

1-Channel Dimmable White Smart Connected Light Bulb Reference Design “AL1663 (PSR PFC Controller) + AP3988 (PSR Switcher)”

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GENERAL DESCRIPTION

The emerging Smart Connected Light (SCL) Bulbs, as Internet of Things (IoT) devices in Smart Home environment, are characterized by integration of wireless-connectivity microcontroller (MCU) in LED light bulbs. Users can manage LED light bulbs through smart phone APPs to achieve the following needs:

- Energy saving (through dimming of brightness) - 1-channel Dimmable White (1-ch DW)
- Light quality management – 2-channel Tunable White (2-ch TW)
- Entertainment lighting – 3-channel Tunable Color (3-ch TC) or 4-channel White+RGB (4-ch W+RGB)

Typical functional block diagram of SCL bulbs consists of:

- AC-DC Power
- LED Driver
- Emitter Module
- Wireless MCU Connectivity

This application note describes the complete reference design of an A19 10W ZigBee-Enabled 1-channel Dimmable White SCL (1-ch DW SCL) bulb. It serves as a good starting point for system designers to further customize SCL bulb design to their desired performance and cost consideration for similar products.

KEY SPECIFICATION

- Model: A19-DD-BU-LO-1CH
- Lamp Shape: A19
- Operating Power: 10W
- Operating Voltage: 100V-240V
- Frequency: 50/60Hz
- Average Lifetime: 25,000Hrs
- Bulb Base: E26/E27
- Lumen: 800 lm
- CCT Range: 2,700K
- CRI: 80Ra
- Wireless: ZigBee Module
- Dimension (L*D): 113mm x 62mm



FUNCTIONAL BLOCK DIAGRAM

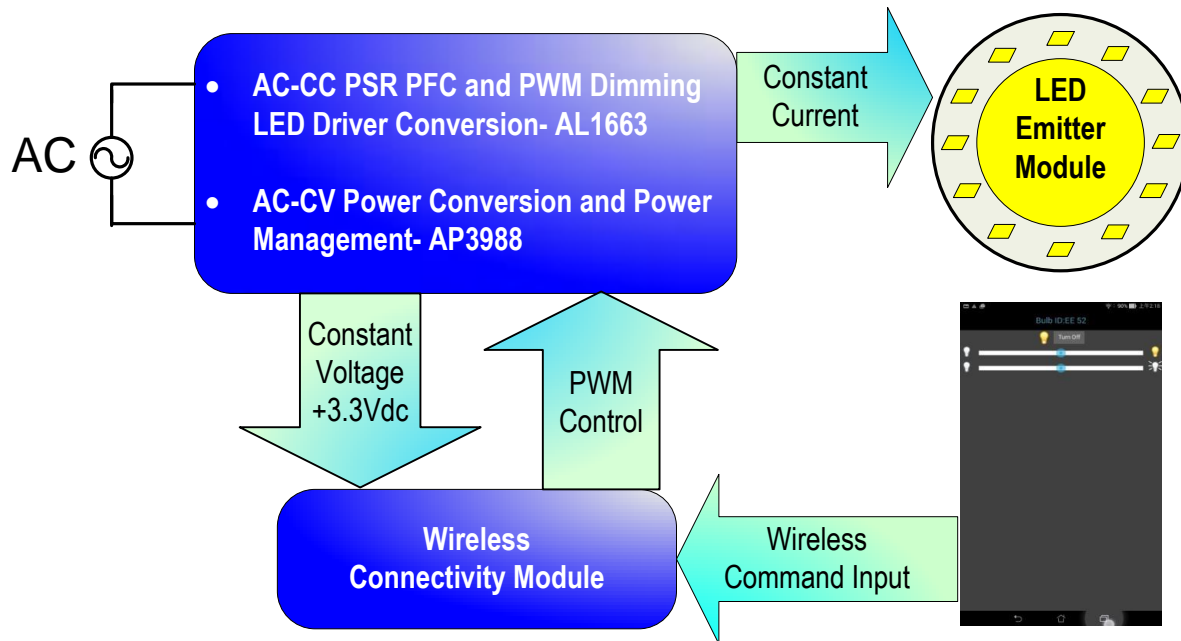


Figure 1 - Functional Block Diagram for Smart Connected Light Bulb

A typical 1-Channel dimming SCL bulb (Figure 1) consists of four major functional blocks:

- 1) AC-CC LED Driver – It converts AC input to generate one Constant Current (CC) to drive LED emitters. The AL1663 is a high performance LED controller which can support PWM dimming mode.
- 2) AC-CV Power Conversion - It converts AC input to DC-3.3V output. For a SCL bulb, 3.3V might be required to DC power requirement from wireless connectivity module.
- 3) Wireless Connectivity Module - The Wireless Connectivity Module consists of an intelligent MCU and RF circuitry to connect a SCL bulb either directly with smartphones or indirectly through Wi-Fi/ZigBee hub, based on a communication protocol (e.g. Bluetooth/BLE, ZigBee, etc.)
- 4) LED Emitter Module - This is the light source for the SCL bulb. Driven by PWM dimming signal from Wireless Connectivity MCU, the LED Emitter Module to generate desired light brightness adjustment.

COMPLETE DESIGN SCHEMATICS

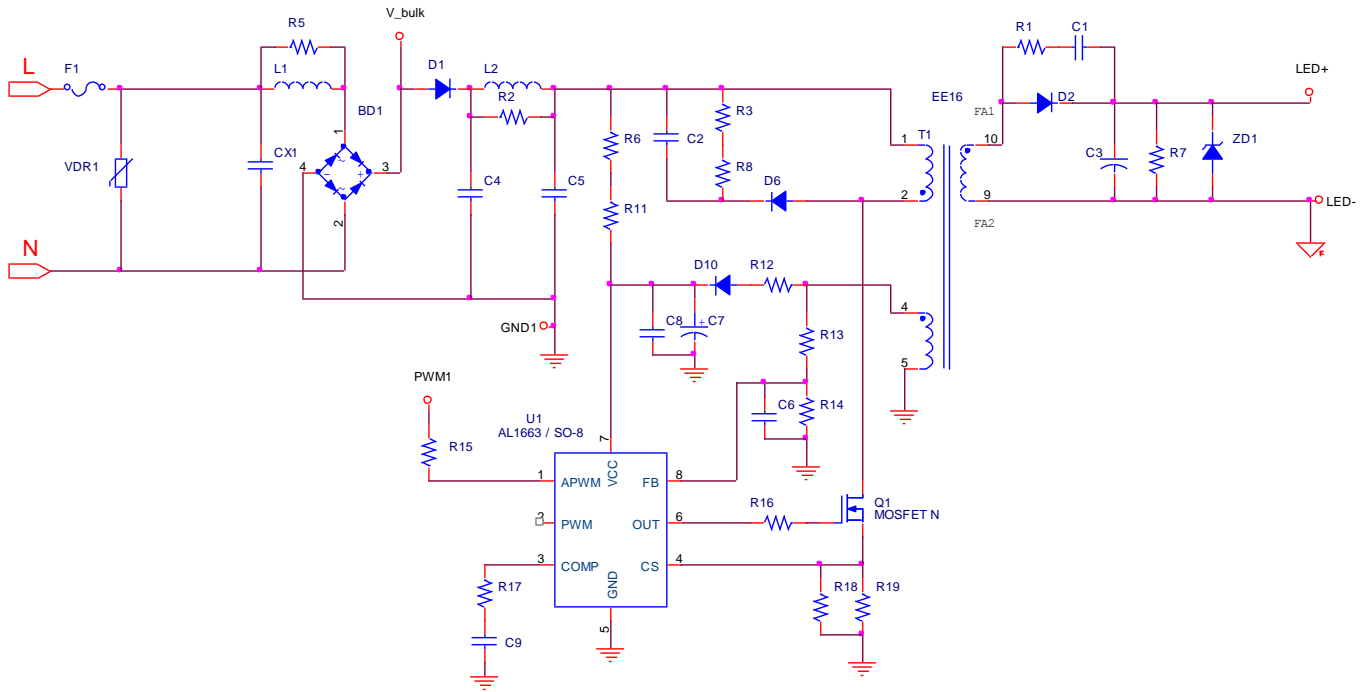


Figure 2.a –Power Board Application Schematics- AC-CC AL1663 section

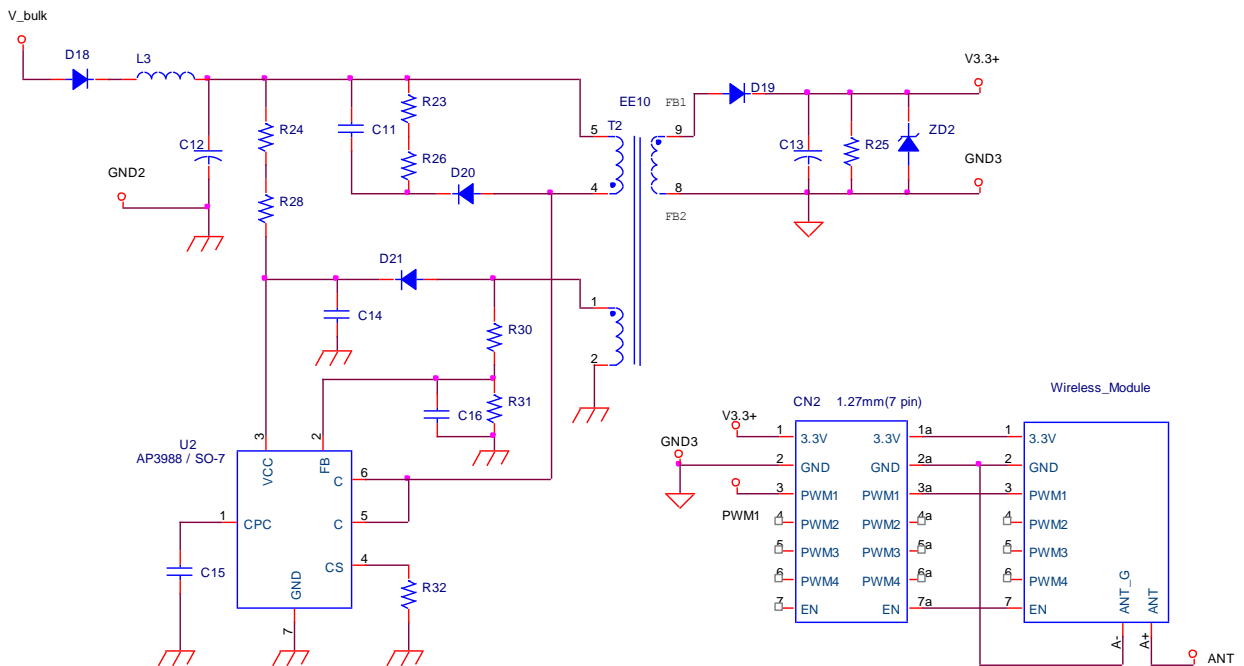


Figure 2.b –Power Board Application Schematics- AC-CV AP3988 section

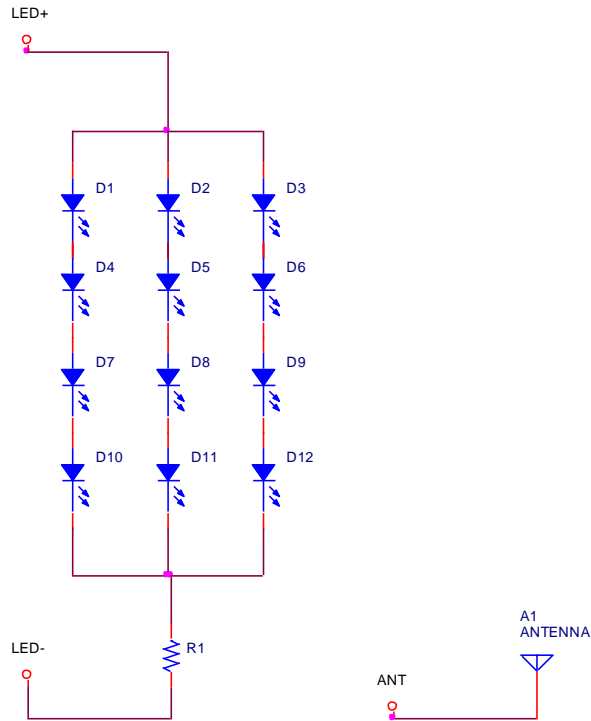


Figure 2.c - LED Emitter Module Schematics

APPLICATION DESCRIPTION

➤ **Power Board (PB) Application Description**

The AC-CC LED driver conversion (AL1663, PSR PFC PWM dimmable LED driver) as well as AC-CV power supply (AP3988 PSR Switcher) co-exist in the same PCB (Figure 3), the outputs two power supplies:

- ✧ AC-CC LED Driver - 360mA@24V for driving LED emitter string. The driver design is based on AL1663 single stage Flyback high PF LED driver with PWM dimming control. (Refer to the Key Components section on page 12). The AL1663 provides accurate constant current (CC) regulation while remove the opto-coupler and secondary control circuitry.

The AL1663 is a high performance LED controller which can support multiple dimming modes. PWM signal of ZigBee module is applied on APWM pin of AL1663, the device works at true PWM dimming mode, and to control the LED current.

For the design principles and design examples of AP1663 LED Driver (e.g. Switching Frequency, Transformer Design, Feedback Resistors Network Design), please refer to Diodes' Application Note of AL1663.

- ✧ AC-CV Power Supply – 3.3V/100mA for driving attached wireless connectivity module. The power supply design is based on AP3988 PSR AC/CV Switcher IC (Refer to the Key Components section on page 12).

AP3988 built-in NPN transistor has fewer component number, smaller size, and lower total cost. The maximum power rating to be capable up to 5.5W.

For the design principles and design examples of AP3988 power supply (e.g. Switching Frequency, Transformer Design, Feedback Resistors Network Design), please refer to Diodes' Application Note of AP3988.

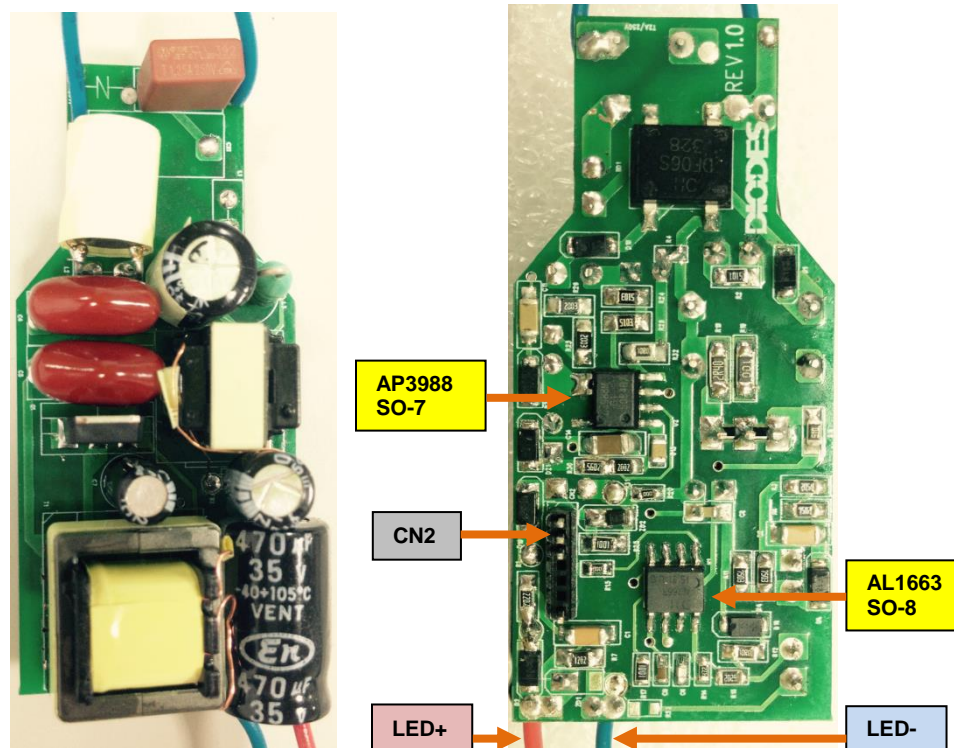


Figure 3 - Power Board (58mmx27mm)

Pin Name	Functions
LED+	Connected to anode of emitter string
LED-	Connected to cathode of emitter string

Output Pin Functions (Connected to Emitter Board)

Pin#	Pin Name	Functions
1	+3.3V	This Pin is attached to the output +3.3V of Power Supply (AP3988). For M56 ZigBee module VDD input.
2	GND	Ground.
3	PWM1	This pin is attached to the APWM of AL1663. Connected to PWM_01 of M56 ZigBee module, for dimming control
7	-	Fixed ZigBee module (No signal)

CN2 Pin Functions (Connected to ZigBee Module)

➤ **Emitter Module Board (EMB) Application Description**

The 1-channel DW EMB (Figure 4) adopts 2,700K CCT warm white emitters, arranged in parallel-serial strings (total of 12 emitter, 3P4S - 3 Parallel and 4 Serial Emitters).

The Forward Voltage Drop (V_F) per emitter, with two 0.5W emitter dies in serial, is around 6.0V and the total V_F per emitter sting is 24.0V (refer to Appendix II Emitter Spec).

The choices of numbers of emitters, emitter structure arrangement, and driving current are based on meeting the required system specification (above 800 lumens for the finished light bulb).

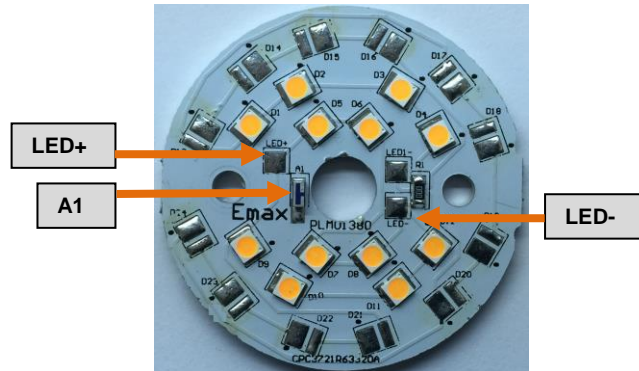


Figure 4 - Emitter Module (Diameter - 46mm)

Pin#	Pin Name	Functions
LED+	LED+	The soldering pad is attached to the common anode of LED (6500K) and LED (2700K) emitter strings.
LED-	2700K LED-	The soldering pad is attached to the cathode of LED (2700K) emitter string.
A1	Antenna	The soldering pad is attached to the Antenna chip.

Output / Input Pin Functions

➤ **M56 ZigBee Module (ZM) Application Description**

For the wireless connectivity, it is enabled by embedding M56 ZigBee Module (Appendix III) inside the 1-ch DW SCL bulb by piggybacking on the other side of the Power board. Embedded ZigBee Light Link (ZLL) in the flash memory, M56 ZigBee module will communicate ZLL commands with a ZLL-capable Gateway Hub.

This ZigBee module board is piggybacked on the reverse side of power board.

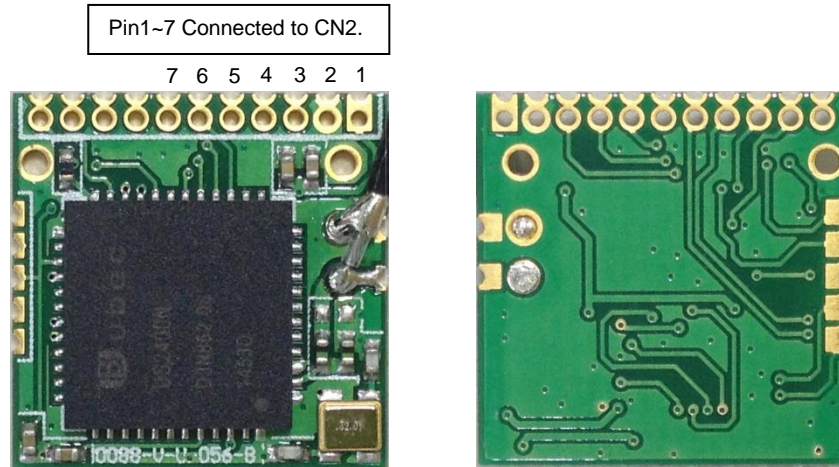


Figure 5 - M56 ZigBee Module (15mm x 15mm)

➤ **Output Assembly Description**

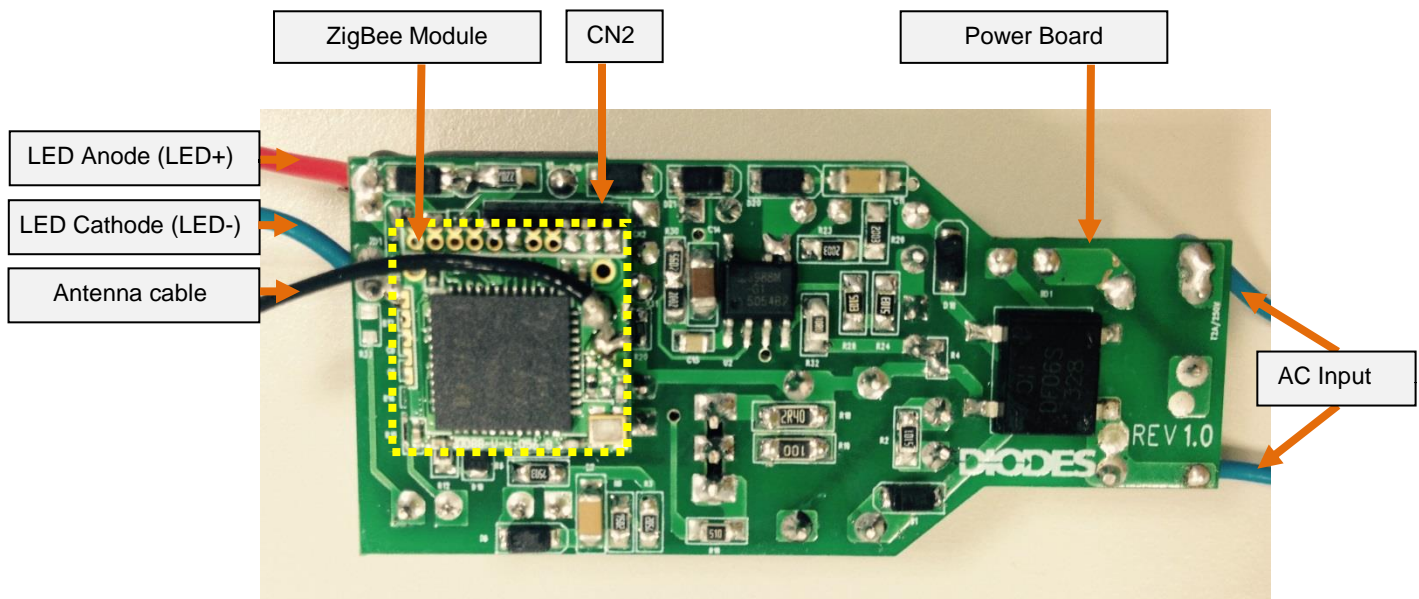


Figure 6 - Power Board + M56 ZigBee board

- ✧ Two wires connected to AC input
- ✧ Two wires for Emitter:
 1. Red wire connected to LED Anode
 2. Blue wire connected to LED Cathode
- ✧ Antenna Cable from M56 ZigBee Module connected to A1 "Antenna Chip" of Emitter board

PERFORMANCE TESTING

The key system performance parameters of 1-ch DW SCL bulb are summarized in Table 1 below.

10W A19 1-Channel Dimmable White Reference Light Bulb			
Item No	Parameter	Condition	Test Result
1	Input Voltage Range	100-240V _{AC} ~ 50/60Hz	
2	Power Factor	> 0.9 Output: 24V/360mA	100V _{AC} : 0.97 230V _{AC} : 0.92
3	Efficiency	Eff > 80%	100V _{AC} : 84% 230V _{AC} : 83%
4	Standby Power	< 0.5Watt (M56 ZigBee module Operating Current is about 35mA)	100V _{AC} /60Hz: 0.23W; 230V _{AC} /50Hz: 0.46W
5	Start-Up Time	< 2 Sec	100 V _{AC} : 1.28 Sec 230 V _{AC} : 1.39 Sec
6	Output Current Ripple (I _{peak-to-peak})	Test Condition Output: 24V/360mA	I _{peak-to-peak} (E-CAP=470uF/35V) 100 V _{AC} /60Hz: 332mA 230 V _{AC} /50Hz: 330mA
7	THD (Total Harmonic Distortion)	Test Condition Output: 24V/360mA	100V _{AC} /60Hz: 12% 230V _{AC} /50Hz: 22%
8	Temperature of IC	< 105°C	AP3988: 40°C (Open Cover) AL1663: 48°C (Open Cover)
9	Line Regulation	<10%	I _{out} : 350~380mA (7.9%)

Table 1 - System Performance Testing of 1-ch DW SCL Bulb

SYSTEM DESIGN CONSIDERATIONS AND TRADE-OFFS

When design a production worthy SCL bulb, the system designers have many considerations:

- 1) Input Voltage Range
- 2) Power Factor (PF)
- 3) Standby Power
- 4) Start-Up Time Sequence

✧ Input Voltage Range Design Considerations:

While 1-ch DW SCL bulbs are designed for full range voltage input, system designs could optimize components for single voltage application (e.g. 120V or 230V). For example, more cost-effective components could be used for 120V-only SCL bulb, including:

- 1) Bridge Diode: BD1 (DF06S, see Figure 2.a on Page 3)
- 2) Switching Device MosFET : Q1 (see Figure 2.a on Page 3)
- 3) Output rectifier Diodes: D2 and D19 (see Figure 2.a and 2.b on Page 3)

✧ Power Factor (PF) Design Considerations:

Per Energy Star Compliance requirement, the Power Factor (PF) for over 5W light bulb needs to be over 0.7. The AL1663 have built-in Active Power Factor Correction circuitry to achieve desired PF over 0.7. AP3988 converter as well as AL1663 LED driver parallel co-exist in the AC input side. As AP3988 is a standard Flyback topology, a bulk capacitor is used at input filter circuit, that will impact to power factor of bulb. The D1 and D18 (see Figure 2.a and 2.b on Page 3) separated the inputs of two converters. The bulb PF will achieve requirement (>0.7).

✧ Standby Power Design Considerations:

While fixed-CCT on-off LED light bulb will have no power consumption when turned off at standby mode, a SCL bulb consumes non-trivial standby power due to constant-on for wireless module connectivity. To save energy consumed during the standby mode, it recommends to stay within 0.5W when in the standby mode for the entire SCL bulb.

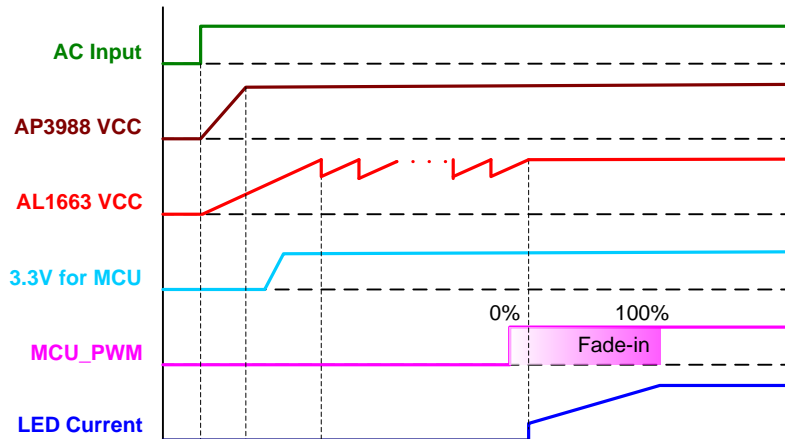
In the 1-ch DW SCL bulb design, the standby power consumption is measured with estimated breakdown as follows:

- | | |
|--------------------------------|---|
| 1) AL1663 LED Driver - | 65 mW (When AL1663 V_{APWM} is lower than 0.3V, the output current is zero) |
| 2) Start-up Resistor Circuit - | 125 mW (R24 and R28 (see Figure 2.b on Page 3) are 330K/1206 resistors) |
| 3) ZigBee Module - | 165 mW (UBEC M56 ZigBee Module standby current is 35mA) |
| 4) Others Power Loss- | 30 mW (AP3988 converter, Snubber and Switching Loss) |

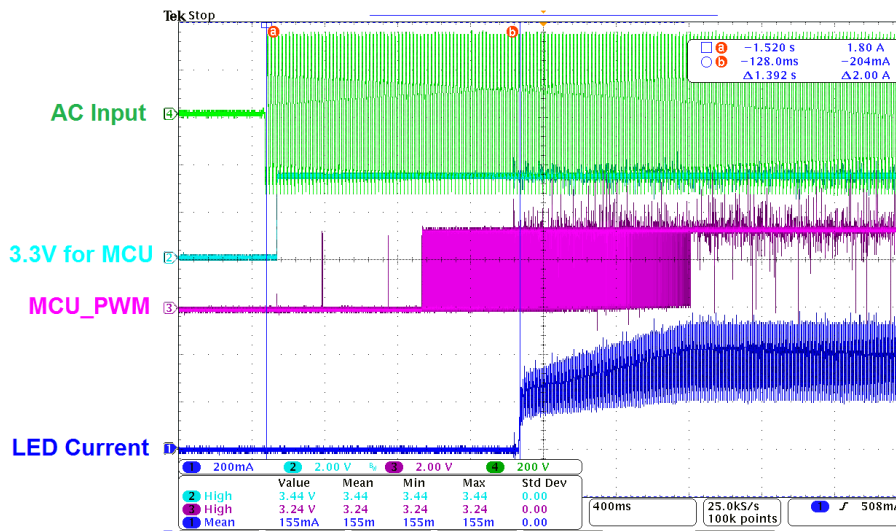
✧ Start-Up Time Sequence Design Considerations:

In the 1-ch DW SCL bulb design, the MCU and LED driver turn-on-time impact the SCL bulb startup performance. MCU could be given priority start, and controlling LED driver startup programming. SCL bulb will achieve high startup performance (e.g. Turn-on no blinking, lamp fade in function, etc.).

For low-cost implementation, a simple start-up circuitry is adopted. In the 1-ch DW bulbs have different start-up resistors, to achieve MCU and LED driver startup sequence. Provide a better start-up performance.



1-ch DW SCL Bulb Startup Timing Sequence

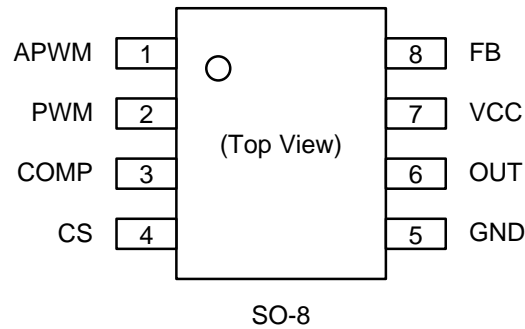


1-ch DW SCL Bulb Startup Test Waveform

KEY COMPONENTS

➤ **AL1663 - LED Driver Controller**

AL1663 IC PIN OUT ASSIGNMENT

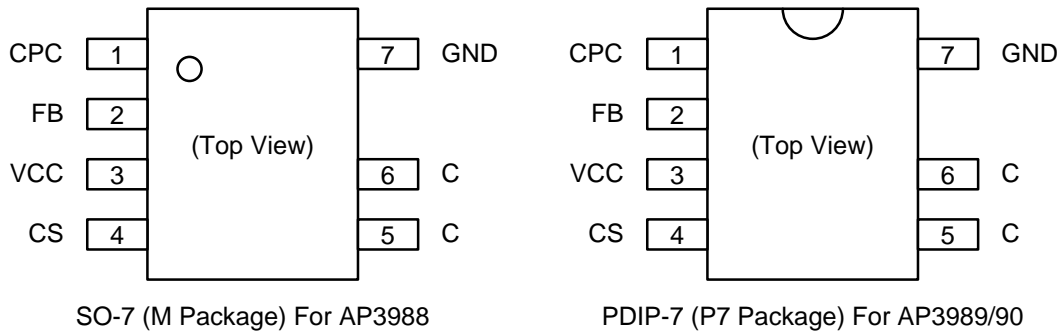


- Primary side control for output current regulation without opto-coupler
- Valley on function to achieve low switching loss
- Low Start-up current
- High PF and low THD
- High efficiency
- Support PWM dimming and analog dimming
- Tight LED current
- Right LED open voltage
- Internal protections
 - Under Voltage Lock Out (UVLO)
 - Output Open Protection
 - Output Short Protection
 - Over Current Protection
 - Over Temperature Protection
- Low system cost
- Package: SO-8
- Totally Lead-Free & Fully RoHS compliant
- Halogen and Antimony Free. "Green" Device
- AL1663 Pin Descriptions:

Pin Number	Pin Name	Descriptions
1	APWM	Analog dimming input pin (or PWM signal input pin in true PWM dimming mode)
2	PWM	PWM signal input pin in PWM to DC dimming mode
3	COMP	Loop compensation pin
4	CS	Primary current sensing
5	GND	Ground
6	Out	Gate driver output
7	VCC	Supply voltage of gate driver and control circuits of the IC
8	FB	The feedback voltage sensing from the auxiliary winding

➤ AP3988/89/90 - AC/CV Controller

AP3988/89/90 IC PIN OUT ASSIGNMENT



- Primary Side control for Eliminating Opto-coupler and Secondary CV/CC Control Circuitry
- Built-In NPN Transistor with $700V_{CBO}$
- Low Start-up current: 0.2uA (Typ.)
- Internal Output Cable Voltage Drop Compensation
- Hiccup Function to Improve Short Circuit Protection
- Better Over Voltage Protection
- Better Over Temperature Protection
- Low Total Cost Solution
- Output Power Range:
 - AP3988 for 5.5W Adapter
 - AP3989 for 8W Adapter
 - AP3990 for 12W Adapter
- Totally Lead-Free & Fully RoHS compliant
- Halogen and Antimony Free. "Green" Device
- AP3988/89/90 Pin Descriptions:

Pin Number	Pin Name	Descriptions
1	CPC	This pin is connected a capacitor to GND for output cable compensation.
2	FB	The voltage feedback from auxiliary winding
3	VCC	This pin receives rectified voltage from the auxiliary winding of the transformer
4	CS	Current sense from primary side of transformer
5, 6	C	The pin is connected with an internal power BJT's collector
7	GND	The pin is the signal reference ground

Bill of Material – Power Board

#	Name	Qty	Part No.	Manufacturer	Description
1	BD1	1	DF06S	Diodes,Inc.	600V/1A bridge diode
2	CX1	1	0.047uF/275Vac		EMI capacitor filter
3	F1	1	T1.5A-T250V		Fuse
4	L1	1	1.5mH/6Φ,I core (0.12mm*240ts)		EMI inductor filter
5	VDR1	1	471K		Reserved for Future Use EMC Part.
AC-CC, AL1663 section					
6	C1	1	470pF/1KV/1206		Snubber capacitor
7	C2	1	1nF/1KV/1206		Snubber capacitor
8	C6	1	10pF/16V/0603		Capacitive filter
9	C8	1	0.1uF/50V/0805		Capacitive filter
10	C9	1	1uF/16V/0603		Comp capacitor
11	C3	1	470uF/35V/10*16		Output capacitor
12	C5	1	68nF/400V,MEF		Capacitor filter
13	C4	1	22nF/400V,MEF		Capacitor filter
14	C7	1	10uF/50V,5*11		Startup and VCC hold-up capacitor
15	D1,D6,D10	3	DFLR1600-7,POWERDI® 123	Diodes,Inc.	1.0A surface mount glass passivated rectifier
16	D2	1	SBR1U200P1-7,POWERDI® 123 APD240KDTR-G1, SOD-123	Diodes,Inc.	Surface mount super barrier rectifier
17	L2	1	3.3mH/8Φ,I core (0.17mm*300ts)		Inductor filter
18	Q1	1	4A/600V,N-Mosfet DMG4N65CT,TO220-3 DMG4N65CTI,ITO220-AB	Diodes,Inc.	N-channel enhancement mode MosFET
19	R2,R5	2	5.1KR/0805		By pass resistor
20	R15	1	0R/0603		Jumper
21	R33	1	0R/0603		Jumper
22	R1	1	22R/0805		Snubber resistor
23	R7	1	12KR/1206		Pre-load
24	R3,R8	2	75KR/1206		Snubber resistor
25	R17	1	1KR/0603		Comp resistor
26	R6,R11	2	750KR/1206		Startup resistor
27	R13	1	62KR/0603		FB resistor
28	R14	1	4.7KR/0603		FB resistor
29	R18	1	3R/1206		CS resistor
30	R19	1	3R/1206		CS resistor
31	R12	1	10R/0805		Snubber resistor
32	R16	1	51R/0805		Gate driver resistor
33	T1	1	EE-16	Emax,Inc.	Transformer
34	U1	1	AL1663,SO-8	Diodes,Inc.	Offline, single stage Flyback high PF controller for LED driver
35	ZD1	1	DFLZ36,1W,POWERDI® 123	Diodes,Inc.	1.0W surface mount power Zener diode
AC-CV, AP3988 section					
36	C11	1	1nF/1KV/1206		Snubber capacitor
37	C14	1	4.7uF/50V,1206		Startup and VCC hold-up capacitor
38	C15	1	10nF/16V		CPC capacitor
39	C12	1	1uF/400V,8*10		Capacitor filter
40	C13	1	220uF/16,6*11		Output capacitor
41	C16	1	10pF/16V/0603		Capacitive filter
42	D18,D20,D21	3	DFLR1600-7	Diodes,Inc.	1.0A surface mount glass passivated rectifier

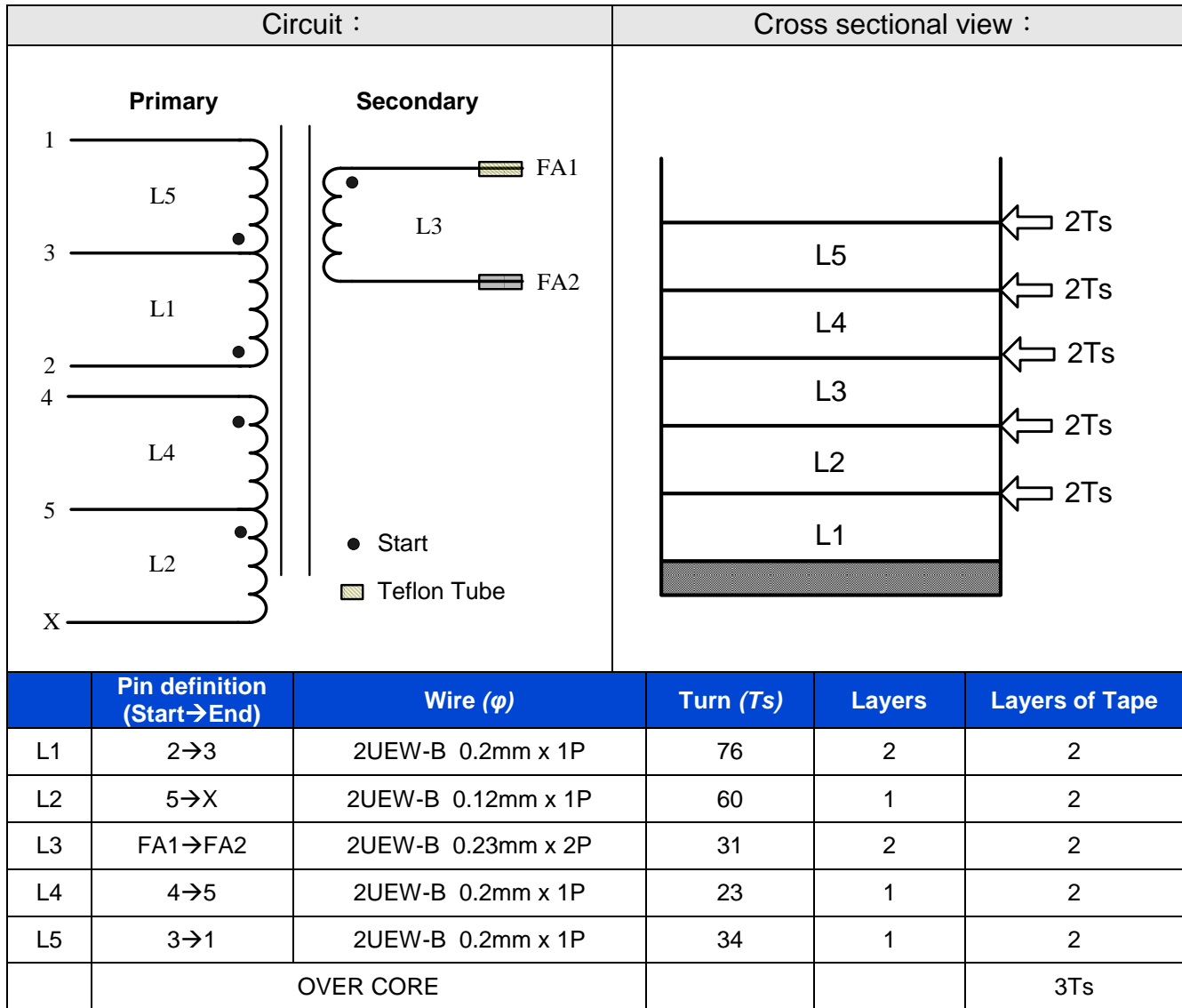
43	D19	1	DFLS140-7,POWERDI® 123	Diodes,Inc.	1.0A/60V surface mount Schottky barrier rectifier
44	L3	1	470uH		Inductor filter
45	R4,R20	2	0R/0603		Jumper
46	R25	1	1KR/0805		Pre-load
47	R23,R26	2	75KR/1206		Snubber resistor
48	R24,R28	2	510KR/1206		Startup resistor
49	R30	1	51KR/0603		FB resistor
50	R31	1	20KR/0603		FB resistor
51	R32	1	5R/1206		CS resistor
52	T2	1	EE-10	Emax,Inc.	Transformer
53	U2	1	AP3988,SO-7	Diodes,Inc.	Primary side power switcher for off-line SMPS
54	ZD2	1	BZT52C3V9,SOD123	Diodes,Inc.	Surface mount Zener diode
55	CN2	1	1.27mm,7pin	CviLux, Inc.	Connector
Wireless module_ZigBee					
56	M56	1	15*15mm,105°C	UBEC	2.4G RF ZigBee module
57	ANT	1	45mm	UBEC	Antenna

Bill of Material – Emitter Board

#	Name	Qty	Part No.	Manufacturer	Description
58	D1~D12	12	LTW3030DZL27	LITEON, Inc.	LTW-3030DZL Emitter Series
59	R1	1	0R/1206		Jumper
60	A1	1	ANT3216LL11R	UBEC	Antenna chip

APPENDIX I - T1, EE-16 Transformer SPEC (AL1663 section)

A. Transformer Pin & Wire Description:

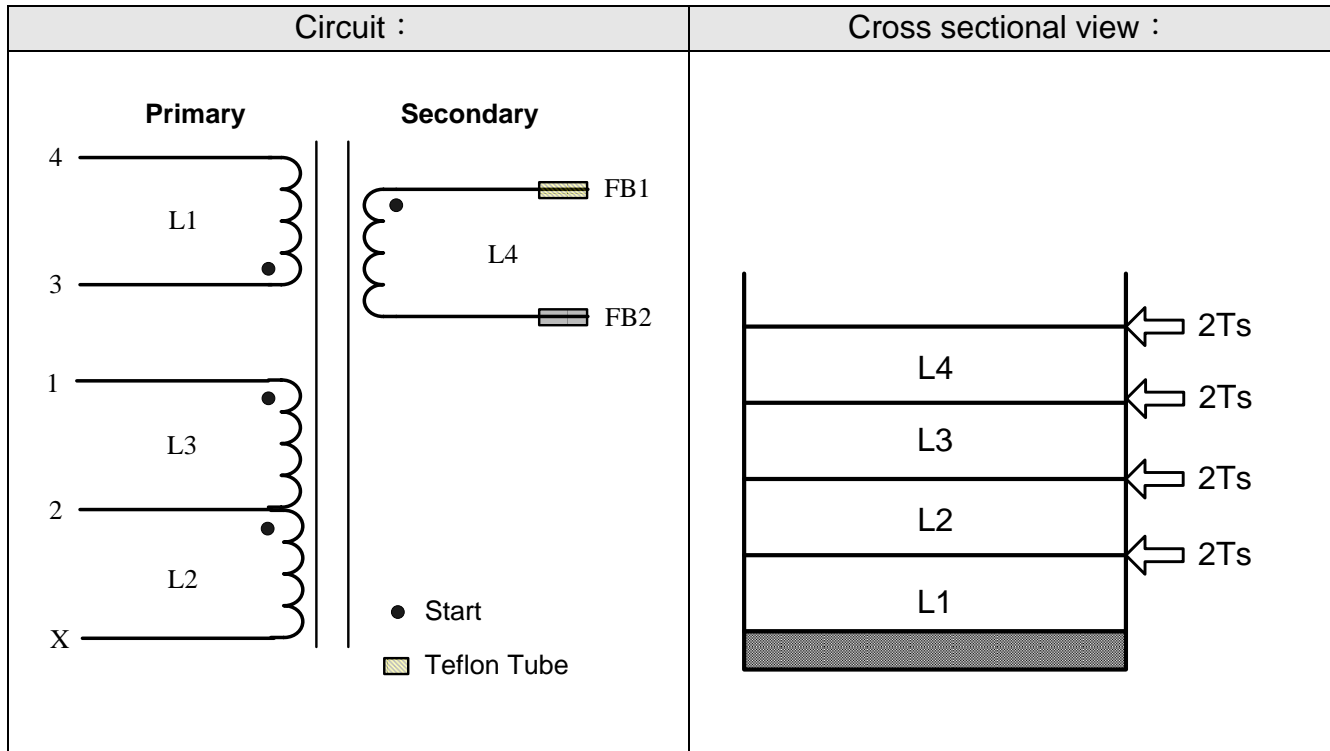


B. Electrical Characteristic:

#	Test Item	Winding	Pin	Rating	Unit	Tolerance	Remark
2.1	Inductance	L1+L5	2 → 1	1	mH	+/-5%	@ 100KHz / 1V

T2, EE-10 Transformer SPEC (AP3988 section)

A. Transformer Pin & Wire Description:



	Pin definition (Start→End)	Wire (ϕ)	Turn (Ts)	Layers	Layers of Tape
L1	3→4	2UEW-B 0.13mm x 1P	160	4	2
L2	2→X	2UEW-B 0.13mm x 1P	42	1	2
L3	1→2	2UEW-B 0.13mm x 1P	35	1	2
L4	FB1→FB2	2UEW-B 0.19mm x 1P	10	1	2
	OVER CORE				3

B. Electrical Characteristic:

#	Test Item	Winding	Pin	Rating	Unit	Tolerance	Remark
2.1	Inductance	L1	3 → 4	2	mH	+/-5%	@ 100KHz / 1V

APPENDIX II - LITE-ON OPTO EMITTER SPEC

 ✧ **LTW-3030DZL Emitter Series (LTW-3030DZL27)**

 ✧ **Typical Performance**

Parameter	Symbol	Values								Unit	Test Condition
		Typ.	2700	3000	3500	4000	5000	5700	6500		
Correlated Color Temperature	CCT	Typ.	2700	3000	3500	4000	5000	5700	6500	'K	
Chromaticity Coordinates	x	Typ.	0.458	0.434	0.408	0.382	0.345	0.329	0.312	-	I _F = 150mA
	y	Typ.	0.410	0.403	0.392	0.380	0.355	0.342	0.328		
Luminous Flux ¹	Φ _v	Min	100	100	100	104	104	104	104	lm	
		Typ.	112	114	116	120	124	124	122		
		Max.	130	130	130	135	135	135	135		
Optical Efficiency	η _{opt}	Typ.	119	121	123	127	131	131	129	lm/W	
Color Rendering Index	CRI	Min.	80						-		
Viewing Angle	2θ _{1/2}	Typ.	120						deg		
Forward Voltage	V _F	Min	5.8						V		
		Typ.	6.3								
		Max.	6.6								
Thermal Resistance	R _{js}	Typ.	11						°C/W		

Notes

- Luminous flux is the total luminous flux output as measured with an integrating sphere.
- I_v (flux Φ_v) classification code is marked on each packing bag.
- The chromaticity coordinates (x, y) is derived from the 1931 CIE chromaticity diagram.
- Caution in ESD:
Static Electricity and surge damages the LED. It is recommended using a wrist band or anti-electrostatic glove when handling the LED. All devices, equipment and machinery must be properly grounded.
- CAS140B is the test standard for the chromaticity coordinates (x, y) & Φ_v.
- The chromaticity coordinates (x, y) guarantee should be added +/- 0.01 tolerance
- CRI measurement allowance is ±5, R9>0

Contact LiteON Opto (光寶科技)
Web Site: www.liteon.com/opto

Contact: Eddie Su (Eddie.Su@liteon.com)

AN203 1-Channel DW SCL Bulb
Reference Design
Document number: Rev 1.0

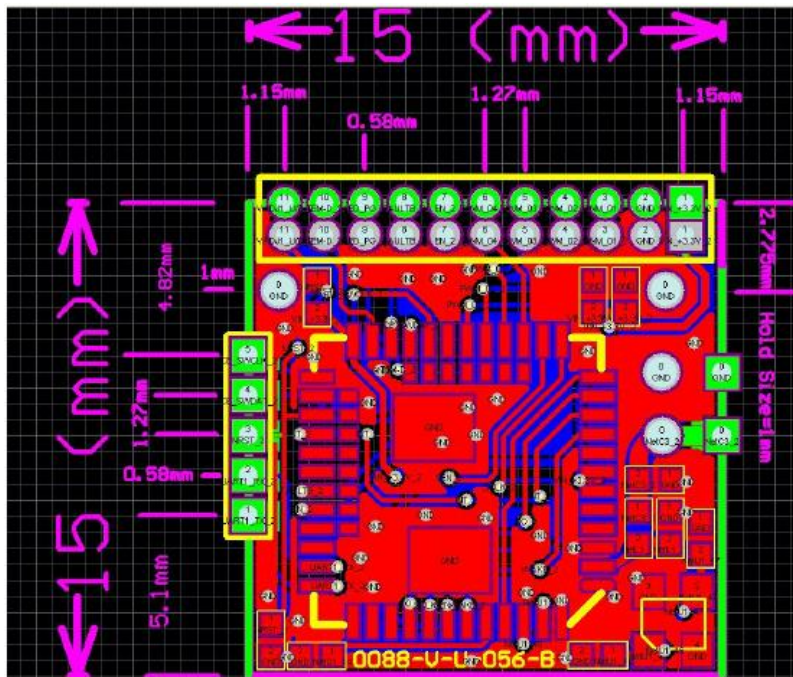
APPENDIX III - ZIGBEE MODULE M56 (UBEC)

◇ **Introduction and Specification**

- M56 Module: 2.4GHz RF module which integrates UBEC's low power 2.4GHz IEEE802.15. 4 RFIC UZ2400D
- MCU: ARM M0-Cortex Low Power Design
- Voltage Input: 2.7V ~ 3.6V
- TX Current (@3.3V, 32MHz): 37.09mA
- RX Current (@3.3V, 32MHz): 33.76mA
- Temperature Range: -20°C ~ 105°C
- Dimension: 15mm x 15mm

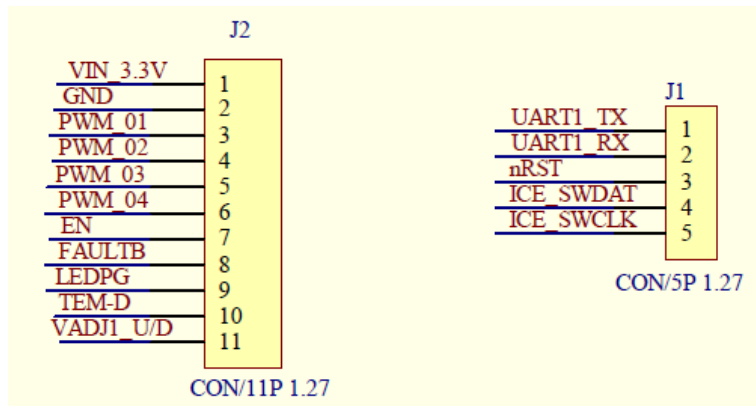
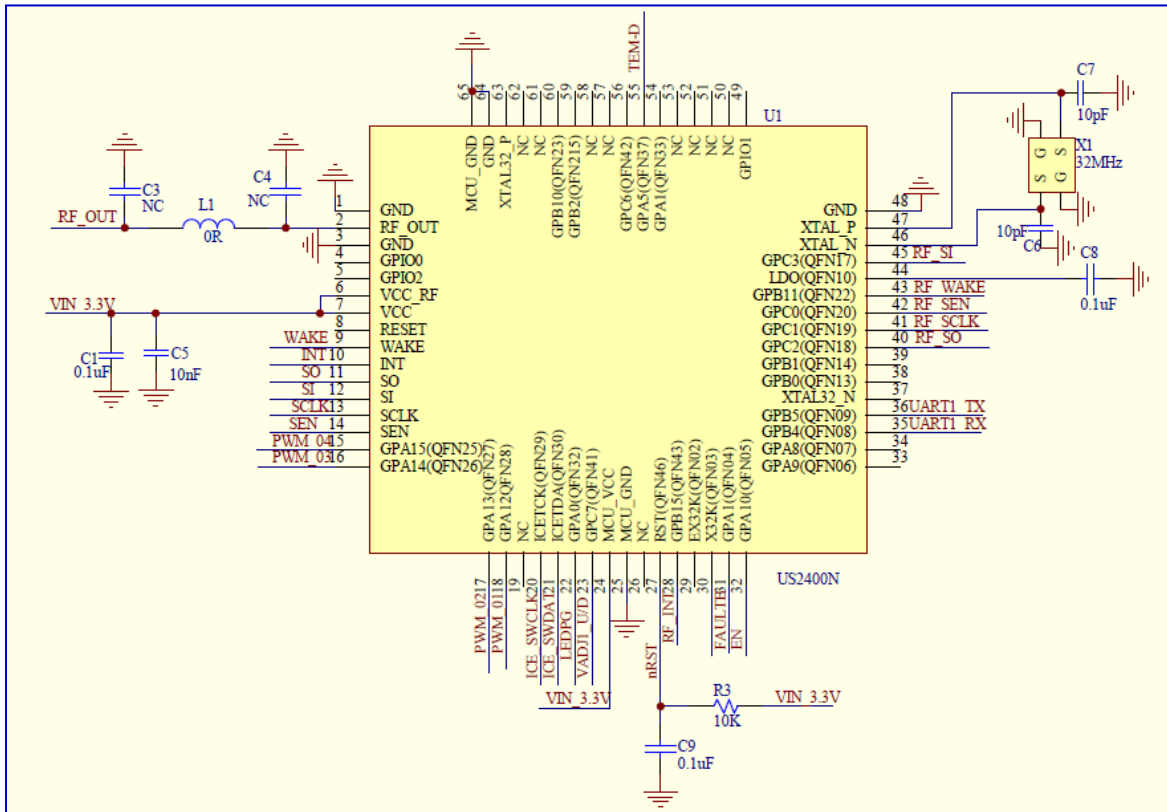
Pin#	Pin Name	Functions
1	VDD	Connected to power board +3.3V (CV output of AP3988)
2	GND	Connected to power board ground
3	PWM_01	Connected to power board APWM (U1_AL1663)
4	PWM_02	Not Available
5	PWM_03	Not Available
6	PWM_04	Not Available
7	EN	Not Available

Output Pin Functions (Connected to power board)



M56 ZigBee Module Outline Drawing

◇ Schematic and Connection Definition



Pin#	Pin Name	Functions	Remark
1	TX	UART1 data transmitter output pin	Connected to GPB5
2	RX	UART1 data receiver input pin	Connected to GPB4
3	NRST	RST	
4	SWDAT	ICE_SWDAT	
5	SWCLK	ICE_SWCLK	

J1 - Serial Wire Debug Port

Pin#	Pin Name	Functions	Remarks
1	VDD	+3.3V	
2	GND	Ground	
3	PWM_01	PWM 0 channel 0 output, GPIO, (PA. 12)	PWM Dimming
4	PWM_02	PWM 0 channel 1 output, GPIO, (PA. 13)	
5	PWM_03	PWM 0 channel 2 output, GPIO, (PA. 14)	
6	PWM_04	PWM 0 channel 3 output, GPIO, (PA. 15)	
7	EN	GPIO, I ² C 1 SDA, (PA. 10)	
8	FAULTB	GPIO, I ² C 1 SCL, (PA. 11)	
9	LEDPG	GPIO, ADC, (PA. 0)	
10	TEM-D	Not Available	
11	VADJI I/D	GPIO, DAC (PC. 7)	

J2 - Application Usage

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