

NCL2801LED2GEVB

Deep Dimming LED Driver 150 W Evaluation Board User's Manual



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OVERVIEW

This manual covers the specification, theory of operation, testing and construction of the NCL2801LED2GEVB demo board. This demo board uses NCL2801 as the front end PFC

and NCP1392 LLC for the output converter which demonstrates a 150W LED driver. This LED driver features deep dimming with a 0–10 V interface.

EVAL BOARD USER'S MANUAL

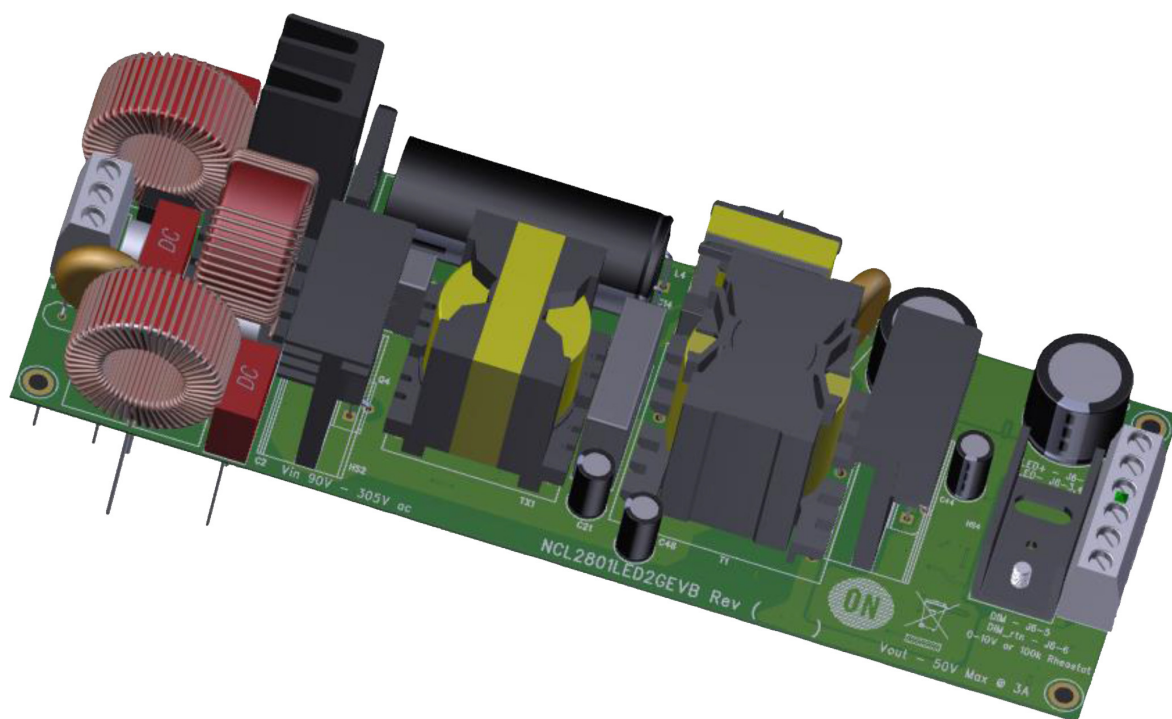


Figure 1.

SPECIFICATIONS

| | | |
|---------------------|------------------|------|
| Input voltage | 90 Vac – 305 Vac | |
| Output Voltage | 50 Vdc | Nom. |
| Output Current | 1.5 A | Max |
| Output Ripple | ± 5% | Max |
| Efficiency | 94% | Max |
| Switching Frequency | 85 kHz – 140 kHz | |
| Dimming Interface | 0 – 10 V | |
| Dimming Range | 0.3% – 100% | |
| PCB Size | 180 mm × 65 mm | |

The key features of this demo board include:

- High Efficiency
- CrM PFC
- LLC Half Bridge
- Dual Dimming Control
- Low Standby Power
- Integrated Thermal Shutdown and UVLO

THEORY OF OPERATION**Overview**

The NCL2801LED2GEVB has 2 converters. The front end converter is based on the NCL2801 PFC controller and the NCP13992 LLC controller regulates the output current to the LEDs. The NCP13992 has hardware handshaking with the NCL2801 to control no load power. At startup, the NCL13992 provides V_{CC} to the NCL2801 while also monitoring the HVDC from the voltage divider that sets the regulated boost voltage. If the boost voltage does not come into regulation within 200 ms, the NCP13992 turns off V_{CC} to the NCL2801. LLC converters work best when the input and output voltage are within a narrow range. The PFC provides the regulated voltage for the LLC input.

PFC

The front end converter is a CrM boost converter based on the NCL2801 PFC controller. This controller is optimized for high power factor and low THD over a broad range of line voltage and loads. The NCL2801 is designed to control high power factor boost converters. This description will focus on aspects which have been optimized to provide very low THDi and high efficiency.

The circuit operates in Critical Conduction Mode (CrM) for high loads, and transitions to Discontinuous Mode at lighter loads by forcing a dead time. This innovative Valley Count Frequency Fold-back method reduces the switching frequency while preserving the benefits of traditional CrM operation. The start of the next switching cycle is timed to the power MOSFET drain voltage ringing after the end of demagnetization which improves efficiency by switching at the valley. Internal circuitry allows near-unity power factor even when the switching frequency is reduced. Introducing

delay lowers the switching frequency and can improve efficiency under certain load conditions. Unlike typical CrM boost converters based on voltage mode control, the NCL2801 utilizes current mode control providing more precise operation. A multiplier is required to condition the envelope of the input current waveform. This IC features a novel multiplier design to deliver very low input current THDi over a broad power range. An offset is introduced to the output of the multiplier to compensate for non-ideal nature of the process. This function maintains sinusoidal input current waveform especially near the zero crossings of the applied input. Line Feedforward compensation adjusts the gain of the controller to improve wide range control. Gain is reduced at high input voltage and increased when the applied voltage drops to a lower level. This gain change maintains the output of the error amplifier, or VCTR, in a more desirable operating range away from low level noise and high level clipping. The gain change occurs in the unused input voltage band between 150 and 180 Vac. The change is clearly visible by monitoring VCTR while applied voltage passes through this range. Range change has no effect while operating in typical global mains voltage ranges. High power factor converters use low loop bandwidth to maintain high PF and low THDi performance. As such, response to input voltage or output load changes is typically slow and suffers large deviation from the regulated value. The NCL2801 features a Dynamic Response Enhancer (DRE) which quickly restores the control loop to the required range in response to changes in power. DRE maintains the output voltage even during an extreme zero to 100% load change. The DRE function is also active during initial startup to speed the process of charging the output capacitor. This DRE function allows use of smaller and lower cost output capacitors in place of larger values often used to mitigate the effects of load changes. Two Over Voltage Protection (OVP) functions are included in this version of NCL2801. The first OVP activates at 105% of nominal output voltage and gradually reduces on-time to zero. This reduces the power processing gradually over a period of time avoiding erratic control of the output voltage. This function typically manages events like rapid changes in applied voltage or load. If the output voltage continues to

rise to 107% of nominal, a second OVP function stops all switching to avoid a run-away situation. Switching resumes when the output voltage returns to normal. The OVP functions can be observed during initial startup and for large reductions in output load. The CS pin links the switch current to the boost control function. This pin also provides over current protection on a cycle by cycle basis. A programming feature is also managed by the CS pin. At initial power up, the NCL2801 outputs a current through the CS pin to read a resistor placed on the circuit board. A lookup table links the measured resistance to one of six levels. Resistance below 50 nominal is interpreted as a shorted pin, or assembly fault which stops the converter from operating. Nominal impedances of 150, 330, 620, and 1 k are linked to one of four thresholds determining when the control function changes from CrM to DCM operation. A resistance measurement greater than about 1.3 k nominal is considered an open circuit, or assembly fault which disables the converter. This feature allows easy configuration of the operating mode and detects faults on the circuit board. This EVB is fitted with 150 which invokes the lowest CrM to DCM threshold.

LLC Power Stage

The power stage is a resonant LLC half bridge. The NCP13992 controls the output by controlling the switching frequency so the output duty cycle is 50%. The NCP13992 operates in current mode so the frequency is slaved to the

primary current. Current control has similar effects in LLC converters has as other current controlled converters:

1) Simplified loop stability 2) Inherent overload protection 3) Stable frequency operation. LLC converters operate at a fixed duty cycle like most resonant converters. Increasing frequency reduces the output current but there are limits to the upper frequency operation. As the load approaches zero, the NCP13992 enters skip modes to regulate the output voltage.

The LLC delivers maximum output at its lowest operating frequency. There is an on time limiter which is hard coded into the NCP13992. The on time limit is selectable by choosing the desired suffix in the part number. The power component values are chosen to work at the frequency limits of the controller.

HV Start

The NCP13992 supplies its own V_{CC} at startup. Simultaneously it turns on the NCL2801 to produce boost voltage. The LLC power stage begins operation when the boost voltage is high enough and supplies V_{CC} power to the NCP13992 and NCL2801 from the bootstrap winding on the power transformer. The bootstrap voltage is regulated by Q5 to about 15 V because the bootstrap voltage is about 25 V in normal operation. The bootstrap voltage needs to be higher than needed so that the V_{CC} power does not reach UVLO during extreme light load operation when the power stage is in skip mode.

Dimming

In order to avoid flicker issues caused by skip mode operation, this deep dimming design uses 2 current control loops. The main loop controls current through the normal feedback control to the NCP13992. Below a predetermined threshold (20% in this case), the second control loop sets the current using a linear regulator made of Q3 & U9. While the

main loop is in control, Q3 is saturated for maximum efficiency. Once Q3 enters the active mode and controls the LED current, Q7 regulates the voltage across Q3 to optimize power losses while allowing Q3 to be in the linear region and provide a very stable output current even though the LLC is in skip mode.

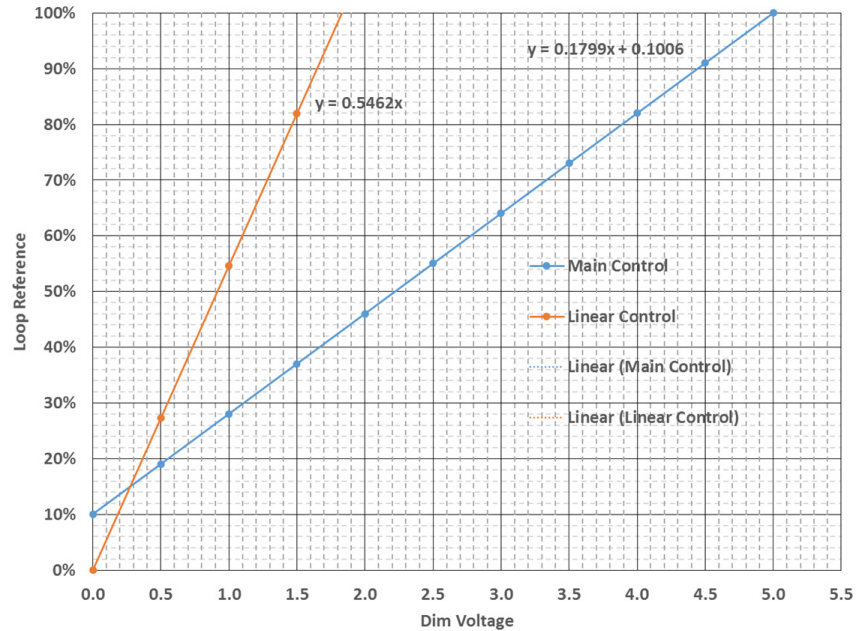


Figure 2. Line Dim Curve

The blue line shows the internal dim voltage (note this is **not** the external 0–10 V dim signal) vs the normalized output current for the main output control. The orange line represents the internal dim voltage vs normalized output for the linear control. For any given dim setting, the lower setting of the 2 control loops will set the output current. As you can see, the blue line (main loop) sets the output current above 20% load and the orange line (linear loop) sets the current below 20%. This dual mode control provides deep stable dimming while maximizing efficiency for higher output loads.

PROTECTION

OVP/Thermal Protection

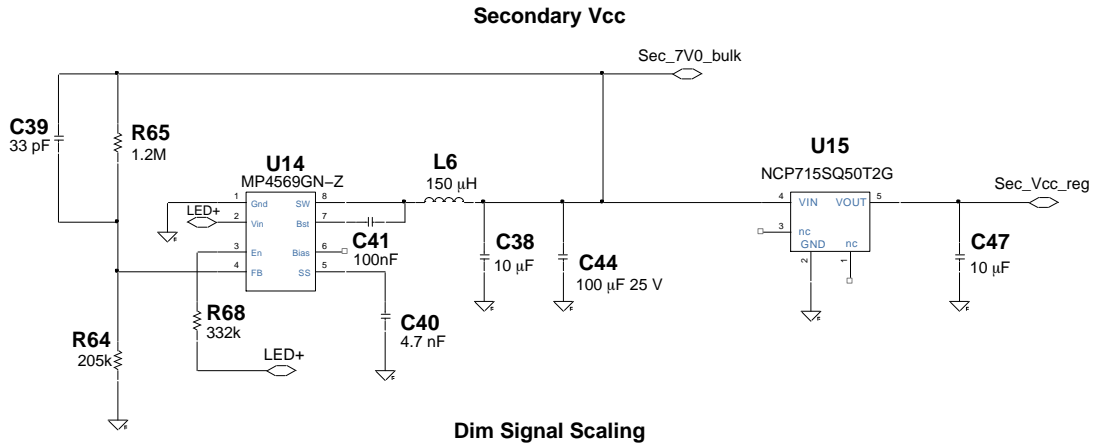
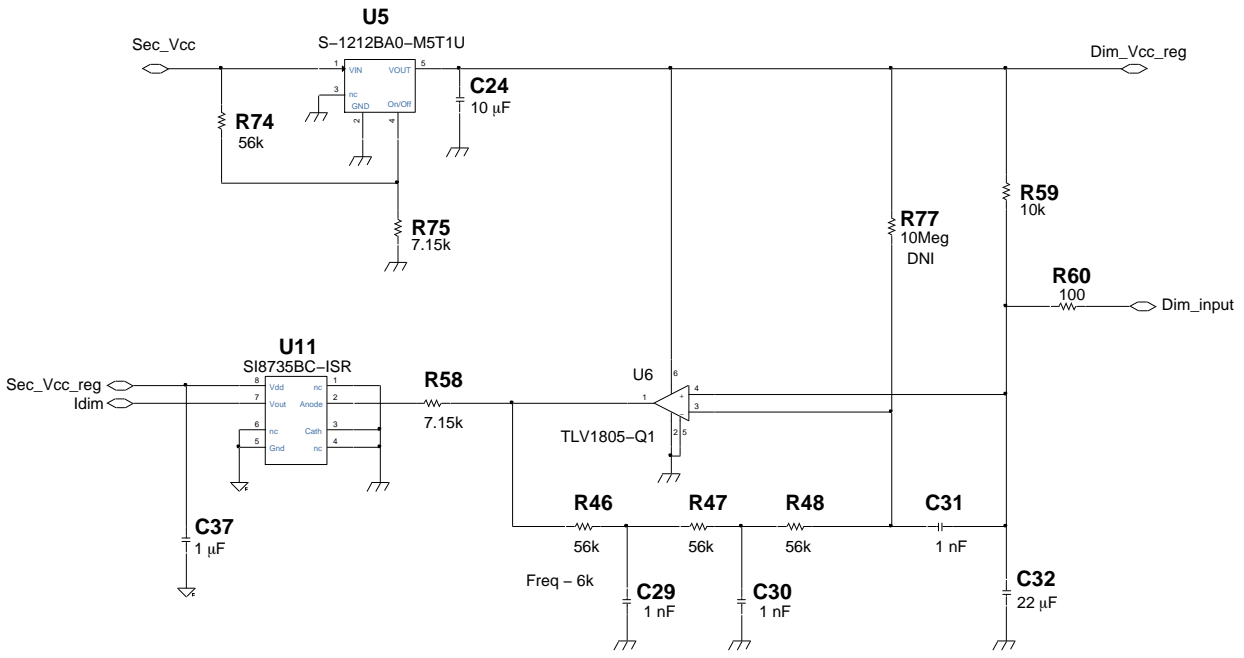
The thermal protection is built into the NCP13992 and shuts down the NCP13992 when the die temperature exceeds 150°C. An NTC can be connected to pin 7 to program the thermal protection. Pulling up pin 7 through a Zener diode is a good way to set the OVP on the primary side. The primary V_{CC} winding is the image of the output voltage through the turns ratio of the power transformer. This is a convenient way to set the OVP threshold.

SCHEMATIC



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NCL2801LED2GEVB



NCL2801LED2GEVB

BILL OF MATERIAL

| Quantity | Reference | Part | Distributor | Dist. P/N | Manufacturer | Mfr_PN | Insert | Safety Controlled |
|----------|---------------------------|---------------|------------------|----------------------|--------------------------|----------------------|--------|-------------------|
| 2 | C1,C2 | 220nF | Digikey | 732-5738-ND | Wurth | 890334024002 | Yes | Yes |
| 1 | C3 | 330nF | Digikey | 732-5739-ND | Wurth | 890334024003CS | Yes | Yes |
| 2 | C4,C28 | 4.7nF Y1 | Digikey | 490-9395-ND | Murata | DE1E3KX472MB4BP01F | Yes | Yes |
| 3 | C5,C41, C49 | 100nF | Digikey | 1276-1001-1-ND | Samsung | CL05B104KO5NNNC | Yes | No |
| 1 | C6 | 220pF | Digikey | 311-1504-1-ND | Yageo | CC1206JKNPOCBN221 | Yes | No |
| 1 | C7 | 22nF 1kV | Digikey | 495-7325-ND | Epcos | B32683A0223K000 | Yes | No |
| 2 | C8,C45 | 22nF | Digikey | 732-7547-1-ND | Wurth | 885012205052 | Yes | No |
| 2 | C9,C10 | 470uF 63V | Digikey | 493-1647-ND | Nichicon | UHE1J471MHD6 | Yes | No |
| 1 | C12 | 10nF | Digikey | 1276-1028-1-ND | Samsung | 1276-1028-1-ND | Yes | No |
| 1 | C13 | 150nF | Digikey | 732-11835-ND | Wurth | 890303325008CS | Yes | No |
| 1 | C14 | 100uF 500V | Digikey | 1189-4273-ND | Rubycon | 500LXW100MEFR18X45 | Yes | No |
| 2 | C15,C22 | 1uF | Digikey | 311-1886-1-ND | Yageo | CC0805KKX7R9BB105 | Yes | No |
| 6 | C16,C17, C27,C29, C30,C31 | 1nF | Digikey | 732-7539-1-ND | Wurth | 885012205044 | Yes | No |
| 1 | C18 | 330nF | Digikey | 732-7968-1-ND | Wurth | 885012206049 | Yes | No |
| 1 | C19 | 2.2uF | Digikey | 732-7665-1-ND | Wurth | 885012207052 | Yes | No |
| 1 | C20 | 2.2uF 100V | Digikey | 445-12947-1-ND | TDK | CGA5L3X7S2A225M160AB | Yes | No |
| 2 | C21,C48 | 10uF 50V | Digikey | 493-15578-ND | Nichicon | UMV1H100MFD | Yes | No |
| 4 | C24,C38, C46,C47 | 10uF | Digikey | 1276-6641-1-ND | Samsung | CL31B106MOHNNNE | Yes | No |
| 2 | C26,C40 | 4.7nF | Digikey | 311-3070-1-ND | Yageo | AC0402KRX7R8BB472 | Yes | No |
| 2 | C32,C36 | 22uF | Digikey | 1276-7076-1-ND | Samsung | CL10A226MO7JZNC | Yes | No |
| 1 | C37 | 1uF | Digikey | 1276-1942-1-ND | Samsung | CL10B105KA8NFNC | Yes | No |
| 1 | C39 | 33pF | Digikey | 311-1020-1-ND | Yageo | CC0402JRNPO9BN330 | Yes | No |
| 2 | C42,C43 | 100pF | Digikey | 732-7533-1-ND | Wurth | 885012205038 | Yes | No |
| 1 | C44 | 100uF25V | Digikey | 493-1548-ND | Nichicon | UHE1E101MED | Yes | No |
| 1 | D1 | GBU6J | Digikey | GBU6JFS-ND | ON Semiconductor | GBU6J | Yes | Yes |
| 5 | D2,D3,D7, D8,D17 | ES1JFL | Fairchild | ES1JFLCT-ND | Fairchild | ES1JFL | Yes | No |
| 1 | D4 | MBRF20100C TG | Digikey | MBRF20100CTGOS-ND | ON Semiconductor | MBRF20100CTG | Yes | No |
| 2 | D5,D6 | RURD660S9A | Digikey | RURD660S9ACT-ND | ON Semiconductor | RURD660S9A | Yes | No |
| 1 | D9 | MMSZ30T1G | ON Semiconductor | MMSZ30T1GOSCT-ND | ON Semiconductor | MMSZ30T1G | Yes | No |
| 1 | D10 | MMSZ5248CT 1G | ON Semiconductor | MMSZ5248CT1GOSCT-N D | ON Semiconductor | MMSZ5248CT1G | Yes | No |
| 2 | D11,D12 | SS13HE | Fairchild | SS13HECT-ND | Fairchild | SS13HE | DNI | No |
| 1 | D13 | MBRS4201T3 G | Fairchild | MBRS4201T3GOSCT-ND | Fairchild | MBRS4201T3G | Yes | No |
| 1 | D16 | MMSZ56T1G | ON Semiconductor | MMSZ56T1GOSCT-ND | ON Semiconductor | MMSZ56T1G | Yes | No |
| 1 | F1 | 3A15 Slo | Digikey | F6803-ND | Littelfuse | 36913150440 | Yes | Yes |
| 1 | HS1 | HS388 | Digikey | HS388-ND | Aavid | 581102B02500G | Yes | No |
| 2 | HS2,HS3 | CSM222-30A E | Digikey | CSM222-30AE-ND | Ohmite | CSM222-30AE | Yes | No |
| 1 | HS4 | V5074B-T | Digikey | AE10804-ND | Assman | V5074B-T | Yes | No |
| 1 | J1 | CON3 | Digikey | 732-2027-ND | Wurth | 691101710003 | Yes | No |
| 1 | J6 | OSTTC062162 | Digikey | ED2613-ND | On Shore Technology Inc. | OSTTC062162 | Yes | No |
| 1 | L1 | 10mH | Digikey | 732-1452-ND | Wurth | 744824310 | Yes | Yes |
| 2 | L2,L3 | 390uH | Digikey | 732-1433-ND | Wurth | 7447071 | Yes | Yes |
| 1 | L4 | 100uH | Digikey | 750317957 | Wurth | 750317957 | Yes | No |
| 1 | L5 | 22uH | Digikey | 732-1211-1-ND | Wurth | 744771122 | Yes | No |

NCL2801LED2GEVB

BILL OF MATERIAL (continued)

| Quantity | Reference | Part | Distributor | Dist. P/N | Manufacturer | Mfr_PN | Insert | Safety Controlled |
|----------|---|----------------|------------------|---------------------|------------------|-------------------|--------|-------------------|
| 1 | L6 | 150uH | Digikey | 732-10761-1-ND | Würth | 74404043151A | Yes | No |
| 2 | Q1,Q2 | FCD9N60NTM | ON Semiconductor | FCD9N60NTMCT-ND | ON Semiconductor | FCD9N60NTM | Yes | No |
| 1 | Q3 | NTD24N06LT4 G | ON Semiconductor | NTD24N06LT4GOSCT-ND | ON Semiconductor | NTD24N06LT4G | Yes | No |
| 1 | Q4 | FCPF190N65S3L1 | ON Semiconductor | FCPF190N65S3L1-ND | ON Semiconductor | FCPF190N65S3L1 | Yes | No |
| 2 | Q5,Q7 | MMBTA06LT1 G | ON Semiconductor | MMBTA06LT1GOSCT-ND | ON Semiconductor | MMBTA06LT1G | Yes | No |
| 1 | RTV-162 | RTV-162 | Digikey | 473-1203-ND | MG Chemicals | RTV162-300ML | Yes | No |
| 1 | R1 | 320 V | Digikey | F1952-ND | Littelfuse | V320LA10P | Yes | Yes |
| 3 | R2,R5,R6 9 | 10 | Digikey | 311-10.0HRCT-ND | Yageo | RC0603FR-0710RL | Yes | No |
| 5 | R3,R35, R37,R60, R72 | 100 | Digikey | 311-100LRCT-ND | Yageo | RC0402FR-07100RL | Yes | No |
| 1 | R4 | 2.4k | Digikey | 311-2.40KLRCT-ND | Yageo | RC0603FR-072K4L | Yes | No |
| 3 | R9,R13, R81 | 4.99k | Digikey | 311-4.99KLRCT-ND | Yageo | RC0402FR-074K99L | Yes | No |
| 7 | R10,R36, R57,R59, R61,R66, R78 | 10k | Digikey | 311-10.0KLRCT-ND | Yageo | RC0402FR-0710KL | Yes | No |
| 1 | R12 | 50m | Digikey | PRL1632.050FCT-ND | Susumu | PRL1632-R050-F-T1 | Yes | No |
| 4 | R14,R15, R16,R18 | 1.5 Meg | Digikey | RHM1.50MAHCT-ND | Rohm | KTR10EZPF1504 | Yes | No |
| 1 | R17 | 56k | Digikey | 311-56.0KCRCT-ND | Yageo | RC0805FR-0756KL | Yes | No |
| 2 | R19,R21 | 20k | Digikey | 311-20.0KLRCT-ND | Yageo | RC0402FR-0720KL | Yes | No |
| 1 | R22 | 150 | Digikey | 311-150LRCT-ND | Yageo | RC0402FR-07150RL | Yes | No |
| 2 | R23,R24 | 0.27 | Digikey | PT.27YCT-ND | Panasonic | RCWE0612R909FKEA | Yes | No |
| 5 | R25,R46, R47,R48, R74 | 56k | Digikey | 311-56.0KLRCT-ND | Yageo | RC0402FR-0756KL | Yes | No |
| 1 | R26 | 15k | Digikey | 311-15.0KLRCT-ND | Yageo | RC0402FR-0715KL | Yes | No |
| 1 | R27 | 56k | Digikey | 311-56.0KCRCT-ND | Yageo | RC0805FR-0756KL | Yes | No |
| 2 | R28,R29 | 1 | Digikey | 311-1.00HRCT-ND | Yageo | RC0603FR-071RL | DNI | No |
| 2 | R30,R55 | 11k | Digikey | 311-11.0KLRCT-ND | Yageo | RC0402FR-0711KL | Yes | No |
| 1 | R31 | 0.4 | Digikey | 311-0.4ARCT-ND | Yageo | PT2512FK-070R4L | Yes | No |
| 1 | R41 | 158k | Digikey | YAG2990CT-ND | Yageo | RC0402FR-07158KL | Yes | No |
| 1 | R42 | 4.7Meg | Digikey | RMCF0402FT4M70CT-ND | Stackpole | RMCF0402FT4M70 | Yes | No |
| 1 | R54 | 100k | Digikey | 311-100KLRCT-ND | Yageo | RC0402FR-07100KL | Yes | No |
| 1 | R56 | 430k | Digikey | 311-430KLRCT-ND | Yageo | RC0402FR-07430KL | Yes | No |
| 2 | R58,R75 | 7.15k | Digikey | YAG3235CT-ND | Yageo | RC0402FR-077K15L | Yes | No |
| 1 | R62 | 1k | Digikey | 311-1.00KLRCT-ND | Yageo | RC0402FR-071KL | Yes | No |
| 2 | R63,R64 | 205k | Digikey | YAG3050CT-ND | Yageo | RC0402FR-07205KL | Yes | No |
| 1 | R65 | 1.2M | Digikey | YAG5649CT-ND | Yageo | AC0402FR-071M2L | Yes | No |
| 1 | R67 | 8.45k | Digikey | YAG3254CT-ND | Yageo | RC0402FR-078K45L | Yes | No |
| 1 | R68 | 332k | Digikey | 311-332KLRCT-ND | Yageo | RC0402FR-07332KL | Yes | No |
| 2 | R70,R71 | 2.7k | Digikey | A129937CT-ND | TE | CRGCQ2010F2K7 | Yes | No |
| 1 | R73 | 1k | Digikey | 311-1.00KLRCT-ND | Yageo | RC0603FR-071KL | Yes | No |
| 1 | R77 | 10Meg | Digikey | 311-10.0MLRCT-ND | Yageo | RC0402FR-0710ML | DNI | No |
| 1 | R79 | 24k | Digikey | 311-24KLRCT-ND | Yageo | RC0402FR-0724KL | Yes | No |
| 1 | R80 | 160k | Digikey | 311-160KCRCT-ND | Yageo | RC0805FR-07160KL | Yes | No |
| 1 | R82 | 1k | Digikey | 311-1.00KLRCT-ND | Yageo | RC0402FR-071KL | Yes | No |
| 1 | TX1 | 180uH | Würth | 750317956 | Würth | 750317956 | Yes | No |
| 0.001 | Thermal Grease | Aavid 249G | Digikey | 249G-ND | Aavid | 249G | Yes | No |
| 1 | T1 | 750318211 | Digikey | 750318211 | Würth | 750318211 | Yes | No |

NCL2801LED2GEVB

BILL OF MATERIAL (continued)

| Quantity | Reference | Part | Distributor | Dist. P/N | Manufacturer | Mfr_PN | Insert | Safety Controlled |
|----------|------------|--------------------|------------------|-----------------------|------------------|-----------------|--------|-------------------|
| 1 | U1 | NCP13992 | Digikey | NCP13992AADR2GOSCT-ND | ON Semiconductor | NCP13992AADR2G | Yes | No |
| 1 | U2 | FODM1007R2 | Digikey | FODM1007R2CT-ND | ON Semiconductor | FODM1007R2 | Yes | No |
| 1 | U4 | NCL2801CDA | ON Semiconductor | NCL2801CDA | ON Semiconductor | NCL2801CDA | Yes | No |
| 1 | U5 | S-1212BA0-M5T1U | Digikey | 1662-2789-1-ND | ABLIC | S-1212BA0-M5T1U | Yes | No |
| 1 | U6 | TLV1805-Q1 | TI | TLV1805-Q1 | TI | TLV1805-Q1 | Yes | No |
| 3 | U9,U10,U12 | TLV271SN2T1G | Digikey | TLV271SN2T1GOSCT-ND | ON Semiconductor | TLV271SN2T1G | Yes | No |
| 1 | U11 | SI8735BC-ISR | Digikey | 336-5079-1-ND | Silicon Labs | SI8735BC-ISR | Yes | No |
| 1 | U14 | MP4569GN-Z | Digikey | 1589-1680-1-ND | MPS | MP4569GN-Z | Yes | No |
| 1 | U15 | NCP715SQ50T2G | Digikey | NCP715SQ50T2GOSCT-ND | ON Semiconductor | NCP715SQ50T2G | Yes | No |
| 0.01 | Z3 | Screw_6-32 X 5/16" | McMaster Carr | | ***** | ***** | Yes | No |
| 0.03 | Z4,Z5,Z6 | Screw_M3X 8 | McMaster Carr | | ***** | ***** | Yes | No |

NCL2801LED2GEVB

TEST DATA

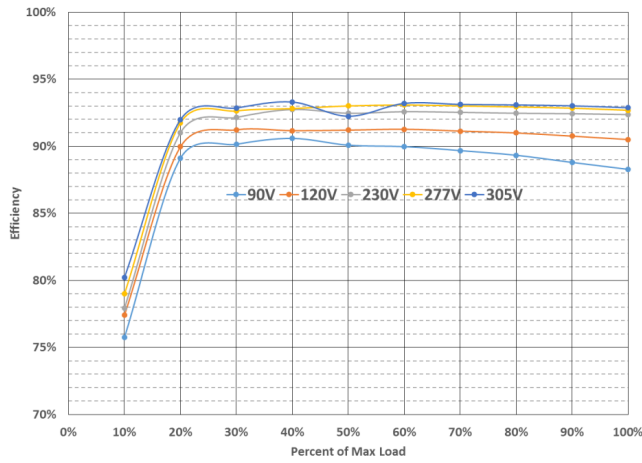


Figure 9. Efficiency

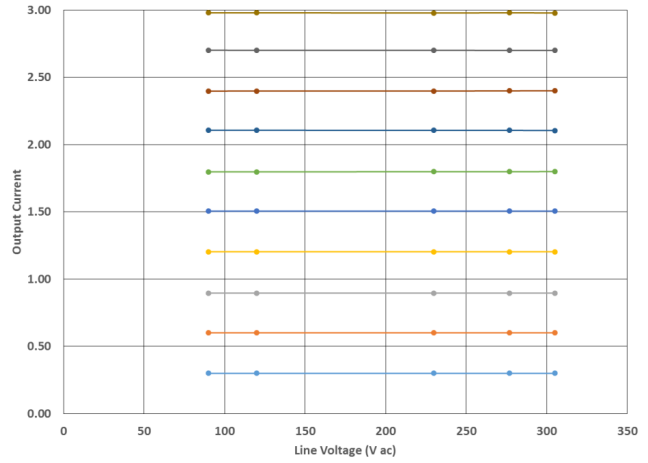


Figure 10. Regulation

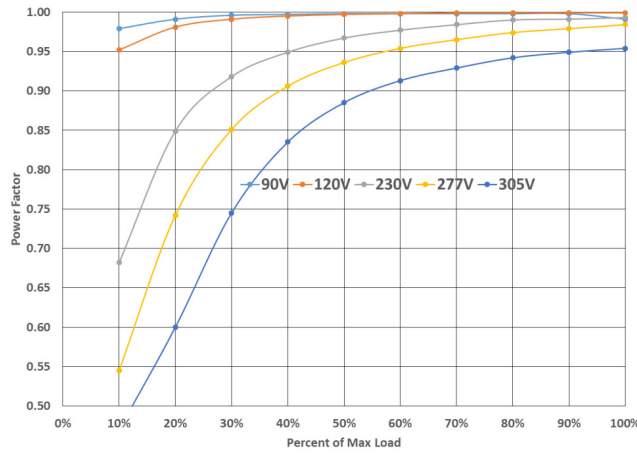


Figure 11. Power Factor

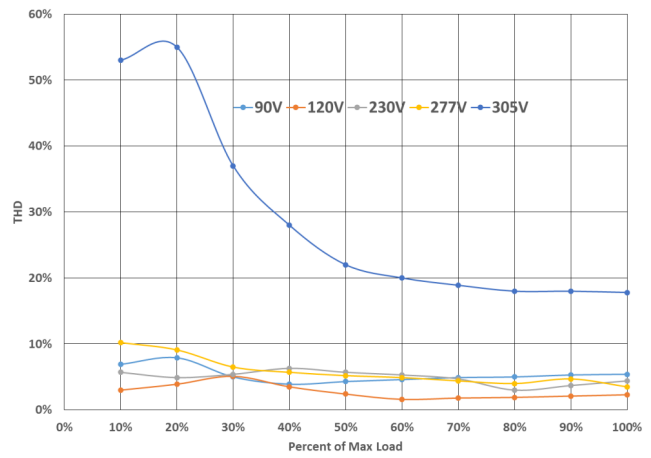


Figure 12. THDi

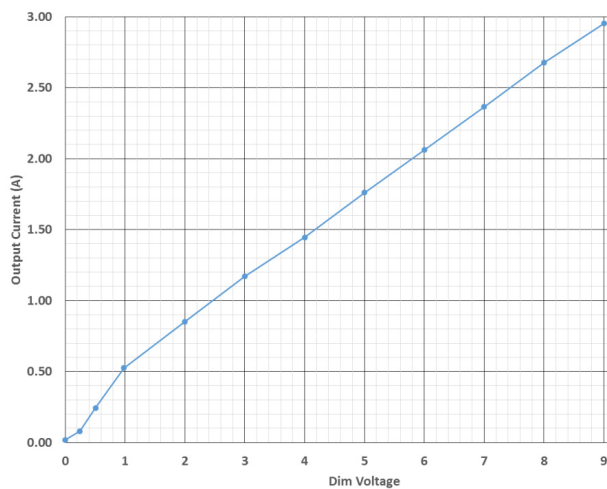


Figure 13. Dim Curve

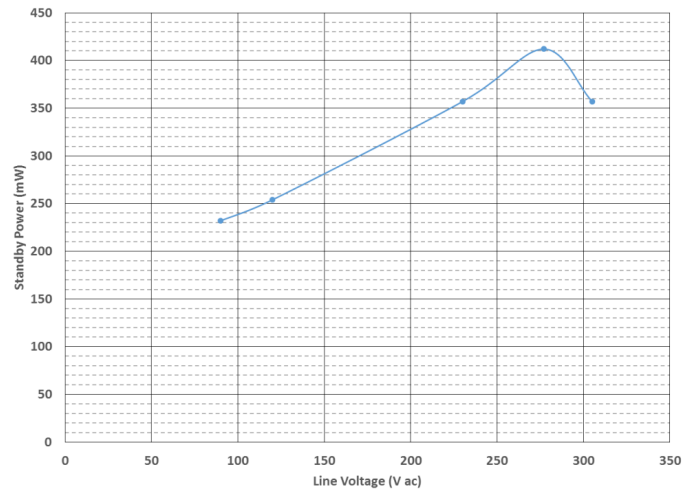


Figure 14. Standby Power

NCL2801LED2GEVB

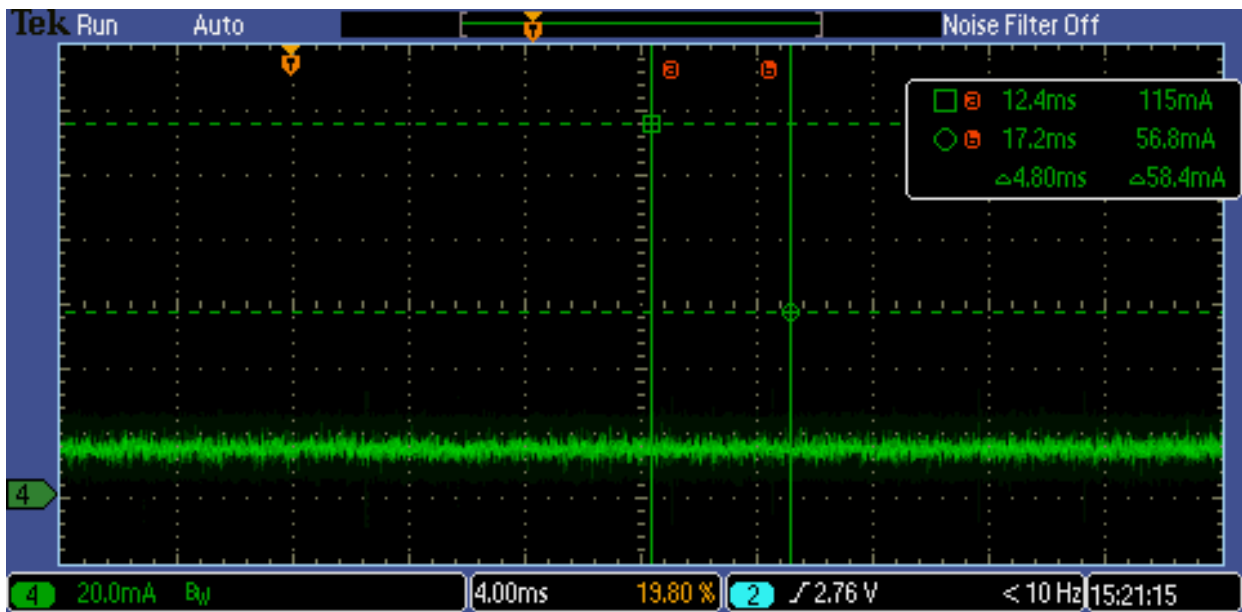


Figure 15. Output @ Min Load

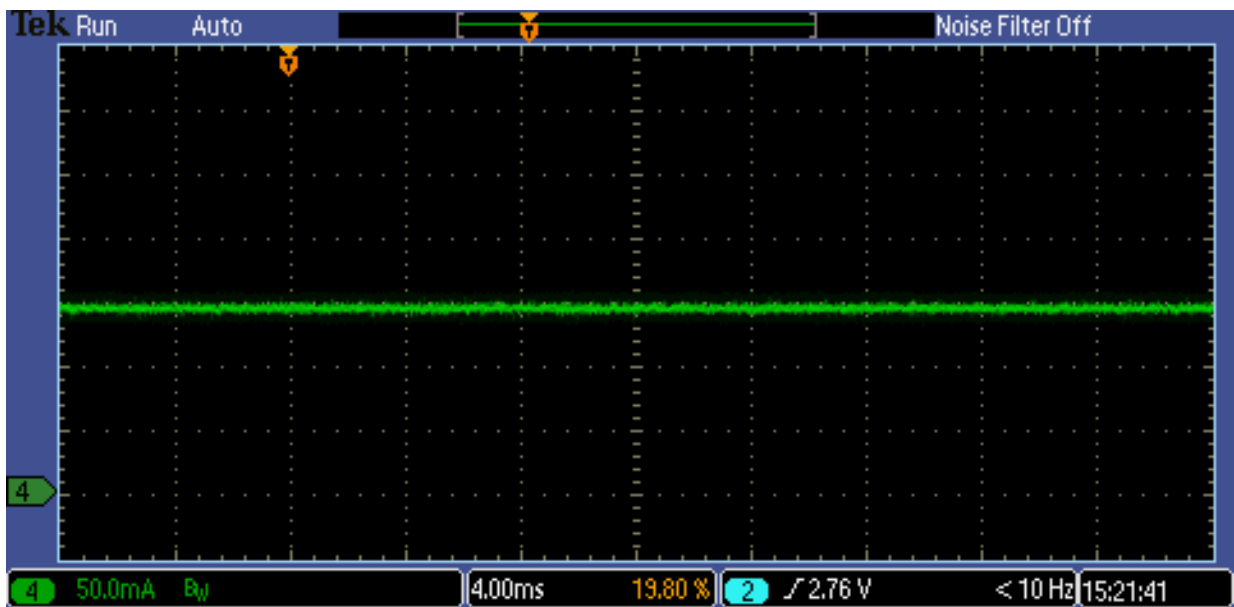


Figure 16. Output @ 150 mA

NCL2801LED2GEVB

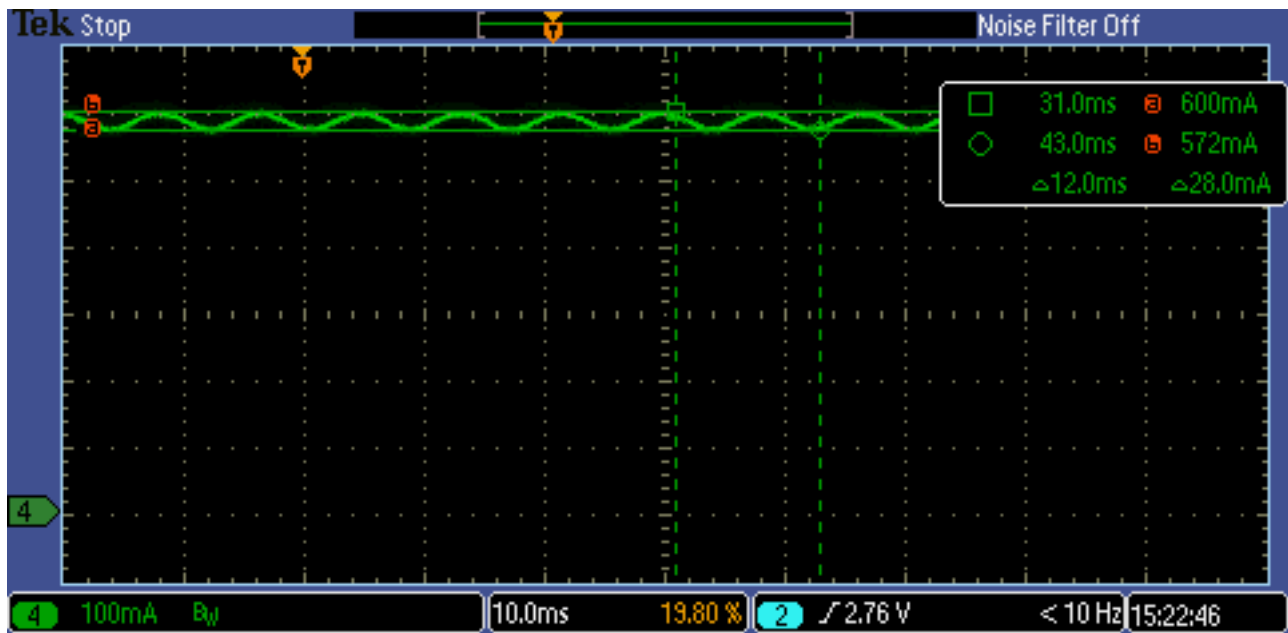


Figure 17. Output @ 600 mA

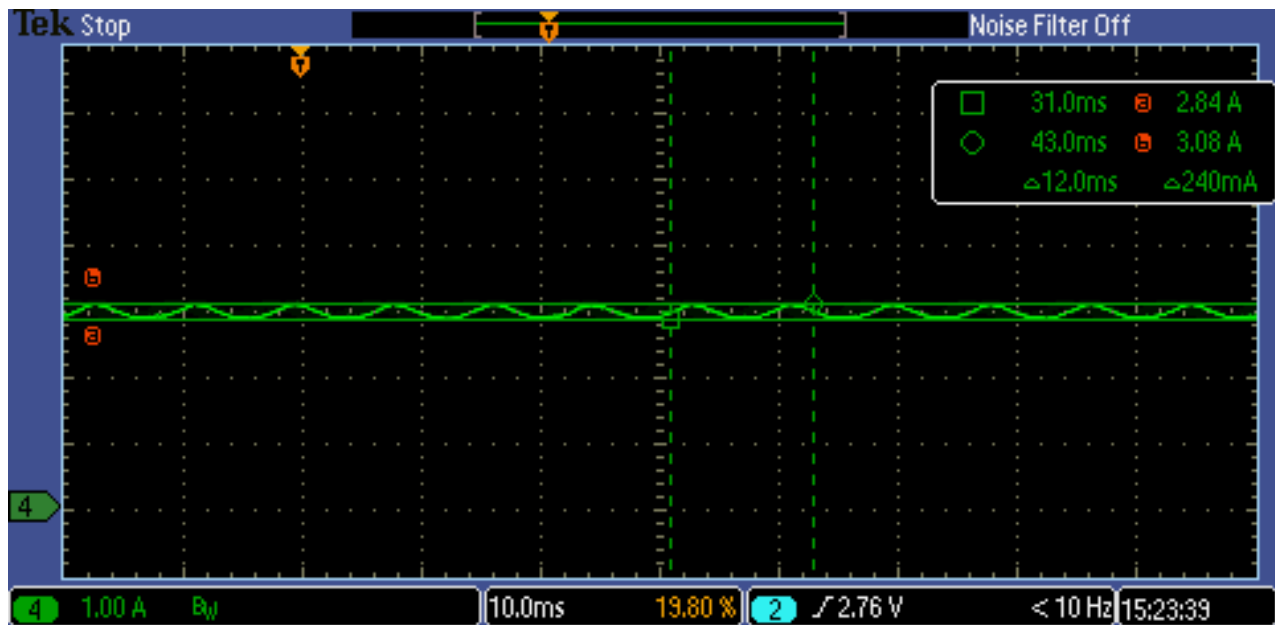


Figure 18. Output @ Max Load

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