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100-W Quasi-Resonant (QR) Buck LED Driver

Wide Analog Dimming and Precise LED Current Regulation

TND6338/D

ON Semiconductor®

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REFERENCE DESIGN

Introduction

This Reference Design includes specifications, testing, typical operating characteristics, and construction of reference design, based on the NCL30076 Quasi−Resonant Buck controller. The Reference Design for 100−W performs accurate LED current regulation and wide analog dimming range.

Table 1. SPECIFICATION FOR REFERENCE DESIGN

Description		Symbol	Value	Comments
Input Voltage		V_{IN}	400 V_{DC}	400 V_{DC} or PFC Output voltage
Output	Current	$I_{OUT.MAX}$	333 mA	
		$I_{OUT.MIN}$	< 1.2 mA	~0.2% dimming level
	Voltage	$V_{OUT.MIN}$	100 V	
		$V_{OUT.MAX}$	300 V	
Maximum Output Power		$P_{OUT.MAX}$	100 W	Condition: V_{OUT} 300 V, I_{OUT} 333 mA
CC Tolerance in wide V_{OUT}: Calculated by 300 dimming curves (100 pcs boards × 100/200/300 V_{OUT})		$CC_{100\%}$	±1.5%	Dimming Range: 0.2%~100% Ambient Temperature: 25°C
		$CC_{10\%}$	±3%	
		$CC_{1\%}$	±20%	
CC Tolerance at single V_{OUT}: Calculated by 100 dimming curves (100 pcs boards × 100 $V_{OUT,}$ worst case)		$CC_{100V-100\%}$	±1.5%	Dimming Range: 0.2%~100% Ambient Temperature: 25°C
		$CC_{100V-10\%}$	±2%	
		$CC_{100V-1\%}$	±10%	
System Efficiency		$Eff._{300V}$	97.66%	V_{OUT}: 300 V I_{LED}: 333 mA, External VDD supply
		$Eff._{200V}$	97.34%	V_{OUT}: 200 V I_{LED}: 333 mA, External VDD supply
		$Eff._{100V}$	96.14%	V_{OUT}: 300 V I_{LED}: 333 mA, External VDD supply
PCB Size			63 × 33 mm	System Size Without IN/OUT Connector

Key Features

- Wide Analog Dimming Range: 0.2~100%
- Excellent CC Tolerance:
  - ±3% in 10~100% Load
  - ±20% at 1% Load
- Low System BOM
- LED Off Mode at Standby
- PWM Dimming Available
- Robust Protection Features
  - LED Short Protection
  - Over Current Protection
  - Thermal Shutdown
  - VDD Over Voltage Protection

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NCL30076LED1GEVB PHOTOGRAPHS

(System Dimensions: 63 mm (L) × 33 mm (W))

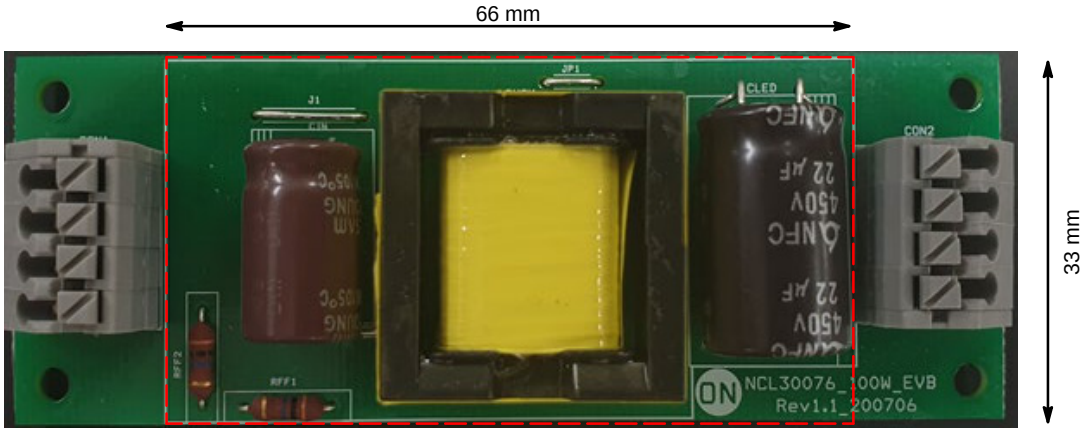


Figure 1. Top View

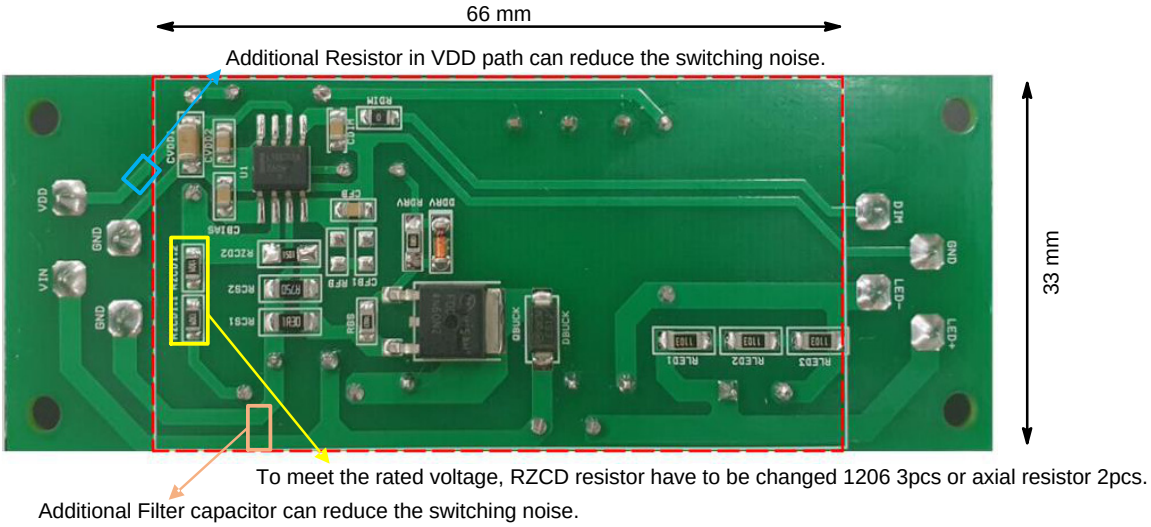


Figure 2. Bottom View

NCL30076LED1GEVB GERBER VIEW

(PCB Outline: 91 mm (L) × 33 mm (W), FR−4, Thickness 1.6T)

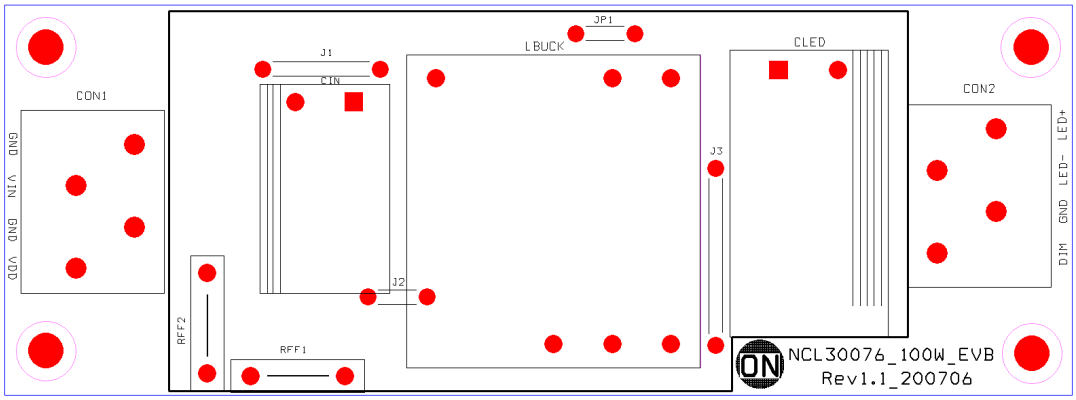


Figure 3. Top View

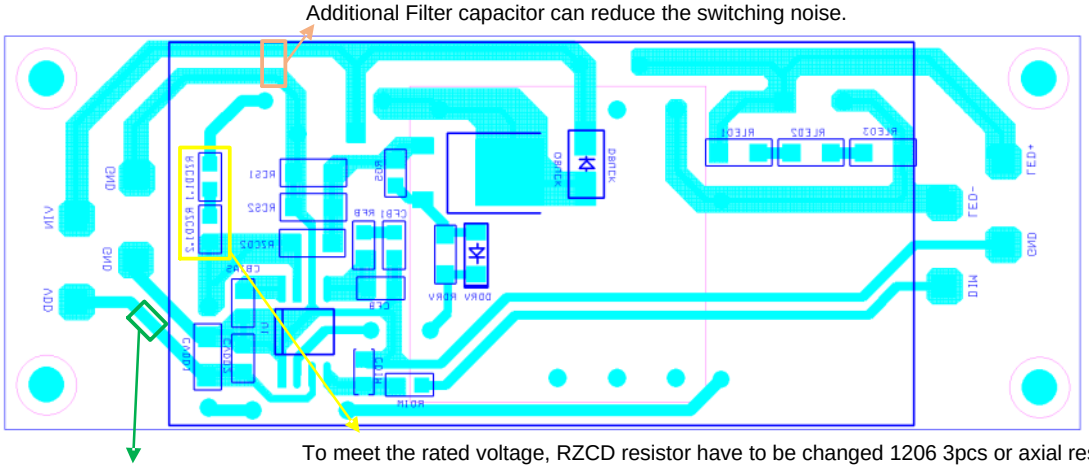
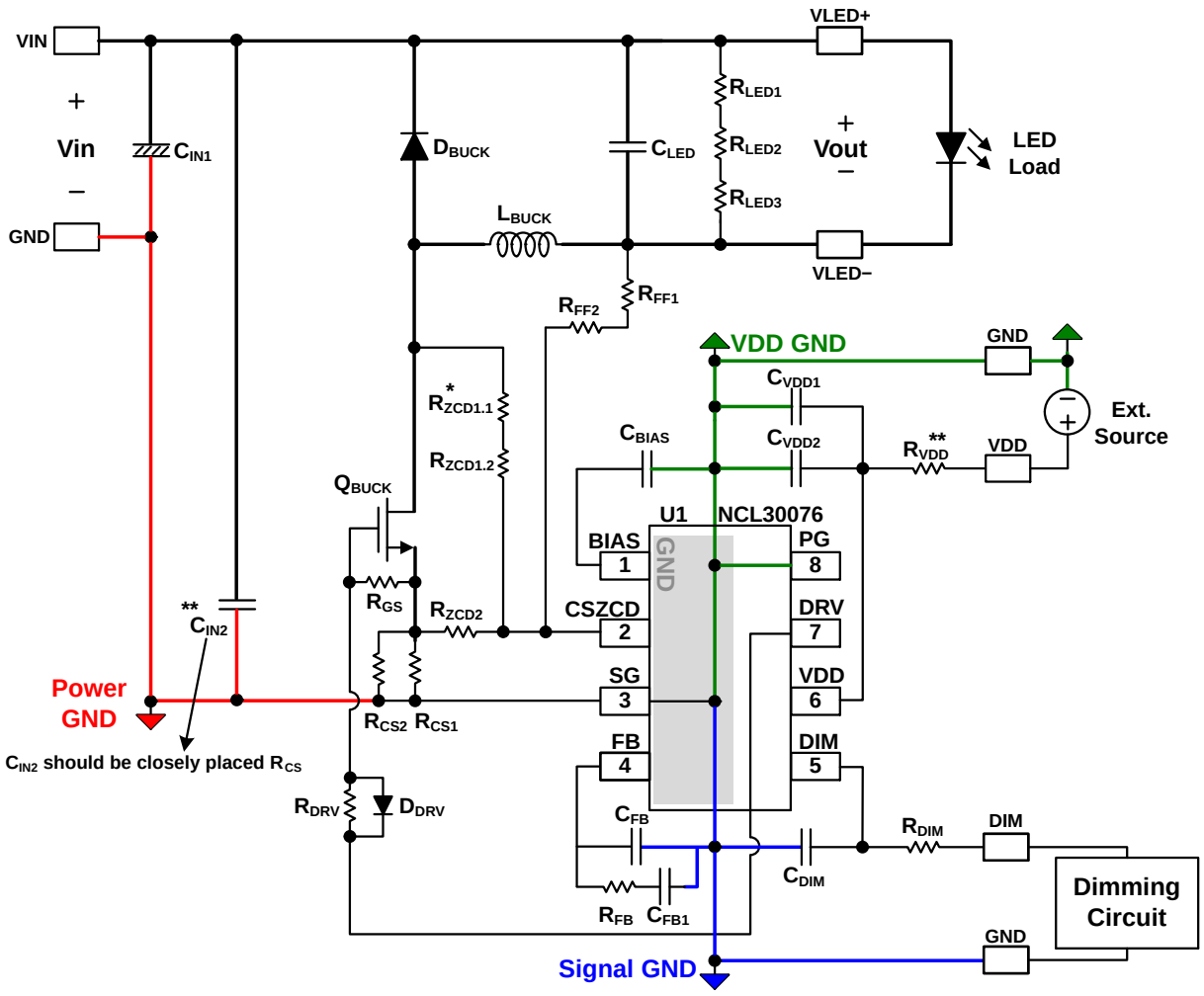


Figure 4. Bottom View

NCL30076LED1GEVB SCHEMATIC



* R_{ZCD1} should be properly selected according to rated voltage. (1206 resistor 3pcs or axial resistor 2pcs)

** R_{VDD} and C_{IN2} must be added for improving switching noise immunity. (not applied in demo board)

Figure 5. Schematic for 100−W Design Reference

BILL OF MATERIAL FOR THE NCL30076LED1GEVB

Table 2. BILL OF MATERIAL FOR NCL30076LED1GEVB

Designator	Qty.	Description	Value	Footprint	Manufacturer	Part Number
U1	1	QR Buck Controller	NCL30076	SOIC−8	ON Semiconductor	NCL30076
CIN	1	Electrolytic Capacitor	450 V/10 μF	10 × 16 mm	Samyoung	NHA series
LBUCK	1	Inductor	1.6 mH (0.1 pi ×12 90 turns)	EFD25/13/9 10pin Bobbin	TDK Electronics Inc	B66422W1010D001
CLED	1	Electrolytic Capacitor	450 V/22 F	12.5 × 20 mm	Samyoung	NFC series
DBUCK	1	Ultra−Fast Recovery Rectifier	600 V/1 A	SMA	ON Semiconductor	ES1J
QBUCK	1	N−Channel MOSFET	600V 3.4 A, 2.5 Ω	DPAK−3	ON Semiconductor	FDD4N60NZ
RFF1, RFF2	2	Resistor Axial (±5%)	30 MΩ	Axial	Stackpole Electronics Inc	MG14JT30M0
RCS1	1	Resistor SMD (±1%)	1.3	3216F	Yageo	
RCS2	1	Resistor SMD (±1%)	0.75	3216F	Yageo	
RLED1, RLED2 RLED3	3	Resistor SMD (±1%)	110 kΩ	3216	Yageo	
RZCD1.1, RZCD1.2	2	Resistor SMD (±1%)	1.3 MΩ	2012	Yageo	
RZCD2	1	Resistor SMD (±1%)	1.5 kΩ	2012	Yageo	
RFB	0	N.C				
RDIM	1	Resistor SMD (±1%)	0	2012	Yageo	
RDRV	1	Resistor SMD (±1%)	10	2012	Yageo	
RGS	1	Resistor SMD (±1%)	100 kΩ	2012	Yageo	
DDRV	1	Small Signal Diode	100 V/0.2 A	SOD80	ON Semiconductor	LL4148
CVDD1	1	MLCC X7R capacitor (±10%)	50 V/10 μF	3216	TDK	
CVDD2	1	MLCC X7R capacitor (±10%)	100 nF	2012	TDK	
CBIAS	1	MLCC X7R capacitor (±10%)	1 nF	2012	TDK	
CFB	1	MLCC X7R capacitor (±10%)	10 nF	2012	TDK	
CFB1	0	N.C				
CDIM	1	MLCC X7R capacitor (±10%)	10 nF	2012	TDK	
J1, J2, J3	3	Jumper Wire	Short	Axial	ANY	
JP1	1	Jumper Wire (For Inductor Current measurement)	Short	Axial	ANY	
CON1, CON2	2	IN/OUT Connector	4Pin	Pitch 3.5 mm	CUI Devices	TBL002A−350−04GY−2GY
PCB	1	FR−4, 1.6T, 91 mm (L) × 33 mm (W)	Single Layer PCB			

BUCK INDUCTOR DESIGN SPECIFICATION

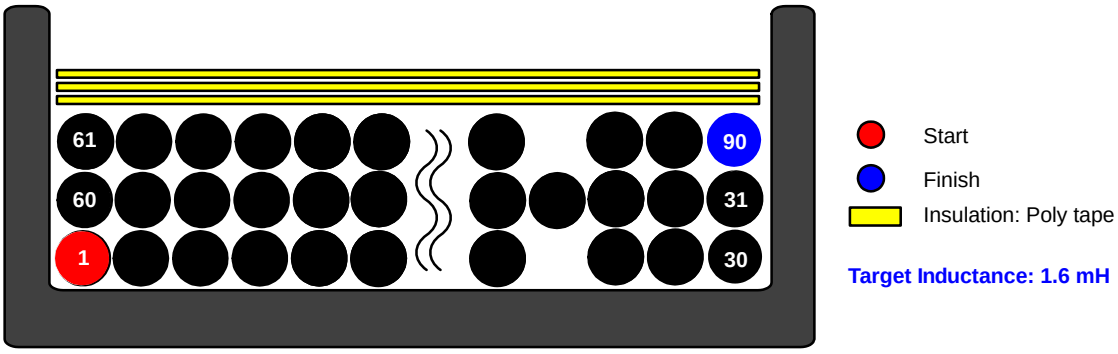


Figure 6. Buck Inductor (L_{BUCK}) Winding Structure

Table 3. BUCK INDUCTOR WINDING SPECIFICATIONS

No.	Winding	Pin (S → F)	Wire	Turns	Winding Layer
1	N_1	1→ 5	Litz 0.1φ × 12	90 Ts	3−layer
2	Insulation: Polyester Tape t = 0.025 mm, 3−Layer				

SYSTEM TEST PROCEDURE

Table 4. NCL35076LED1GEVB TEST CONDITION AND EQUIPMENT LIST

Ambient Temperature	T_A = 25°C
Test Equipment	DC Power Source (V_{IN}): PCR500L by Kikusui Power Analyzer: PZ4000000 by Yokogawa Output Load: 100 V/200 V/300 V LED load Multi Meter: 8808A by FLUK, 34401A by Agilent Oscilloscope: 104Xi by LeCroy Thermometer: Thermal CAM T620 by FLIR SYSTEMS

The NCL30076 100−W Reference Board connection is shown the below figure.

Supply the Dimming signal and External V_{DD} source after applying V_{IN}.

Figure 7. NCL30076LED1GEVB Test Set up Configuration

SYSTEM PERFORMANCE

Figure 8. shows dimming curve linearity and Constant Current (CC) tolerance of 100 pcs system boards. The test condition is variable output voltage (100, 200, 300 V) in 400VDC input and dimming range is 100% to 0%. The dimming ratio is calculated by (VDIM−0.2)/1.6 *100 [%].

As a result, total CC tolerance in the wide output condition is ±1.5% at 100% load and ±20% at 1% load. In the single output condition, CC tolerance is ±1.5% at 100% load and ±10% at 1% load.

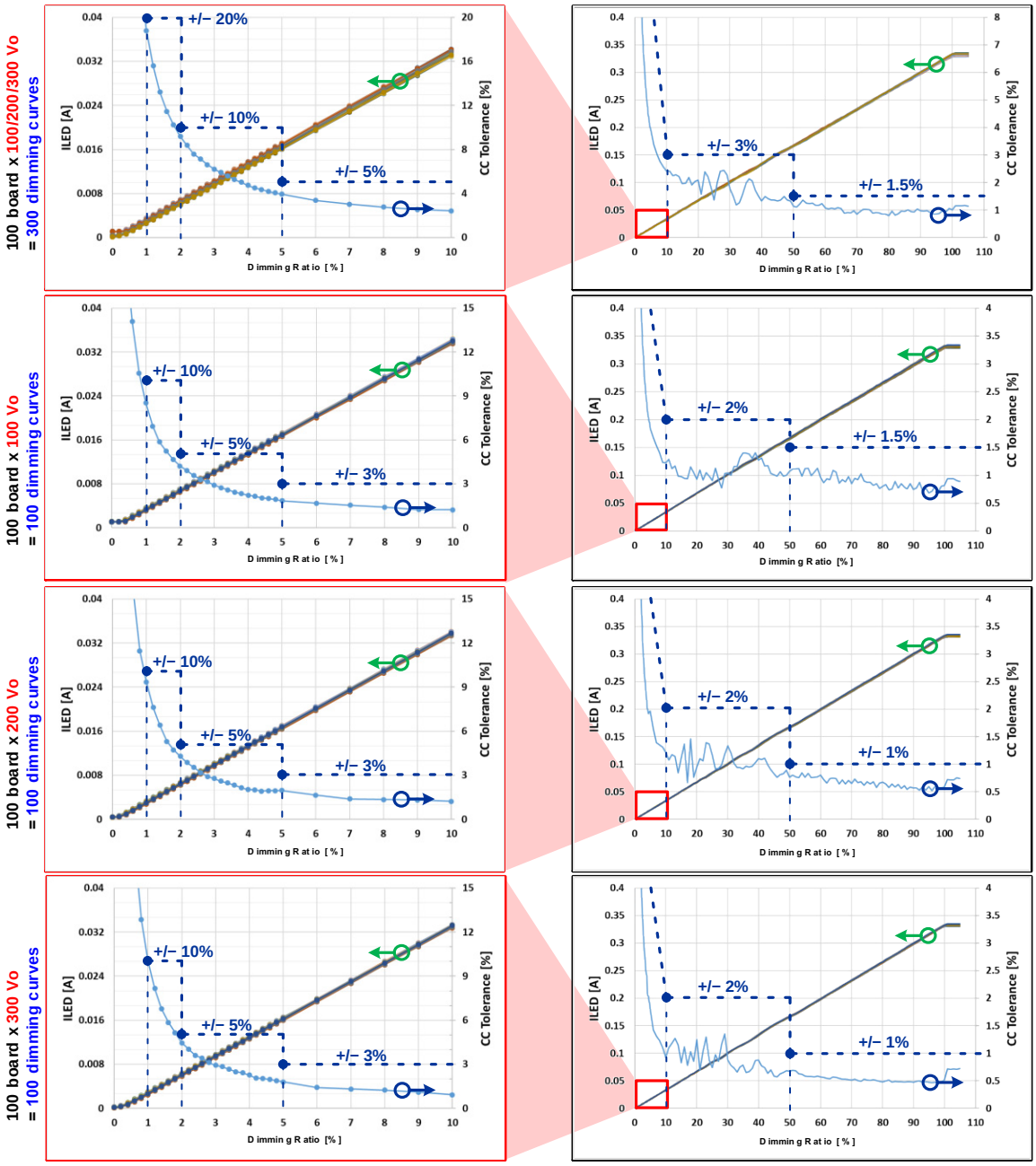


Figure 8. NCL30076LED1GEVB Dimming Curve and CC Tolerance

Start−up

NCL30076 starts up with soft start function to smoothly set the LED current at a steady state level without overshoot. At full load condition, startup time is 60 ms with no overshoot as shown in Figure 9.

1. T_{OFF} is reduced from 1300 μs ($T_{OFF.MAX}$) by Internal Soft start counter.
2. When internally calculated LED current is close to a reference level, V_{FB} start to find a steady state level.
3. V_{FB} is settled to the steady state level. T_{OFF} is set by either ZCD signal in QR or FB signal in DCM.

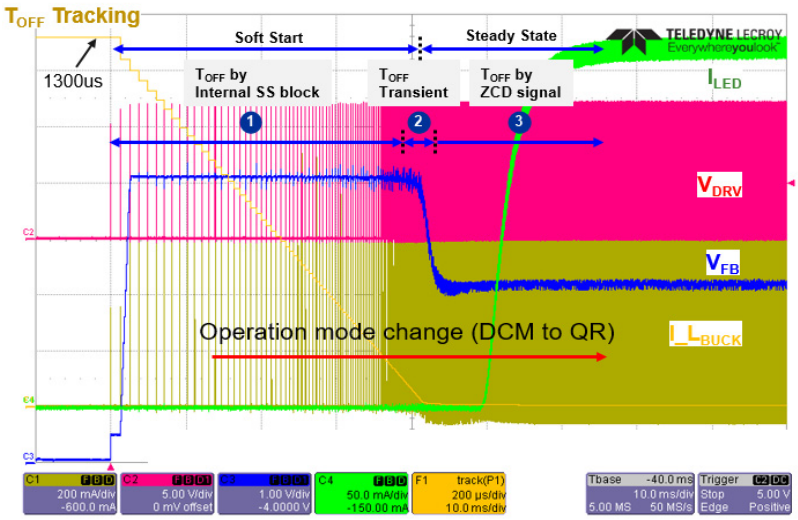


Figure 9. Startup Operation (Condition: 300 V_{OUT}, 333 mA, V_{DIM} 1.9 V)

Steady State

The NCL30076 operates in multi−mode between CrM(QR) and DCM according to the dimming condition.

The multi−mode operation provides high system efficiency with minimized switching loss by QR at heavy load and wide analog dimming by DCM at light load.

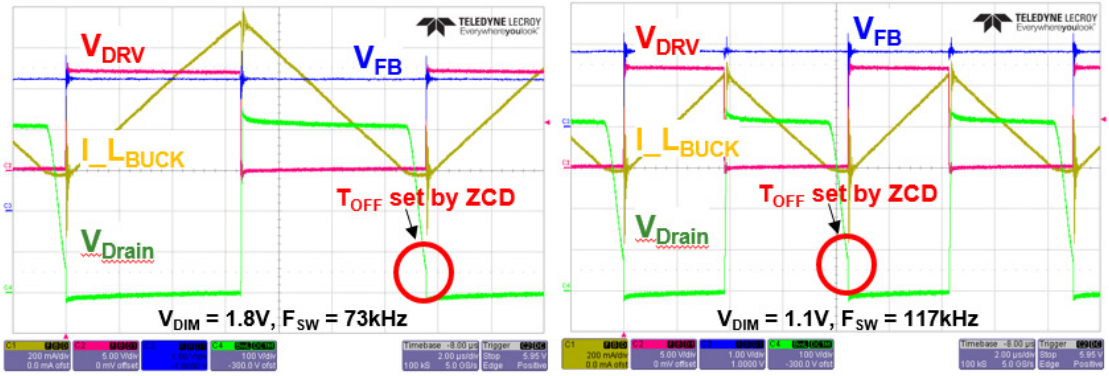


Figure 10. Steady−state QR Operation (V_{OUT}: 200 V)

When NCL30076 entered DCM operation mode at light load condition, T_{OFF} is set by V_{FB}.

When V_{DIM} is lower than 0.2 V, internal reference is set to 0 V and V_{FB} is pulled down 0.5 V clamping voltage.

In this period, the LED current is under open loop control and T_{OFF} is set by $T_{OFF.MAX}$ (1300 μs).

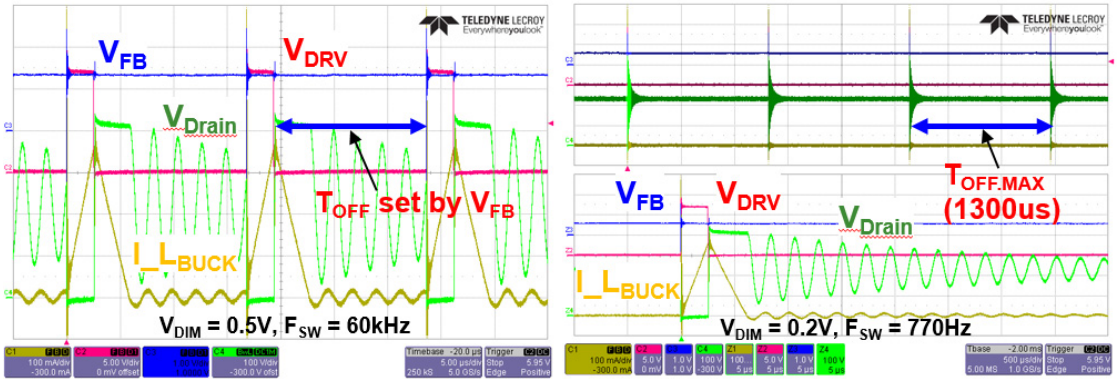


Figure 11. Steady−state DCM Operation (V_{OUT}: 200 V)

Standby Mode

When V_{DIM} is lower than a standby threshold voltage ($V_{DIM(SB-ENA)}$) for 10 ms, Standby mode is triggered with LED turn−off and IC operating current is minimized. When V_{DIM} is higher than a standby disable threshold voltage ($V_{DIM(SB-DIS)}$), Standby mode is immediately terminated.

Table 5. NCL30076 STANDBY MODE SPECIFICATION

Parameter	Symbol	Min	Typ	Max	Unit
Standby Enabling DIM Voltage	$V_{DIM(SB-ENA)}$	50	75	100	mV
Standby Disabling DIM Voltage	$V_{DIM(SB-DIS)}$	50	100	150	mV
Standby Delay Time	$t_{SB(DELAY)}$	9	10	11	ms

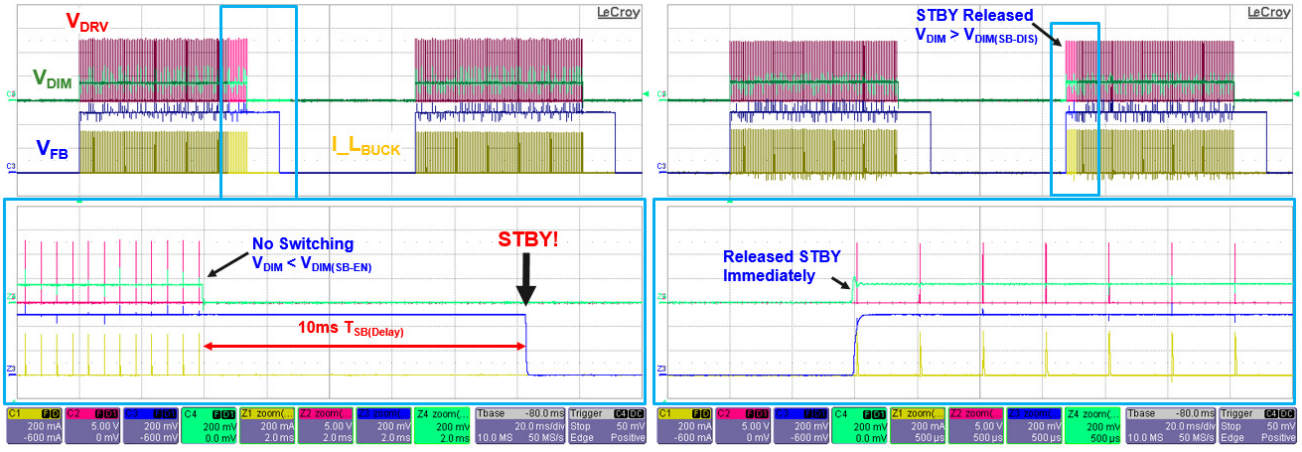


Figure 12. Standby Mode Operation (V_{OUT}: 200 V, V_{DIM}: Rectangular Pulse 0/150 mV)

Protection – Over Current Protection (OCP)

When CSZCD voltage exceeds the over current threshold voltage ($V_{CS(OCP)}$) in the short circuit condition of the freewheeling diode (D_{BUCK}), the controller is immediately shut down after leading edge blanking time. After auto recovery time 1 second, startup sequence reinitiates. This behavior lasts until the fault condition is removed.

Table 6. NCL30076 OCP SPECIFICATION

Parameter	Symbol	Min	Typ	Max	Unit
CS Over Current Protection Threshold	$V_{CS(OCP)}$	0.9	1.0	1.1	V
Auto Restart Time at Protection	$t_{AR(PROT)}$	0.9	1	1.1	s

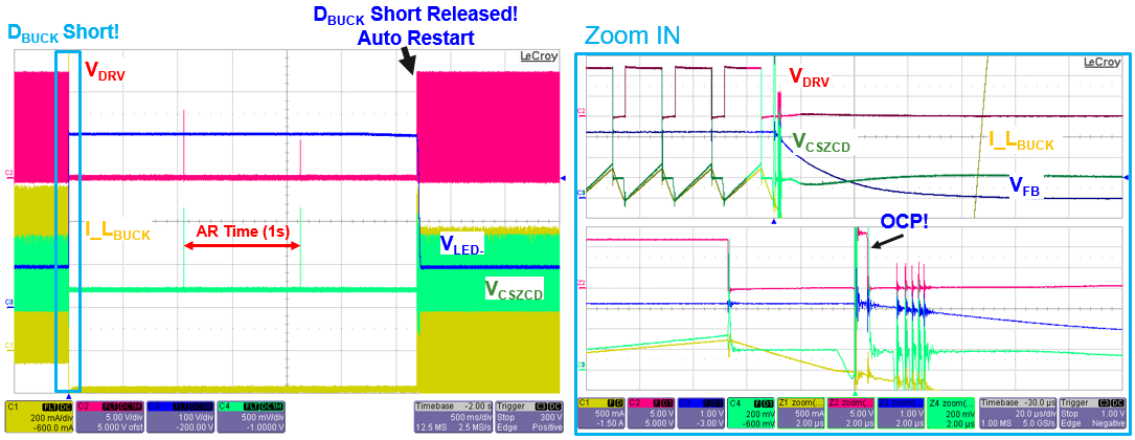


Figure 13. Over Current Protection (OCP)
(DBUCK Short and Released at Max Load: 300 V_{OUT}, 333 mA, V_{DIM} 1.9 V)

Protection – LED Short Protection (SLP)

When LED load is short−circuited, the system operates at minimum switching frequency, so the maximum turn−off time control protects the freewheeling diode (D_{BUCK}) from thermal stress. Figure 14 shows Short LED Protection performance at max load condition (V_{OUT}: 300 V, I_{LED}: 333 mA). When LED load is short−circuited, average diode current (310 mA) is lower than Max I_{LED} (333 mA).

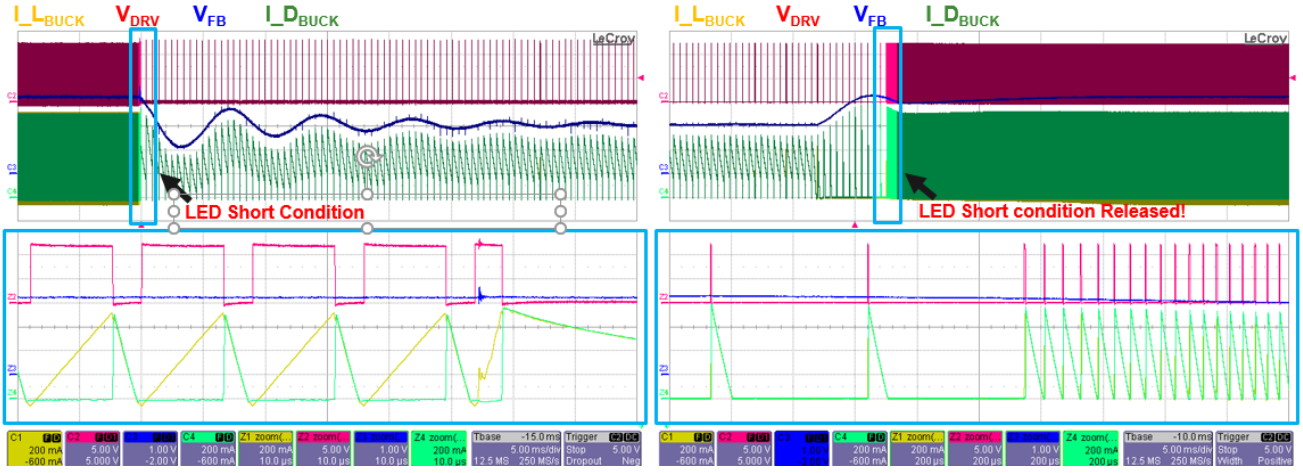


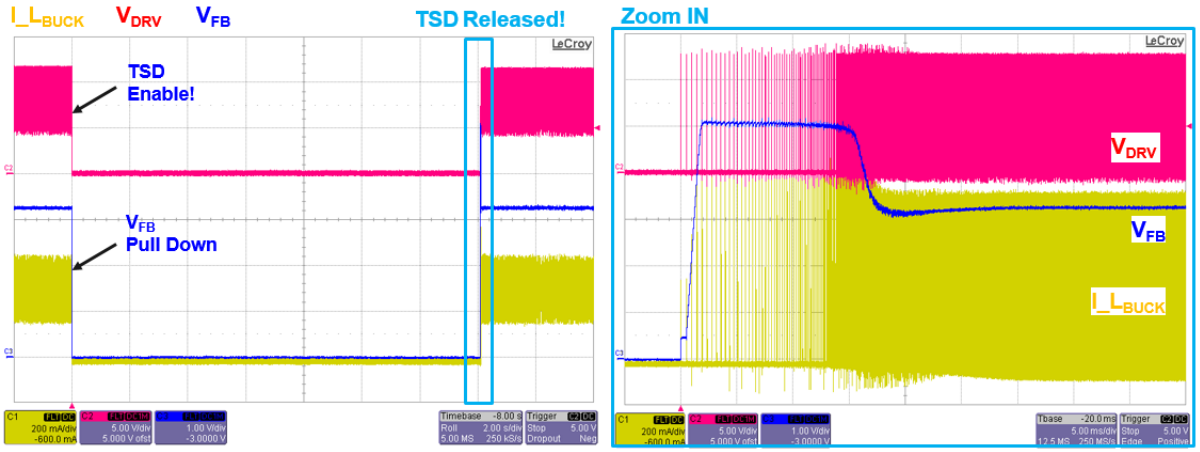
Figure 14. LED Short Protection (SLP)
(LED Load Short and Released at Max Load: 300 V_{OUT}, 333 mA, V_{DIM} 1.9 V)

Protection – Thermal Shut Down (TSD)

When IC junction temperature is higher than 150°C Thermal Shut Down (TSD) is triggered and released when the temperature is lower than 120°C.

Table 7. NCL30076 TSD SPECIFICATION

Parameter	Symbol	Min	Typ	Max	Unit
Thermal Shut Down Temperature	T_{SD}	130	150	170	°C
Thermal Shut Down Hysteresis	$T_{SD(HYS)}$	25	30	35	°C



<TSD (Thermal Shut Down) Operation>

<Auto Restart when TSD is Terminated>

Figure 15. Thermal Shut Down Protection (TSD)
(Thermal Stress at Max Load: 300 V_{OUT}, 333 mA, V_{DIM} 1.9 V)

Operating Temperature

The temperature result were measured at Max load (100 W) condition after 30 minutes burn−in. (T_A: 25°C)

<Max Load Top Side>

<Max Load Bottom Side>

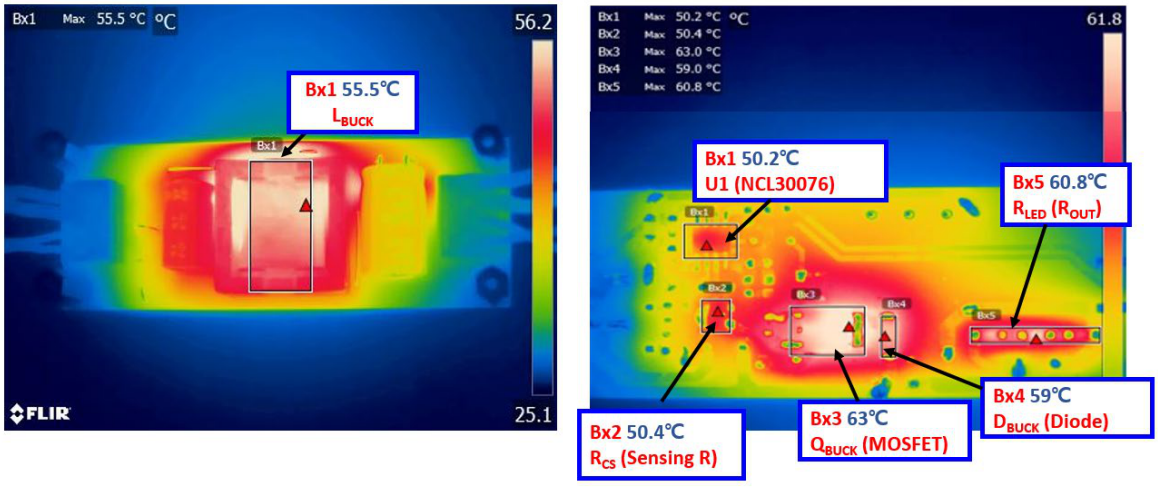


Figure 16. Operating System Temperature (Max Load: 300 V_{OUT}, 333 mA)

Efficiency

Figure 17 shows system efficiency data at the output voltage range from 100 V to 300 V from 10% to 100% load condition. The system efficiency is over 97% from 200~300 V_{OUT} with 100% load condition.

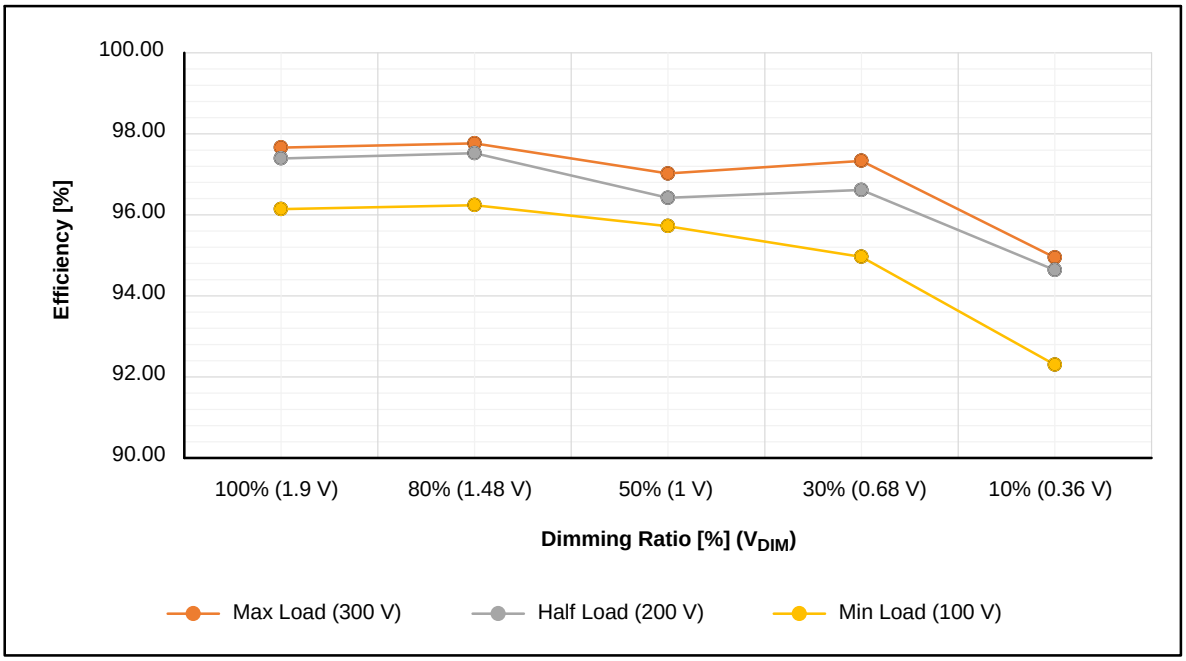


Figure 17. NCL30076LED1GEVB System Efficiency

Table 8. NCL30076LED1GEVB SYSTEM EFFICIENCY DATA

Load	V_{DIM} [V]	Pin [W]	V_{OUT} [V]	I_{OUT} [mA]	P_{OUT} [W]	Eff [%]
Max 300 V (6 VLED × 51 pcs)	1.90 V (100%)	101.7	301	330.0	99.3	**97.7**
	1.48 V (80%)	79.3	294	263.4	77.5	**97.8**
	1.00 V (50%)	48.7	284	166.4	47.2	**97.0**
	0.68 V (30%)	28.2	277	99.1	27.4	**97.3**
	0.36 V (10%)	9.3	266	33.1	8.8	**94.9**
Half 200 V (6 VLED × 34 pcs)	1.90 V (100%)	68.5	202	331.2	66.8	**97.4**
	1.48 V (80%)	53.4	197	264.4	52.1	**97.5**
	1.00 V (50%)	32.8	190	166.6	31.6	**96.4**
	0.68 V (30%)	19.1	185	99.8	18.5	**96.6**
	0.36 V (10%)	6.3	178	33.5	6.0	**94.6**
Min 100 V (6 VLED × 17 pcs)	1.90 V (100%)	34.7	101	329.9	33.4	**96.1**
	1.48 V (80%)	27.1	99	263.9	26.1	**96.2**
	1.00 V (50%)	16.5	95	165.3	15.7	**95.7**
	0.68 V (30%)	9.9	93	101.1	9.4	**95.0**
	0.36 V (10%)	3.3	89	33.7	3.0	**92.3**

PCB LAYOUT GUIDANCE

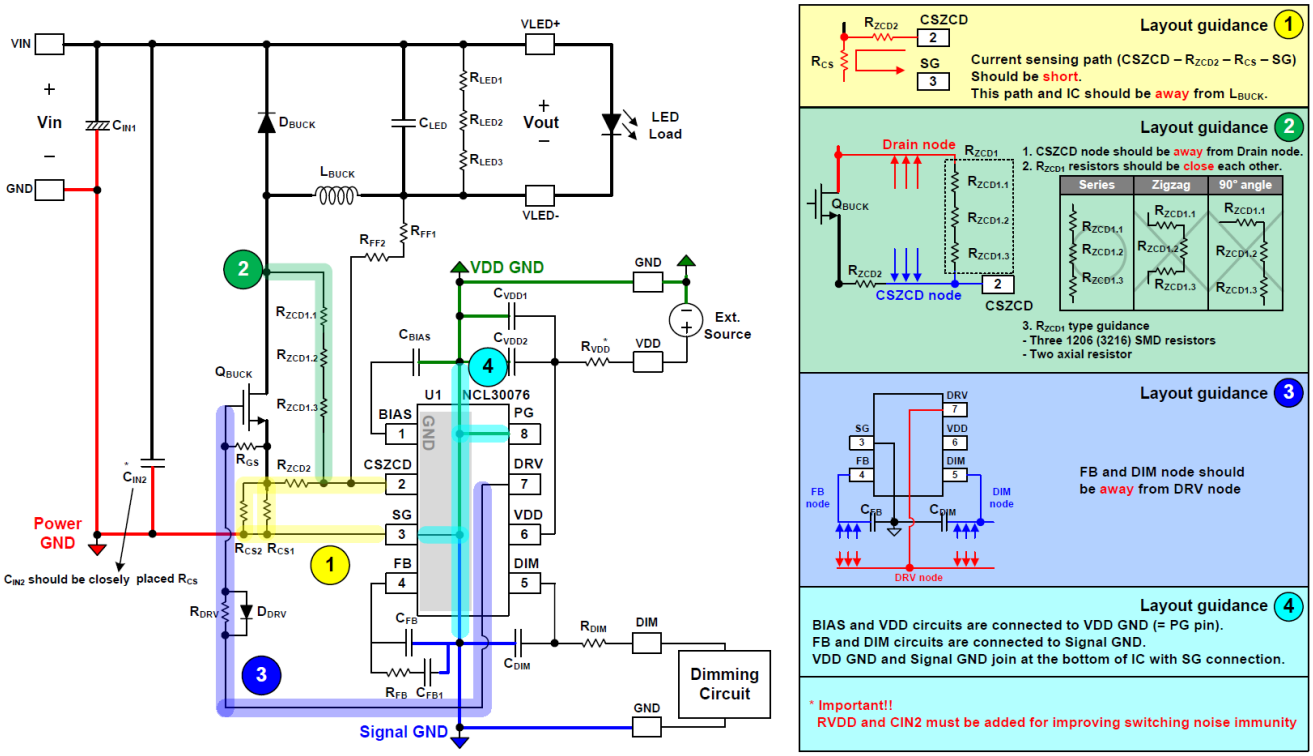


Figure 18. PCB Layout Guidance

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