UM10938

OM15031 smart lighting module for CCTW applications

Rev. 1.0 — 16 November 2015 **User manual**

Document information

Info	Content
Keywords	SSL5251T, SSL5255TE, SSL5236TE, SSL5257TE, JN5168, JN5169, ZigBee remote control, QN9021 Bluetooth Low Energy (BLE) remote control, lighting, LED driver, LED,PCB antenna, ZigBee, Color Changeable Tunable White (CCTW), Bluetooth Low Energy (BLE)
Abstract	This user manual describes the 120 V SSL5251T CCTW LED application board for smart lighting. This board is intended to apply with the OM15008 Small Signal Board (SSB) that contains the JN5169 wireless ZigBee microcontroller, or with the OM15016 SSB that contains the QN9021 BLE microcontroller. These two boards together with a LED load form a complete wireless controllable lamp application from which the brightness and color temperature can be controlled independently from each other.

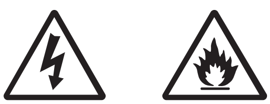
Revision history

Rev	Date	Description
0.0	20150616	Draft version of the OM15031 user manual
0.1	20151005	Add SSB BLE board OM15016 (in addition to the ZigBee board OM15008) Replace LED driver SSL5231 with SSL5251 Replace LED driver SSL5235 with SSL5255 Replace LED driver SSL5237 with SSL5257
1.0	20151116	First released

Contact information

For more information, please visit: http://www.nxp.com

1. Safety warning

Warning	
Lethal voltage and fire hazard	
	The non-insulated high voltages that are present when operating this product constitute a risk of electric shock, personal injury, death and/or ignition of fire. This product is intended for evaluation purposes only. It shall be operated in a designated test area by personnel qualified according to local requirements and labor laws to work with non-insulated mains voltages and high-voltage circuits. This product shall never be operated unattended.

The board must be connected to (rectified) mains voltage. Avoid touching the demo board while it is connected to the mains voltage. An isolated housing is obligatory when used in uncontrolled, non-laboratory environments. Galvanic isolation, of the mains phase using a variable transformer is always recommended.

a. Isolated b. Non isolated

Fig 1. Variable transformer isolation symbols

2. Introduction

The OM15031 board is a Large Signal Board (LSB) with a SSL5251T that is used in non-isolated flyback topology. This topology is chosen for two reasons:

The circuit acts as a LED driver as well as a power supply for the wireless microcontroller, both when the LED is on as well as when the LED's are off. In the latter situation, the auxiliary voltage is controlled at a level such that the LED's do not conduct any current, so do not emit any light.

The second reason is that LED current is measured with a sense resistor, and the average voltage across this sense resistor is controlled by the SSL5251T resulting in a very good line regulation.

The board is designed to connect two LED strings with a different color temperature e.g. 2700° K and 6500° K. Then the brightness and color temperature of the light can be controlled independently from each other with a remote control.

The OM15031 board is designed to be used with an OM15008 SSB designed around a JN5169 wireless microcontroller. This SSB adds the wireless connectivity to the OM15031 board. One PWM output of the JN5169 is used to control the brightness of the light another PWM output is used to control the color temperature of the light. OM15031 can also be used with the SSB OM15016 designed around QN9021, for control via BLE.

a. OM15031 LSB with OM15008 SSB on top of it.

b. Bottom of the OM15031 LSB.

Fig 2. OM15031 LSB with OM15008 SSB on top of it

3. Specification

- Brightness and color temperature can be controlled independently from each other
- Flyback topology LED driver that also serves as microcontroller supply
- SSL5251T driver IC
- Linear dimming
- Surge protection with MOV and TVS
- Integrated open string protection via DEMOVP pin
- Seamless operation with OM15008 or OM15016 SSB

- matches with A19 screw type lamp casing

Table 1. OM15031 module specification

Parameter	Min	Typ	Max	Units	Comment
AC supply voltage	85	120	140	V	
Input power	-	11.3	-	W	
Output current	-	190	-	mA	measured with 8 x 3030 LED string
Output voltage	-	49.5	-	V	8 x 3030 LED string
Efficiency	-	83	-	%	including supply for OM15008 board with JN5169
Power factor	-	0.95	-		
THD	-	19	-	%	
Line regulation	-	1%	-		V_{MAINS} = 120 V ± 10%
SSB supply voltage	-	2.9	-	V	
Standby power	-	230	-	mW	using OM15008 board with JN5169

4. Board dimensions

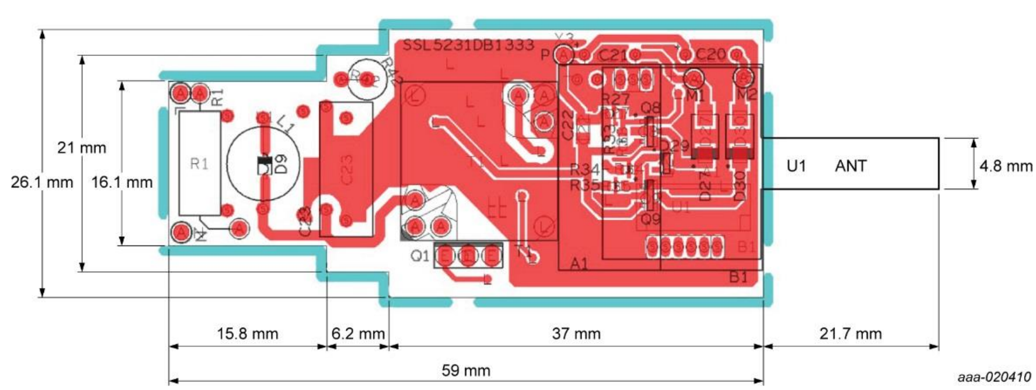
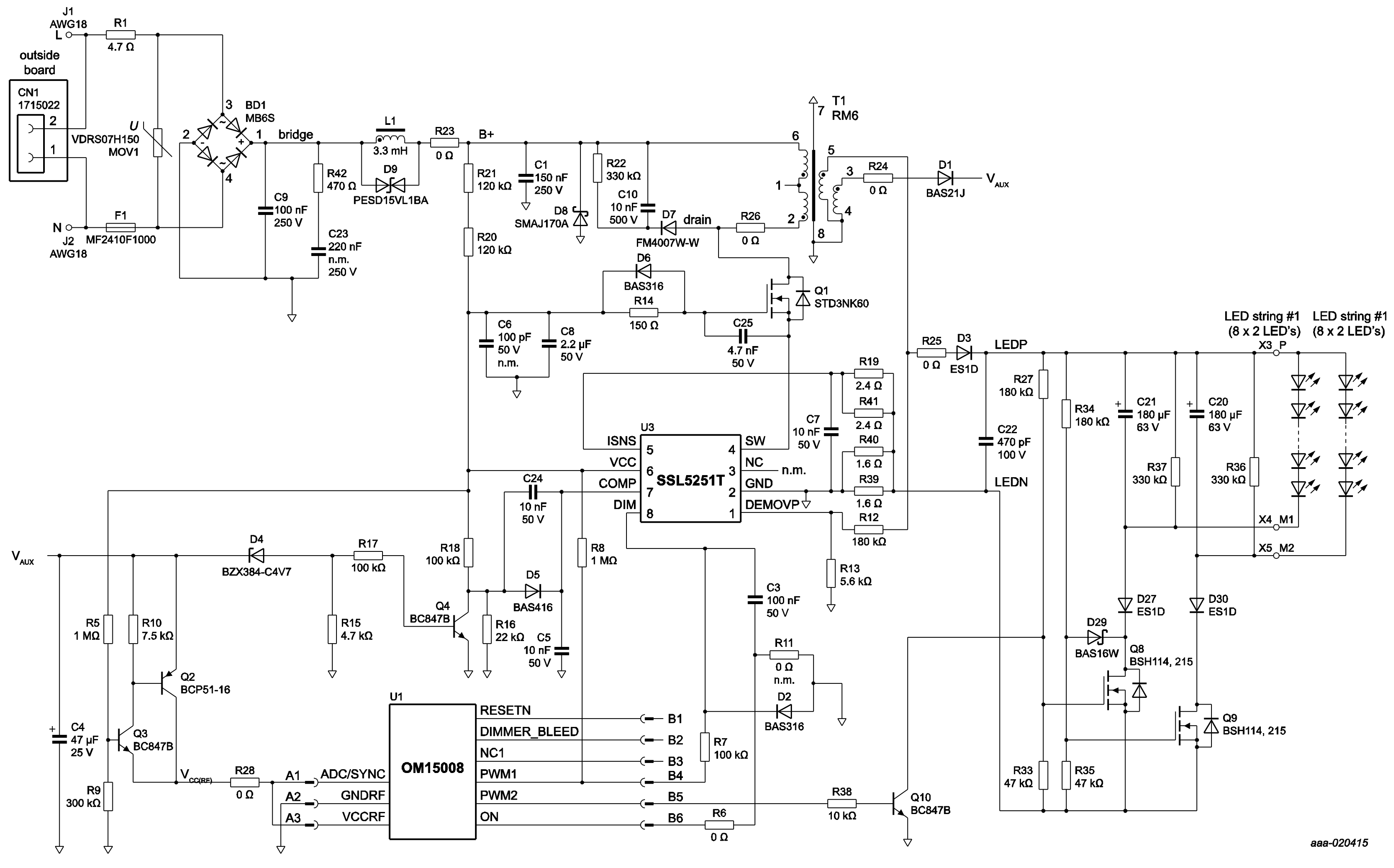


Fig 3. OM15031 board dimensions

Dimensions of the OM15008 or OM15016 are 17.2 mm x 18.5 mm (without antenna)

Dimensions of the antenna 21.7 mm x 4.8 mm

5. Schematic OM15031 board



(1) Application details: V_{MAINS} = 230 V_{ac}, P_{in} = 11.5 W, I_{led} = 190 mA, V_{led} = 50 V.

Fig 4. OM15031 schematic

6. Bill Of Material (BOM) OM15031 application

Table 2. BOM

Ref.des	Description and values	Part number	Manufacturer
BD1	Bridge Rect.; 600 V; 800 mA	MB6S	Multicomp
C1	Capacitor; 150 nF; 5 %; 250 V; PET; THT	ECQ-E2154JF	Panasonic
C3	Capacitor; 100 nF; 10 %; 50 V; X7R; 0603	Any Man. Part Number	Any Manufacturer
C4	Capacitor; 47 μF; 20 %; 25 V; ALU; THT	EEUFM1E470	Panasonic
C5	Capacitor; 10 nF; 10 %; 50 V; X7R; 0603	Any Man. Part Number	Any Manufacturer
C6	N.M.		
C7	N.M.		
C8	Capacitor; 2.2 μF; 10 %; 50 V; X5R; 0805	C2012X7R1H225K125AC	TDK
C9	Capacitor; 100 nF; 5 %; 250 V; PET; THT	ECQE2104JF	Panasonic
C10	Capacitor; 10 nF; 10 %; 500 V; X7R; 1206	C1206C103KCRACTU	Kemet
C20	Capacitor; 180 μF; 20 %; 63 V; ALU; 10X20	EEUFR1J181	Panasonic
C21	Capacitor; 180 μF; 20 %; 63 V; ALU; 10X20	EEUFR1J181	Panasonic
C22	Capacitor; 470 pF; 5 %; 100 V; NP0; 0805	CGA4C2C0G2A471J060AA	TDK
C23	Capacitor; 220 nF; 5 %; 250 V; PET; THT	ECQ-E2224JF	Panasonic
C24	Capacitor; 10 nF; 10 %; 50 V; X7R; 0603	GRM188R71H103KA01D	Murata
C25	Capacitor; 4.7 nF; 10 %; 50 V; X7R; 0603	GRM188R71H472KA01D	Murata
D1	Diode; 300 V; 200 mA	BAS21J	NXP
D2	Diode; 100 V; 250 mA	BAS316	NXP
D3	Diode; Ultrafast; 200 V; 1 A	ES1D	Fairchild
D4	Diode; Zener; 4.7 V; 250 mA	BZX384-C4V7	NXP
D5	Diode; 85 V; 200 mA; Low leakage	BAS416	NXP
D6	Diode; 100 V; 250 mA	BAS316	NXP
D7	Diode; 700 V; 1 A	FM4007W-W	Rectron Semi.
D8	TVS; 170 V;	SMAJ170A	STMicroElectronics
D9	TVS; 44 V; 5 A	PESD15VL1BA	NXP
D27	Diode; Ultrafast; 200 V; 1 A	ES1D	Fairchild
D29	Diode; 100 V; 175 mA	BAS16W,115	NXP
D30	Diode; Ultrafast; 200 V; 1 A	ES1D	Fairchild
F1	Fuse; 1 A; Fast Blow	MF2410F1.000TM	AEM Inc.
L1	Inductor; 3.3 mH; 140 mA	ELC09D332F	Panasonic
MOV1	VDR; 150 V_{AC}; 20 J; Disc	VDRS07H150BSE	Vishay
Q1	MOSFET-N; 600 V; 2.4 A; 3R3	STD3NK60	ST
Q2	Transistor; PNP; 45 V; 1 A		NXP
Q3	Transistor; NPN; 45 V; 100 mA	BC847B	NXP
Q4	Transistor; NPN; 45 V; 100 mA	BC847B	NXP
Q8	MOSFET-N; 100 V; 500 mA	BSH114,215	NXP
Q9	MOSFET-N; 100 V; 500 mA	BSH114,215	NXP
Q10	Transistor; NPN; 45 V; 100 mA	BC847B	NXP
R1	Resistor; 4.7 Ω; 5 %; 1 W; THT	AC01000004708JA100	Vishay
R5	Resistor; 1 M Ω; 1 %; 63 mW; 0603	Any Man. Part Number	Any Manufacturer
R6	Resistor; 0 Ω; jumper; 63 mW; 0603	Any Man. Part Number	Any Manufacturer
R7	Resistor; 100 k Ω; 1 %; 63 mW; 0603	Any Man. Part Number	Any Manufacturer
R8	Resistor; 1 M Ω; 1 %; 63 mW; 0603	Any Man. Part Number	Any Manufacturer
R9	Resistor; 300 k Ω; 1 %; 63 mW; 0603	Any Man. Part Number	Any Manufacturer
R10	Resistor; 7.5 k Ω; 1 %; 63 mW; 0603	Any Man. Part Number	Any Manufacturer
R11	N.M.		
R12	Resistor; 180 k Ω; 1 %; 250 mW; 1206	Any Man. Part Number	Any Manufacturer

Ref.des	Description and values	Part number	Manufacturer
R13	Resistor; 5.6 k Ω; 1 %; 63 mW; 0603	Any Man. Part Number	Any Manufacturer
R14	Resistor; 150 Ω; 1 %; 63 mW; 0603	Any Man. Part Number	Any Manufacturer
R15	Resistor; 4.7 k Ω; 1 %; 63 mW; 0603	Any Man. Part Number	Any Manufacturer
R16	Resistor; 22 k Ω; 1 %; 63 mW; 0603	Any Man. Part Number	Any Manufacturer
R17	Resistor; 100 k Ω; 1 %; 63 mW; 0603	Any Man. Part Number	Any Manufacturer
R18	Resistor; 100 k Ω; 1 %; 63 mW; 0603	Any Man. Part Number	Any Manufacturer
R19	Resistor; 2.4 Ω; 1 %; 250 mW; 0805	ERJ6BQF2R4V	Panasonic
R20	Resistor; 120 k Ω; 1 %; 250 mW; 200 V; 1206	RC1206FR-07120KL	Yageo
R21	Resistor; 120 k Ω; 1 %; 250 mW; 200 V; 1206	RC1206FR-07120KL	Yageo
R22	Resistor; 330 k Ω; 5 %; 250 mW; 200 V; 1206	RC1206FR-07330KL	Yageo
R27	Resistor; 180 k Ω; 1 %; 100 mW; 0603	RC0603FR-07180KL	Yageo
R33	Resistor; 47 k Ω; 1 %; 100 mW; 0603	RC0603FR-0747KL	Yageo
R34	Resistor; 180 k Ω; 1 %; 100 mW; 0603	RC0603FR-0747KL	Yageo
R35	Resistor; 47 k Ω; 1 %; 100 mW; 0603	RC0603FR-0747KL	Yageo
R36	Resistor; 330 k Ω; 1 %; 100 mW; 0603	RC0603FR-07330KL	Yageo
R37	Resistor; 330 k Ω; 1 %; 100 mW; 0603	RC0603FR-07330KL	Yageo
R38	Resistor; 10 k Ω; 1 %; 63 mW; 0603	Any Man. Part Number	Any Manufacturer
R39	Resistor; 1.6 Ω; 1 %; 330 mW; 1206	ERJ8BQF1R6V	Panasonic
R40	Resistor; 1.6 Ω; 1 %; 330 mW; 1206	ERJ8BQF1R6V	Panasonic
R41	Resistor; 2.4 Ω; 1 %; 250 mW; 0805	ERJ6BQF2R4V	Panasonic
R42	Resistor; 470 Ω; 5 %; 1 W;	AC01000004700JA100	Vishay
T1	Transformer; RM6	750315266r00	Wuerth
U2	LED Drv. Dim.; SSL5251T	SSL5251T	NXP

When replacing components by types from other manufactures verify that they are suited for operation at 125 °C.

7. Transformer

The transformer has the number of turns as given in Table 3.

Table 3. Transformer construction

Winding	Number of turns
Primary	74
Secondary	40
Auxiliary	10

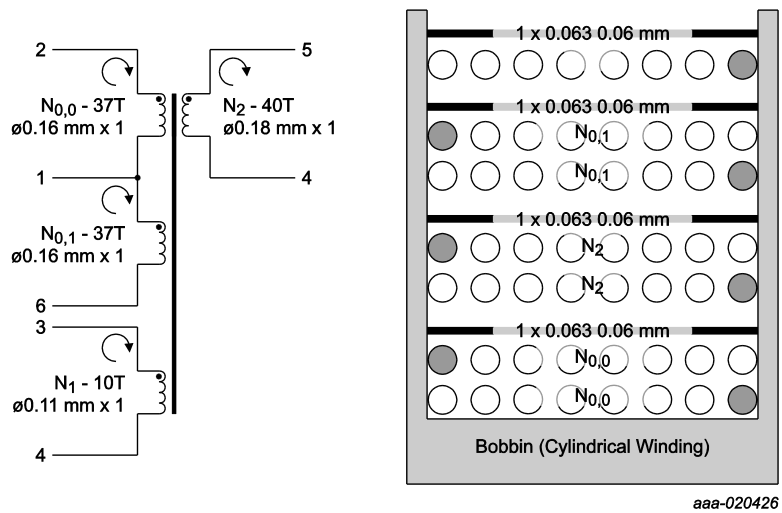
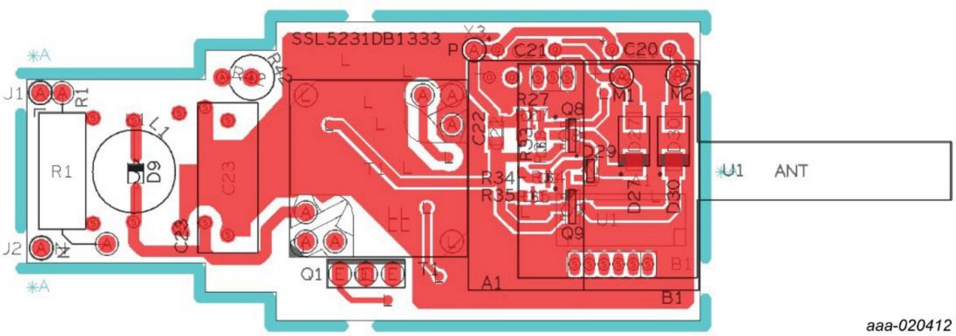
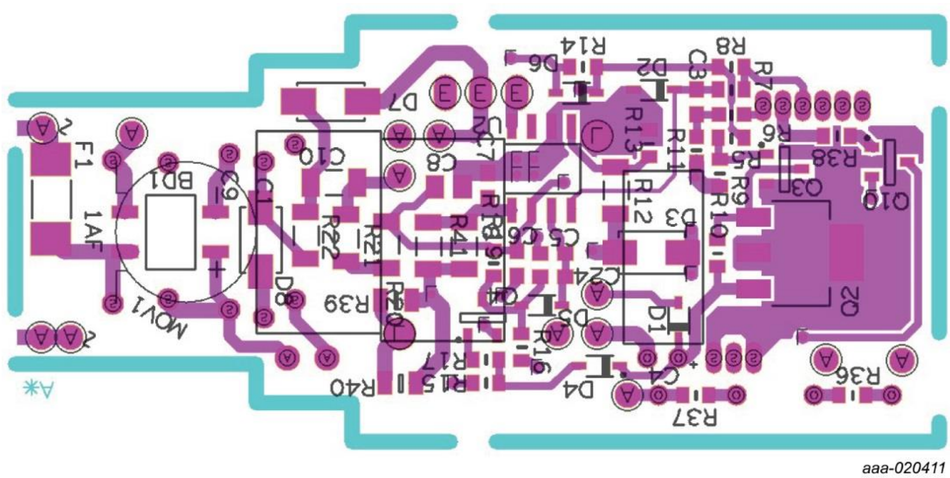


Fig 5. Transformer construction

8. Board layout



(1) Top.



(2) Bottom.

Fig 6. OM15031 layout

Note: the top side of the OM15008 (or OM15016) board is facing towards the top side of the OM15031 LSB.

9. Functional description

9.1 Block diagram

Fig 7 shows a high level block diagram of the OM15031 application.

Note: there is no main separation in the circuit.

The LED string and electrolytic capacitor inside the gradient filled block "CCTW block" represents the CCTW circuit that is described in detail in chapter 10. For the operation of the rest of the circuit it makes no difference if a CCTW block or single LED string is connected as output load. The circuit is built around the SSL5251T LED driver IC and a three winding transformer. The SSL5251T is driving an external mosfet in source switching mode. In this way there is only an external resistor needed for startup and supply of the SSL5251T.

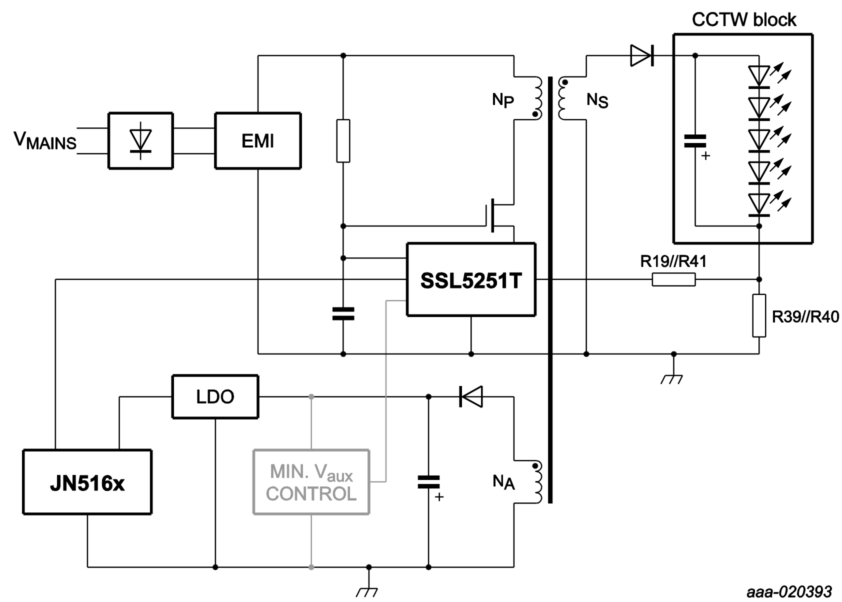


Fig 7. Block diagram of the OM15031 board

The JN5168x (or QN9021) is supplied from the auxiliary winding via a Low Dropout (LDO) linear voltage regulator.

9.2 LED current control circuit

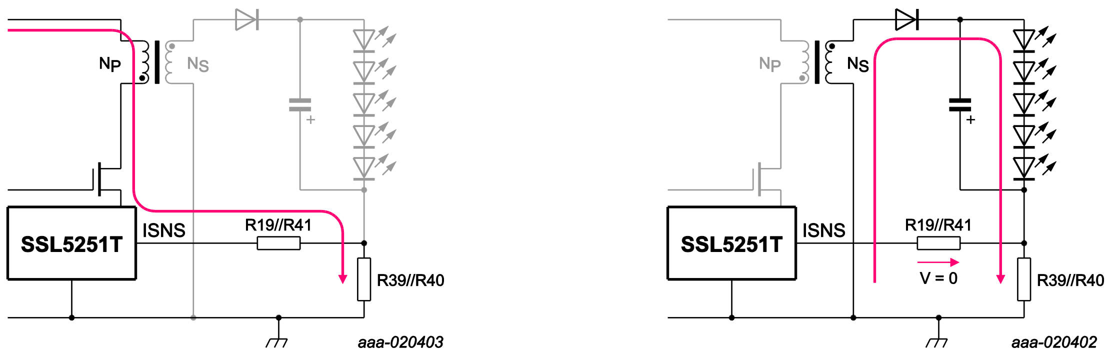
The OM15031 board uses two sense resistors:

- The value of R39//R40 sets the LED current
- The value of R39//R40 + R19//R41 determines the maximum primary current, in other words: it prevents the core from saturating.

The notation R39//R40 means "R39 in parallel to R40" so the resistance is:

$$R39 \,//\, R40 = \frac{R39 \times R40}{R39 + R40} \quad (1)$$

Because two sense resistors are used, both the current during the forward stroke and the flyback stroke can be monitored.



a. Forward stroke.

b. Flyback stroke.

Fig 8. Current sensing during forward and flyback stroke

During the forward stroke, the primary current is flowing through R19//R41 and R39//R40. The mosfet will be switched off if the voltage on the sense pin reaches 1.8 V.

So the maximum primary peak current is given by:

$$\hat{I}_{PRIM,\max} = \frac{1.2V}{(R19 // R41) + (R39 // R40)} \tag{2}$$

During the flyback stroke the secondary current is flowing through R39//R40. The voltage across R39//R40 is supplied to the SSL5251T via R19//R41. There is no voltage drop across R19//R41, so the voltage that is sensed on the ISNS pin is equal to the voltage across R39//R40.

Fig 9 shows the control circuit: the DC voltage on the DIM pin is fed to the dimming control transfer function and it output is supplied to an Operational Transconductance Amplifier (OTA) together with the voltage across the sense resistor. Note that the OTA is only active during the flyback stroke. The output current of the OTA is charging/discharging the capacitor on the COMP pin depending on if the average voltage across the sense resistor is lower/higher than the set value. The DC voltage on the COMP pin is converted into an ON-time in the t_{ON} block according to the function that is shown in Fig 10.

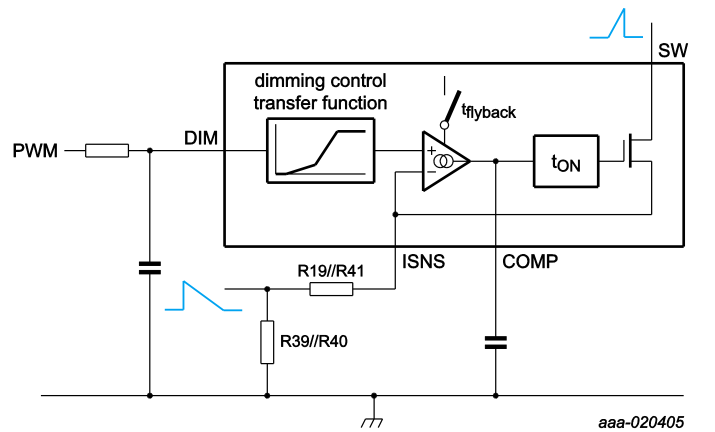


Fig 9. LED current control circuit

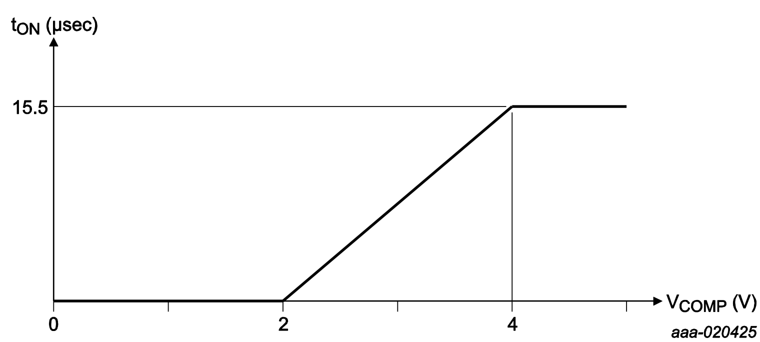


Fig 10. t_{ON} as function of the voltage on the COMP pin

Recapitulating the previous, it means that the ON-time is regulated such that the average voltage across the sense resistor R39//R40 is equal to the output voltage of the dimming control transfer function effectively keeping the LED current constant.

The output voltage of the dimming control transfer function is clamped at 310 mV (see Fig 17). The maximum (undimmed) average LED current can be calculated with:

$$I_{LED(Average)} = \frac{0.155V}{R39 // R40} \quad (3)$$

When the lamp is dimmed, then the lamp current will be lower. The dimming of the lamp is described in detail in paragraph 9.4.

9.3 Supply of the SSB

9.3.1 Supply of the SSB when the lamp is ON

The SSB is supplied from the auxiliary voltage both when the lamp is on as well as when the lamp is in standby. When the lamp is ON, the current through the LED string is kept constant by the SSL5251T as is shown in Fig 11 and the voltage across the secondary winding is determined by the LED string voltage. Fig 12 shows the current through a LED string that consists of 8 pieces of 3030 2D LED's, as function of the LED voltage.

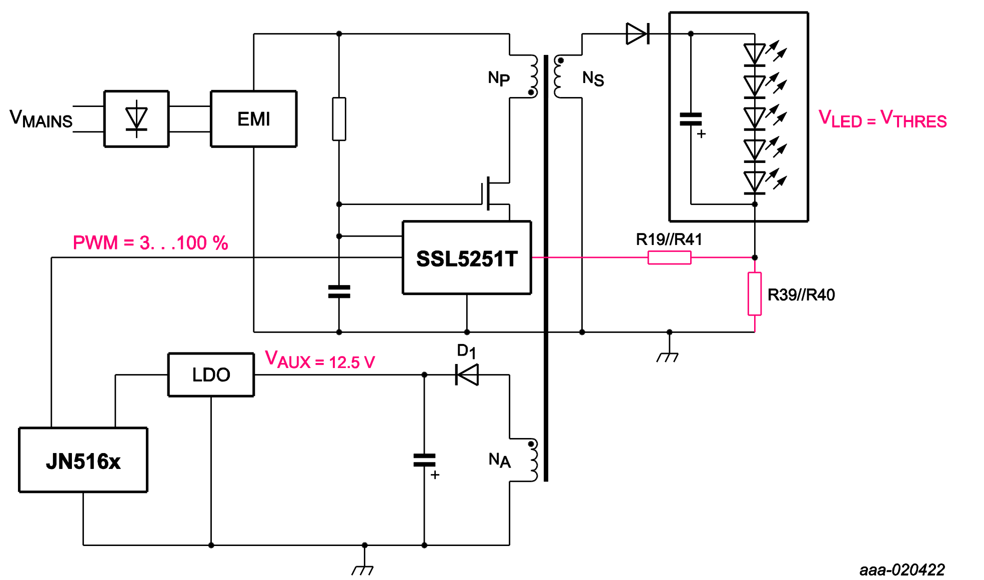


Fig 11. Situation when the lamp is ON

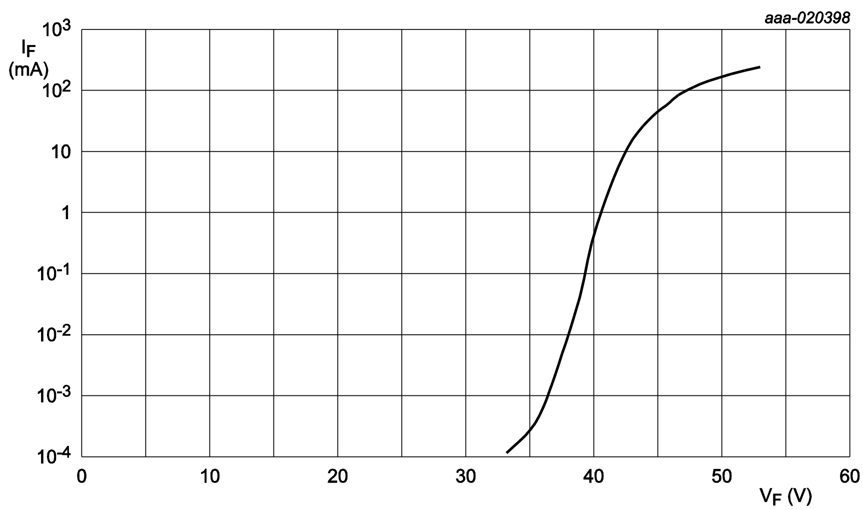


Fig 12. Current (mA) through 8 x 3030 LED string versus forward voltage (V)

Now the auxiliary voltage can be calculated from:

$$V_{AUX,LampON} = \frac{N_{AUX}}{N_{SEC}}\left(V_{LEDSTRING} + V_{Forw,D3}\right) - V_{Forw,D1} \quad (4)$$

The auxiliary voltage is supplied to a linear regulator who reduces the voltage to about 3 V. This linear regulator can both be an integrated LDO as is shown in the block diagram of Fig 7, or a discrete solution. The advantage of using a discrete solution in the OM15031 application is that the V_{CC} (15.8 V) of the SSL5251T can be used as reference, so there is no Zener diode needed as normally would be needed for a discrete regulator. The schematic of this solution is shown in Fig 13.

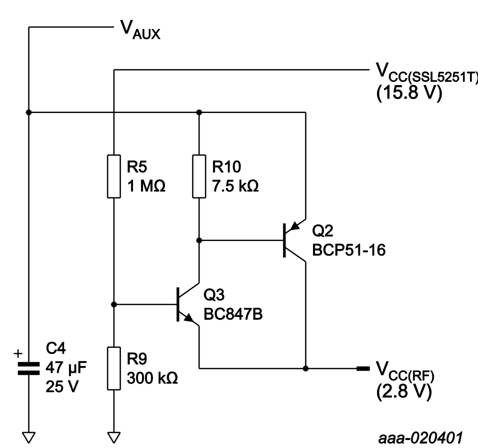


Fig 13. Discrete linear regulator using V_{CC} as reference

If it is assumed that the current through R5 is 1.1 time the current through R9 and that V_{BE} = 0.6 V then the value of $V_{CC(RF)}$ can be calculated with:

$$V_{CC(RF)} = \frac{R9 \times V_{CC(SSL5251T)} - 0.6(R9 + 1.1R5)}{R9 + 1.1R5} \quad (5)$$

Filling in values for $V_{CC(SSL5251T)}$, R5 and R9 in this equation yields the following results:

Table 4. Results of equation (5)

$V_{CC(SSL5251T)}$ (V)	R5 (MΩ)	R9 (kΩ)	$V_{CC(RF)}$ (V)
15.8	1	300	2.8
15.8	1	330	3.05
15.8	1	360	3.3

Note: V_{AUX} and $V_{CC(SSL5251T)}$ must be present before $V_{CC(RF)}$ is available. When the temperature rises, then $V_{CC(RF)}$ rises as well. This is not a problem as the JN5169 has a supply voltage range from 2 V to 3.6 V.

$V_{CC(RF)}$ is only intended to supply the OM15008 or OM15016 module. Connecting other loads e.g. RF amplifiers to this supply might result in light flicker or a too low $V_{CC(RF)}$ supply voltage.

9.3.2 Supply of the SSB when the lamp is OFF

When the lamp is OFF, i.e. standby, then the wireless microcontroller still must be supplied to receive messages via the wireless network but no current should flow through the LED string. These two requirements are accomplished by making the PWM1 to 0%, and controlling the auxiliary voltage to such a value that the voltage across the LED string is below the threshold value. For a 8 x 3030 LED string this is about 35 V.

Note: even a current of 1μA through the LED string is already visible in a dark room.

Now the auxiliary voltage should be controlled to a value that is below:

$$V_{AUX\_MAX,LampOFF} = \frac{N_{AUX}}{N_{SEC}}\left(V_{THRESHOLD} + V_{Forw,D3}\right) - V_{Forw,D1} \quad (6)$$

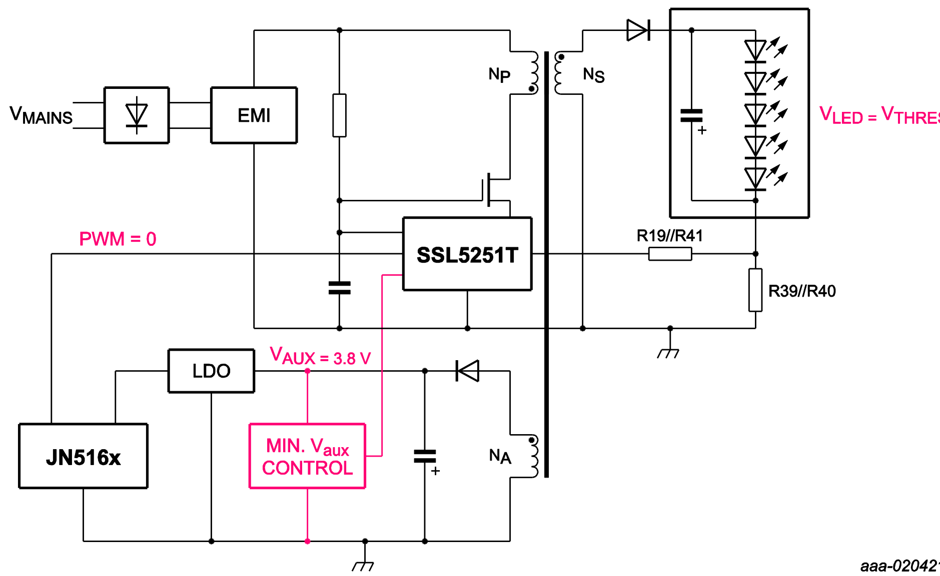


Fig 14. Situation when the lamp is OFF i.e. during standby

Fig 15 shows the components in the schematic that are involved in the V_{AUX} control circuit.

Note: V_{DIM} = 0 V, C5 is discharged by the COMP pin (i.e. the output of the transconductance amplifier: $I_{dch(COMP)}$ = 550 nA), t_{ON} will drop and when t_{ON} = 0 µs, then the SSL5251T will stop switching. C4 will be discharged by the supply current for the linear regulator + JN5169, so V_{AUX} will drop. Q4 is conducting as long as V_{BE} is larger than 0.5 V. So Q4 stops conducting when the voltage across R15 is 0.5 V. At that moment there is a current of 106 µA flowing through Zener diode D4.

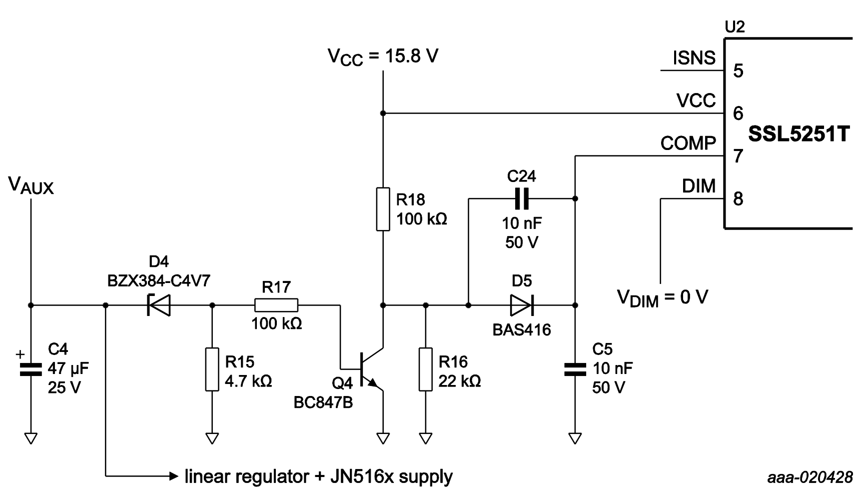


Fig 15. V_{AUX} control circuit

The first order approximation is that a 4V7 diode starts to conduct at a voltage of 4.7 V, but as Fig 16 shows, at lower voltages there is already a current flowing through the Zener diode. At a current of 106 μA, the voltage across the 4V7 Zener diode is about 3.4 V.

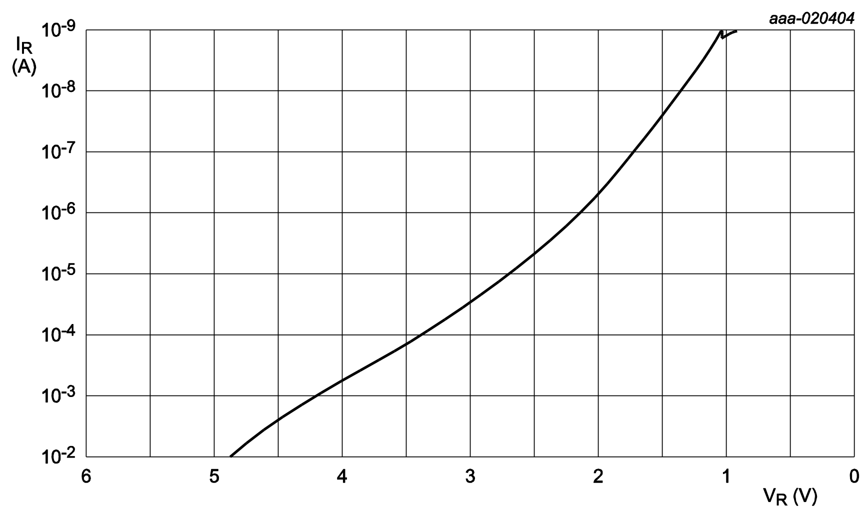


Fig 16. I_R versus V_R of a 4V7 Zener diode

This means that Q4 is conducting when V_{AUX} is larger than 3.4 V + 0.5 V = 3.9 V.

R16 is shortcutted when Q4 is conducting so capacitor C5 and C24 are in parallel and the V_{AUX} control circuit does not affect the voltage on the COMP pin.

Q4 stops conducting when V_{AUX} drops below 3.9 V and now the anode of D5 is connected to a voltage that can be calculated with:

$$V_{COMP} = \frac{R16}{R16 + R18} V_{CC(SSL5251T)} - V_{Forw,D5} \tag{7}$$

The voltage on the COMP pin is just above 2 V, so t_{ON} will be larger than 0 μs and the IC starts switching, effectively rising the auxiliary voltage above 3.9 V, so that Q4 is switched on again.

Note: D5 must be a diode with a very low leakage as otherwise the performance is deteriorated. The purpose of C24 is increasing the switching speed: if Q4 switches, then there is immediately a voltage rise or drop of the voltage on the COMP pin.

The auxiliary voltage is kept at 3.9 V and the voltage across the LED string can be calculated with:

$$V_{LED} = \frac{N_{SEC}}{N_{AUX}} \left(V_{AUX} + V_{Forw,D1}\right) - V_{Forw,D3} \tag{8}$$

The voltage across the LED string should remain below the threshold voltage, but due to the leakage in the transformer there is some ringing and the output voltage will slowly creep towards the threshold voltage. Then the LED string will start to conduct a few micro amps and the LED string will be glowing during standby. Bleeder resistors R36 and R37 are placed across the LED strings to provide a bypass for this current.

The easiest way to tweak the auxiliary voltage a bit is to change the value of R15.

9.3.3 Optimum transformer turns ratio's

In order to have minimum standby power it is the best to keep V_{AUX} just above the minimum input voltage of the linear regulator. Then the voltage across the LED string must be just below the LED string threshold voltage. In this way, the auxiliary voltage has the lowest possible voltage when the lamp is ON, resulting in maximum efficiency.

9.4 Dimming

The dimming input (DIM) of the SSL5251T can both be supplied with a DC voltage as well as a PWM signal. In both cases the LED current is linear controlled by means of changing t_{ON} and not by switching the controller ON/OFF.

Fig 9 shows the situation where the PWM signal from the microcontroller is supplied to a low-pass filter so that the voltage on the DIM pin is a pure DC voltage. This DC voltage is supplied to the dimming control transfer function and the output of this function is compared to the voltage across the sense resistor.

The output voltage of the low-pass filter depends on the "HIGH" level the PWM signal and the duty cycle, assuming that the "LOW" level is 0 V. The value can be calculated with:

$$V_{DIM} = \delta V_{HIGH} \tag{9}$$

In practice the value of V_{HIGH} is equal to the supply voltage of the microcontroller.

Fig 17 shows the dimming control transfer function and it shows that voltage changes below 0.23 V and above 2 V do not have effect on the LED current.

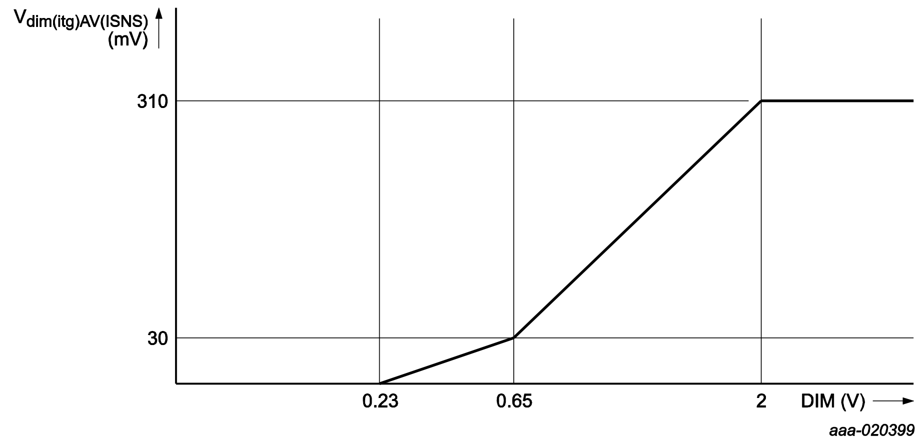


Fig 17. Dimming control transfer function in the SSL5251T

Assuming a microcontroller supply voltage of 2.9 V, this means that the effective duty cycle control range is between 7.9% and 69%.

It takes some time before the lamp switches on when the lamp is switched ON with the remote control if it has been switched OFF at a low dimming level. In order to speed this up, the capacitor of the low-pass filter (C3) has not been connected to ground, but to the ON pin instead. When now the lamp is switched ON, then the ON pin will go HIGH and immediately rise the voltage on the DIM pin so that the lamp switches on immediately. Diode D2 is mounted to prevent large negative spikes on the DIM pin.

Fig 18 shows the situation where the PWM signal from the microcontroller is directly supplied to the DIM pin of the SSL5251T. In this case the PWM signal is bypassed by the dimming control transfer curve. When the PWM signal is high, then the capacitor on the COMP pin is charged, and when the PWM signal is LOW, then the capacitor will be discharged. If the PWM frequency and the capacitor on the COMP pin are HIGH enough, then the voltage on the COMP capacitor will be constant and so will be t_{ON}

Typical values for the PWM frequency and COMP capacitor are respectively 300 Hz and 10 nF.

The LED current is now linear regulated although the voltage on the DIM pin is a PWM signal. The advantage of linear LED current regulation is that the LED current only contains a 100 Hz/120 Hz (double mains frequency) ripple and not the PWM frequency. Best dimming performance is achieved when f_{PWM} is synchronized with f_{MAINS} as this matches best with the different power modes that the LED converter can operate in. A 4.7 nF capacitor (C25) is placed between the gate and source of Q1 to prevent gate oscillations.

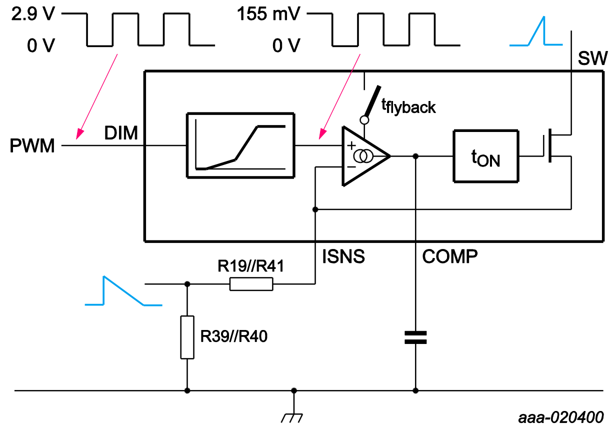


Fig 18. Dimming with PWM input signal

9.5 Overvoltage protection

Pin 1 (DEMOVP) of the SSL5251T has two functions:

- Demagnetization detection which detects the end of a switching cycle
- Overvoltage Protection

The overvoltage protection prevents that the voltage across the electrolytic output capacitor rises too high in case the LED string is open due to a broken LED or disconnected wire.

The level where the overvoltage protection triggers is calculated with:

$$V_{LED,OVP} = \frac{R12 + R13}{R13} 1.81V \quad (10)$$

When the overvoltage protection is triggered, then the LED voltage is regulated to the value that is calculated in equation (10), so it is not a latched protection.

Note: the auxiliary voltage is also higher in an overvoltage situation, so take care that the auxiliary electrolytic capacitor (C4) and the linear regulator can withstand this higher voltage.

9.6 Miscellaneous

The diode (D7) in the snubber circuit is a slow type. In this way the diode does not only conduct during a half cycle of the ringing, but remains on during the total time the ringing is present. So effectively a capacitor (C10) is placed in parallel during the time the ringing is present. This reduces the oscillation frequency and maximum voltage of the ringing.

The maximum mains voltage at which the lamp switches on is determined by the value of the resistors R20, R21, R16, R18, R5 and R9 as well as the startup current and clamp voltage of the SSL5251T and can be calculated with the following equation:

$$V_{Startup} = \frac{\left(\frac{15.35V}{R16+R18} + \frac{15.35V}{R5+R9} + 170\mu A\right)(R20+R21) + 15.35V}{\sqrt{2}} \quad (11)$$

Equation (2) shows that the peak current can be set with R19//R41 + R39//R40 and equation (3) shows that the maximum (undimmed) average LED current is set with the value of R39//R40. It is best to first select the right value of R39//R40 and then adapt the value of R19 to set the maximum primary peak current. The value of R19 also affects the THD and power factor: the smaller the value of R19//R41, the larger the primary peak current, the larger the power factor and the smaller the THD will become.

10. Color Changeable Tunable White (CCTW) stage

The operation principle of the CCTW circuit is shown in Fig 19: a current is supplied to two parallel LED strings from which one is always conducting. The LED strings have a different color temperature e.g. 2700° K and 6500° K, and now the color temperature can be controlled with the duty cycle of the PWM2 signal. The brightness i.e. the output current of the AC/DC converter is controlled with PWM1. The LED strings do not need to have the same string voltage as they are supplied from a current source.

Fig 20 shows the practical implementation of this circuit: Q8 and Q9 are the switches that are switching the currents through the LED strings. The resistive dividers (R27, R33 and R34, R35) are chosen such that Q8 and Q9 are fully conducting when the LED's are ON.

Now the gate of Q9 is connected to the drain of Q8 with a diode. In this way the gate of Q9 is pulled low when Q8 is conducting. If Q8 is not conducting, then the gate of Q9 is pulled above the threshold voltage by divider R34, R35 and then Q9 is conducting. In this way there is always one mosfet conducting and one LED string is emitting light.

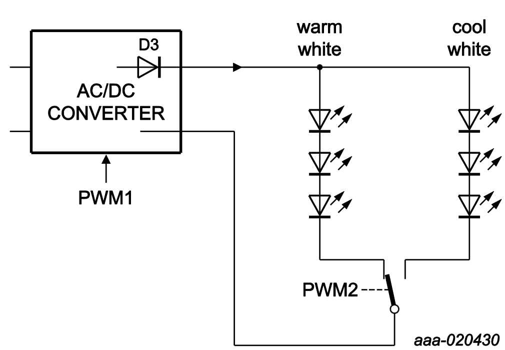


Fig 19. Working principle of the CCTW stage

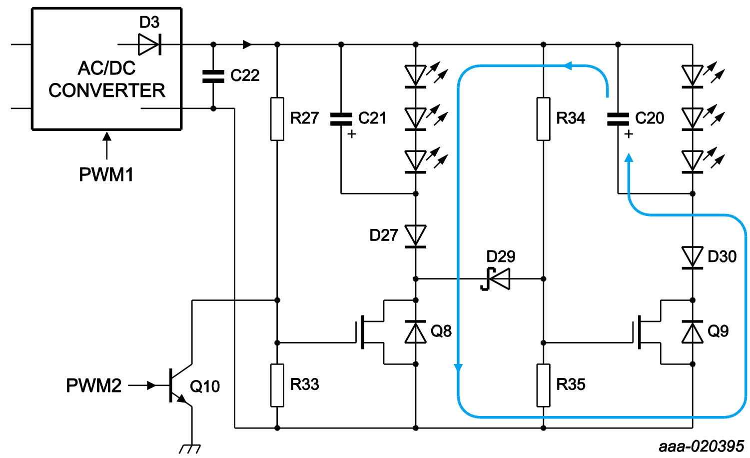


Fig 20. CCTW stage

The LED current in the circuit of Fig 19 is switching between 0 mA and the nominal output current of the AC/DC converter. In the practical implementation of Fig 20, electrolytic capacitors (C20 and C21) are placed across each individual LED string. Now the LED string current is not switching between 0 mA and the nominal current, but is constant with a 100 Hz/120 Hz ripple on top of it. See Fig 22.

D27 and D30 are placed in order to prevent that the electrolytic capacitors (elcap) (C20, C21) are discharged via the body diode of the mosfets when they are OFF. The blue line in Fig 20 shows one of the two discharge paths: i.e. the discharge path that is discharging C20 via the body diode of Q9 when Q8 is conducting. This path is blocked by D30.

The efficiency might be further increased by using Schottky diodes instead of normal rectifier diodes due to their smaller voltage drop.

Due to the fact that each LED string has its own output elcap and blocking diode, the LED strings can have different LED string voltages.

C22 is a small ceramic capacitor that is placed to filter the switching noise from the AC/DC converter so that there is no ripple voltage on the gates of the mosfets Q8 and Q9.

Fig 21 shows a circuit where both strings are connected to the same elcap. This circuit is fundamental different from the circuit of Fig 19 as now the LED strings are not connected to a current source any more, but to a voltage source i.e. the elcap. A difference in LED string voltage between the two LED strings now will result in current spikes through the LED string with the lowest voltage. The LED string currents will be switching between 0 mA and the nominal output current of the AC/DC converter so it is necessary to synchronize the PWM2 frequency with the mains frequency to prevent flicker due to the beat frequency of the PWM2 frequency and N times the mains frequency, N being a positive integer.

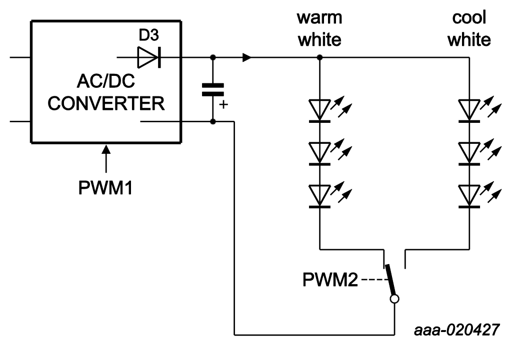
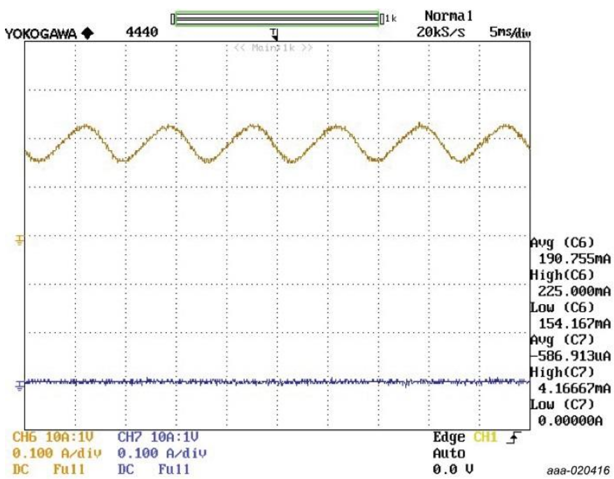
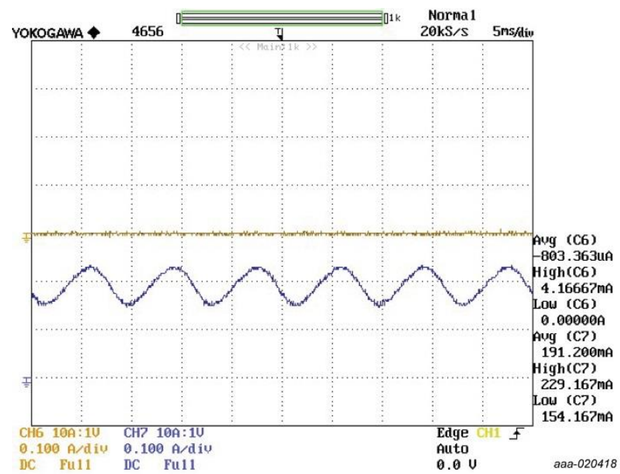


Fig 21. Two LED strings connected to a single electrolytic capacitor

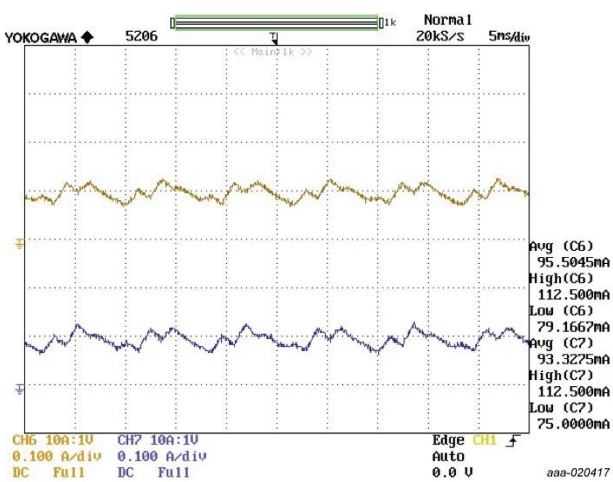
11. Measurements



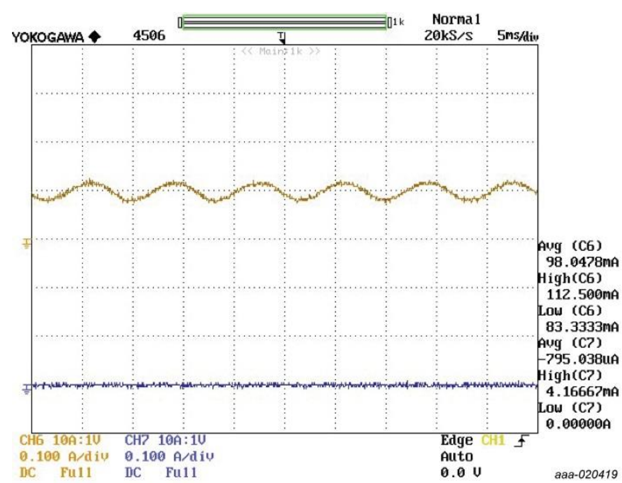
a. Output power = 100%, T = 2700° K.
Ch6: current through the 2700° K LED string.
Ch7: current through the 6500° K LED string.



b. Output power = 100%, T = 6500° K.
Ch6: current through the 2700° K LED string.
Ch7: current through the 6500° K LED string.

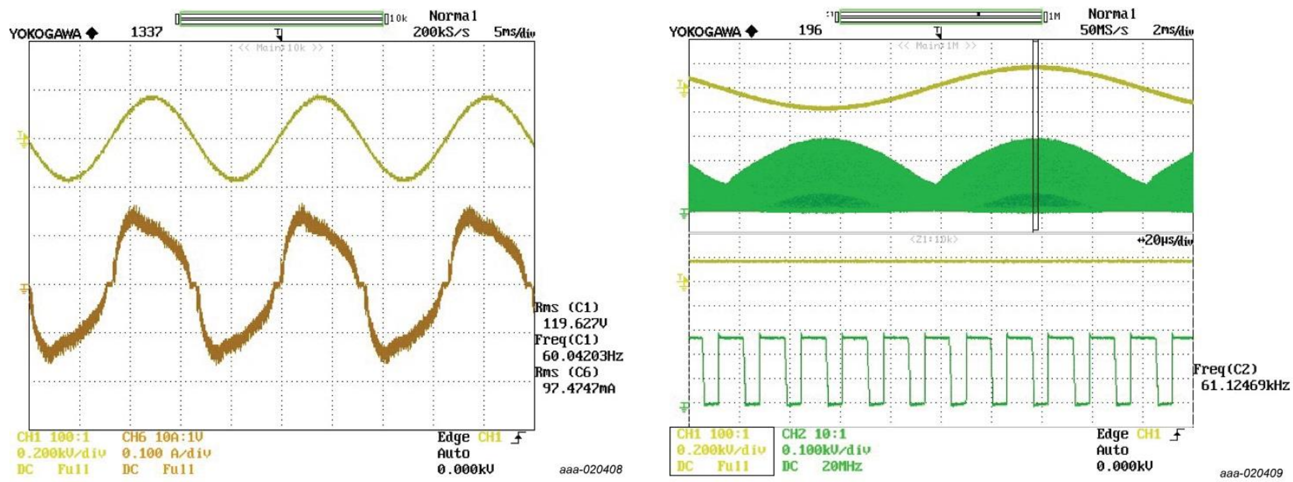


c. Output power = 100%, T = 4600° K.
Ch6: current through the 2700° K LED string.
Ch7: current through the 6500° K LED string.



d. Output power = 50%, T = 2700° K.
Ch6: current through the 2700° K LED string.
Ch7: current through the 6500° K LED string.

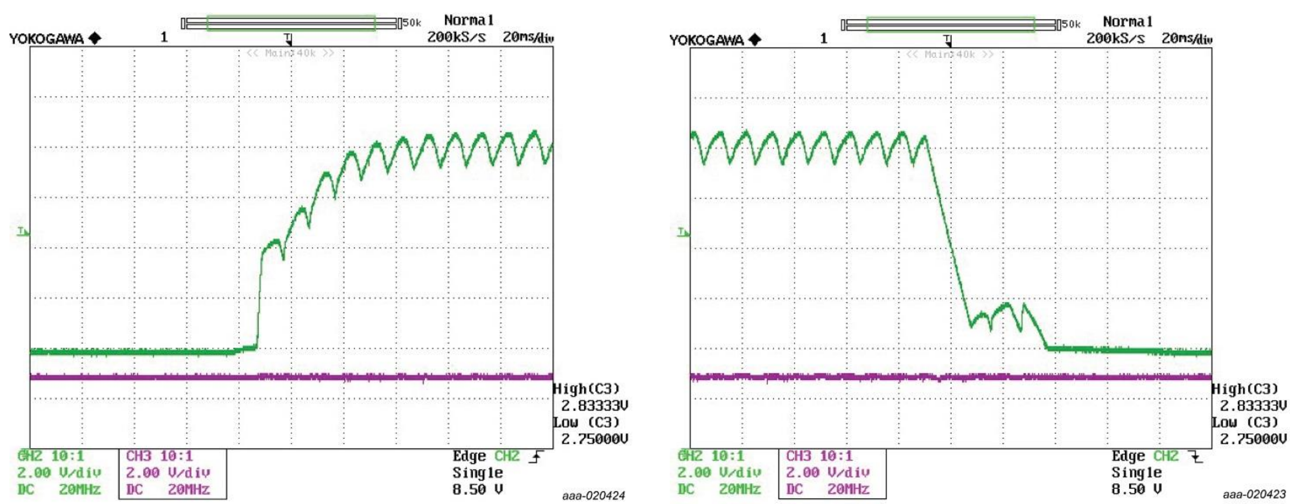
Fig 22. LED string currents at different settings of power and color temperature



a. Mains voltage and current at nominal power.
Ch1: mains voltage.
Ch6: mains current.

b. Mains voltage and voltage on the drain of the mosfet at nominal power.
Ch1: mains voltage.
Ch2: drain voltage.

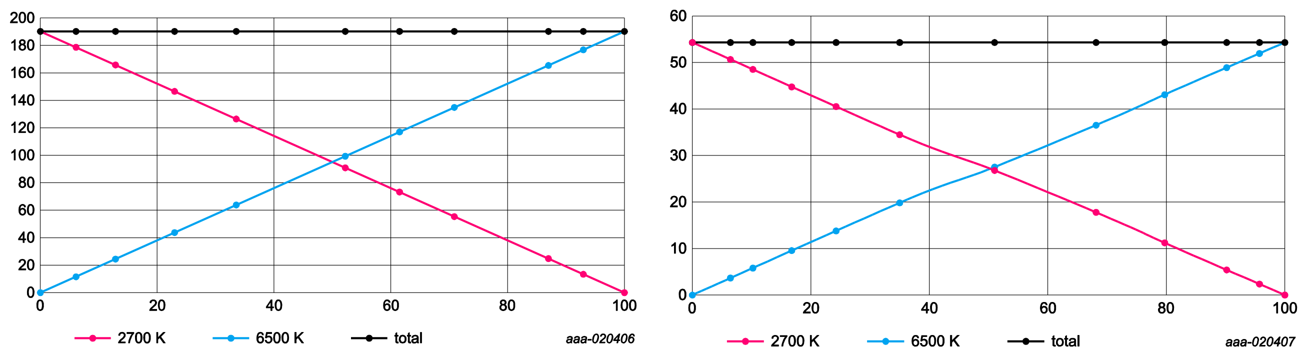
Fig 23. Mains voltage, current and drain voltage at nominal power



a. Switching lamp from standby to nominal power.
Ch2: V_{AUX}.
Ch3: $V_{CC(RF)}$.

b. Switching lamp from nominal power to standby.
Ch2: V_{AUX}.
Ch3: $V_{CC(RF)}$.

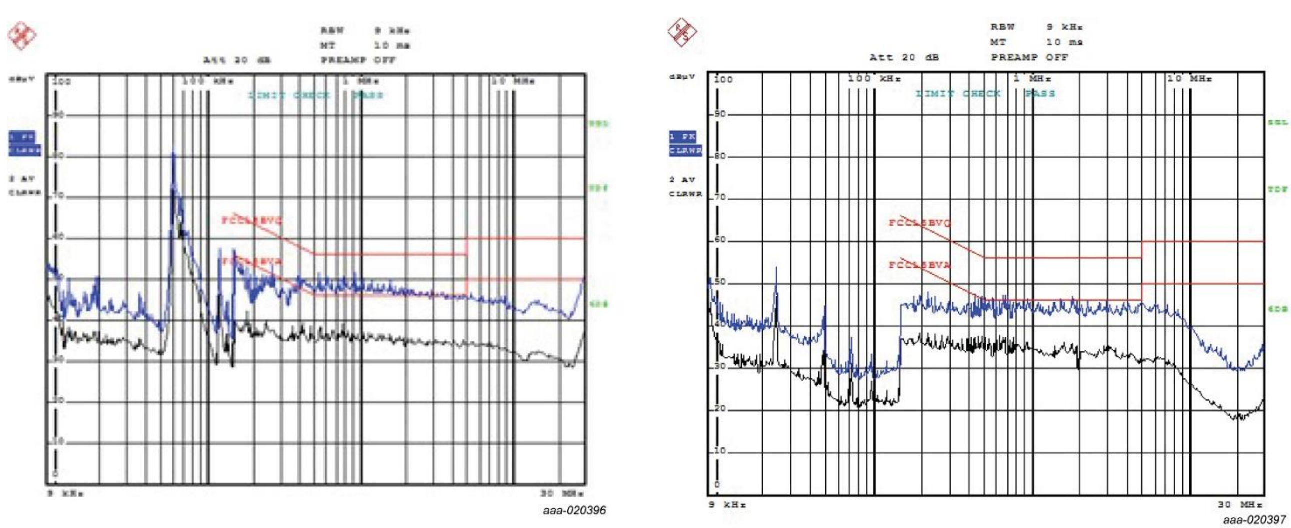
Fig 24. $V_{CC(RF)}$ during switching actions



a. LED string currents as function of the PWM2 duty cycle when the PWM1 duty cycle is 100%.

b. LED string currents as function of the PWM2 duty cycle when the PWM1 duty cycle is 32.5%.

Fig 25. LED string currents as function of the duty cycle of PWM2 for 2 settings of the PWM1 duty cycle



a. Conducted EMI during nominal operation at a color temperature of 4600° K.

b. Conducted EMI during standby.

Fig 26. EMI measurements

Note: the EMI measurements were don on the board as shown in Fig 2. Measurements on a complete bulb might give different results.

12. Frequently asked questions

Q: Can the OM15031 board be used behind a (triac) wall dimmer?

A: Yes. When R42 and C23 are mounted, it is possible to operate the OM15031 board behind a wall dimmer. Then it is possible to dim the lamp flicker free down between 10% and 20% of the nominal LED current with the RF remote while the wall dimmer remains at 100% dimming level. See Fig 27 for more details.

It is also possible to dim the lamp somewhat down with the wall dimmer while the RF dimming level is kept at 100%. The results of this are shown in Fig 28.

The best results were achieved using the component values given in Table 5:

Table 5. Component values for performance improvement behind wall dimmer

R1	R42	C23	Min. dimming level without flicker	Efficiency drop
4R7	470	220 nF	~ 20%	~ 0.5%
47R	470	220 nF	~ 10%	~ 4%

Note: modifying the values of R1, R42 and C23 also affects the EMI performance, power factor and THD.

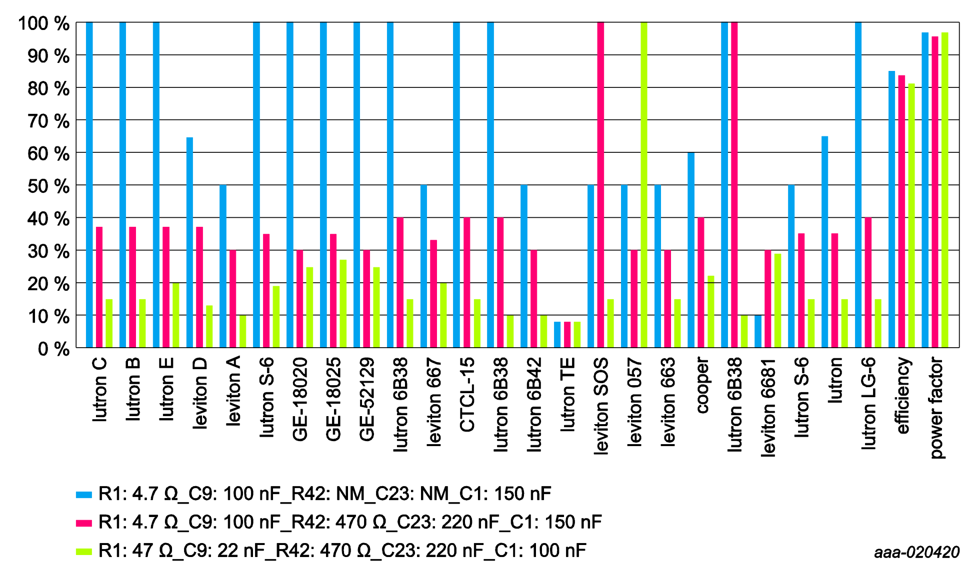


Fig 27. RF dimming level where the lamp starts flickering when the dimmer is set to 100%

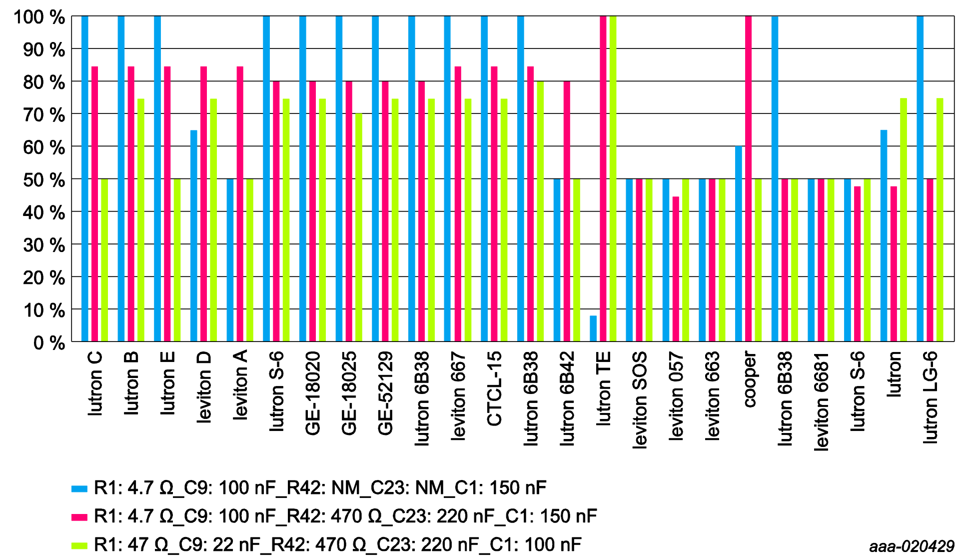


Fig 28. Wall dimmer dimming level where the lamp starts flickering when the RF dimming level is at 100%

Q: Is there also a LED driver IC available with integrated switch?

A: Yes, this is the SSL5255TE. Fig 29 shows the OM15031 schematic when this IC is used.

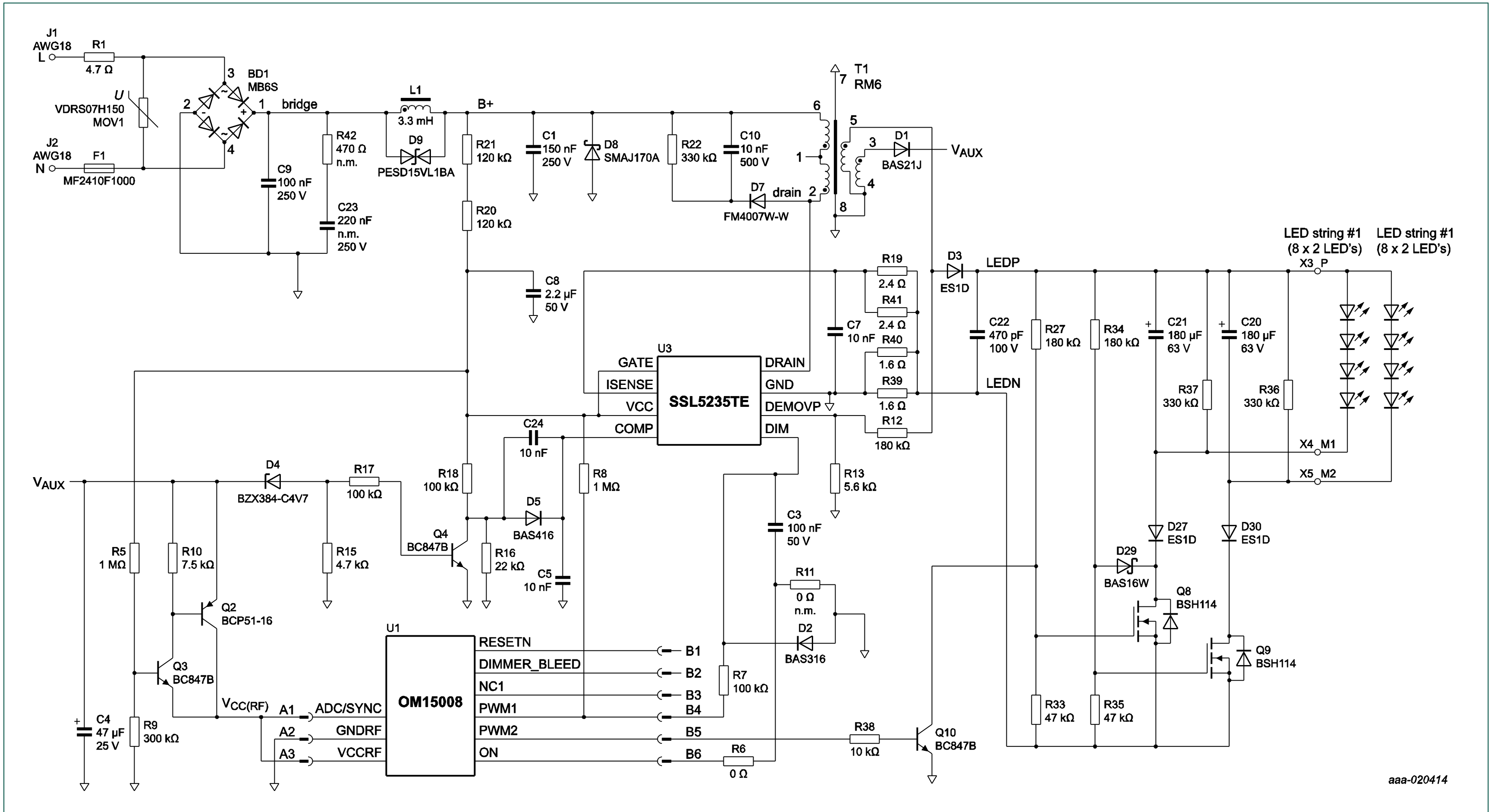


Fig 29. OM15031 schematic if SSL5255TE is used instead of SSL5251T

Note: the difference between the SSL5255TE and the SSL5255BTE: the latter is only used in Buck applications and is not suited in this application as this is a flyback application.

The SSL5255TE has an exposed die pad that must soldered to the ground plane underneath the IC in order to have sufficient cooling.

The SSL5255TE has an internal mosfet with a breakdown voltage of 550 V. For 230 V applications there are also versions available with a breakdown voltage of 700 V. The table below gives an overview of the different IC's that are available:

Table 6. Overview SSL523x IC's

IC	Internal switch	V_{DRAIN_max}	R_{DSon}	Target application
SSL5251T	No	n.a.	n.a.	120 V/230 V high power applications
SSL5255TE	Yes	550 V	4 Ω	120 V medium power (~11 W) applications
SSL5236TE	Yes	700 V	20 Ω	230 V low power (~5 W) applications
SSL5257TE	Yes	700 V	10 Ω	230 V medium power (~11 W) applications

Q: I want to have a different LED voltage/LED current than in this application. How do I change this?

A: We have developed an Excel calculation tool in order to adapt the circuit to your specification. Please contact your local sales representative to obtain this calculation tool.

13. Abbreviations

Table 7. Abbreviations

Acronym	Description
AC	Alternative Current
BLE	Bluetooth Low Energy
BOM	Bill Of Materials
CCTW	Color Changeable Tunable White
DC	Direct Current
elcap	electrolytic capacitors
EMI	Electromagnetic Interference
IC	Integrated Circuit
LDO	Low Dropout
LED	Light Emitting Diode
LSB	Large Signal Board
MOV	Metal Oxide Varistor
OTA	Operational Transconductance Amplifier
PCB	Printed Circuit Board
PWM	Pulse Width Modulation
RF	Radio Frequency
SSB	Small Signal Board
THD	Total Harmonic Distortion
TVS	Transient Voltage Suppressor

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