AP3983C (PSR Switcher) + AL1791+AL1793 (1-Channel and 3-Channel Linear CCR LED Drivers)

4-Channel White+RGB Tunable Color Smart Connected Light Bulb Reference Design

Jason Lo, Lighting Business Unit, Diodes Inc.

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 Conversion
- LED Driver
- Emitter Module
- Wireless MCU Connectivity

This application note describes the complete reference design of an A19 10W ZigBee-Enabled 4-channel White+RGB SCL (4-ch W+RGB SCL) bulb, capable of generating the more than 16 million colors application and delivers 800 lumens white lighting requirement. 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-UB-LO-4WRGB
- 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: 1,800K to 8,000K
- Color Range: More than 16 million colors
- CRI: 80Ra
- Wireless: ZigBee Module
- Dimension (L*D): 113mm x 62mm

FUNCTIONAL BLOCK DIAGRAM

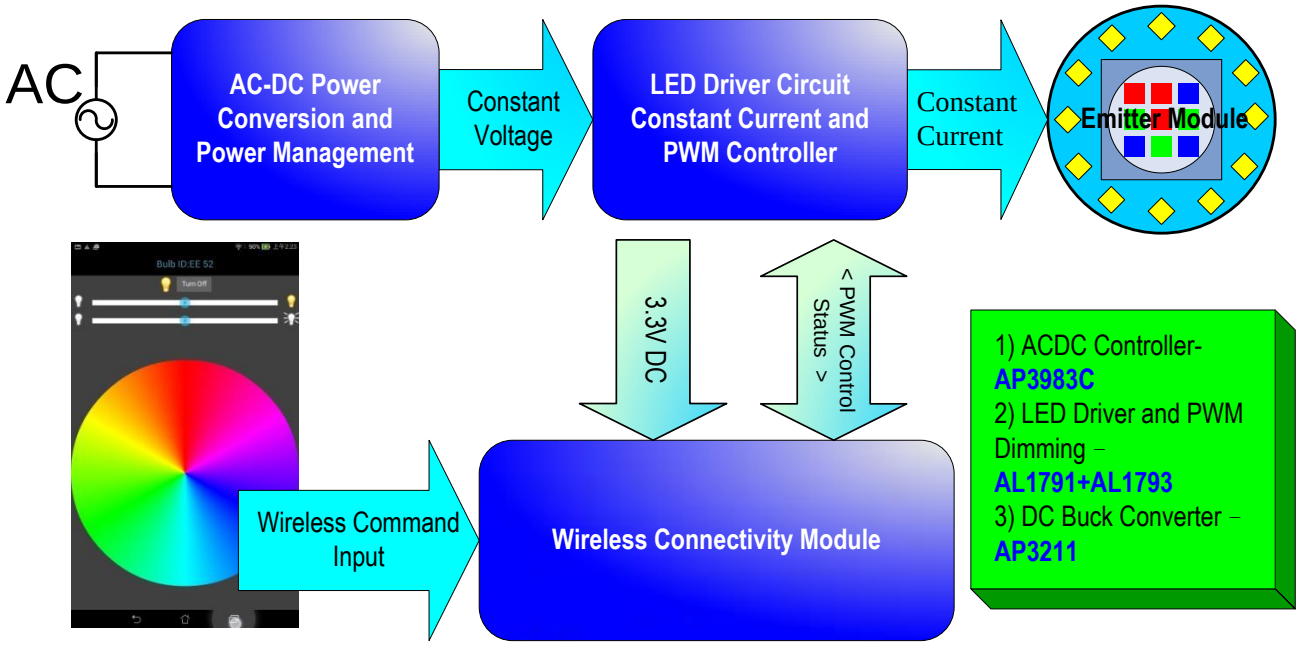


Figure 1 - Functional Block Diagram for W+RGB Smart Connected Light Bulb

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

1) AC-DC Power Conversion - It converts AC input to one or multiple desired output DC Constant Voltages (CV). For a SCL bulb, two or more CVs might be required to better support various DC power requirements from Emitters and Wireless Connectivity Module.
2) LED Driver - Taking CV inputs to relevant LED driver channels, the LED driver circuitry generates one or more Constant Current (CC) to drive associated LED emitters.
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 WiFi/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(s) from Wireless Connectivity Module, emitters on the LED Emitter Module are properly mixed to generate desired light output - either brightness adjustment, Corellated Color Temperature (CCT) tuning, or color mixing.

COMPLETE DESIGN SCHEMATICS

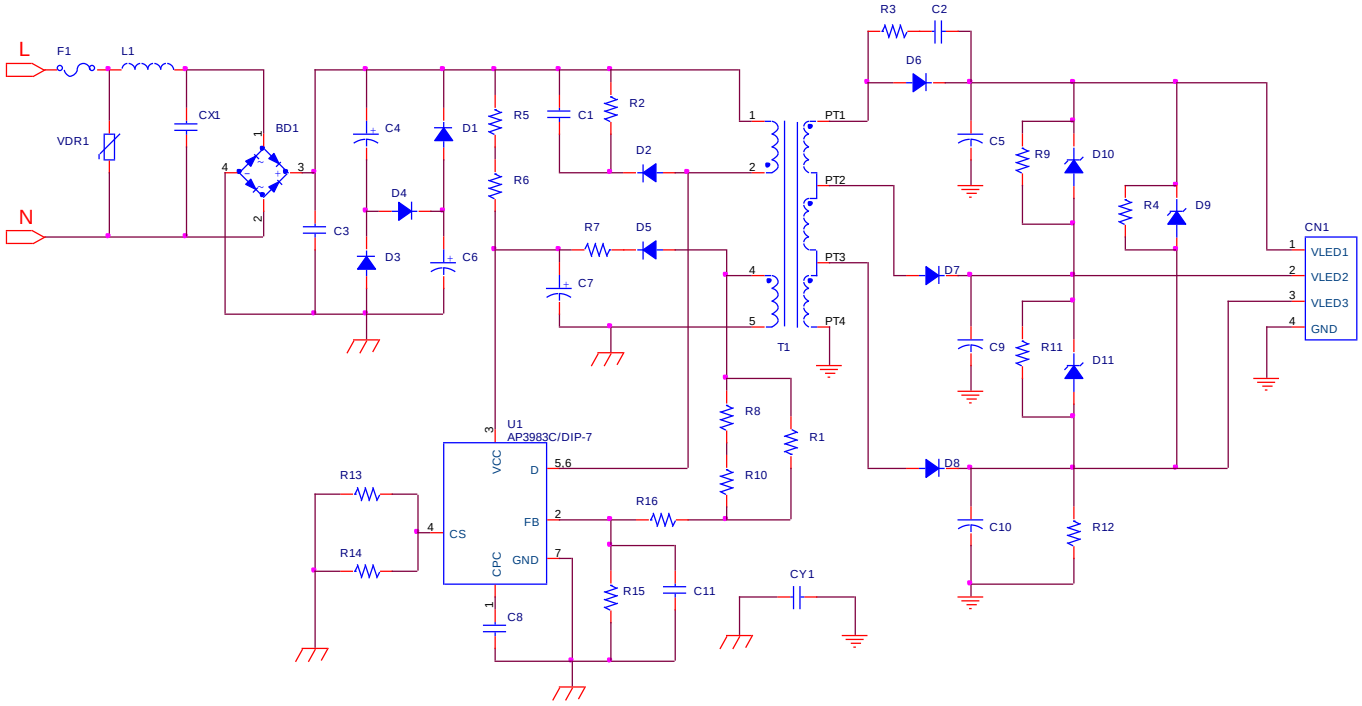


Figure 2.a - AP3983C Power Board Schematics

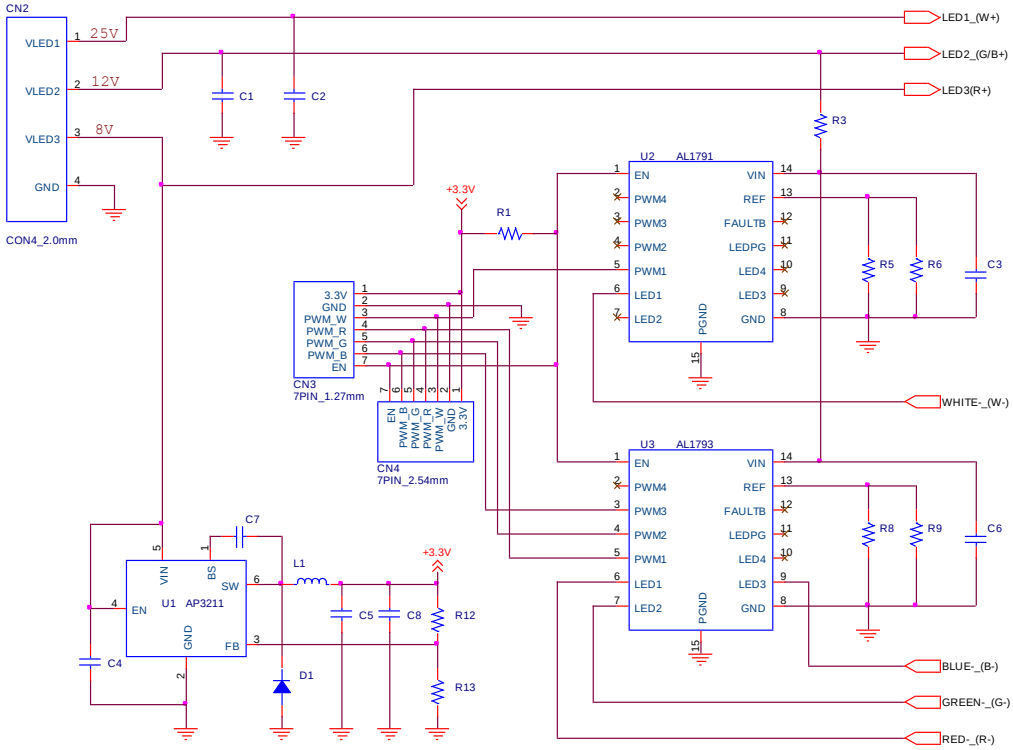


Figure 2.b - LED Driver - AL1791+AL1793+M56 ZigBee Module Schematics

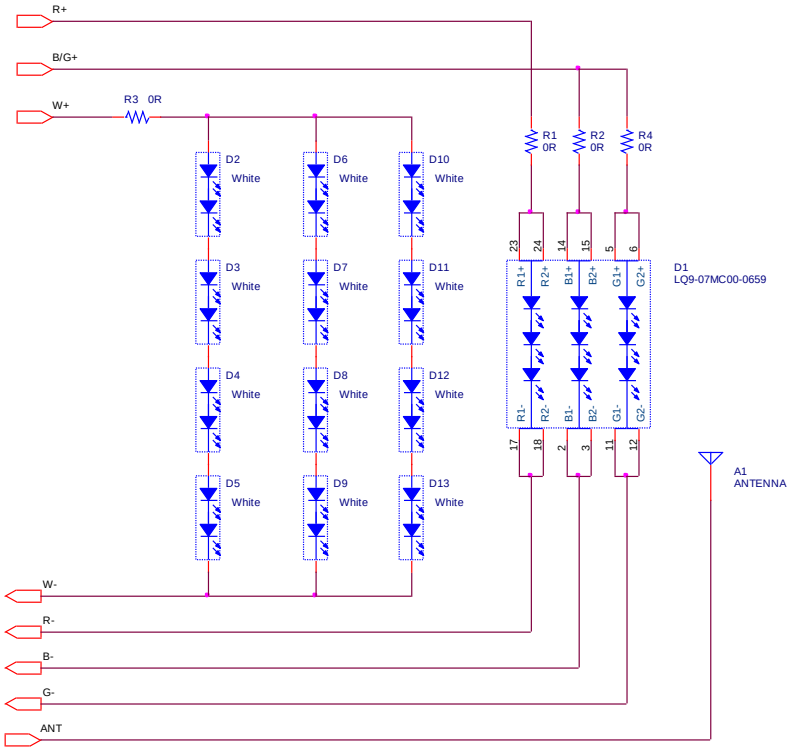


Figure 2.c - LED Emitter Module Schematics

APPLICATION DESCRIPTION

➢ Power Board (PB) Application Description

The PB design (Figure 3) is based on AP3983C PSR AC/DC Switcher IC (integrated MOSFET switch) (refer to the Key Component Section) to be capable of power rating up to 12W. In the AL179x family, for 350mA channel current, the maximum LEDs (voltage headroom) is 0.4V. To support four emitter strings with adequate voltage headroom to Forward Voltage Drop (VF) and attached MCU power, the PB outputs three CVs:

- ✧ VLED1 - 25V for driving White LED emitter string.
- ✧ VLED2 - 12V for driving Green & Blue LED emitter strings, and supplying power source to LED driver regulators (U2_AL1791 and U3_AL1793, Refer to the Key Component Section).
- ✧ VLED3 - 8V for driving Red LED emitter string, and supplied to the asynchronous DC-DC buck converter (AP3211) generate a constant voltage (3.3V) to drive wireless connectivity module.

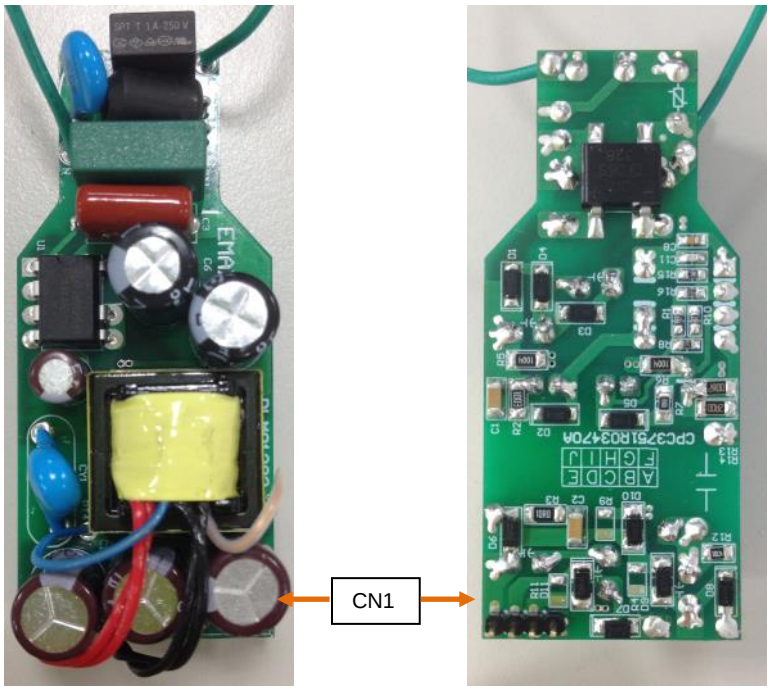


Figure 3 - AP3983C Power Board (58mmx27mm)

For the design principles and design examples of AP3983C power board (e.g. Swithcing Frequency, Transformer Design, Feedback Resistors Nework Design), please refer to Diodes' Application Note of AP3983.

Pin#	Pin Name	Functions
1	VLED1	25V output, for driving White emitter string
2	VLED2	12V output, for driving Green and Blue LED Emitter strings and supplying LED drivers of U2_AL1791 and U3_AL1793
3	VLED3	8V output, for deriving Red LED Emitter string and supplying to Wireless MCU power source
4	GND	Ground
Note_ Pin#1 is the one close to the edge of the PCB (long side).		

CN1 - Pin Functions (Connected to LED Driver Board)

➢ Emitter Module Board (EMB) Application Description

The 4-ch W+RGB EMB (Figure 4) adopt two types of Emitters. One of RGB silicone emitter at the centers of PCB. Another type of white emitter is distributed at the circumference of emitter board, as follows:

- ✧ 2,700K CCT White Emitters (total of 12 Emitters 4S3P), CCT_{warm} (refer to Appendix II - LITEON OPTO - LTW-3030DZL Emitter Series)
- ✧ LQ9 – 9-die RGB silicone emitter – Red (3 dies in serial), Green (3 dies in serial) and Blue (3 dies in serial) in parallel strings. (refer to Appendix II - LED Engin LQ9 Emitter).

The Forward Voltage Drop (V_F) per white emitter, with two 0.5W emitter dies in serial, is around 6.0V and the total V_F per emitter sting is 24.0V. The cathodes of emitter strings are attached to LED1 pin of AL1791. 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).

In the RGB silcone emitter, the V_F of each strings are as follows:

- ✧ The V_F of red emitters is 6.7V for 350mA maximum channel current.
- ✧ The V_F of green emitters is 10.1V for 350mA maximum channel current.
- ✧ The V_F of blue emitters is 9.1V for 350mA maximum channel current.

Figure 4 - 4-Ch W+RGB Emitter Module (Diameter - 46mm)

Pin Name	Functions
W+	The soldering pad is attached to the anode of White emitter string.
B/G+	The soldering pad is attached to the common anodes of Green and Blue emitter strings.
R+	The soldering pad is attached to the anode of Red emitter string.
W-	The soldering pad is attached to the cathode of White emitter string.
R-	The soldering pad is attached to the cathode of Red emitter string.
G-	The soldering pad is attached to the cathode of Green emitter string.
B-	The soldering pad is attached to the cathode of Blue emitter string.
A1	The soldering pad is attached to the antenna chip

Output / Input Pin Functions

➢ LED Driver Board (LDB) Application Description

In this 4-Ch LDB of W+RGB SCL bulb design, have one asynchronous DC-DC buck converter to supplying wireless connectivity module and two sets device to control White, Red, Green and Blue 4-channels LED current.

- ✧ U1_AP3211 is a asynchronous DC-DC buck converter. The required constant voltage to drive wireless module (3.3V) is generated from this converter with input from VLED3 (8V).
- ✧ U2_AL1791 is for white LED driver, the REF (reference current setting resistor) is 16.5KΩ (R5_33KΩ and R6_33KΩ two resistors parallel, in Figure 2.b) to regulate channel current around 350mA for AL1791 LED1.
- ✧ U3_AL1793 is for RGB LED strings driver, the REF is 8.57KΩ (R8_20KΩ and R9_15KΩ two resistors parallel, in Figure 2.b) to regulate channels current around 350mA for AL1793 LED1_Red, LED2_Green and LED3_Blue.

The LED input power for each fixed CCT emitter strings is around 8.4W (24V*350mA). By applying suitable PWM signal patterns to control white and RGB emitter strings, The CCT tuning ranging from 1,800K to 8,000K can be achieved and support 800lm lighting requirement.

That also capable of generating more than 16 million colors by applying suitable PWM signal patterns to control RGB emitter strings.

Note that an wireless chip antenna (A1) is placed on the EMB for wireless connectivity.

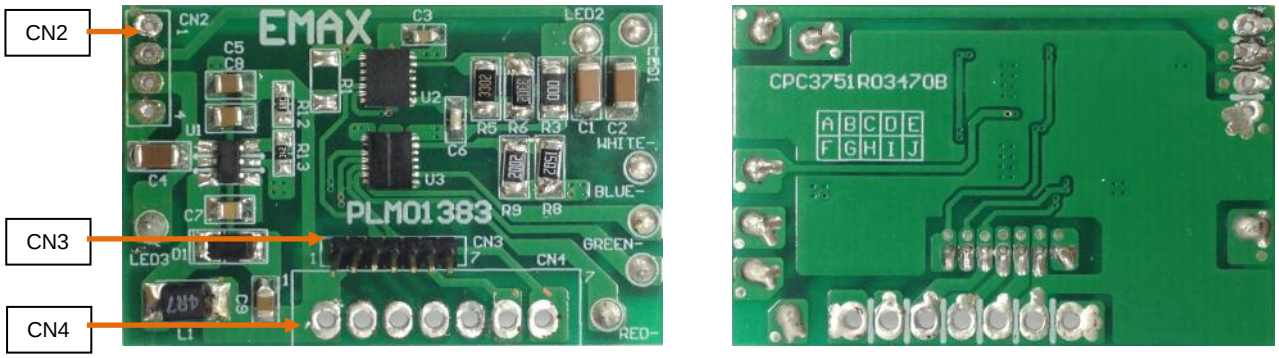


Figure 5 - LED Driver Module (38mmx24mm)

The LED current is expressed as below:

For AL1791	$ILED1 = 4000 \times \frac{VREF}{RSET}$
For AL1793	$ILED1 = 2000 \times \frac{VREF}{RSET}$ $ILED2 = 2000 \times \frac{VREF}{RSET}$ $ILED3 = 2000 \times \frac{VREF}{RSET}$
Where VREF=1.5V nominally for all devices	

Pin#	Pin Name	Functions
1	VLED1	25V input, for driving white emitter string
2	VLED2	12V input, for driving Green and Blue emitter strings and supplying to LED drivers (U2_AL1791 and U3_AL1793)
3	VLED3	8V input, for deriving Red emitter and supplying to converter (AP3211). The converter output (3.3V) is supplying Wireless MCU
4	GND	Ground

CN2 – Pin Functions (Connected to Power Board)

Pin#	Pin Name	Functions
1	3.3V	This pin is attached to the output 3.3V of converter. For M56 ZigBee module VDD input
2	GND	Ground
3	PWM1	This pin is attached to the PWM1 of U2_AL1791. Connected to PWM_01 of M56 ZigBee Module for controlling white emitter
4	PWM2	This pin is attached to the PWM1 of U3_AL1793. Connected to PWM_02 of M56 ZigBee Module for controlling Red emitter
5	PWM3	This pin is attached to the PWM2 of U3_AL1793. Connected to PWM_03 of M56 ZigBee Module for controlling Green emitter
6	PWM4	This pin is attached to the PWM3 of U3_AL1793. Connected to PWM_04 of M56 ZigBee Module for controlling Blue emitter
7	EN	This pin is attached to the EN of U2_AL1791 and U3_AL1793. Connected to interface pin of M56 ZigBee to control on/off function of U2 and U3.
Note_ CN3 – Connected to ZigBee Module CN4 – For Customer Development Kit “CDK”		

CN3/CN4- Pin Functions (Connected to ZigBee Module)

Pin Name	Functions
LED1	25V for driving white emitter string
LED2	12V for driving Green and Blue emitter strings
LED3	8V for driving Red emitter string
WHITE-	This soldering pad is attached to LED1 pin of U2_AL1791. Connected to cathode terminal of white emitter string.
RED-	This soldering pad is attached to LED1 pin of U3_AL1793. Connected to cathode terminal of Red emitter string.
GREEN-	This soldering pad is attached to LED2 pin of U3_AL1793. Connected to cathode terminal of Green emitter string.
BLUE-	This soldering pad is attached to LED3 pin of U3_AL1793. Connected to cathode terminal of Blue emitter string.

Output / Input Pin Functions (Connected LED Emitter Board)

➢ M56 Zigbee Module (ZM) Application Description

For the wireless connectivity, it is enabled by embedding M56 ZigBee Module (Appendix III) inside the 4-ch W+RGB SCL bulb by piggybacking on the other side of the LED driver 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 piggybacking on the LED driver board on the side opposite to the Power Board.

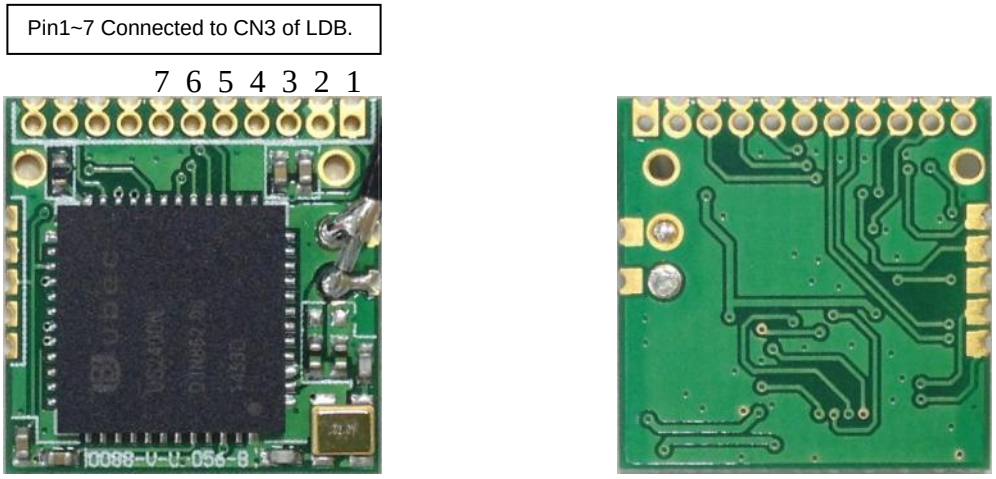


Figure 6 - M56 ZigBee Module (15mm x 15mm)

➢ **Output Assembly Description**

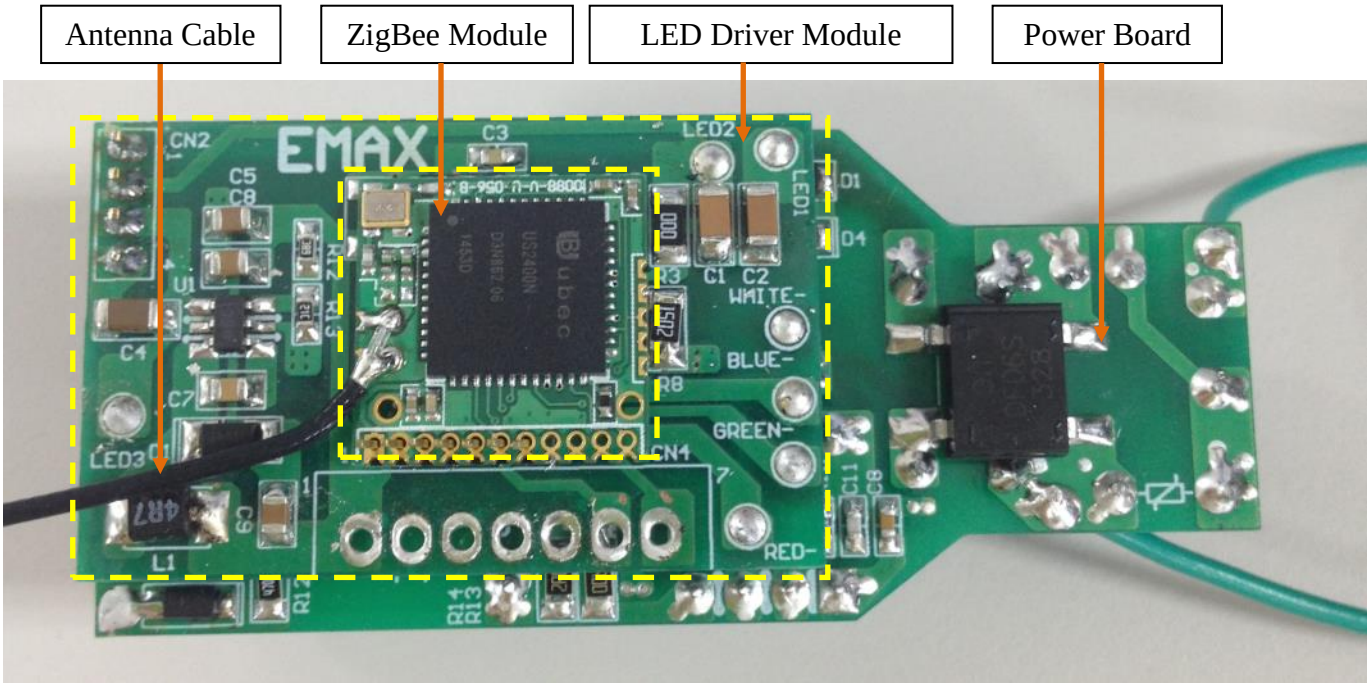


Figure 7 - Power Board + LED Driver Board + M56 ZigBee board

- ✧ Two green wires are connected to AC input
- ✧ Antenna cable from M56 Zigbee Module connected to A1 ”Antenna Chip” of Emitter board
- ✧ There are others seven wires connected to emitter board, as following table:

Pin# of LDB	Pin# of EMB	Functions
LED1	W+	25V drives white emitter string
LED2	B/G+	12V drives green and blue emitter strings
LED3	R+	8V drives Red emitter string
WHITE-	W-	Connected to U2_AL1791_LED1 and to control white emitter string
RED-	R-	Connected to U3_AL1793_LED1 and to control red emitter string
GREEN-	G-	Connected to U3_AL1793_LED2 and to control green emitter string
BLUE-	B-	Connected to U3_AL1793_LED3 and to control blue emitter string

Output / Input Pin Functions (Connected LED Emitter Board)

PERFORMANCE TESTING

The key system performance parameters of 4-ch W+RGB SCL bulb are summarized in Table 1 below.

10W A19 4-Channel W+RGB Reference Light Bulb			
Item No	Parameter	Condition	Test Result
1	Input Voltage Range	100-240V_{AC} ~ 50/60Hz	
2	Power Factor	> 0.7 (CCT: initial. The bulb is at maximum brightness)	110V_{AC}: 0.8451 (10.7W_in) 230V_{AC}: 0.7621 (10.38W_in)
3	Efficiency - PB Only	~ 85% (at VLED1: 360mA, VLED2: 20mA and VLED3: 20mA)	110 V_{AC}: 82.631% 230 V_{AC}: 85.478%
4	Standby Power	< 0.5Watt, Bulb is at standby mode (M56 ZigBee module Operating Current is about 35mA)	110 V_{AC} /60Hz: 0.283W 230 V_{AC} /50Hz: 0.402W
5	Start-Up Time from Wall Switch	110 V_{AC} (1M+1M Startup Resistor)	$T_{start-up}$: 892mS (PB only) $T_{start-up}$: 1740mS (Bulb turn-ON)
6	Output Ripple Voltage ($V_{peak-to-peak}$)	Test Condition (at 110V_{AC}) (at VLED1: 360mA, VLED2: 20mA and VLED3: 20mA)	VLED1_25V: 496mVp-p VLED2_12V: 280mVp-p VLED3_8V: 560mVp-p
7	THD (Total Harmonic Distortion)	Test Condition VLED1: 350mA, VLED2: No Load	110 V_{AC} /60Hz: 51.09% 230 V_{AC} /50Hz: 73.28%
8	Temperature of U2_AL1791 and U3_AL1793	< 105°C> Load condition: AL1791 is at 360mA, AL1793 is at 250mA+250mA	AL1791: 68°C (Open Cover) AL1793: 85°C (Open Cover)

Table 1 - System Performance Testing of 4-ch W+RGB 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) Efficiency
4) Standby Power
5) Start-Up Time
6) Thermal Management

While 4-ch W+RGB SCL bulb is 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) BD1 (DF06S)
2) Passive Valley Fill (PVF) Circuit: C4, C6, D1, D3 and D4 (see figure 8 below).

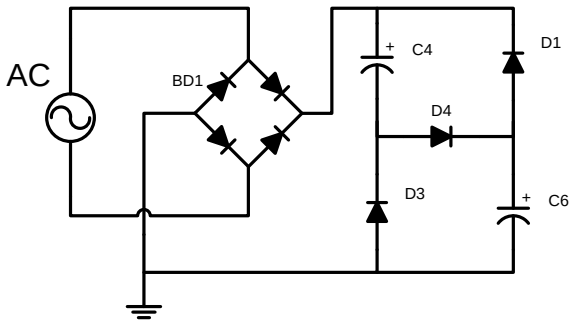


Figure 8 - Bridge and Valley Fill Circuit

AP3983C, with integrated MOSFET switch, has its advantages of supporting a cost-effective power board design. The relative small ripple of output voltage for CVs of AP3983C ($V_{peak\text{-}to\text{-}peak}$ ripple < 2.9% of the CV of Emitter Strings) is ideal to support linear Constant Current Regulation (CCR) based LED driver, such as AL1791 and AL1793, with optimal voltage headroom for attached LED emitter strings.

Per Energy Star Compliance requirement, the Power Factor (PF) for over 5W light bulb need to be over 0.7. As the AP3983C does not have built-in Active Power Factor circuitry, a PVF Circuit, consists of C4, C6. D1, D3 and D4 is designed to achieve desired PF over 0.7. A high PF value could be achieved by using larger capacitors (C4 and C6), however the trade-offs will be a longer start-up time, PCB space and cost. The system designers need to select the right balance for the PF value and other considerations.

The system efficiency of 10W typical 4-ch W+RGB SCL bulb needs to be above 75% based on the proposed two-stage designs. For the Power stage (first stage) efficiency, it is designed to achieve 85%. The factors impacting power board efficiency include:

1) CV Output Voltage
2) Pre-loading circuit (D9, D10, D11, R4, R9, R11 and R12, see figure 2.a on page 3) to prevent spurious output voltage at no load situation for one CV output, but sudden current is drawn by the other CV output.
3) Low V_F Drop Super Barrier Rectifier (D6, D7 and D8, see figure 2.a on page 3).

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 recommded to stay within 0.5W when in the standby mode for the entire SCL bulb.

In the 4-ch W+RGB SCL bulb design, the standby power consumption is measured with estimated breakdown as follows:

1) AL1791 and AL1793 IC - 5 mW (EN of AL1791 and AL1793 are disabled).
2) Dummy Loading - 50 mW (Pre-load circuitry power consumption)
3) Start-up Resistor Circuit - 50 mW (R5 and R6 are 1M/1206 resistor)
4) ZigBee Module - 250 mW (UBEC M56 ZigBee Module standby current is 35mA)
5) Others Power Loss- 50 mW (AP3983, Snubber and Switching Loss)

- **Improved Power Consumption Suggestion**
  - **Startup Circuit**

For low-cost implementation, a simple start-up circuity is adopted (R5 and R6, see figure 2.a on page 3). Trade-offs involved are start-up time (time when LED light could be turned on upon instruction to actual light output) and standby power consumption. Increasing the value of resistance of R5 and R6, the standby power will decrease at the expense of longer start-up time (Table 3).

Values of R5 & R6	startup time at 110 V_{AC} (after fully whole circuit discharged)	Standby Power at 230 V_{AC} LED OFF Mode (<0.5W)
two 1M = 2,000KΩ	0.89 Sec	0.395 W
two 510K = 1,020KΩ	0.62 Sec	0.416 W
two 392K = 784KΩ	0.21 Sec	0.455 W

Table 3 - Start-Up Resistor Circuit on Startup Time and Standby Power

An alternative quick dynamic startup circuit can be used to replace the resistor start-up circuit to shorten start-up time without static standby power consumption (Figure 7). During the AC power initial input, Transistor Q1 is turned ON to charge VCC input to AP3983C. Q1 will be shut off after initial start-up time until shut off by returning path from the auxiliary winding when VCC is highter than one threshold voltage below 18V where the Zener diode is clamped at.

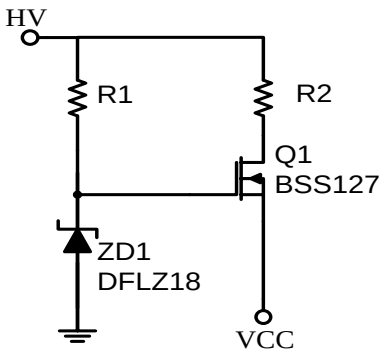


Figure 9 - Dynamic Fast Start-Up Circuit

➢ Thermal Management Design Suggestion

Thermal management is a critical design consieration as it impacts safety and reliability of the SCL bulbs. Among many good practices used in the power board design for managing thermal issues of SCL bulbs, system designers also need to fine tune the CV output to compensate for V_F fluctuation due to temperature effect. Depending on thermal characteristics of emitters, V_F drops around 5% to 10% range when temperature is increased from 25°C to 125°C. The proposed design is based on a low-cost open-loop CV fine tuning approach by adopting a Negative Temperature Coeffient (NTC) resistor 10K (The Circuit is not shown). The VLED1 output of the 4-ch W+RGB SCL bulb design is in the range of 25V down to 23.5V (-6%).

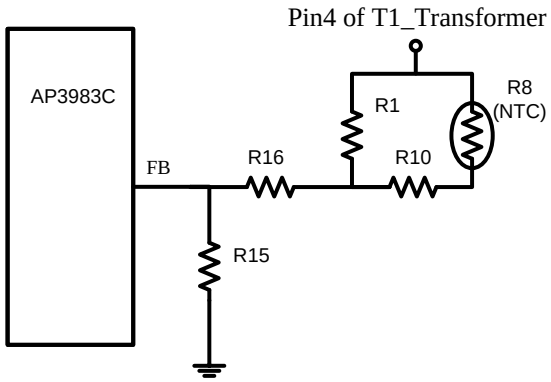
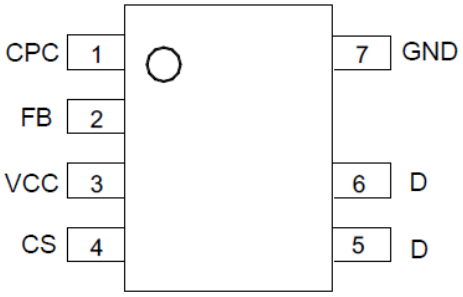


Figure 10 - Thermal Management Circuit

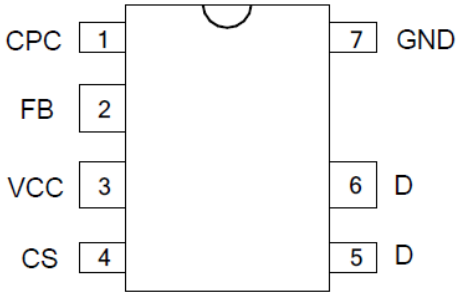
KEY COMPONENTS

➢ AP3983C - AC/DC Controller

AP3983C IC PIN OUT ASSIGNMENT



SO-7 (M Package) For AP3983B/C



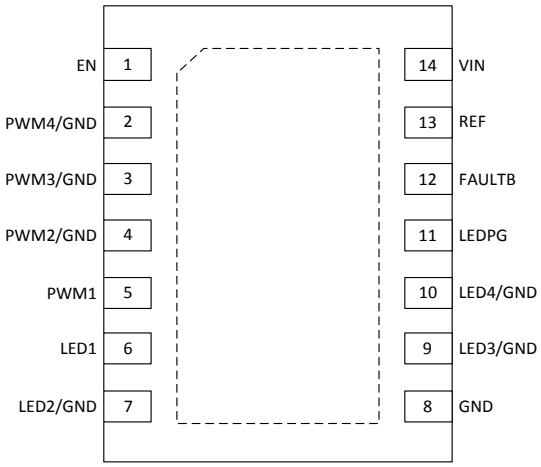
PDIP-7 (P7 Package) For AP3983D

- Primary Side control for Eliminating Opto-coupler and Secondary CV/CC Control Circuitry
- Built-In HV power MOSFET with 650V BVdss
- Valley-turn on to reduce switching loss
- Up to 80KHz operating frequency at full load for compact size application
- Piece-wise frequency reduction to enhance conversion efficiency and suppress audio noise
- ±5% constant voltage accuracy
- ±7% constant current accuracy
- Open Circuit Protection (OCP), Over Voltage Protection (OVP), Over Temperature Protection (OTP)
- Short Circuit Protection (SCP) with hiccup
- 3-Segment Drive Current for Radiative EMI Suppression
- AP3983 Pin Descriptions:

Pin Name	Symbol	Descriptions
	SO-7 / PDIP-7	
CPC	1	This pin is connected a capacitor to GND to serve as cable compensation function. Additional resistor in parallel with the capacitor will weaken cable compensation to meet cable-less applications.
FB	2	The voltage feedback is from auxiliary winding.
VCC	3	This pin receives rectified voltage from the auxiliary winding of the transformer.
CS	4	It is used for current sense from primary side of the transformer.
D	5, 6	This pin is connected with an internal power MOSFET's drain.
GND	7	This pin is the signal reference ground.

➢ AL1791/2/3/4 - LED Driver Controller

AL1791/2/3/4 IC PIN OUT ASSIGNMENT



- Input Voltage Range: 6.5V to 30V
- 1/2/3/4-channel LED drivers: independent Analog or PWM dimming control for each channel
- Reference Current: Adjustable by an external reference resistor
- Ratio-optimized currents for 4 independent LED channels (AL1794 only): Suitable for Tunable White and Tunable Color
- Low Standby Power: With EN pin
- E-flicker free High Frequency PWM dimming with Deep Dimming Capability: Support 10KHz down to 1.0%, 4KHz down to 0.4%, or 1KHz down to 0.1%
- Internal Protections: Under Voltage Lockout (UVLO), LED string open/short protection
- Over temperature protection (OTP): Thermal shut down and auto thermal recovery
- Fault Reporting: UVLO, OTP, Open, and Short
- LED Power Good Reporting
- Low system BOM cost
- Ambient Temperature Range -40°C to +125°C (Automotive Grade)
- U-DFN4030-14: Available in “Green” Molding Compound (No Br, Sb)
- Totally Lead-Free & Fully RoHS Compliant
- Halogen and Antimony Free. “Green” Device

- **AL1791/2/3/4 Pin Descriptions**

Pin Name	Part Number	Descriptions
	U-DFN4030-14	
EN	1	Active-high to Enable, Internally Pulled Down
PWM4/GND	2	PWM Signal Input for channel 4, Internally Pulled Down for AL1794. GND for AL1791, AL1792, and AL1793.
PWM3/GND	3	PWM Signal Input for channel 3, Internally Pulled Down for AL1793 and AL1794. GND for AL1791 and AL1792.
PWM2/GND	4	PWM Signal Input for channel 2, Internally Pulled Down for AL1792, AL1793, and AL1794. GND for AL1791.
PWM1	5	PWM Signal Input for channel 1, Internally Pulled Down (Tied to GND when this channel is NOT used).
LED1	6	Channel 1 LED Cathode
LED2/GND	7	Channel 2 LED Cathode for AL1792, AL1793, and AL1794. GND for AL1791.
GND	8	Ground
LED3/GND	9	Channel 3 LED Cathode for AL1793 and AL1794. GND for AL1791 and AL1792.
LED4/GND	10	Channel 4 LED Cathode for AL1794. GND for AL1791, AL1792, and AL1793.
LEDPG	11	LED Power Good Indication. Asserted Low to report insufficient headroom. Needs an external pull-up resistor.
FAULTB	12	Fault Report. Asserted Low to report faulty conditions. Needs an external pull-up resistor.
REF	13	Reference Current Setting through External Resistor (R_{SET})
VIN	14	Voltage Input
Exposed PAD	Exposed PAD	Exposed pad. Internally connected to GND. It should be externally connected to GND and thermal mass for enhanced thermal impedance. It should not be used as electrical conduction path.

Bill of Material - ACDC Board

#	Name	QTY	Part Number	Manufacturer	Description
1	U1	1	AP3983C/DIP-7	Diodes, Inc.	ACDC PSR converter (build in 650V MosFET)
2	BD1	1	DF06S	Diodes, Inc.	600V/1A bridge diode
3	D1, D2, D3, D4, D5	5	DFLR1600-7	Diodes, Inc.	1.0A surface mount glass passivated rectifier NO need for D1, D3, D4 for low PF (< 0.7) design
4	D6	1	SBR1U200P1-7	Diodes, Inc.	1A200V surface mount super barrier rectifier POWERDI® 123
5	D7,D8	2	DFLS160-7	Diodes, Inc.	1.0A/60V surface mount schottky barrier rectifier POWERDI® 123
6	CX1	1	0.047uF/275Vac		EMI filter
7	CY1	1	1000PF/Y1		EMI capacitor
8	C1,C2	2	1nF/1KV/1206		Snubber capacitor
9	C3	1	0.22uF/450V		EMI filter
10	C4,C6	2	10uF/200V/8*14		Valley Fill Input Bulk Capacitor Without Valley Fill. C4 and C6 need to be changed to 4.7uF/400V
11	C5	1	270uF/35V/8*16		VLED1 output filter capacitor
12	C7	1	4.7uF/50V/5*11		AP3983C startup and VCC hold-up capacitor
13	C8	1	0.1uF/50V/0603		AP3983C output cable compensation
14	C9,C10	2	330uF/16V/8*12		VLED2,VLED3 output filter capacitors
15	C11	0	-		Not fitted (Feedback compensation)
16	R1	1	39K/0603		AP3983C voltage feedback resistor
17	R2	1	100K/1206		Snubber resistor
18	R3	1	10R/1206		Snubber resistor
19	R5,R6	2	1M/1206		Startup resister (must for high voltage stress >200V)
20	R7	1	10R/0805		Snubber resistor
21	R8	1	10K/0603/NTC		AP3983C voltage feedback resistor
22	R10	1	6.8K/0603		AP3983C voltage feedback resistor
23	R12	1	4.7K/1206		Pre-load
24	R13, R14	2	2R/1206		AP3983C current sense resistor
25	R16	1	43K/0603		AP3983C voltage feedback resistor
26	R15	1	15K/0603		AP3983C voltage feedback resistor
27	D9	1	DFLZ22-7	Diodes, Inc.	Improved load regulation
28	D10	1	DFLZ15-7	Diodes, Inc.	Improved load regulation
29	D11	1	DFLZ6V2-7	Diodes, Inc.	Improved load regulation
30	R4,R9,R11	0	-		Not fitted (Pre-load)
31	T1	1	EE16	Emax, Inc	EE16 Transformer (Np:Na:Ns25V:Ns12V:Ns8V=110:13:4:8; 0.9mH)
32	F1	1	T1A-T250V		Fuse
33	CON1	1	CON4*1_2mm (CH1101S)	CviLux, Inc	Output connector

34	L1	**1**	1.0mH/6Φ I core		EMI filter inductance
35	VDR1	**1**	471K		Reserved for Future Use EMC Part.
TOTAL		**43**			Power Board Electronic Parts

Bill of Material – LED Drive Board

#	Name	QTY	Part Number	Manufacturer	Description
1	U1	1	AP3211KTRG1	**Diodes, Inc.**	WIDE INPUT VOLTAGE RANGE, 150mA ULDO REGULATOR, SOT-23-5
2	U2	1	AL1791AFE-13	**Diodes, Inc.**	Single Channel Current-Ratio-Optimized LED Driver with Analog and PWM Dimming U-DFN-4030-14
3	U3	1	AL1793AFE-13	**Diodes, Inc.**	Triple Channels Current-Ratio-Optimized LED Driver with Analog and PWM Dimming U-DFN-4030-14
4	D1	1	APD204	**Diodes, Inc.**	Buck converter flywheel diodes
5	R1	0	-		Not fitted. (AL1791/3 EN pull high resistor)
6	R3	1	0R/1206		Jumper
7	R8	1	20K/1206		U3_AL1793 LED current setup resistor.
8	R9	1	15K/1206		U3_AL1793 LED current setup resistor.
9	R5,R6	2	33K/1206		U2_AL1791 LED current setup resistor.
10	R12	1	49.9K/0603		AP3211 Feedback resistor
11	R13	1	16.3K/0603		AP3211 Feedback resistor
12	C1,C2	2	1.0uF/50V/1206		VLED1, VLED2, input filter capacitors
13	C5	1	4.7uF/6.3V/0805		3.3V output filter capacitor
14	C3,C6	1	0.1uF/50V/0805		AL1791/3 Vin filter capacitor
15	C4	1	2.2uF/50V/1206		VLED3, input filter capacitor
16	C8	0	-		Not fitted. (3.3V output filter capacitor)
17	C7	1	0.01uF/0805		Boost capacitor
18	CN2	1	Pitch 1.27mm 6Pin (CH0101S)	CviLux, Inc.	For M56 ZigBee Module
19	L1	1	4.7uH/SMA		Buck converter power inductor
TOTAL		**19**			LD Board Electronic Parts

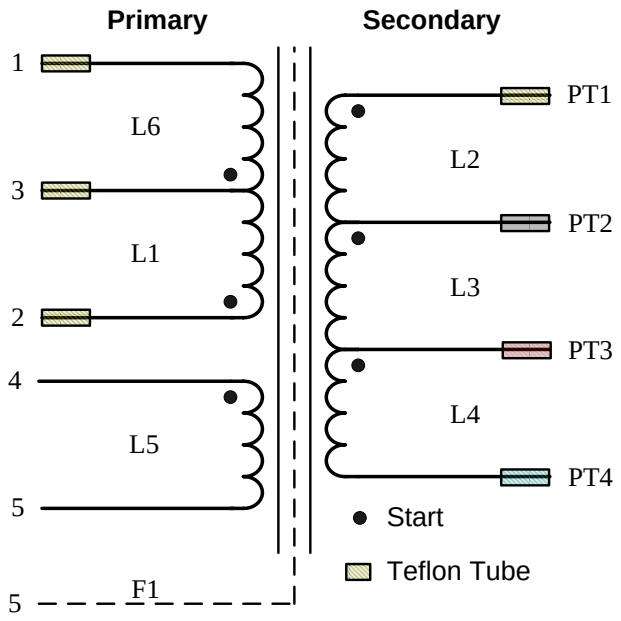
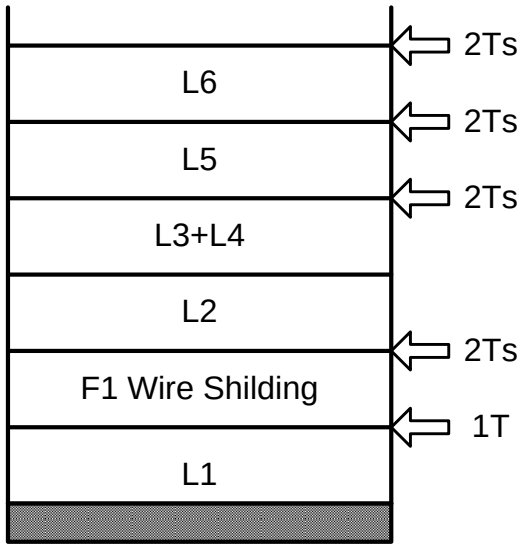
Bill of Material – Emitter Board

#	Name	QTY	Part Number	Manufacturer	Description
1	D1, D2, D3, D4, D5, D6, D7, D8, D9, D10, D11, D12	12	LTW-3030AZD27	LITEON, Inc.	LTW-3030AZD Emitter Series
2	LQ9	1	LQ9-07MC00-0659	LED Engin, Inc.	9-die RGB silicone dome emitter
3	R1,R2, R3,R4	4	0ohm/1206		VF (Forward Voltage) matching resistor
4	A1	1	ANT3216LL11R2400A		
TOTAL		**18**			LD Board Electronic Parts

APPENDIX I - EE16 TRANSFORMER SPEC

EE16 transformer with (Appendix X).

A. Transformer Pin & Wire Description:

Circuit：	Cross sectional view：
	

	Pin definition (Start→End)	Wire (φ)	Turn (Ts)	Layers	Layers of Tape
L1	2→ 3	2UEW-B 0.19mm x 1P	76	2	1T
F1	5→	2UEW-B 0.13mm x 1P	52	1	1T
L2	PT1→ PT2	Triple wire-B 0.35mm x 1P	13	1	
L3	PT2→ PT3	Triple wire-B 0.35mm x 1P	4	0.3	
L4	PT3→ PT4	Triple wire-B 0.35mm x 1P	8	0.7	1T
L5	4→ 5	2UEW-B 0.13mm x 1P	18	1	1T
L6	3→ 1	2UEW-B 0.19mm x 1P	34	1	2T
	OVER CORE				3Ts

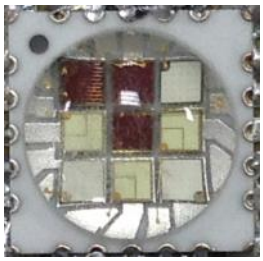
B. Electrical Characteristic :

#	Test Item	Winding	Pin	Rating	Unit	Tolerance	Remark
2.1	Inductance	L1+L6	1 → 2	0.9	mH	+/-5%	@ 100KHz / 1V

APPENDIX II - LED ENGIN LQ9 AND LITEON OPTO EMITTER

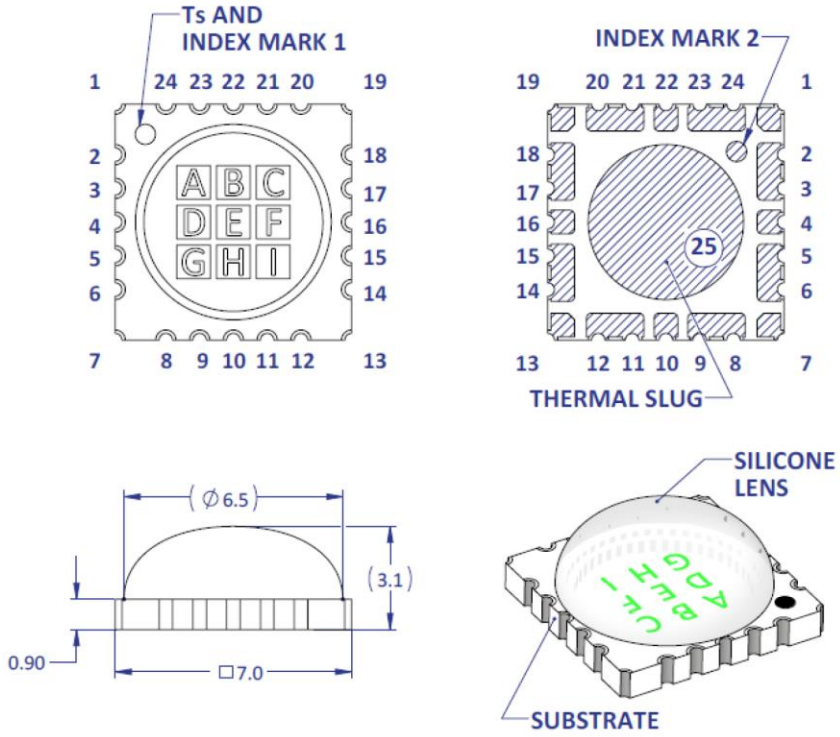
✧ **LQ9-07MC00-0659 9-die RGB Silicone Dome emitter**

Key Features



- 9-die RGB silicone dome emitter
- Can dissipate up to 20W
- Ultra-small foot print – 7.0mm x 7.0mm
- Surface mount ceramic package
- Low Thermal Resistance (1.3°C/W)
- Lead (Pb) free and RoHS compliant

Mechanical Dimensions (mm)

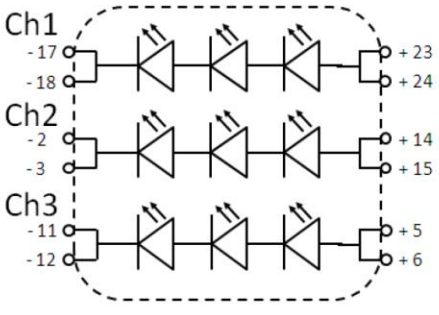


Emitter pin layout			
Emitter channel	**Emitter pin**	**Die**	**Color**
Ch1 -	17, 18	A	Red
Ch1		B	Red
Ch1 +	23, 24	E	Red
Ch2 -	2, 3	C	Blue
Ch2		G	Blue
Ch2 +	14, 15	I	Blue
Ch3 -	11, 12	D	Green
Ch3		F	Green
Ch3+	5, 6	H	Green
NC pins: 1, 4, 7, 8, 9, 10, 13, 16, 19, 20, 21, 22			
DNC pins: none			

Notes:
NC = Not internally Connected (Electrically isolated)
DNC = Do Not Connect (Electrically Non isolated)

Figure 1: Package outline drawing.

Notes for Figure 1:
1. Index mark indicates case temperature measurement point.
2. Unless otherwise noted, the tolerance = ± 0.20 mm.



Absolute Maximum Ratings

Table 3:

Parameter	Symbol	Value	Unit
DC Forward Current at T_{jmax}=125°C [1]	I_F	700	mA
Peak Pulsed Forward Current [2]	I_{FP}	1000	mA
Reverse Voltage	V_R	See Note 3	V
Storage Temperature	T_{stg}	-40 ~ +100	°C
Junction Temperature	T_J	125	°C
Soldering Temperature [4]	T_{sol}	260	°C
Allowable Reflow Cycles		3	

Notes for Table 3:
1. Maximum DC forward current (per die) is determined by the overall thermal resistance and ambient temperature.
2: Pulse forward current conditions: Pulse Width ≤ 10msec and Duty Cycle ≤ 10%.
3. LEDs are not designed to be reverse biased.
4. Solder conditions per JEDEC 020c. See Reflow Soldering Profile Figure 3.
6. LED Engin recommends taking reasonable precautions towards possible ESD damages and handling the LQ9-07MC00-0659 in an electrostatic protected area (EPA). An EPA may be adequately protected by ESD controls as outlined in ANSI/ESD S6.1.

Optical Characteristics @T_C = 25°C

Table 5:

Parameter	Symbol	Typical			Unit
		3 Red	3 Green	3 Blue [1]	
Luminous Flux (@ I_F = 350mA)	Φ_V	115	220	50	lm
Dominant Wavelength [2,3,4]	λ_D	623	523	460	nm
Viewing Angle [5]	$2\Theta_{½}$		TBD		Degrees
Total Included Angle [6]	$\Theta_{0.9}$		TBD		Degrees

Notes for Table 5:
1. When operating the Blue LED, observe IEC 60825-1 class 2 rating. Do not stare into the beam.
2. Viewing Angle is the off axis angle from emitter centerline where the luminous intensity is ½ of the peak value.
3. Total Included Angle is the total angle that includes 90% of the total luminous flux.

Electrical Characteristics @T_C = 25°C

Table 6:

Parameter	Symbol	Typical			Unit
		3 Red	3 Green	3 Blue	
Forward Voltage (@ I_F = 350mA)	V_F	6.7	10.1	9.1	V
Temperature Coefficient of Forward Voltage	$\Delta V_F/\Delta T_J$	-5.7	-8.7	-6.0	mV/°C
Thermal Resistance (Junction to Case)	$R\Theta_{J-C}$		1.3		°C/W

Contact LED Engin
Web Site: www.ledengin.com
Contact: Cindy Xu (cindyxu@ledengin.com)

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

✧ **Typical Performance**

Parameter	Symbol	Values								Unit	Test Condition
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	-	
	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	I_F = 150mA
Color Rendering Index	CRI	Min.	80							-	
Viewing Angle	$2\theta_{1/2}$	Typ.	120							deg	
Forward Voltage	V_F	Min	5.8							V	
		Typ.	6.3								
		Max.	6.6								
Thermal Resistance	Rjs	Typ.	11							°C/W	

Notes

1. Luminous flux is the total luminous flux output as measured with an integrating sphere.
2. Iv (flux Φ_v) classification code is marked on each packing bag.
3. The chromaticity coordinates (x, y) is derived from the 1931 CIE chromaticity diagram.
4. 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.
5. CAS140B is the test standard for the chromaticity coordinates (x, y) & Φ_v.
6. The chromaticity coordinates (x, y) guarantee should be added +/- 0.01 tolerance
7. CRI measurement allowance is ±5, R9>0

Contact LiteON Opto (光寶科技)

Web Site: **www.liteon.com/opto**

Contact: **Eddie Su**

E-mail: **(Eddie.Su@liteon.com)**

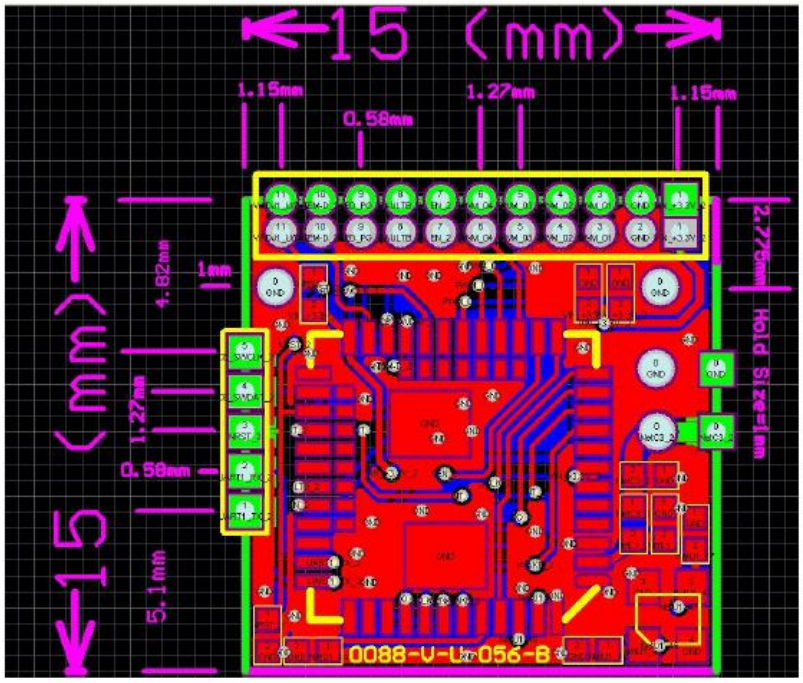
APPENDIX III - ZIGBEE MODULE M56 (UBEC)

✧ 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-Cotex 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

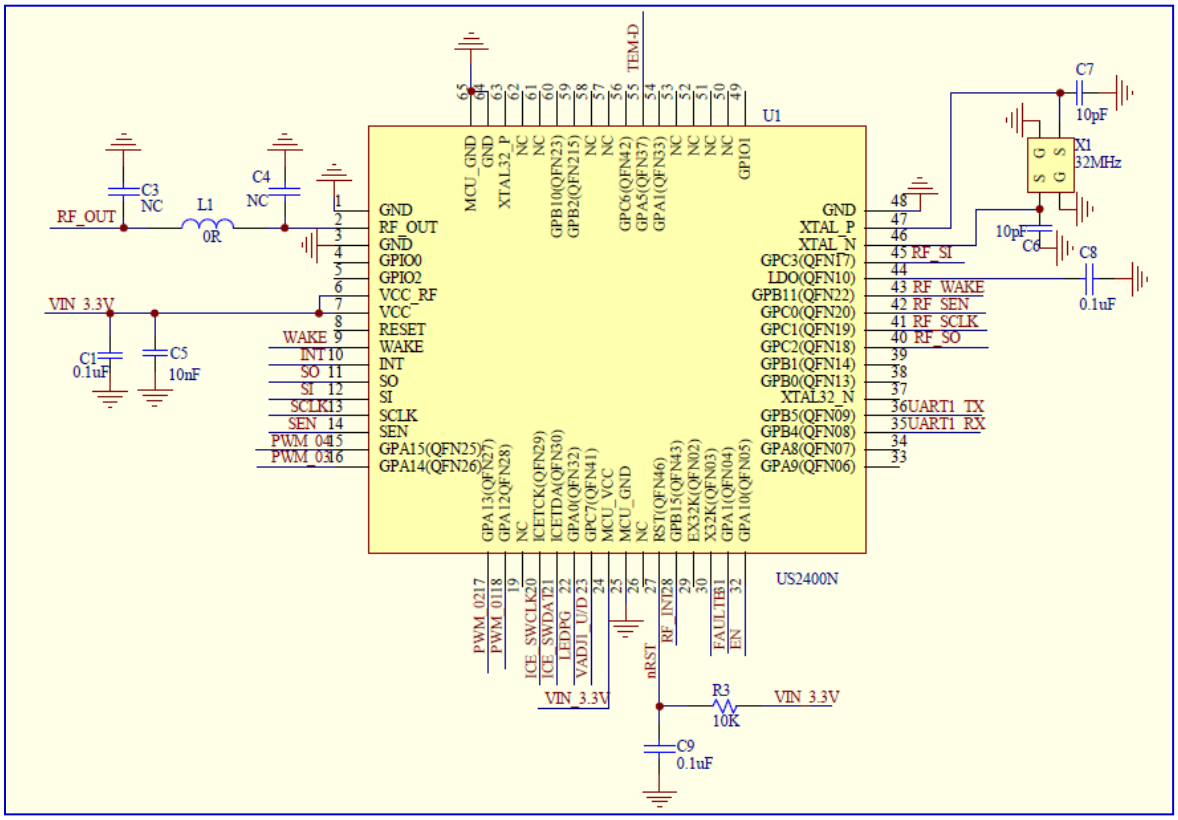
Pin#	Pin Name	Functions
1	VDD	Connected to LED driver board - 3.3V
2	GND	Connected to LED driver board Ground
3	PWM_01	Connected to LED driver board – PWM1 of U2_AL1791 To control white emitter string
4	PWM_02	Connected to LED driver board – PWM1 of U3_AL1793 To control red emitter string
5	PWM_03	Connected to LED driver board – PWM2 of U3_AL1793 To control green emitter string
6	PWM_04	Connected to LED driver board – PWM3 of U3_AL1793 To control blue emitter string
7	EN	Connected to AL1791 and AL1793 Pin#1-EN, enable/disable LED driver

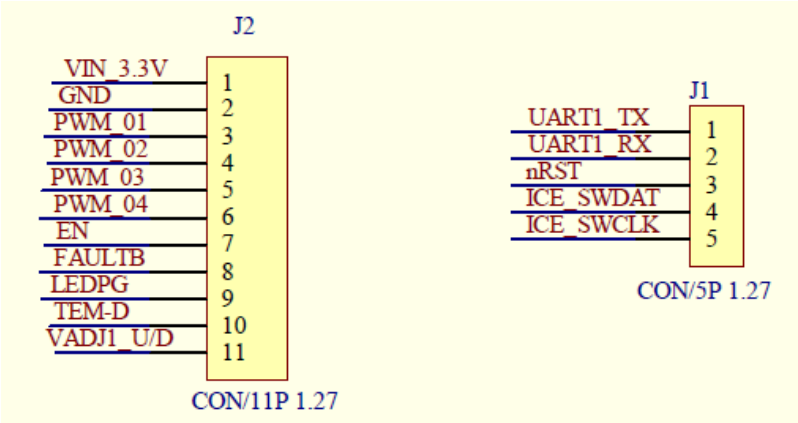
Output Pin Define (Assembled to the LED Driver Board)



M56 ZigBee Module Outline Drawing

✧ Schematic and Connection Define





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	GND	
3	PWM_01	PWM 0 channel 0 output, GPIO, (PA. 12)	WHITE
4	PWM_02	PWM 0 channel 1 output, GPIO, (PA. 13)	RED
5	PWM_03	PWM 0 channel 2 output, GPIO, (PA. 14)	GREEN
6	PWM_04	PWM 0 channel 3 output, GPIO, (PA. 15)	BLUE
7	EN	GPIO, I^2C 1 SDA, (PA. 10)	EN
8	FAULTB	GPIO, I^2C 1 SCL, (PA. 11)	
9	LEDPG	GPIO, ADC, (PA 0)	
10	TEM-D	No Available	
11	VADJI I/D	GPIO, DAC (PC. 7)	

J2 - Application Usage

Contact UBEC:
Headquarters
Address: 6F-1, No. 192, Dongguang Rd., Hsinchu, 300 Taiwan
Tel: +886-3-5729898
Fax:+886-3-5718599
Website: http://www.ubec.com.tw
Sales Services
E-mail: sales@ubec.com.tw

IMPORTANT NOTICE

DIODES INCORPORATED MAKES NO WARRANTY OF ANY KIND, EXPRESS OR IMPLIED, WITH REGARDS TO THIS DOCUMENT, INCLUDING, BUT NOT LIMITED TO, THE IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE (AND THEIR EQUIVALENTS UNDER THE LAWS OF ANY JURISDICTION).

Diodes Incorporated and its subsidiaries reserve the right to make modifications, enhancements, improvements, corrections or other changes without further notice to this document and any product described herein. Diodes Incorporated does not assume any liability arising out of the application or use of this document or any product described herein; neither does Diodes Incorporated convey any license under its patent or trademark rights, nor the rights of others. Any Customer or user of this document or products described herein in such applications shall assume all risks of such use and will agree to hold Diodes Incorporated and all the companies whose products are represented on Diodes Incorporated website, harmless against all damages.

Diodes Incorporated does not warrant or accept any liability whatsoever in respect of any products purchased through unauthorized sales channel.

Should Customers purchase or use Diodes Incorporated products for any unintended or unauthorized application, Customers shall indemnify and hold Diodes Incorporated and its representatives harmless against all claims, damages, expenses, and attorney fees arising out of, directly or indirectly, any claim of personal injury or death associated with such unintended or unauthorized application.

Products described herein may be covered by one or more United States, international or foreign patents pending. Product names and markings noted herein may also be covered by one or more United States, international or foreign trademarks.

This document is written in English but may be translated into multiple languages for reference. Only the English version of this document is the final and determinative format released by Diodes Incorporated.

LIFE SUPPORT

Diodes Incorporated products are specifically not authorized for use as critical components in life support devices or systems without the express written approval of the Chief Executive Officer of Diodes Incorporated. As used herein:

A. Life support devices or systems are devices or systems which:

1. are intended to implant into the body, or
2. support or sustain life and whose failure to perform when properly used in accordance with instructions for use provided in the labeling can be reasonably expected to result in significant injury to the user.

B. A critical component is any component in a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or to affect its safety or effectiveness.

Customers represent that they have all necessary expertise in the safety and regulatory ramifications of their life support devices or systems, and acknowledge and agree that they are solely responsible for all legal, regulatory and safety-related requirements concerning their products and any use of Diodes Incorporated products in such safety-critical, life support devices or systems, notwithstanding any devices- or systems-related information or support that may be provided by Diodes Incorporated. Further, Customers must fully indemnify Diodes Incorporated and its representatives against any damages arising out of the use of Diodes Incorporated products in such safety-critical, life support devices or systems.

www.diodes.com