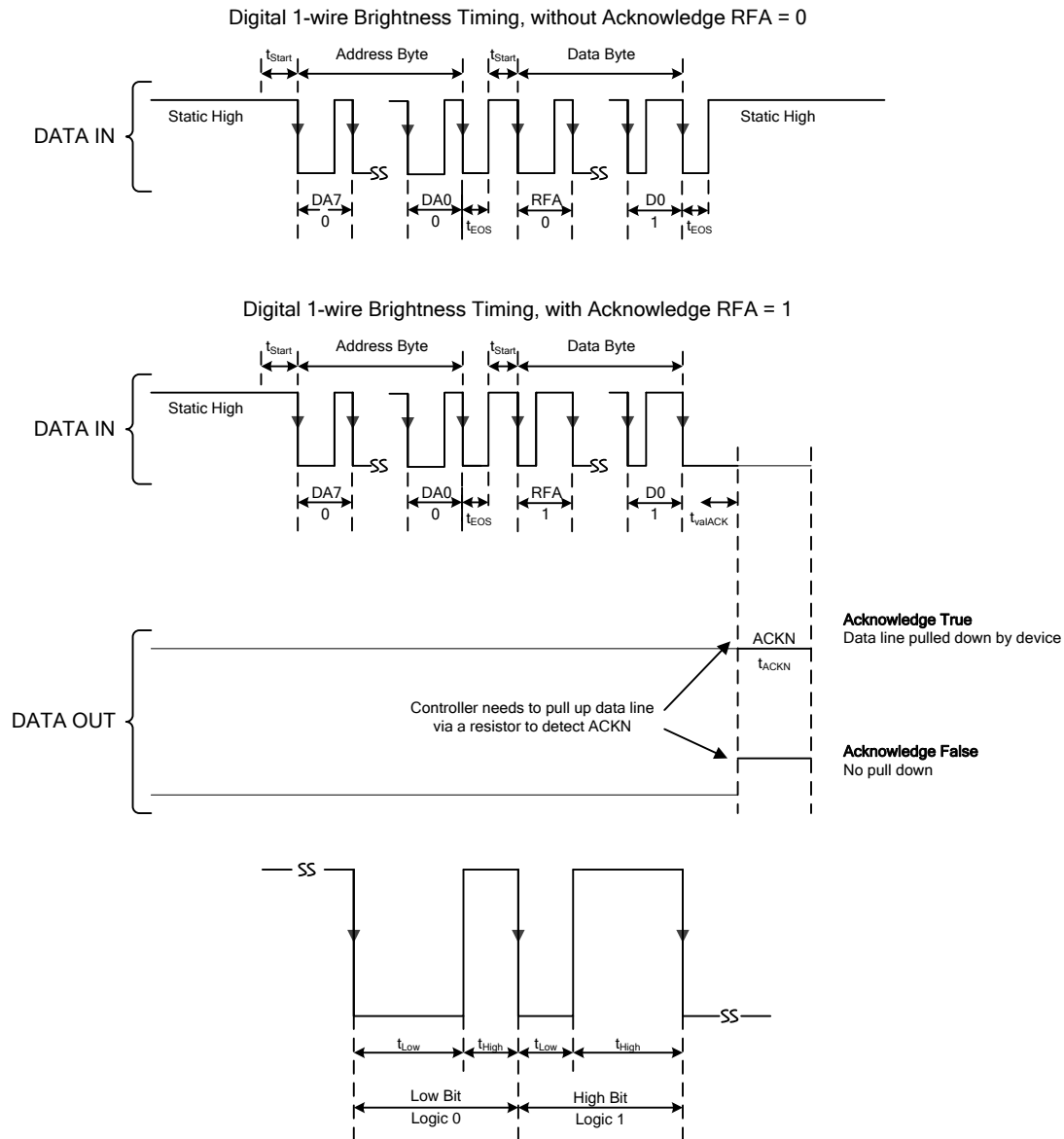
	FB voltage (mV)	D4	D3	D2	D1	D0
0	0	0	0	0	0	0
1	5	0	0	0	0	1
2	8	0	0	0	1	0
3	11	0	0	0	1	1
4	14	0	0	1	0	0
5	17	0	0	1	0	1
6	20	0	0	1	1	0
7	23	0	0	1	1	1
8	26	0	1	0	0	0
9	29	0	1	0	0	1
10	32	0	1	0	1	0
11	35	0	1	0	1	1
12	38	0	1	1	0	0
13	44	0	1	1	0	1
14	50	0	1	1	1	0
15	56	0	1	1	1	1
16	62	1	0	0	0	0
17	68	1	0	0	0	1
18	74	1	0	0	1	0
19	80	1	0	0	1	1
20	86	1	0	1	0	0
21	92	1	0	1	0	1
22	98	1	0	1	1	0
23	104	1	0	1	1	1
24	116	1	1	0	0	0
25	128	1	1	0	0	1
26	140	1	1	0	1	0
27	152	1	1	0	1	1
28	164	1	1	1	0	0
29	176	1	1	1	0	1
30	188	1	1	1	1	0
31	200	1	1	1	1	1

**Table 3 1-wire Digital Interface Bit Description**

Byte	Bit Number	Name	Transmission Direction	Description
Device Address Byte(72 hex)	7	DA7	IN	0 MSB device address
	6	DA6		1
	5	DA5		1
	4	DA4		1
	3	DA3		0
	2	DA2		0
	1	DA1		1
	0	DA0		0 LSB device address
Data Byte	7 (MSB)	RFA	IN	Request for acknowledge. If high, acknowledge is applied by device
	6	A1		0 Address bit 1
	5	A0		0 Address bit 0
	4	D4		Data bit 4
	3	D3		Data bit 3
	2	D2		Data bit 2
	1	D1		Data bit 1
	0 (LSB)	D0		Data bit 0
		ACK	OUT	Acknowledge condition active 0, this condition will only be applied in case RFA bit is set. Open drain output, line needs to be pulled high by the host with a pull-up resistor. This feature can only be used if the master has an open drain output stage. In case of a push-pull output stage acknowledge condition may not be requested.



**Figure 19 Digital 1-wire Interface Protocol Overview**



**Figure 20 Digital 1-wire Interface Bit Coding**

All bits are transmitted MSB first and LSB last. [FIGURE 20](#) shows the protocol without acknowledge request (Bit RFA = 0), and the protocol with acknowledge (Bit RFA = 1) request. Prior to both bytes, device address byte and data byte, a start condition must be applied. For this, the CTRL pin must be pulled high for at least  $t_{start}$  (2 $\mu$ s) before the bit transmission starts with the falling edge. If the CTRL pin is already at high level, no start condition is needed prior to the device address byte. The transmission of each byte is closed with an End of Stream condition for at least  $t_{EOS}$  (2 $\mu$ s).

The bit detection is based on a logic detection scheme, where the criterion is the relation between  $t_{Low}$  and  $t_{High}$ . It can be simplified to:

High Bit:  $t_{High} > t_{Low}$ , but with  $t_{High}$  at least  $2 \times t_{Low}$ , see [FIGURE 20](#).

Low Bit:  $t_{Low} > t_{High}$ , but with  $t_{Low}$  at least  $2 \times t_{High}$ , see [FIGURE 20](#).

The bit detection starts with a falling edge on the CTRL pin and ends with the next falling edge. Depending on the relation between  $t_{High}$  and  $t_{Low}$ , the logic 0 or 1 is detected.

The acknowledge condition is only applied if:

- Acknowledge is requested by a set RFA bit.

- The transmitted device address matches with the device address of the device.
- 16 bits is received correctly.

If the device turns on the internal ACKN-MOSFET and pulls the CTRL pin low for the time  $t_{ACKN}$ , which is 512 $\mu$ s maximum then the Acknowledge condition is valid after an internal delay time  $t_{valACK}$ . This means that the internal ACKN-MOSFET is turned on after  $t_{valACK}$ , when the last falling edge of the protocol was detected. The master controller keeps the line low in this period. The master device can detect the acknowledge condition with its input by releasing the CTRL pin after  $t_{valACK}$  and read back a logic 0. The CTRL pin can be used again after the acknowledge condition ends.

Note that the acknowledge condition may only be requested in case the master device has an open drain output. For a push-pull output stage, the use a series resistor in the CTRL line to limit the current to 500 $\mu$ A is recommended to for such cases as:

- an accidentally requested acknowledge, or
- to protect the internal ACKN-MOSFET.

## EMI CONTROL BITS

To adjust the EMI(electromagnetic interference) issue arisen by the periodic change of inductor current, AW9961 sets an EMI control register EMI\_CTL<1:0>, of which default value is 00. By configuring the EMI bits, the EMI performance can be adjusted. EMI control register is detailed in the table below.

**Table 4 EMI Control Register Description**

Register	A1	A0	D4	D3	D2	D1	D0	Default
PROTECT	1	1	0	1	0	1	0	0
EMI_CTL	1	0	-	-	-	EMI_CTL<1>	EMI_CTL<0>	00

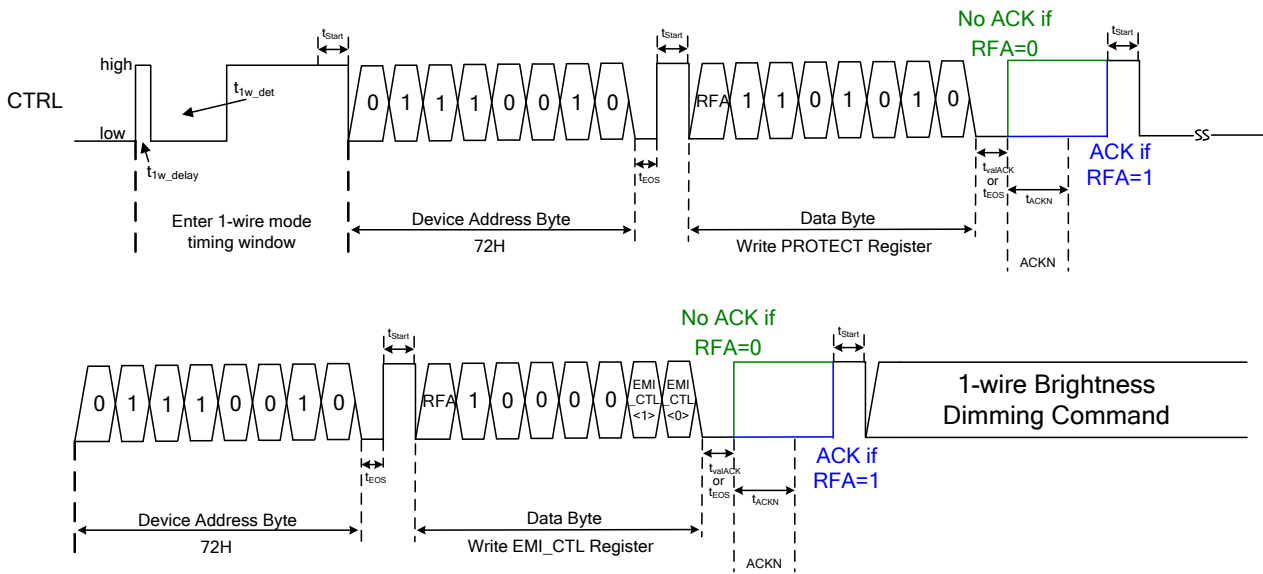
Note that the EMI\_CTL register cannot be written unless the PROTECT register has been written firstly. And the PROTECT bits sequence which needs to be followed is fixed to “1101010”, from A1 to D0. The PROTECT register would be cleared automatically when the next write operation happens.

Among all of the EMI bits configuration, “00” has been set for default condition. The other three conditions would be described in terms of EMI performance/ efficiency compared to default status as follows: 01(EMI worst, efficiency best), 10(EMI best, efficiency worst), 11(EMI better, efficiency worse).

AW9961 supports the EMI adjustment under either 1-wire or PWM brightness dimming mode, and the register should be configured by means of 1-wire interface protocol in both modes. While there are still some differences between the two configure methods, below are more details:

### 1-wire Mode

Under 1-wire mode, EMI\_CTL register can be configured in the same way as dimming register. [FIGURE 21](#) shows a timing diagram for EMI adjustment under 1-wire mode.

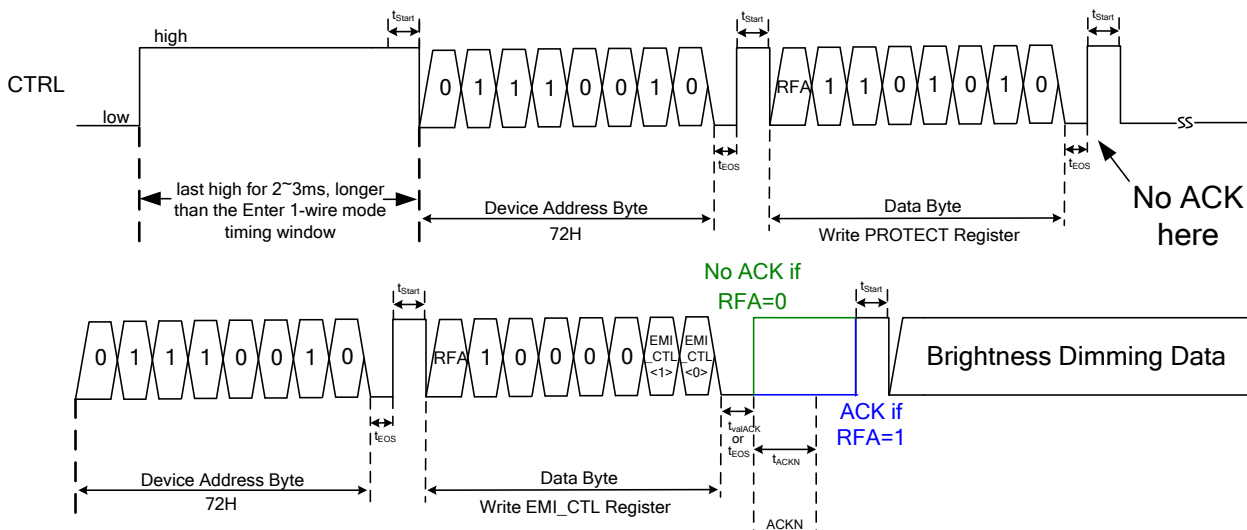


**Figure 21 EMI\_CTL Register Configuration Timing under 1-wire Mode**

**PWM Mode**

In PWM mode, EMI\_CTL register configuration would be implemented with the 1-wire interface protocol, while there are some different timing requirements from those under 1-wire mode at the CTRL pin: Firstly, Host should pull the CTRL pin high for 2~3ms when enabling the chip, to avoid making confusion with the mode detection window. On the other hand, no ACK would be applied at the CTRL pin unless the following sequence is satisfied:

- a) PROTECT register be configured correctly only one time (non-repetitive)
- b) EMI\_CTL bits be configured correctly
- c) the RFA bit of EMI\_CTL Data Byte has been set to request an acknowledge. See [FIGURE 22](#).



**Figure 22 EMI\_CTL Register Configuration Timing under PWM Mode**

**THERMAL SHUTDOWN**

An internal thermal shutdown turns off the device when the typical junction temperature of is exceeded 165°C. The device is released from shutdown automatically when the junction temperature decreases by 16°C.

## APPLICATION INFORMATION

### MAXIMUM OUTPUT CURRENT

The over-current limit in a boost converter limits the maximum input current and thus maximum input power for a given input voltage. Maximum output power is less than maximum input power due to power conversion losses. Therefore, the current limit setting, input voltage, output voltage and efficiency can all change maximum current output. The current limit clamps the peak inductor current. Therefore, the ripple has to be subtracted to derive maximum DC current. The ripple current is a function of switching frequency, inductor value and duty cycle. The following equations take into account of all the above factors for maximum output current calculation.

$$I_P = \frac{1}{[L \times F_s \times (\frac{1}{V_{OUT} + V_F - V_{IN}} + \frac{1}{V_{IN}})]} \quad (3)$$

Where:

$I_P$  = inductor peak to peak ripple

$L$  = inductor value

$V_F$  = Schottky diode forward voltage

$F_S$  = switching frequency

$V_{OUT}$  = output voltage of the boost converter. It is equal to the sum of  $V_{FB}$  and the voltage drop across LEDs.

$$I_{out\_max} = \frac{V_{IN} \times (I_{lim} - I_P / 2) \times \eta}{V_{OUT}} \quad (4)$$

Where:

$I_{out\_max}$  = maximum output current of the boost converter

$I_{lim}$  = over-current limit, for worst case calculation the minimum value has to be chosen.

$\eta$  = efficiency

### INDUCTOR SELECTION

The selection of the inductor affects steady state operation as well as transient behavior and loop stability. These factors make it the most important component in power regulator design. There are three important inductor specifications, inductor value, DC resistance and saturation current. Considering inductor value alone is not enough.

The inductor value determines the inductor ripple current. Choose an inductor that can handle the necessary peak current without saturating, according to half of the peak-to-peak ripple current given by equation 3, pause the inductor DC current given by:

$$I_{IN\_DC} = \frac{V_{OUT} \times I_{out}}{V_{IN} \times \eta} \quad (5)$$

Inductor values can have  $\pm 20\%$  tolerance with no current bias. When the inductor current approaches saturation level, its inductance can decrease 20% to 35% from the 0A value depending on how the inductor vendor defines saturation current. Using an inductor with a smaller inductance value forces discontinuous

PWM when the inductor current ramps down to zero before the end of each switching cycle. This reduces the boost converter's maximum output current, causes large input voltage ripple and reduces efficiency. Large inductance value provides much more output current and higher conversion efficiency. For these reasons, a 10μH to 22μH inductor value range is recommended. A 22μH inductor optimized the efficiency for most application while maintaining low inductor peak to peak ripple. [TABLE 5](#) lists the recommended inductor for the AW9961. When recommending inductor value, the factory has considered -40% and +20% tolerance from its nominal value.

AW9961 has built-in slope compensation to avoid sub-harmonic oscillation associated with current mode control. If the inductor value is lower than 10μH, the slope compensation may not be adequate, and the loop can be unstable. Therefore, customers need to verify the inductor in their application if it is different from the recommended values.

**Table 5 Recommended Inductors for AW9961**

Part Number	L (μH)	DCR Max (Ω)	Saturation Current (mA)	Size (L x W x H mm)	Vendor
VLCF5020T-220MR75-1	22	0.4	750	5 x 5 x 2.0	TDK
LQH3NPN100NM0	10	0.3	750	3 x 3 x 1.5	Murata
A997AS-220M	22	0.4	510	4 x 4 x 1.8	TOKO
CDH3809/SLD	10	0.3	570	4 x 4 x 1.0	Sumida

## SCHOTTKY DIODE SELECTION

The high switching frequency of the AW9961 demands a high-speed rectification for optimum efficiency. Ensure that the diode average and peak current rating exceeds the average output current and peak inductor current. In addition, the diode's reverse breakdown voltage must exceed the open LED over-voltage protection voltage. The ONSemiconductor MBR0540 and the ZETEX ZHCS400 are recommended for AW9961.

## COMPENSATION CAPACITOR SELECTION

For most applications, ceramic capacitors with X7R or X5R temperature characteristic are preferred for use with the AW9961. These capacitors have tight capacitance tolerance (as good as ±10%) and hold their value over temperature (X7R: ±15% over -55°C to 125°C; X5R: ±15% over -55°C to 85°C).

Capacitors with Y5V or Z5U temperature characteristic are generally not recommended for use with the AW9961. Capacitors with these temperature characteristics typically have wide capacitance tolerance (+80%, -20%) and vary significantly over temperature (Y5V: +22%, -82% over -30°C to +85°C range; Z5U: +22%, -56% over +10°C to +85°C range). Under some conditions, a nominal 1μF Y5V or Z5U capacitor could have a capacitance of only 0.1μF. Such detrimental deviation is likely to cause Y5V and Z5U capacitors to fail to meet the minimum capacitance requirements of the AW9961.

The compensation capacitor  $C_{COMP}$  (see the application circuit), connected from COMP pin to GND, is used to stabilize the feedback loop of the AW9961. Use 220nF X5R or X7R ceramic capacitor for  $C_{COMP}$ .

## INPUT AND OUTPUT CAPACITORS SELECTION

The output capacitor is mainly selected to meet the requirements for the output ripple and loop stability. This ripple voltage is related to the capacitor's capacitance and its equivalent series resistance (ESR). Assuming a capacitor with zero ESR, the minimum capacitance needed for a given ripple can be calculated by:

$$C_{OUT} = \frac{(V_{OUT} - V_{IN}) \times I_{out}}{V_{OUT} \times F_s \times V_{ripple}} \quad (6)$$

Where,  $V_{\text{ripple}}$  = peak-to-peak output ripple. The additional output ripple component caused by ESR is calculated using:

$$V_{\text{ripple\_ESR}} = I_{\text{out}} \times R_{\text{ESR}} \quad (7)$$

Due to its low ESR,  $V_{\text{ripple\_ESR}}$  can be neglected for ceramic capacitors, but must be considered if tantalum or electrolytic capacitors are used.

Care must be taken when evaluating a ceramic capacitor's derating under dc bias, aging and AC signal. For example, larger form factor capacitors (in 1206 size) have a resonant frequency in the range of the switching frequency. So the effective capacitance is significantly lower. The DC bias can also significantly reduce capacitance. Ceramic capacitors can lose as much as 50% of its capacitance at its rated voltage. Therefore, leave the margin on the voltage rating to ensure adequate capacitance at the required output voltage.

An X5R or X7R capacitor of 10 $\mu$ F is recommended for input side. The output requires a X5R or X7R capacitor in the range of 0.47 $\mu$ F to 4.7 $\mu$ F. A 100nF capacitor and a 33 pF capacitor are recommended to use in parallel with the input capacitor and the output capacitor to suppress high frequency noise.

The output capacitor affects the loop stability of the boost regulator. If the output capacitor is below the range, the boost regulator can potentially become unstable. For example, if use the output capacitor of 0.1 $\mu$ F, a 470nF compensation capacitor has to be used for the loop stable.

Note that capacitor degradation increases the ripple much. Select the capacitor with 50V rated voltage to reduce the degradation at the output voltage. If the output ripple is too large, change a capacitor with less degradation effect or with higher rated voltage could be helpful.

## POWER DISSIPATION

The maximum IC junction temperature should be restricted to 125°C under normal operating conditions. This restriction limits the power dissipation of the AW9961. Calculate the maximum allowable dissipation,  $P_{D(\text{max})}$ , and keep the actual dissipation less than or equal to  $P_{D(\text{max})}$ . The maximum-power-dissipation limit is determined by using the following equation:

$$P_{D(\text{max})} = \frac{T_{J\text{max}} - T_A}{\theta_{ja}}$$

Where,  $T_{J\text{max}}$  is the Maximum Junction Temperature,  $T_A$  is the maximum ambient temperature for the application.  $\theta_{ja}$  is the thermal resistance junction-to-ambient given in Power Dissipation Table.

The AW9961 comes in a thermally enhanced TDFN package. Compared with the TSOT package, the TDFN package has better heat dissipation. This package includes a thermal pad that improves the thermal capabilities of the package. The  $\theta_{ja}$  of the TDFN package greatly depends on the PCB layout and thermal pad connection. The thermal pad must be soldered directly to the analog ground on the PCB. After soldering, the PCB can be used as a heatsink. In addition, through the use of thermal vias, the thermal pad can be attached directly to the appropriate copper plane, or alternatively, can be attached to a special heatsink structure designed into the PCB. This design optimizes the heat transfer from the integrated circuit(IC).

Using thermal vias underneath the thermal pad as illustrated in the layout example.



## PCB LAYOUT CONSIDERATION

As for all switching power supplies, especially those high frequency and high current ones, layout is an important design step. If layout is not carefully done, the regulator could suffer from instability as well as noise problems. To reduce switching losses, the SW pin rise and fall times are made as short as possible. To prevent radiation of high frequency resonance problems, proper layout of the high frequency switching path is essential. Minimize the length and area of all traces connected to the SW pin and always use a ground plane under the switching regulator to minimize inter-plane coupling. The loop including the PWM switch, Schottky diode, and output capacitor, contains high current rising and falling in nanosecond and should be kept as short as possible. The input capacitor needs not only to be close to the VIN pin, but also to the GND pin in order to reduce the IC supply ripple.

Connect the exposed paddle to the PCB ground plane using at least two vias. The input and the output bypass capacitors should be placed as close to the IC as possible. Minimize trace lengths between the IC and the inductor, the diode and the output capacitor; keep these traces short, direct, and wide.

A recommended PCB Layout is shown in [FIGURE 23](#). In order to dissipate the package heat, the package thermal pad must be connected to a large copper area on the ground plane underneath using multiple vias.

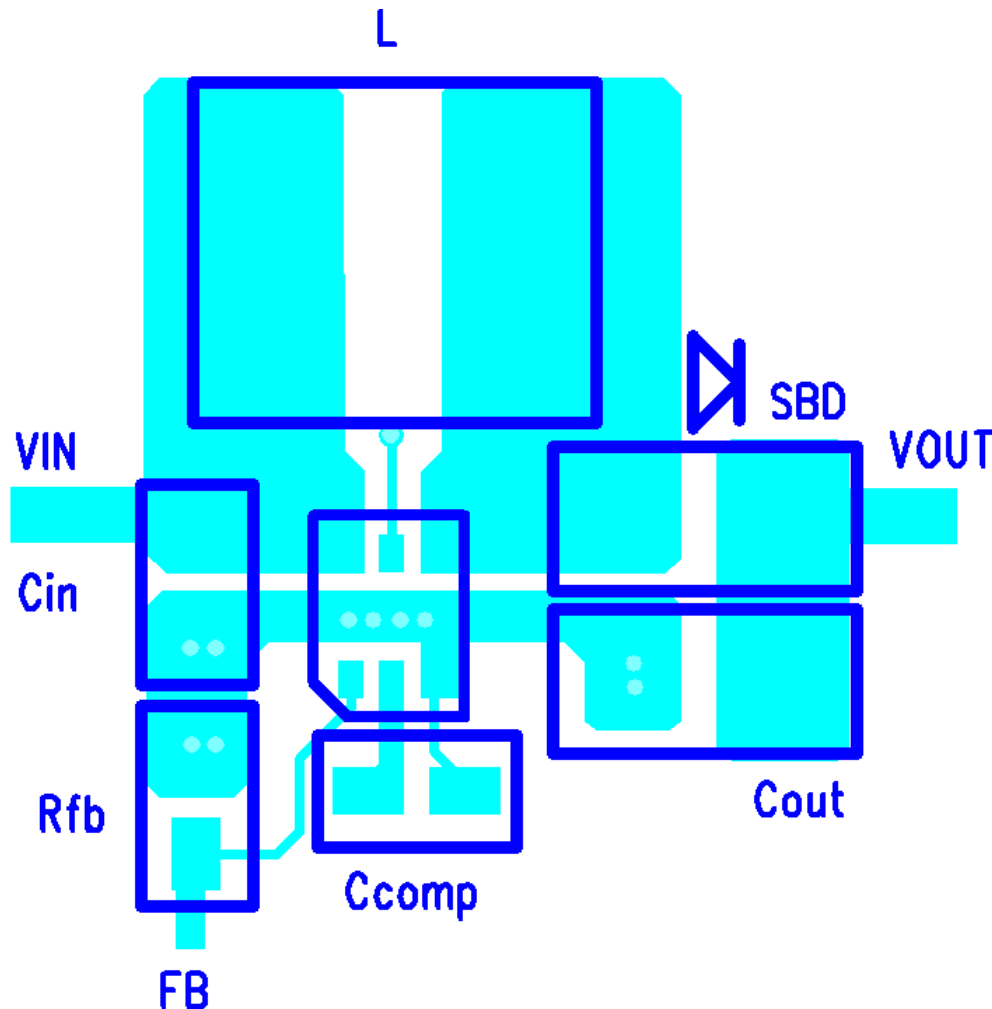
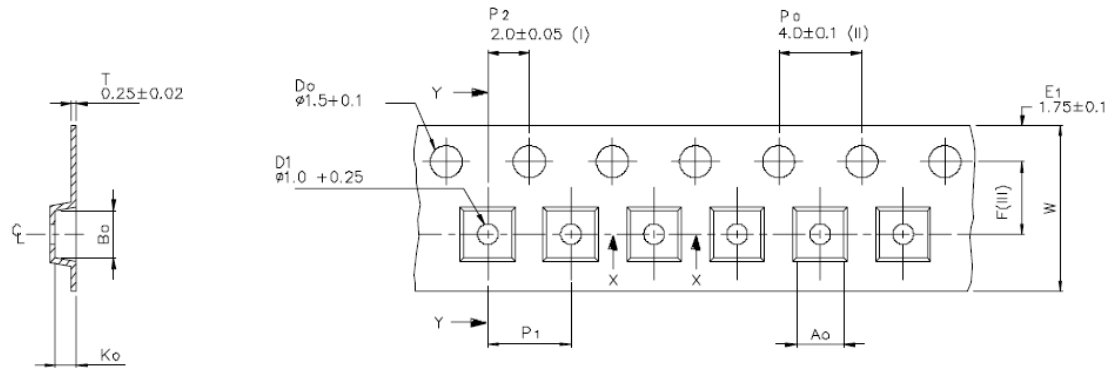


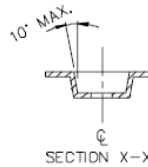
Figure 23 Recommended PCB Layout

## TAPE AND REEL INFORMATION

### Carrier Tape



SECTION Y-Y



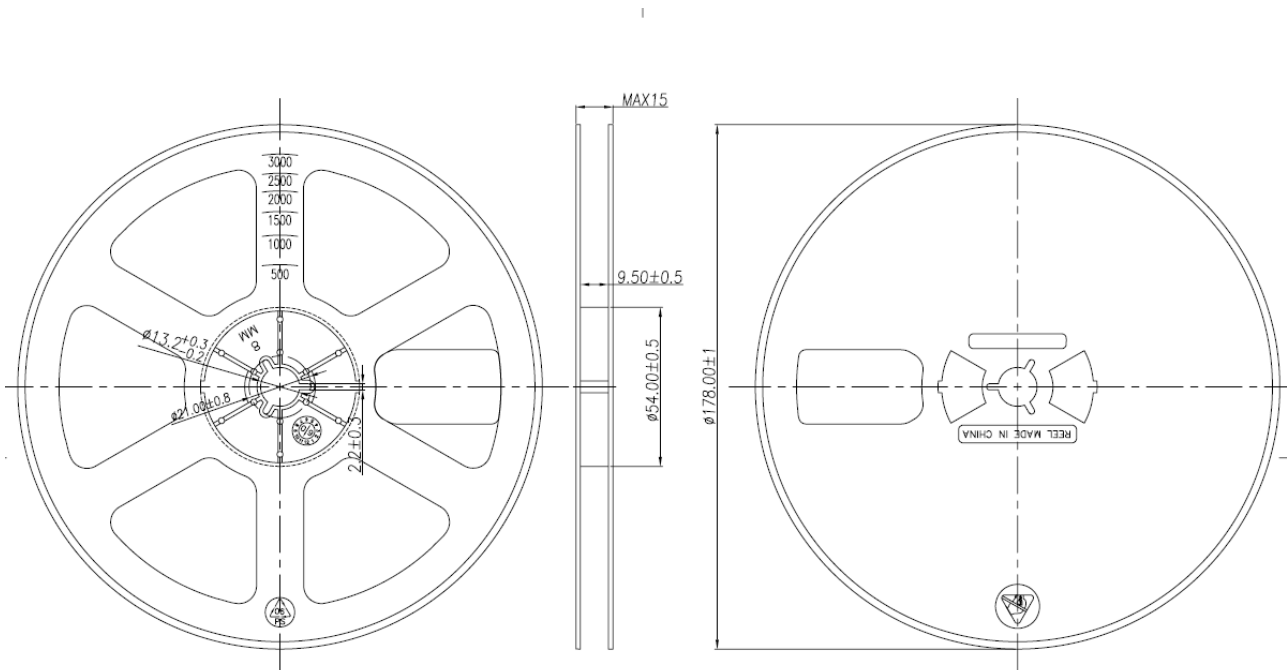
SECTION X-X

A <sub>0</sub>	2.30	+/-0.05
B <sub>0</sub>	2.30	+/-0.05
K <sub>0</sub>	1.00	+/-0.05
F	3.50	+/-0.05
P <sub>1</sub>	4.00	+/-0.1
W	8.00	+0.3/-0.1

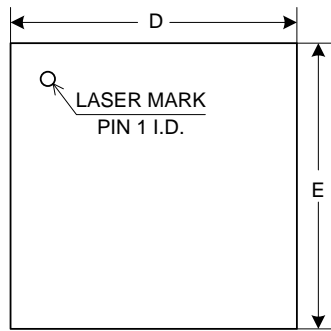
- (I) Measured from centreline of sprocket hole to centreline of pocket.
- (II) Cumulative tolerance of 10 sprocket holes is  $\pm 0.20$ .
- (III) Measured from centreline of sprocket hole to centreline of pocket.
- (IV) Other material available.
- (V) Typical SR of form tape Max  $10^8$  OHM/SQ

ALL DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE STATED

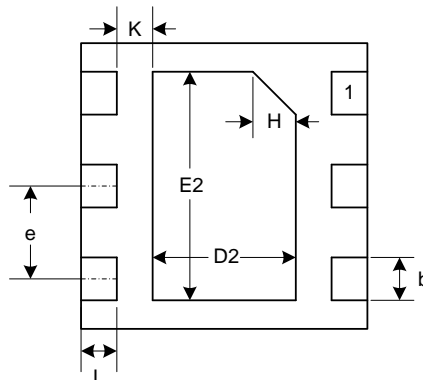
### Reel



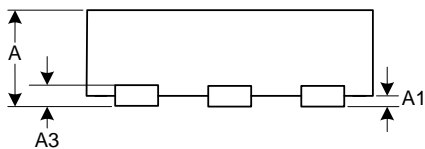
## PACKAGE DESCRIPTION



TOP VIEW



BOTTOM VIEW



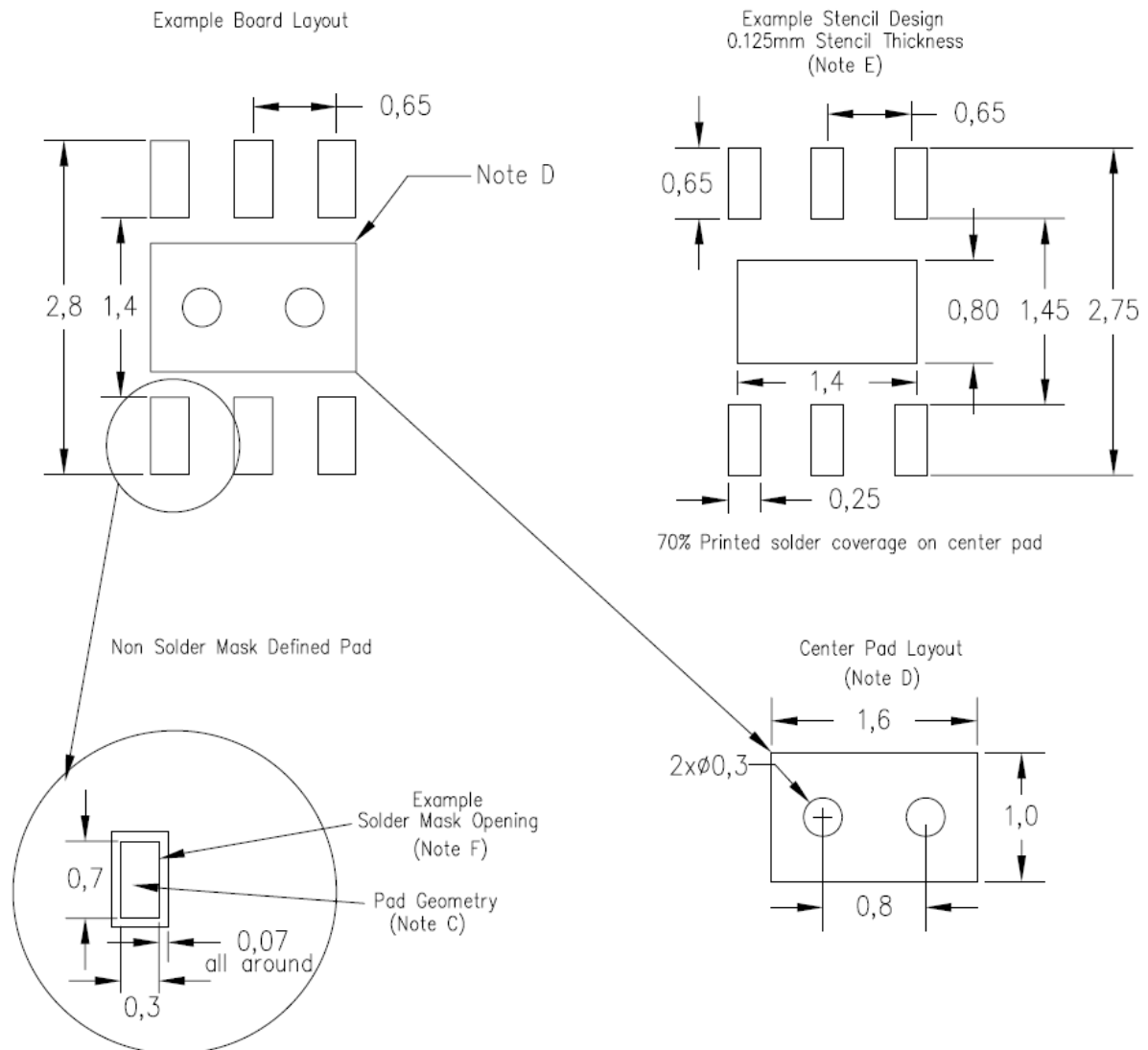
SIDE VIEW

COMMON DIMENSIONS  
 (UNITS OF MEASURE=MILLIMETER)

Symbol	Min	Typ	Max
A	0.70	0.75	0.80
A1	0.00	0.02	0.05
A3	0.20REF		
b	0.25	0.30	0.35
D	1.90	2.00	2.10
E	1.90	2.00	2.10
D2	0.90	1.00	1.10
E2	1.50	1.60	1.70
e	0.55	0.65	0.75
K	0.15	0.25	0.35
L	0.20	0.25	0.30
H	0.20REF		

NOTES:  
 ALL DIMENSIONS REFER TO JEDEC STANDARD MO-229  
 DO NOT INCLUDE MOLD FLASH OR PROTRUSIONS.

## LAND PATTERN DATA



**NOTE A:** All linear dimensions are in millimeters.

**NOTE B:** This drawing is subject to change without notice.

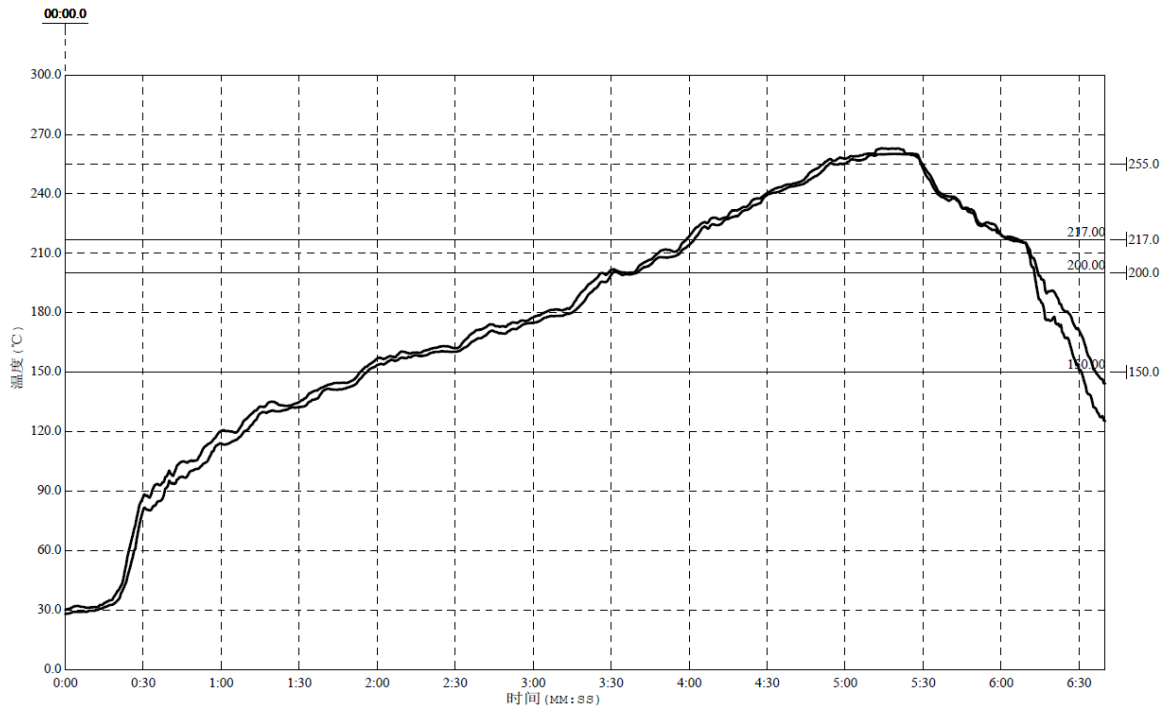
**NOTE C:** Publication IPC-7351 is recommended for alternate designs.

**NOTE D:** This land pattern is designed to be soldered to a thermal pad on the board.

**NOTE E:** Laser cutting aperture with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil design recommendations. Refer to IPC-7525 for stencil design considerations.

**NOTE F:** Customers should contact their board fabrication site for solder mask tolerances.

**REFLOW**



**Figure 24 Package Reflow Oven Thermal Profile**

Reflow Note	Spec
Average ramp-up rate (217°C to Peak)	Max. 3°C/sec
Time of Preheat temp.(from 150°C to 200°C)	60-120sec
Time to be maintained above 217°C	60-150sec
Peak Temperature	>260°C
Time within 5°C of actual peak temp	20-40sec.
Ramp-down rate	Max. 6°C/sec
Time from 25°C to peak temp	Max. 8min.

## REVISION HISTORY

Vision	Date	Change Record
V0.9	August 2014	Datasheet V0.9 Released
V1.0	March 2015	Datasheet V1.0 Released
V1.1	May 2015	1、 Refreshed C <sub>IN</sub> information; 2、 Refreshed Figure 5; 3、 Added EMI_CTL register and configuration description.
V1.1.1	June 2015	1、 Added Figure 6; 2、 Corrected some literal mistakes.
V1.1.2	November 2015	1、 Added PWM DIMMING TIMING information in the Electrical Characteristics 2、 Corrected some literal mistakes.

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