2-Channel Tunable White / 1-Channel Dimmable White Smart Connected Light Bulb Reference Design

"AP3983 (PSR Switcher) + AL1792 (2-Channel Linear CCR LED Driver)"

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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 Conversion
- LED Driver
- Emitter Module
- Wireless MCU Connectivity

This application note describes the complete reference design of an A19 10W ZigBee-Enabled 2-channel Tunable White SCL (2-ch TW SCL) bulb, capable of generating white light in the Correlated Color Temperature (CCT) ranging from 2,700K to 6,500K. It serves as a good starting point for system designers to further customize SCL bulb design to their desired performance and cost consideration. Driving emitter strings with AL179X (multiple-channel LED driver) family, the 1-ch DW light bulb is a derivative design by not populating components specifically for 2-ch TW (e.g. CCT emitters) and replacing AL1792 (2-ch LED driver IC) with a pin-to-pin compatible AL1791 (1-ch LED driver IC).

KEY SPECIFICATION

- Model: A19-DD-UB-LO-2TW
- 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 to 6,500K
- CRI: 80Ra
- Wireless: ZigBee Module
- Dimension (L*D): 113mm x 62mm

FUNCTIONAL BLOCK DIAGRAM

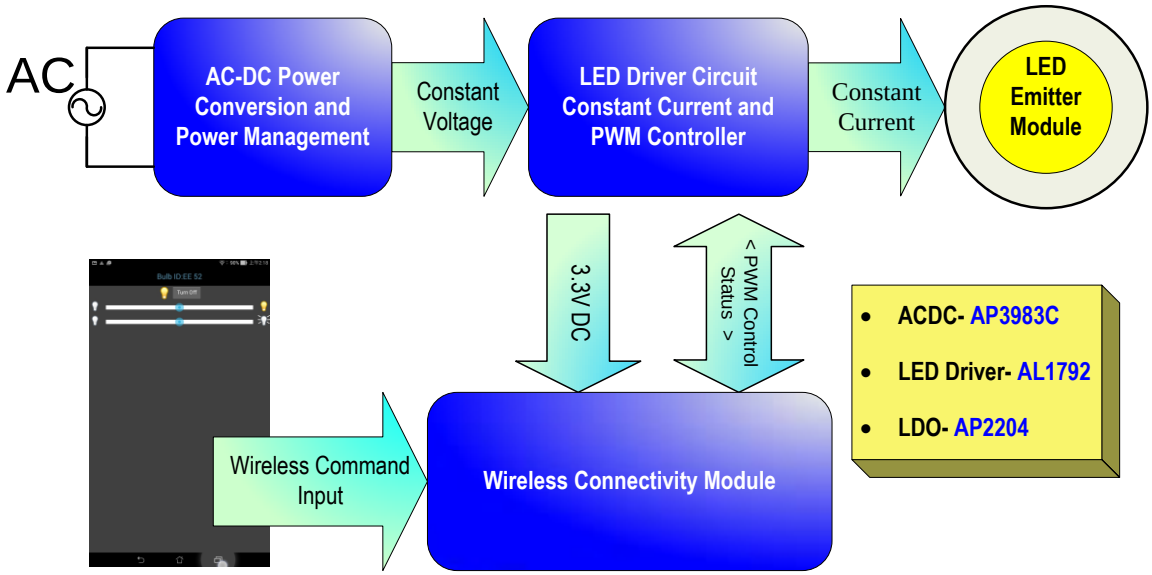


Figure 1 - Functional Block Diagram for Smart Connected Light Bulb

A typical 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 MCU.
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 MCU, 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

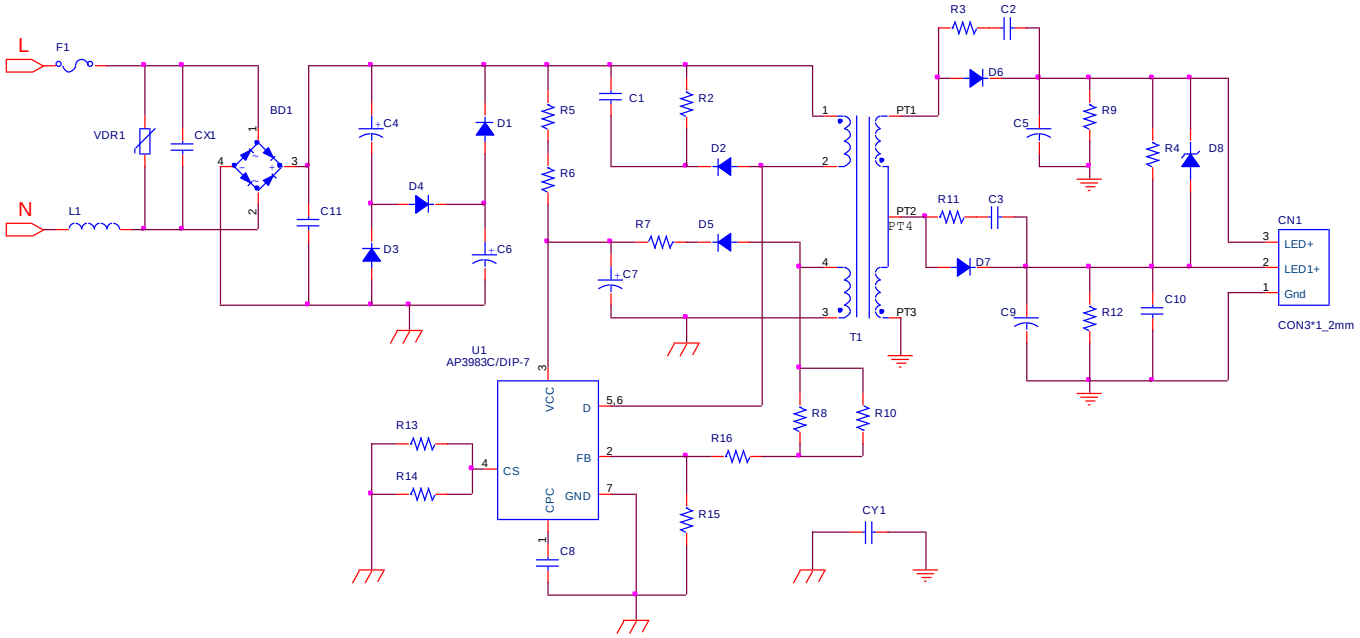


Figure 2.a - AP3983C Power Board Schematics

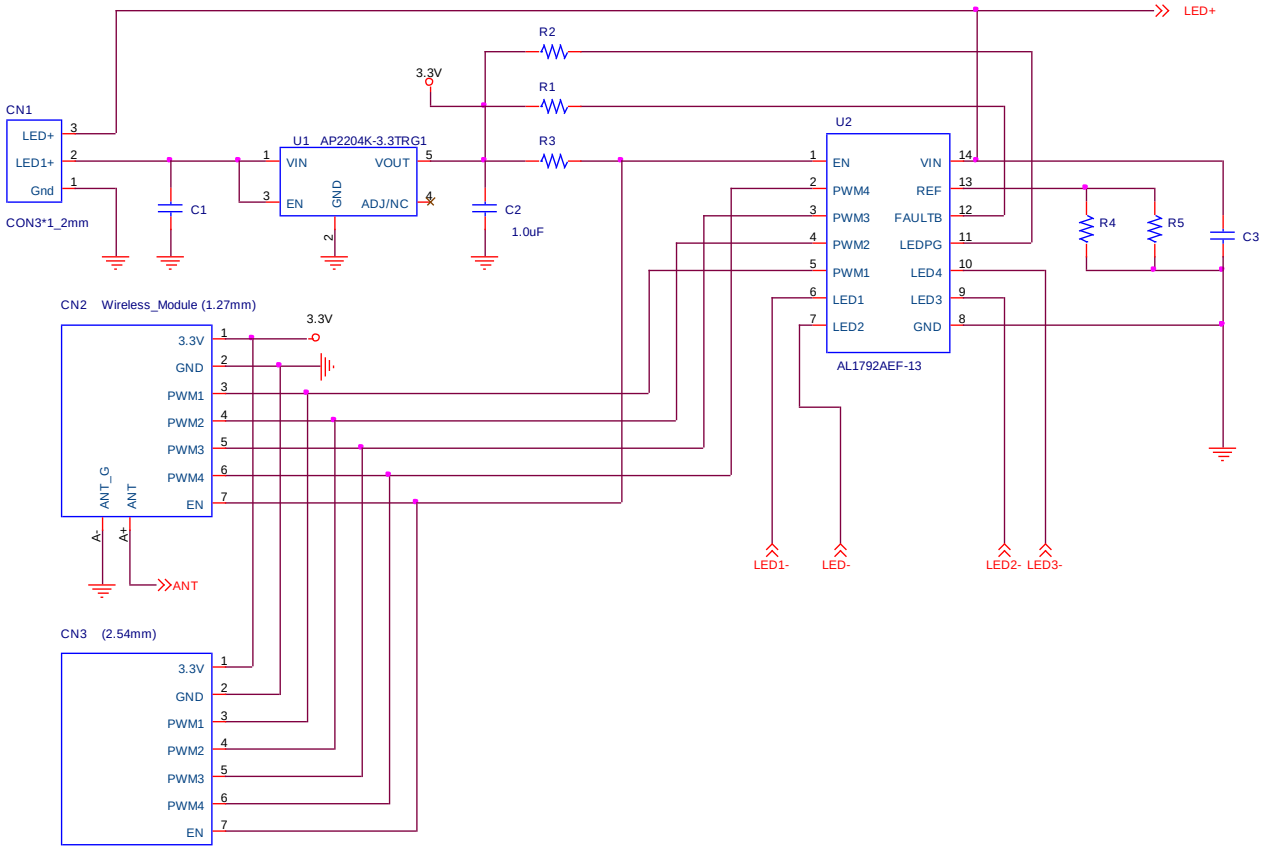


Figure 2.b - LED Driver - AL1792+M56 ZigBee Module Schematics

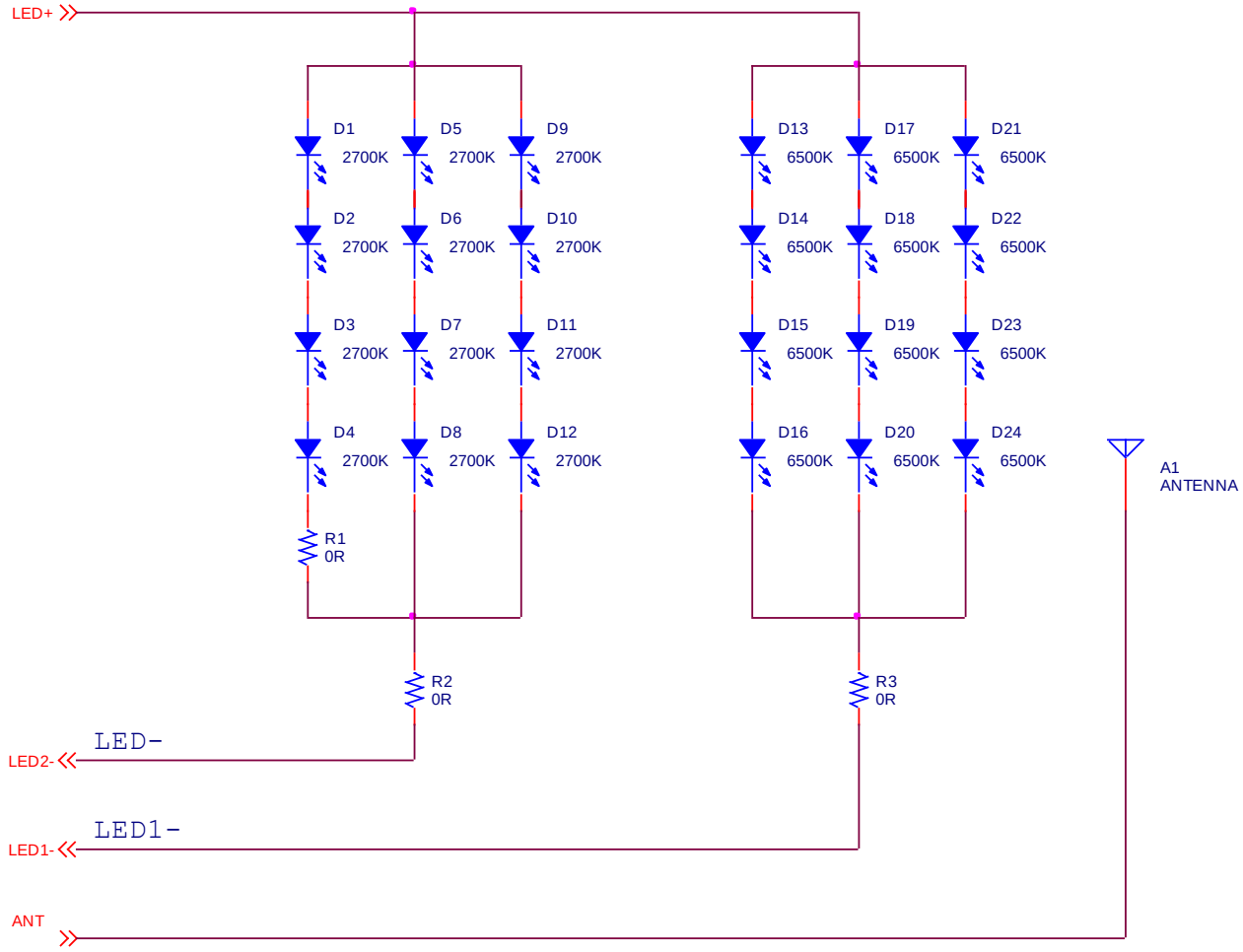


Figure 2.c - LED Emitter Module Schematics

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. To support both emitter strings and attached MCU power, the PB outputs two CVs:

- ✧ LED+ : 25V for driving emitter strings with adequate voltage headroom to Forward Voltage Drop (VF) and AL1792 LED driver regulator (Refer to the Key Component Section)
- ✧ LED1+ : 4.5V for deriving power to Wireless MCU

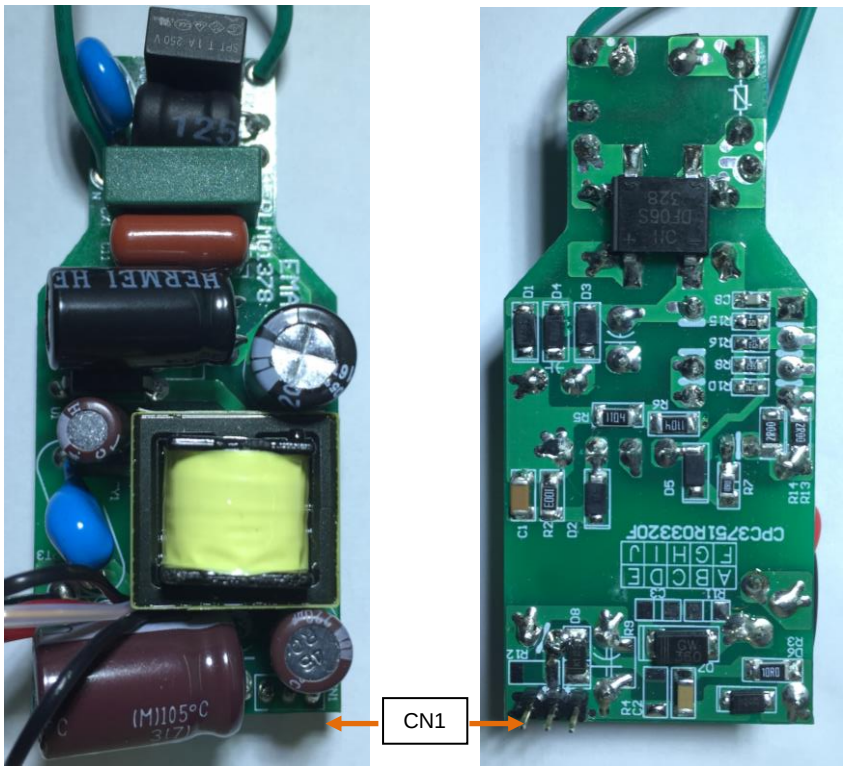


Figure 3 - AP3983C Power Board (58mmx27mm)

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	GND	Ground
2	LED1+	4.5V for driving power to Wireless MCU
3	LED+	25V for driving emitter strings and supplying AL1792
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 2-Ch TW EMB (Figure 4) adopts two types of CCT Emitters, arranged in parallel-serial strings (3P4S - 3 Parallel and 4 Serial Emitters) as follows:

- ✧ 2,700K CCT White Emitters (total of 12 Emitters 4S3P), CCT_{warm}
- ✧ 6,500K CCT White Emitters (total of 12 Emitters 4S3P), CCT_{cold}

The Forward Voltage Drop (V_F) per emitter, with two 0.5W emitter dies in serial, is around 6.0V and the toal V_F per emitter sting is 24.0V (refer to Appendix II Emitter Spec). The cathodes of CCT_{warm} and CCT_{cold} emitter strings are attached to LED1 and LED2 pins of AL1792 IC, respectively.

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).

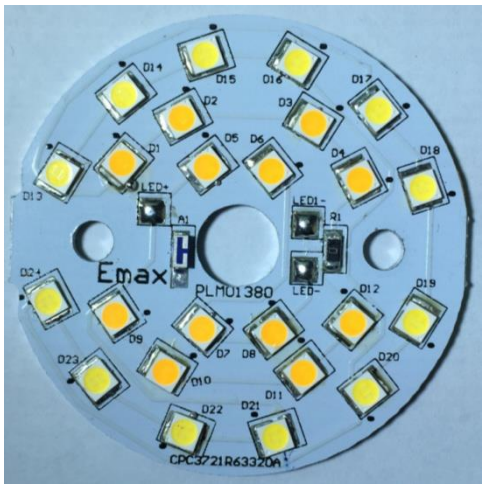


Figure 4 - 2-Ch TW Emitter Module (Diameter - 46mm)

Pin#	Pin Name	Functions
LED+	+25V	The soldering pad is attached to the common anode of LED(6500K) and LED(2700K) emitter strings.
LED1-	6500K LED-	The soldering pad is attached to the cathode of LED(6500K) emitter string.
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

➢ LED Driver Board (LDB) Application Description

In this 2-Ch TW SCL bulb design, the REF (reference current setting resistor) for LED Driver circuit is 9.1KΩ (R4 in Figure 2.b) to regulate a total channel current around 330mA for both LED1 and LED2 of AL1792. The LED input power for each fixed CCT emitter strings is around 8.0W (24V*330mA). By applying suitable PWM signal patterns to both CCT_{warm} and CCT_{cold} emitter strings (2,700K and 6,500K), CCT tuning ranging from 2,700K to 6,500K can be achieved.

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

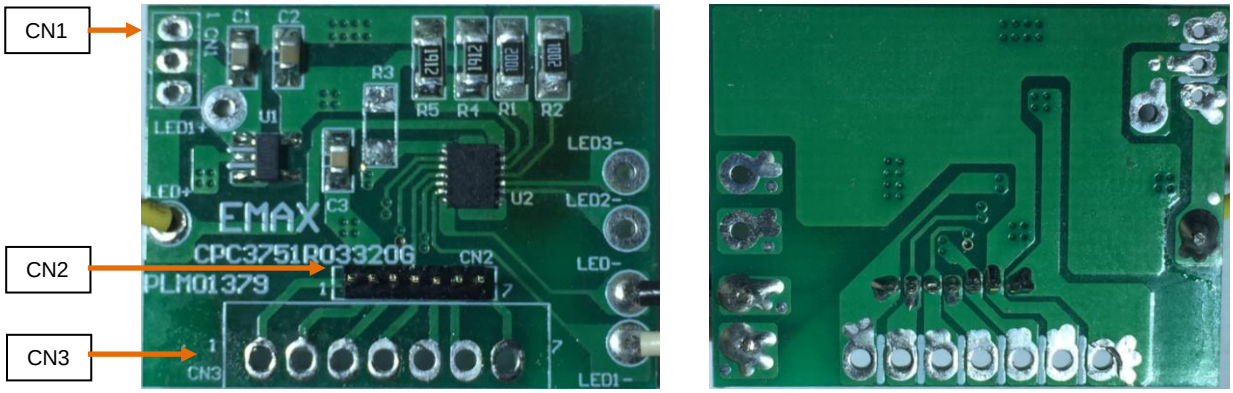


Figure 5 - AL1792 LED Driver Module (30mmx24mm)

Pin#	Pin Name	Functions
1	GND	Ground.
2	LED1+	4.5V input, supplying LDO for Wireless MCU.
3	LED+	25V input, for driving emitter strings and supplying AL1792

CN1 - Pin Functions (Connected to Power Board)

Pin#	Pin Name	Functions
1	3.3V	This Pin is attached to the output 3.3V of LDO, For M56 ZigBee module VDD input.
2	GND	Ground
3	PWM1	This pin is attached to the PWM1 of U2_AL1792, Connected to PWM_01 of M56 ZigBee Module, for controlling 6500K emitter string.
4	PWM2	This pin is attached to the PWM2 of U2_AL1792, Connected to PWM_02 of M56 ZigBee Module, for controlling 2700K emitter string.
5	PWM3	This pin is attached to the PWM3 of U2_AL179X, Connected to PWM_03 of M56 ZigBee Module.

6	PWM4	This pin is attached to the PWM4 of U2_AL179X, Connected to PWM_04 of M56 ZigBee Module
7	EN	This pin is attached to the EN of U2_AL1792, Connected to GPIO of M56 ZigBee, to control on/off function of U2_AL1792.

CN2 and CN3- Pin Functions (Connected to ZigBee Module)

Pin#	Pin Name	Functions
LED+	+25V	25V, for driving emitter strings.
LED1+	+4.5V	4.5V, (Reserved for future use)
LED1-	6500K LED-	This soldering pad is attached to the LED1 pin of U2_AL1792, and connected to the cathode terminal of LED1- (6,500K).
LED-	2700K LED-	This soldering pad is attached to the LED2 pin of U2_AL1792, and connected to the cathode terminal of LED- (2,700K).
LED2-	LED3	This soldering pad is attached to the LED3 pin of U2_AL179X,Connected to LED cathode terminal (Reserved for future use)
LED3-	LED4	This soldering pad is attached to the LED4 pin of U2_AL179X,Connected to LED cathode terminal (Reserved for future use)

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 2-ch TW SCL bulb by piggybacking on the other side of the AL1792 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 opposited to the Power Board.

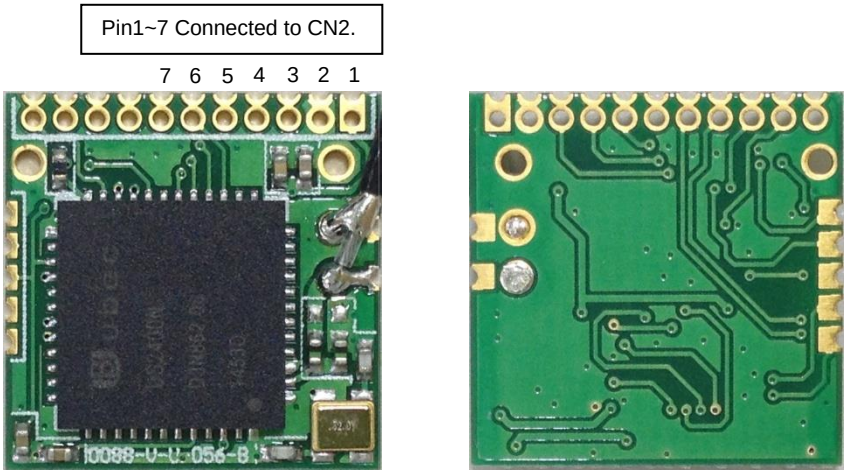


Figure 6 - M56 ZigBee Module (15mm x 15mm)

➢ Output Assembly Description

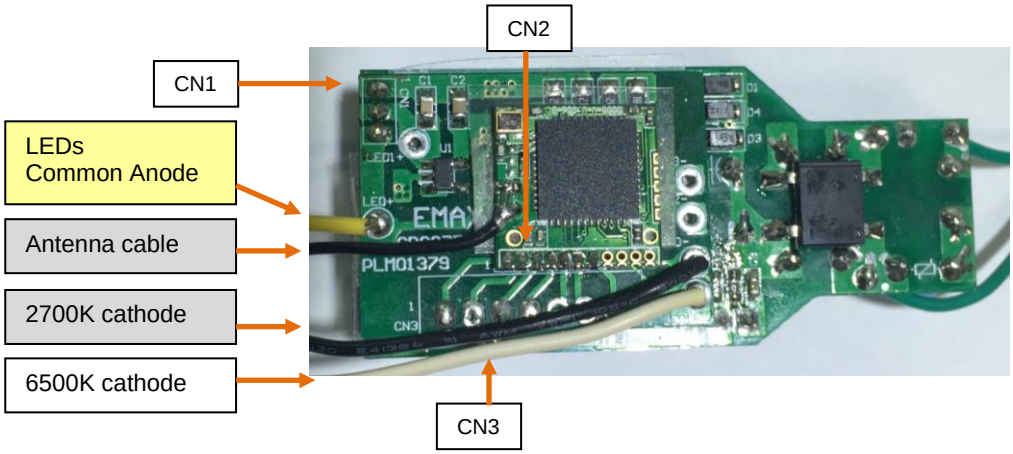


Figure 7 - Power Board + LED Driver Board + M56 ZigBee board

- ✧ Two green wires connected to AC input
- ✧ Three wires for Emitter:
    1. Yellow wire connected to LED's Common Anode
    2. Black wire connected to LED_ 2700K cathode
    3. White wire connected to LED_ 6500K cathode
- ✧ Antenna Cable from M56 Zigbee Module connected to A1 "Antenna Chip" of Emitter board

PERFORMANCE TESTING

The key system performance parameters of 2-ch TW SCL bulb are summarized in Table 1 below.

10W A19 2-Channel Tunable White Reference Light Bulb			
Item No	Parameter	Condition	Test Result
1	Input Voltage Range	100-240V_{AC} ~ 50/60Hz	
2	Power Factor	> 0.7 (LED1: 330mA, LED2: No Load)	110V_{AC}: 0.85 230V_{AC}: 0.73
3	Efficiency - PB Only	~ 85% (at LED1: 330mA, LED2: No Load)	110V_{AC}: 82.15% 230V_{AC}: 84.9%
4	Standby Power	< 0.5Watt (M56 ZigBee module Operating Current is about 33mA)	110V_{AC}/60Hz: 378mW; 230V_{AC}/50Hz: 450mW
5	Start-Up Time from Wall Switch	110V_{AC} (1.1MΩ+1.1MΩ Startup Resistor)	1.33 Sec
6	Output Ripple Voltage ($V_{peak-to-peak}$)	Test Condition at 230 V_{AC} LED1: 330mA LED2: 40mA	LED+_25V: 90mV (±1.9%) LED1+_5V: 56mV (±1.2%)
7	THD (Total Harmonic Distortion)	Test Condition LED1: 330mA LED2: No Load	110V_{AC}/60Hz: 51.58% 230V_{AC}/50Hz: 72.21%
8	Temperature of AL1792	< 105°C	70°C (Open Cover)
9	Line Regulation		LED+_25V = 26.06~24.93V LED1+_5V = 5.46~5.09V
10	Load Regulation		LED+_25V = 26.06~22.7V LED1+_5V = 5.46~3.8V

Table 1 - System Performance Testing of 2-ch TW SCL Bulb

Using a light measurment device (e.g. Integrating Sphere), key parameters of light outputs for a 2-Ch TW SCL bulb is measured and summarized in Table 2.

Based on the measured results, we could conclude that:

A19 10W 2-Ch TW SCL bulb could deliver desired output (over 800 lumens) at reasonable light quality (CRI > 80) and achieve a CCT Tuning with range from 2,700K to 6,500K with acceptable result (Duv < 0.006). The metric "Duv" is primarily used in connection with the expression of a “generally white” chromaticity in terms of CCT and Planckian locus offset.

No.	1	2	3	4	5	6	7	8	9	10	11
PWM $_{cold}$ (%)	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
PWM $_{warm}$ (%)	100%	90%	80%	70%	60%	50%	40%	30%	20%	10%	0%
Lumen	824	826	843	872	883	882	892	886	878	870	864
Efficacy (Lumen/Watt)	78.40	79.19	80.98	83.77	84.74	84.56	85.60	85.03	84.18	83.49	82.52
CCT (K)	2675	2874	3094	3331	3600	3909	4243	4637	5098	5622	6243
CIE x	0.4634	0.4446	0.4274	0.4119	0.3969	0.3824	0.3692	0.3558	0.3424	0.3297	0.3168
CIE y	0.4136	0.4039	0.3953	0.3875	0.3796	0.3719	0.3652	0.3579	0.3502	0.3434	0.3366
CIE u'	0.2634	0.2556	0.2482	0.2414	0.2348	0.2284	0.2223	0.2162	0.2102	0.2041	0.1978
CIE v'	0.529	0.5225	0.5164	0.5109	0.5053	0.4997	0.4947	0.4893	0.4836	0.4783	0.4729
Duv	0.0008	-0.0010	-0.0022	-0.0028	-0.0031	-0.0029	-0.0021	-0.0010	0.0004	0.0024	0.0050
Ra	81.4	83.1	84.6	85.8	86.6	87.0	87.0	86.8	86.2	85.6	84.2
Input Power (W)	10.51	10.43	10.41	10.41	10.42	10.43	10.42	10.42	10.43	10.42	10.47
PF	0.883	0.883	0.883	0.883	0.883	0.882	0.882	0.882	0.882	0.883	0.883
V LED+ (V)	24.7	24.7	24.7	24.7	24.7	24.7	24.7	24.7	24.7	24.7	24.7
I LED+ (mA)	344	342	342	342	342	342	342	342	342	342	342
Headroom (2700K) V_LED- _ON [V]	1.28	1.14	1.14	1.14	1.02	0.98	0.90	0.86	0.82	1.02	N/A
Headroom (6500K) V_LED1- _ON [V]	N/A	1.00	0.84	0.84	0.84	0.84	0.84	0.84	0.88	0.98	0.98

Table 2 - Light Output Measurement of 2-Ch TW SCL Bulb @110V_{AC}

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 2-ch TW 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 2.a on page 3)

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 AL1792, with optimal voltage headroom for attached LED emitter strings.

Per Energy Start Compliance requirement, the Power Factor (PF) for over 5W light bulb need to be over 0.70. 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 2-ch TW 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 (D8, R4, R9 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, 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 2-ch TW SCL bulb design, the standby power consumption is measured with estimated breakdown as follows:

1) AL1792 IC - 50 mW (Quiescent Supply Current of AL1792 EN Enable)
2) Dummy Loading - 50 mW (Added 22V zener diode between LED+ and LED1+)
3) Start-up Resistor Circuit - 50 mW (R5 and R6 are 1M/1206 resistor)
4) ZigBee Module - 300 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 $110V_{AC}$ (after fully whole circuit discharged)	Standby Power at $230V_{AC}$ LED OFF Mode (<0.5W)
two 1.1M = 2.2MΩ	1.33 Sec	450 mW
two 510K = 1020KΩ	0.62 Sec	470 mW
two 392K = 784KΩ	0.20 Sec	508 mW

*Vcc cap(C7)=4.7uF/50V

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

An alternative quick dynsmic 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 V_{CC} 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.

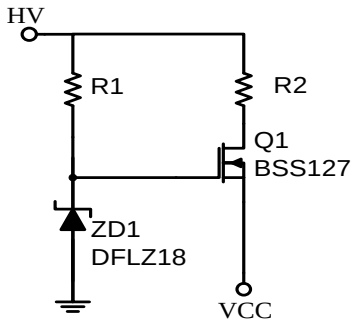


Figure 7 - Dynamic Fast Start-Up Circuit

▪ AL1792 Standby consumption

MCU can enable/disable the “EN” (Enable Pin) to save power while the AL1792 IC is in standby mode.

Input AC	AL1792 Standby Power With EN Enable	AL1792 Standby Power With EN Disable	Improved Power Saving
At $110V_{AC}$	378mW	350mW	28mW
At $230V_{AC}$	450mW	425mW	25mW

Table 4 - AL1792 Enable/Disable Power Consumption

➢ 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 CV output of The 2-ch TW SCL bulb design is in the range of 25V down to 23.5V.

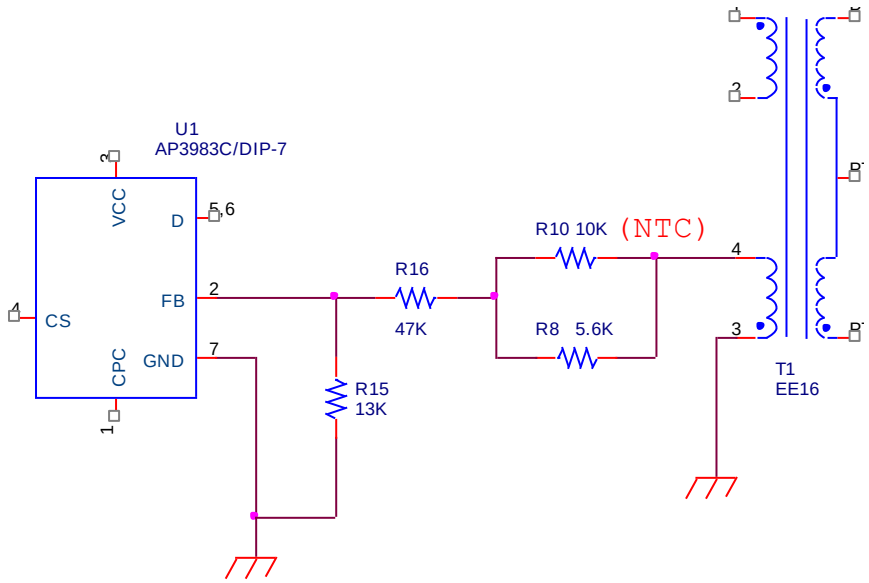
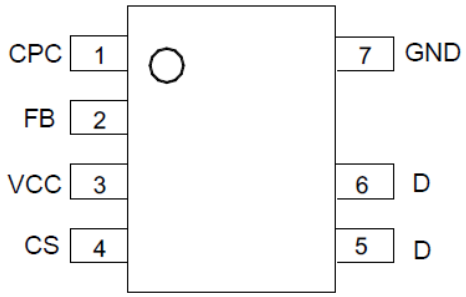


Figure 8 - Thermal Management Circuit

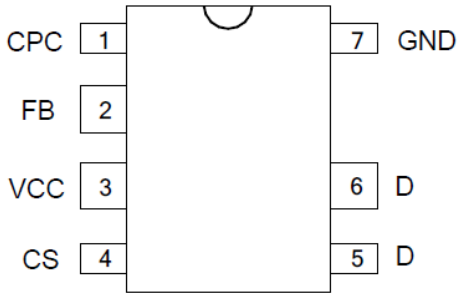
KEY COMPONENTS

➢ AP3983C - AC/DC Controller

AP3983C IC PIN OUT ASSIGNMENT



SO-7 (M Package) For AP3983B/C



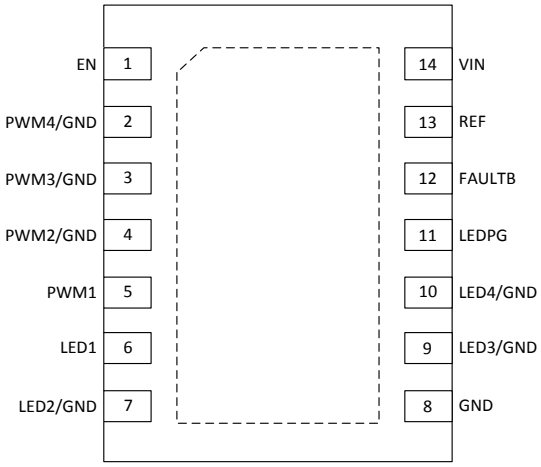
PDIP-7 (P7 Package) For AP3983D

- 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

Pin Name	Symbol SO-7 / PDIP-7	Descriptions
CPC	1	This pin is connected a capacitor to GND to serve as a 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	The pin is connected with an internal power MOSFET's drain.
GND	7	The 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 U-DFN4030-14	Descriptions
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, POWERDI 123	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	Diodes, Inc.	1A200V Surface mount super barrier rectifier POWERDI® 123
5	D7	1	DFLS160-7	Diodes, Inc.	1.0A/60V surface mount Schottky barrier rectifier POWERDI® 123
6	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.
7	C5	1	470uF/35V/10*16		LED+ output filter capacitor
8	C9	1	220uF/16V/6.3*11		LED1+ output filter capacitor
9	C7	1	4.7uF/50V/5*11		AP3983C startup and VCC hold-up capacitor
10	C8	1	0.1uF/50V/0603		AP3983C output cable compensation
11	C1,C2	2	1nF/1KV/1206		Snubber capacitor
12	C3	0	-		Not fitted. (Snubber capacitor)
13	C10	0	-		Not fitted. (Snubber capacitor)
14	C11	1	0.22uF/450V		EMI filter
15	CX1	1	0.047uF/275V_{AC}		EMI filter
16	CY1	1	1000pF/Y1		EMI capacitor
17	R5,R6	2	1.1M/1206		Startup resistor (must for high voltage stress >200V)
18	R1	1	0R/0805		Jumper resistor
19	R2	1	100K/1206		Snubber resistor
20	R3	1	10R/1206		Snubber resistor
21	R7	1	2R/0805		Snubber resistor
22	R8	1	5.6K/0603		AP3983C voltage feedback resistor
23	R10	1	10K/0603		AP3983C voltage feedback resistor
24	R16	1	47K/0603		AP3983C voltage feedback resistor
25	R15	1	13K/0603		AP3983C voltage feedback resistor
26	R13, R14	2	2R/1206		AP3983C current sense resistor
27	D8	1	BZT52C22-7-F	Diodes, Inc.	Fitted a 22V zener diode, for pre load of "LED+"
28	R4,R9,R12	0	-		Not fitted. (For dummy load)
29	R11	0	-		Not fitted. (Snubber resistor)
30	T1	1	EE16	Emax	EE16 Transformer (N_P:N_A:N_S_25V:N_S_5V=118: 19: 23: 6; 0.82mH)
31	F1	1	T1A-T250V		Fuse
32	CN1	1	CON3*1_2mm	CviLux	Output connector

			(CH1101S)		
33	L1	1	1.0mH/6Φ I core		EMI filter inductance
34	VDR1	1	471K		Surge Absorber
TOTAL		38			Power Board Electronic Parts

Bill of Material – LED Driver Board

#	Name	QTY	Part Number	Manufacturer	Description
1	U1	1	AP2204K-3.3TRG1	Diodes, Inc.	Wide input voltage range, 150mA ULDO regulator, SOT23-5
2	U2	1	AL1792AFE-13	Diodes, Inc.	Dual channel LED driver with analog and PWM dimming U-DFN-4030-14 Replace AL1792 with AL1791 for 1-ch DW
3	R4	1	9.1K/1206		AL1792 LED current setup resistor
4	R5	0	-		Not fitted
5	R1,R2,R3	3	10K/1203		
6	R9,R10	2	0R/0603		
7	R6,R7	2	0R/0603		
8	C1	1	1.0uF/50V/0805		
9	C2	1	4.7uF/6.3V/0805		
10	C3	1	0.1uF/50V/0805		
11	CN2	1	Pitch 1.27mm 7Pin (CH0101S)	CviLux	For M56 ZigBee module
12	CN3	0	Pitch 2.54 7pin, (CH3101S)	CviLux	Being used for CDK module
TOTAL		14			LD board electronic parts

Bill of Material – Emitter Board

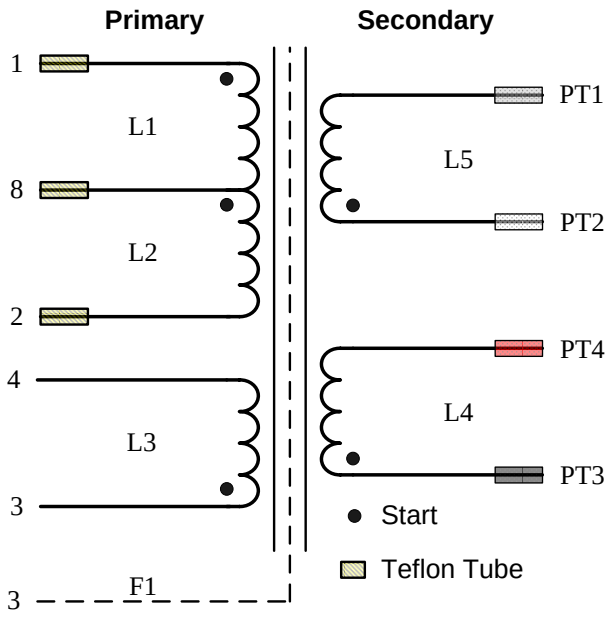
#	Name	QTY	Part Number	Manufacturer	Description
1	D1, D2, D3, D4, D5, D6, D7, D8, D9, D10, D11, D12	12	LTW-3030DZL27	LITEON, Inc.	LTW-3030DZL Emitter Series
2	D13, D14, D15, D16, D17 D18, D19, D20, D21, D22 D23, D24	12	LTW-3030DZL65	LITEON, Inc.	LTW-3030DZL Emitter Series (NO need for 1-ch DW light bulb)
3	R1	1	0R/0805		Jumper
4	R2, R3	2	0R/1206		Jumper(Reserved for future use)
5	A1	1	ANT3216LL11R2400A		
TOTAL		28			LD Board Electronic Parts

APPENDIX I - EE16 TRANSFORMER SPEC

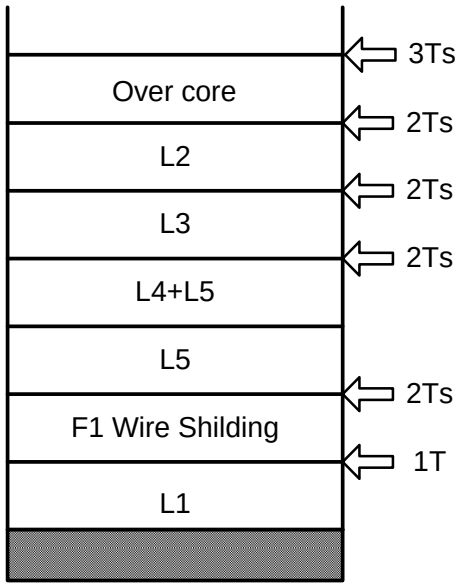
EE16 transformer with (Appendix X).

A. Transformer Pin & Wire Description:

Circuit：



Cross sectional view：



	Pin definition (Start→End)	Wire (φ)	Turn (Ts)	Layers	Layers of Tape
L1	1→ 8	2UEW-B 0.21mm x 1P	72	2	1T
F1	3→	2UEW-B 0.1mm x 1P	75	1	2Ts
L5	PT2→ PT1	Triple wire-B 0.35mm x 1P	23	1.5	
L4	PT3→ PT4	Triple wire-B 0.35mm x 1P	6	0.5	2Ts
L3	3→ 4	2UEW-B 0.2mm x 1P	19	1	2Ts
L2	8→ 2	2UEW-B 0.21mm x 1P	46	2	2Ts
	OVER CORE				

B. Electrical Characteristic :

#	Test Item	Winding	Pin	Rating	Unit	Tolerance	Remark
2.1	Inductance	L1 and L2	1 → 2	0.82	mH	+/-5%	@ 100KHz / 1V

APPENDIX II - LITEON OPTO 2-CHANNEL TW EMITTER MODULE

✧ LTW-3030DZL Emitter Series (LTW-3030DZL27 and LTW-3030DZL65) -

✧ 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

SINGLE Voltage to Emitter Strings based on LiteON 10W Emitter Module					
Item	Category	Channel 1 - Cold CCT White	Channel 2 - Warm CCT White	Total	Comment
1	Current (mA)	330.0	330.0	660.0	Rset = 9.1KΩ for 330mA (Channel 1 and 2)
2	Voltage / Emitter (volts)	6.06	6.06		Two Die in one Emitter, VF/Emitter = 6.11V
3	No. of Emitters	4	4	8	* Two emitter strings (6,500K and 2,700K), Each emitter has 3 parallel strings of 4 emitters in serial.
4	V_F of Emitter String	24.24	24.24		
5	Voltage Supply LED+ (volts)	24.74	24.74		* Assume +0.5V voltage headroom
6	LED Input Power (Watt)	7.999	7.999	7.999	
7	Luminous Flux / Spec Drive Current	1,010.0	1,010.0		* Lm for one emitter (3 * @120mA)
8	Spec Drive Current	120.0	120.0		* 3 Emitter string, each emitter string has 4 serial emitters
9	Potential Luminous Flux (lm)	925.8	925.8		* Linearly scale lumen to 110mA vs 120mA
10	Effective Lumen Output (lm)	805.5	805.5	87.0%	* Assuming 87% from emitters to lamp lumens
11	Total Input Power to Emitter + IC	8.164	8.164	8.164	
12	Power Efficiency (%)	98.0%	98.0%	98.0%	

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

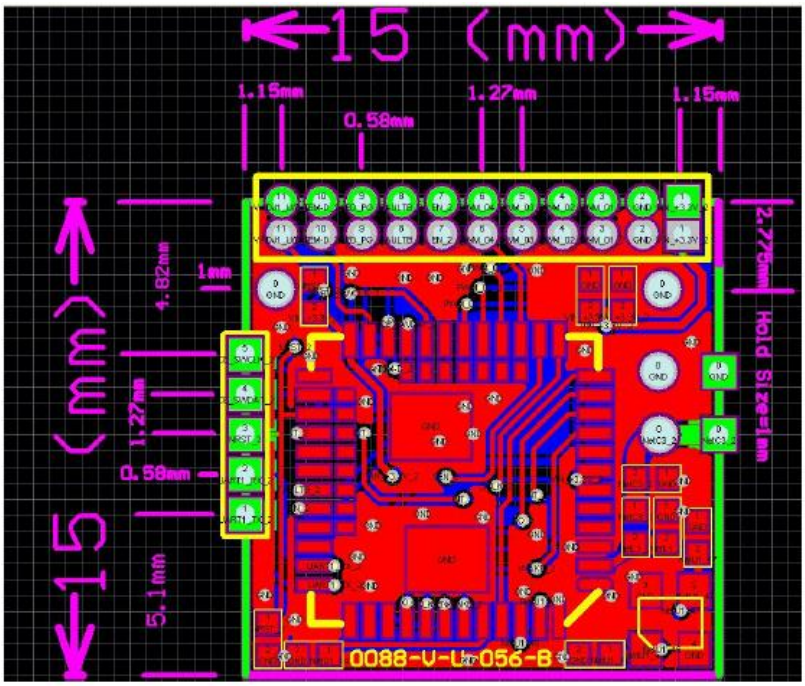
APPENDIX III - ZIGBEE MODULE M56 (UBEC)

✧ 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

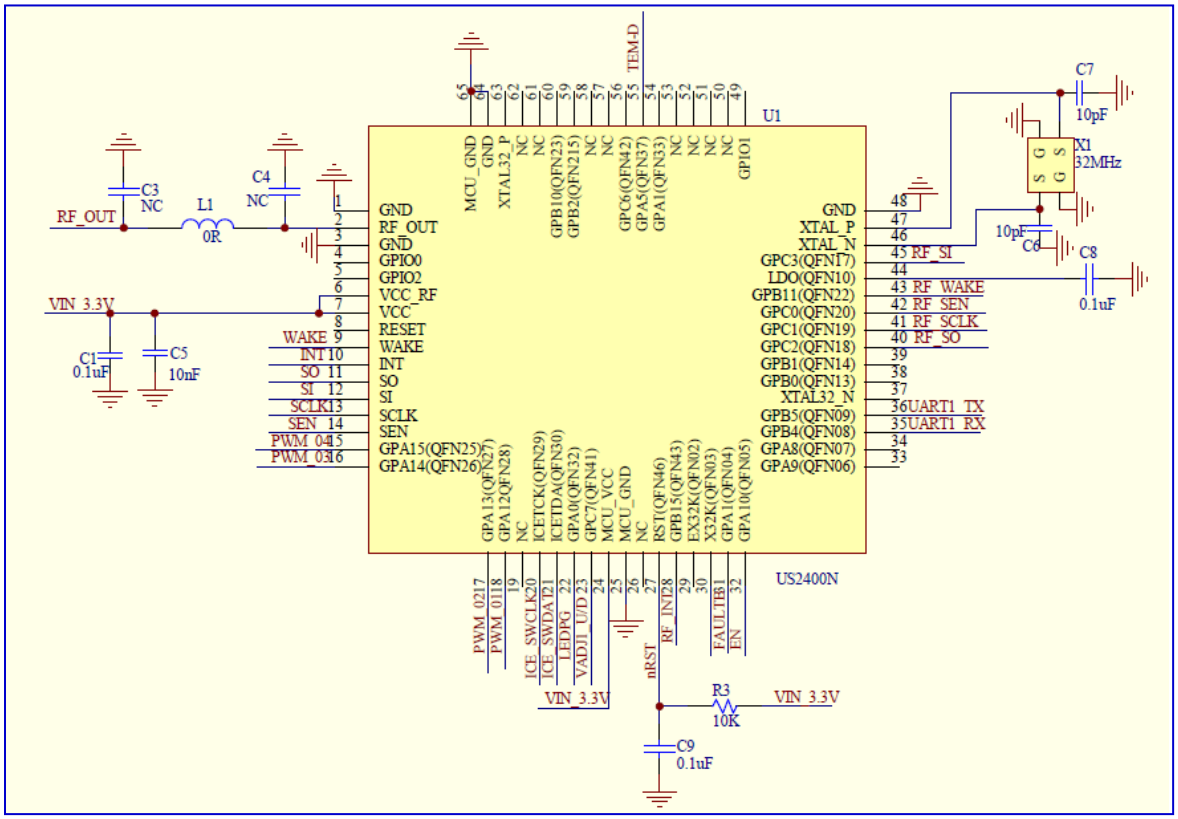
Pin#	Pin Name	Functions
1	VDD	Connected to LED driver board - 3.3V
2	GND	Connected to LED driver board Ground
3	PWM_01	Connected to LED driver board – PWM1 of AL1792 To control 6,500K LED
4	PWM_02	Connected to LED driver board – PWM2 of AL1792 To control 2,700K LED
5	PWM_03	Connected to LED driver board – Reserved for future use
6	PWM_04	Connected to LED driver board – Reserved for future use
7	EN	Connected to AL1792 Pin#1-EN, Enable AL1792.

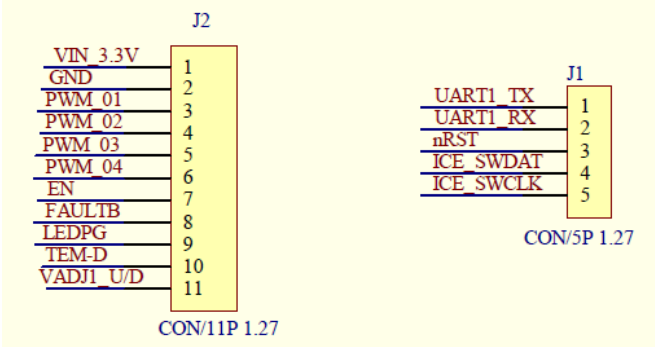
Output Pin Functions (Connected to LED Driver Board Module)



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)	6,500K
4	PWM_02	PWM 0 channel 1 output, GPIO, (PA. 13)	2,700K
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^2C 1 SDA, (PA. 10)	EN
8	FAULTB	GPIO, I^2C 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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