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# NCL30030

## Combination Power Factor Correction and Quasi-Resonant Flyback Controllers for LED Lighting

This combination IC integrates power factor correction (PFC) and quasi-resonant flyback functionality necessary to implement a compact and highly efficient LED driver for high performance LED lighting applications.

The PFC stage utilizes a proprietary multiplier architecture to achieve low harmonic distortion and near-unity power factor while operating in a Critical Conduction Mode (CrM). The circuit incorporates all the features necessary for building a robust and compact PFC stage while minimizing the number of external components.

The quasi-resonant current-mode flyback stage features a proprietary valley-lockout circuitry, ensuring stable valley switching. This system works down to the 4<sup>th</sup> valley and toggles to a frequency foldback mode with a minimum frequency clamp beyond the 4<sup>th</sup> valley to eliminate audible noise. Skip mode operation allows excellent efficiency in light load conditions while consuming very low standby power consumption.

### Common General Features

- Wide V<sub>CC</sub> Range from 9 V to 30 V with Built-in Overvoltage Protection
- High-Voltage Startup Circuit
- Integrated High-Voltage Brown-Out Detector
- Fault Input for Severe Fault Conditions, NTC Compatible (Latch and Auto-Recovery Options)
- 0.5 A / 0.8 A Source / Sink Gate Drivers
- Internal Temperature Shutdown

### PFC Controller Features

- Critical Conduction Mode with a Multiplier
- Accurate Overvoltage Protection
- Optional Bi-Level Line-Dependent Output Voltage (2:1 / 1.77:1 Versions)
- Fast Line / Load Transient Compensation
- Boost Diode Short-Circuit Protection
- Feed-Forward for Improved Operation across Line and Load
- Adjustable PFC Disable Threshold Based on Output Power

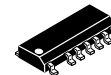
### QR Flyback Controller Features

- Valley Switching Operation with Valley-Lockout for Noise-Free Operation
- Frequency Foldback with Minimum Frequency Clamp for Highest Performance in Standby Mode



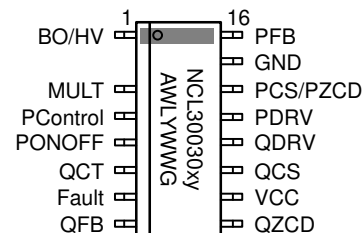
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SOIC-16 NB MISSING PIN 2  
CASE 751DT

### MARKING DIAGRAM



NCL30030 = Specific Device Code

- x = A or B
- y = 1, 2 or 3
- A = Assembly Location
- WL = Wafer Lot
- Y = Year
- WW = Work Week
- G = Pb-Free Package

### ORDERING INFORMATION

See detailed ordering and shipping information on page 31 of this data sheet.

- Minimum Frequency Clamp Eliminates Audible Noise
- Timer-Based Overload Protection (Latched or Auto-Recovery options)
- Adjustable Overpower Protection
- Winding and Output Diode Short-Circuit Protection
- 4 ms Soft-Start Timer
- These are Pb-Free Devices

### Typical Applications

- High Power LED Drivers
- Commercial LED ballasts
- LED Signage Power Supplies
- Adapters
- Open Frame Power Supplies
- LED Electronic Control Gear

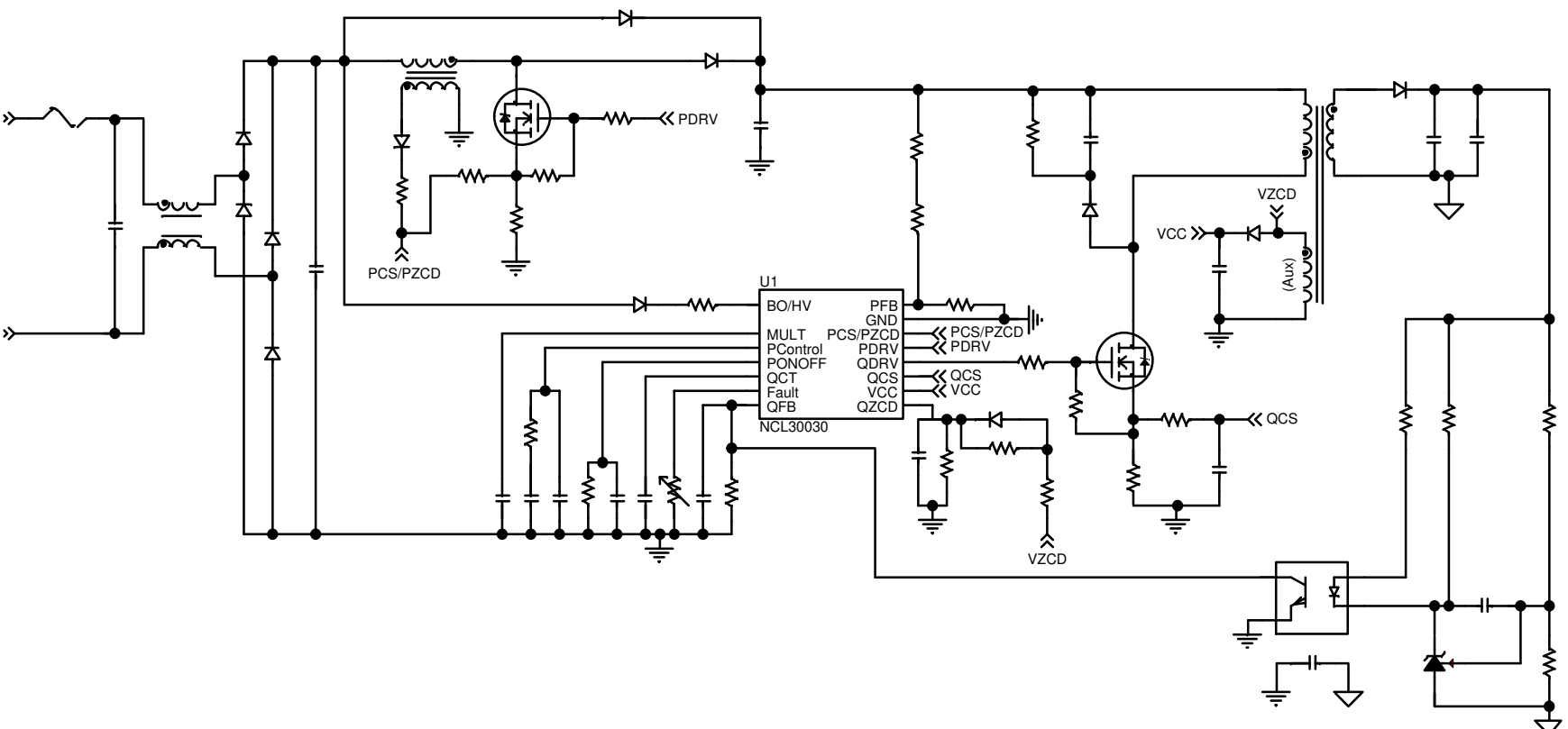


Figure 1. NCL30030 Typical Application Circuit



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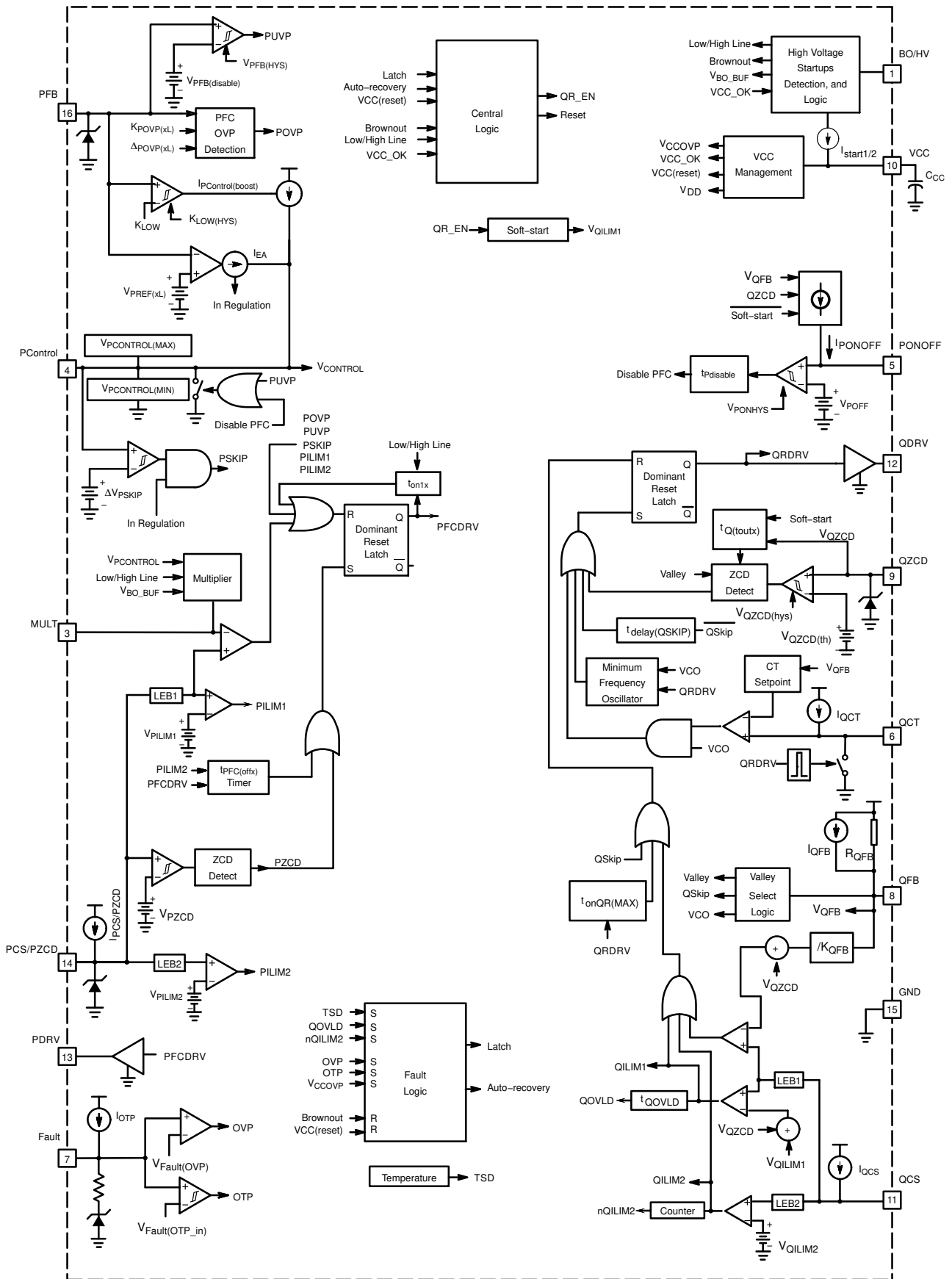


Figure 2. NCL30030 Functional Block Diagram

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**Table 1. PIN FUNCTION DESCRIPTION**

Pin Out	Name	Function
1	BO/HV	Performs input brown-out detection and line voltage range detection.
2		Removed for creepage distance.
3	MULT	This is the output of the multiplication of the BO and Control signals. A capacitor should be put on this pin for filtering. Suggested values from 1 nF – 20 nF.
4	PControl	Output of the PFC transconductance error amplifier. A compensation network is connected between this pin and ground to set the loop bandwidth.
5	PONOFF	A resistor between this pin and ground sets the PFC turn off threshold. The voltage on this pin is compared to an internal voltage signal proportional to the output power. The PFC disabled threshold is determined by the resistor on this pin and the internal pull-up current source, I <sub>PONOFF</sub> .
6	QCT	An external capacitor sets the frequency in VCO mode for the QR flyback controller.
7	Fault	The controller enters fault mode if the voltage of this pin is pulled above or below the fault thresholds. A precise pull up current source allows direct interface with an NTC thermistor. Fault detection triggers a latch or auto-recovery depending on device option.
8	QFB	Feedback input for the QR Flyback controller. Allows direct connection to an optocoupler.
9	QZCD	Input to the demagnetization detection comparator for the QR Flyback controller. Also used to set the overpower compensation.
10	VCC	Supply input.
11	QCS	Input to the cycle-by-cycle current limit comparator for the QR Flyback section.
12	QDRV	QR flyback controller switch driver.
13	PDRV	PFC controller switch driver.
14	PCS/PZCD	Input to the cycle-by-cycle current limit comparator for the PFC section. Also used to perform the demagnetization detection for the PFC controller.
15	GND	Ground reference.
16	PFB	PFC feedback input from external resistor divider used to sense the PFC bulk voltage. This pin voltage is compared to an internal reference. There are three different reference voltage combinations depending on ac mains voltage and version of the part.

**Table 2. NCL30030 DEVICE OPTIONS**

Device	Flyback Overload Protection	Fault OTP	PFC Reference Voltage (High Line / Low Line)
NCL30030B1DR2G	Auto-Recovery	Auto-Recovery	3.55 / 2 V
NCL30030B2DR2G	Auto-Recovery	Auto-Recovery	4 / 2 V
NCL30030B3DR2G	Auto-Recovery	Auto-Recovery	4 / 4 V
NCL30030A1DR2G*	Latch	Latch	3.55 / 2 V
NCL30030A2DR2G*	Latch	Latch	4 / 2 V
NCL30030A3DR2G*	Latch	Latch	4 / 4 V

\*Please contact local sales representative for availability

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**Table 3. MAXIMUM RATINGS** (Notes 1 through 6)

Rating	Pin	Symbol	Value	Unit
High Voltage Brownout Detector Input Voltage	1	$V_{BO/HV}$	-0.3 to 700	V
High Voltage Brownout Detector Input Current	1	$I_{BO/HV}$	20	mA
PFC Low Voltage Feedback Input Voltage	16	$V_{PFB}$	-0.3 to 9	V
PFC Low Voltage Feedback Input Current	16	$I_{PFB}$	0.5	mA
PFC Zero Current Detection and Current Sense Input Voltage (Note 1)	14	$V_{PCS/PZCD}$	-0.3 to $V_{PCS/PZCD(MAX)}$	V
PFC Zero Current Detection and Current Sense Input Current	14	$I_{PCS/PZCD}$	-2/+5	mA
PFC Control Input Voltage	4	$V_{PCControl}$	-0.3 to 5	V
PFC Control Input Current	4	$I_{PCControl}$	10	mA
Supply Input Voltage	10	$V_{CC(MAX)}$	-0.3 to 30	V
Supply Input Current	10	$I_{CC(MAX)}$	30	mA
Supply Input Voltage Slew Rate	10	$dV_{CC}/dt$	1	V/ $\mu$ s
Fault Input Voltage	7	$V_{Fault}$	-0.3 to ( $V_{CC} + 1.25$ )	V
Fault Input Current	7	$I_{Fault}$	10	mA
PFC Multiplier pin	3	$V_{MULT}$	-0.3 to 10	V
PFC Multiplier pin	3	$I_{MULT}$	3	mA
QR Flyback Zero Current Detection Input Voltage	9	$V_{QZCD}$	-0.9 to ( $V_{CC} + 1.25$ )	V
QR Flyback Zero Current Detection Input Current	9	$I_{QZCD}$	-2/+5	mA
QR Feedback Input Voltage	6	$V_{QCT}$	-0.3 to 10	V
QR Feedback Input Current	6	$I_{QCT}$	10	mA
QR Flyback Current Sense Input Voltage	11	$V_{QCS}$	-0.3 to 10	V
QR Flyback Current Sense Input Current	11	$I_{QCS}$	10	mA
QR Flyback Feedback Input Voltage	8	$V_{QFB}$	-0.3 to 10	V
QR Flyback Feedback Input Current	8	$I_{QFB}$	10	mA
PFC Driver Maximum Voltage (Note 2)	13	$V_{PDRV}$	-0.3 to $V_{PDRV(high2)}$	V
PFC Driver Maximum Current	13	$I_{PDRV(SRC)}$ $I_{PDRV(SNK)}$	500 800	mA
Flyback Driver Maximum Voltage (Note 2)	12	$V_{QDRV}$	-0.3 to $V_{QDRV(high2)}$	V
Flyback Driver Maximum Current	12	$I_{QDRV(SRC)}$ $I_{QDRV(SNK)}$	500 800	mA
PFC ON/OFF Threshold Adjust Input Voltage	5	$V_{PONOFF}$	-0.3 to 10	V
PFC ON/OFF Threshold Adjust Input Current	5	$I_{PONOFF}$	10	mA
Operating Junction Temperature	N/A	$T_J$	-40 to 125	$^{\circ}$ C
Storage Temperature Range	N/A	$T_{STG}$	-60 to 150	$^{\circ}$ C

Stresses exceeding those listed in the Maximum Ratings table may damage the device. If any of these limits are exceeded, device functionality should not be assumed, damage may occur and reliability may be affected.

- $V_{PCS/PZCD(MAX)}$  is the maximum voltage of the pin shown in the electrical table. When the voltage on this pin exceeds 5 V, the pin sinks a current equal to  $(V_{PCS/PZCD} - 5 V)/(2 \text{ k}\Omega)$ . A  $V_{PCS/PZCD}$  of 7 V generates a sink current of approximately 1 mA.
- Maximum driver voltage is limited by the driver clamp voltage,  $V_{XDRV(high2)}$ , when  $V_{CC}$  exceeds the driver clamp voltage. Otherwise, the maximum driver voltage is  $V_{CC}$ .
- Maximum Ratings are those values beyond which damage to the device may occur. Exposure to these conditions or conditions beyond those indicated may adversely affect device reliability. Functional operation under absolute maximum-rated conditions is not implied. Functional operation should be restricted to the Recommended Operating Conditions.
- This device contains Latch-up protection and has been tested per JEDEC JESD78D, Class I and exceeds +100/-100 mA.
- Low Conductivity Board. As mounted on 80 x 100 x 1.5 mm FR4 substrate with a single layer of 50 mm<sup>2</sup> of 2 oz copper traces and heat spreading area. As specified for a JEDEC51-1 conductivity test PCB. Test conditions were under natural convection of zero air flow.
- Pin 1 is rated to the maximum voltage of the part, or 700 V.

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**Table 3. MAXIMUM RATINGS** (Notes 1 through 6)

Rating	Symbol	Value	Unit
Power Dissipation ( $T_A = 75^\circ\text{C}$ , 1 Oz Cu, 0.155 Sq Inch Printed Circuit Copper Clad) Plastic Package SOIC-16NB	$P_D$	550	mW
Thermal Resistance, Junction to Ambient 1 Oz Cu Printed Circuit Copper Clad) Plastic Package SOIC-16NB	$R_{\theta JA}$	145	$^\circ\text{C/W}$
ESD Capability (Note 6) Human Body Model per JEDEC Standard JESD22-A114F. Machine Model per JEDEC Standard JESD22-A115-A. Charge Device Model per JEDEC Standard JESD22-C101E.	HBM MM CDM	3000 200 750	V

Stresses exceeding those listed in the Maximum Ratings table may damage the device. If any of these limits are exceeded, device functionality should not be assumed, damage may occur and reliability may be affected.

- $V_{PCS/PZCD(MAX)}$  is the maximum voltage of the pin shown in the electrical table. When the voltage on this pin exceeds 5 V, the pin sinks a current equal to  $(V_{PCS/PZCD} - 5\text{ V})/(2\text{ k}\Omega)$ . A  $V_{PSC/PZCD}$  of 7 V generates a sink current of approximately 1 mA.
- Maximum driver voltage is limited by the driver clamp voltage,  $V_{XDRV(high2)}$ , when  $V_{CC}$  exceeds the driver clamp voltage. Otherwise, the maximum driver voltage is  $V_{CC}$ .
- Maximum Ratings are those values beyond which damage to the device may occur. Exposure to these conditions or conditions beyond those indicated may adversely affect device reliability. Functional operation under absolute maximum-rated conditions is not implied. Functional operation should be restricted to the Recommended Operating Conditions.
- This device contains Latch-up protection and has been tested per JEDEC JESD78D, Class I and exceeds +100/-100 mA.
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- Pin 1 is rated to the maximum voltage of the part, or 700 V.

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**Table 4. ELECTRICAL CHARACTERISTICS:** ( $V_{CC} = 12\text{ V}$ ,  $V_{BO/HV} = 120\text{ V}$ ,  $V_{Fault} = \text{open}$ ,  $V_{PFB} = 1.9\text{ V}$ ,  $V_{PControl} = 4\text{ V}$ ,  $V_{PCS/PZCD} = 0\text{ V}$ ,  $V_{QFB} = 3\text{ V}$ ,  $V_{PONOFF} = 4\text{ V}$ ,  $V_{QCS} = 0\text{ V}$ ,  $V_{QZCD} = 0\text{ V}$ ,  $C_{MULT} = 2\text{ nF}$ ,  $C_{VCC} = 100\text{ nF}$ ,  $C_{QCT} = 220\text{ pF}$ ,  $C_{PDRV} = 1\text{ nF}$ ,  $C_{QDRV} = 1\text{ nF}$ , for typical values  $T_J = 25^\circ\text{C}$ , for min/max values,  $T_J$  is  $-40^\circ\text{C}$  to  $125^\circ\text{C}$ , unless otherwise noted)

Characteristics	Conditions	Pin	Symbol	Min	Typ	Max	Unit
<b>STARTUP AND SUPPLY CIRCUITS</b>							
Supply Voltage Startup Threshold Minimum Operating Voltage Operating Hysteresis Internal Latch / Logic Reset Level Transition from $I_{start1}$ to $I_{start2}$	$V_{CC}$ increasing $V_{CC}$ decreasing $V_{CC(on)} - V_{CC(off)}$ $V_{CC}$ decreasing $V_{CC}$ increasing, $I_{HV/HV} = 650\ \mu\text{A}$	10	$V_{CC(on)}$ $V_{CC(off)}$ $V_{CC(HYS)}$ $V_{CC(reset)}$ $V_{CC(inhibit)}$	16 8.2 7.7 4.5 0.3	17 8.8 – 5.5 0.7	18 9.4 – 7.5 0.95	V
Blanking Duration After $V_{CC(off)}$		10	$t_{UVLO(blank)}$	3	–	25	$\mu\text{s}$
Startup Current in Inhibit Mode	$V_{CC} = 0\text{ V}$	10	$I_{start1A}$	0.20	0.50	0.65	mA
Startup Current Operating Mode	$V_{CC} = V_{CC(on)} - 0.5\text{ V}$ , $V_{BO/HV} = 100\text{ V}$	10	$I_{start2A}$	2.5	–	5	mA
Minimum Startup Voltage	$I_{start2A} = 1\text{ mA}$ , $V_{CC} = V_{CC(on)} - 0.5\text{ V}$	1	$V_{BO/HV(MIN)}$	–	–	40	V
$V_{CC}$ Overvoltage Protection Threshold		10	$V_{CC(OVP)}$	27	28	29	V
$V_{CC}$ Overvoltage Protection Delay		10	$t_{delay(VCC\_OVP)}$	20.0	30.0	40.0	$\mu\text{s}$
Supply Current Before Startup, Fault or Latch Flyback in Skip, PFC Disabled Flyback in Skip, PFC in Skip Flyback Enabled, QDRV Low, PFC Disabled Flyback Enabled, QDRV Low, PFC in Skip PFC and Flyback switching at 70 kHz PFC and Flyback switching at 70 kHz	$V_{CC} = V_{CC(on)} - 0.5\text{ V}$ $V_{QFB} = 0.35\text{ V}$ $V_{QFB} = 0.35\text{ V}$ , $V_{PControl} < V_{PSKIP}$ $V_{QZCD} = 1\text{ V}$ $V_{QZCD} = 1\text{ V}$ , $V_{PControl} < V_{PSKIP}$ $C_{QDRV} = C_{PDRV} = \text{open}$	10	$I_{CC2}$ $I_{CC3a}$ $I_{CC3b}$ $I_{CC4}$ $I_{CC5}$ $I_{CC6}$ $I_{CC7}$	– – – – – – –	0.15 0.3 0.5 0.85 1.1 1.5 2.8	0.28 0.43 1.03 1.38 1.83 4.03 5.23	mA
<b>BROWN-OUT DETECTION</b>							
System Startup Threshold	$V_{BO/HV}$ increasing	1	$V_{BO(start)}$	102	111	120	V
System Shutdown Threshold	$V_{BO/HV}$ decreasing	1	$V_{BO(stop)}$	86	101	116	V
Brown-out Hysteresis	$V_{BO/HV}$ increasing	1	$V_{BO(hys)}$	4	–	16	V
Brown-out Detection Blanking Time	$V_{BO/HV}$ decreasing, duration below $V_{BO(stop)}$ for a Brown-out fault	1	$t_{BO(stop)}$	43	54	65	ms
Brown-out Drive Disable Threshold	$V_{BO/HV}$ decreasing, threshold to disable drive	1	$V_{BO(DRV\_disable)}$	20	30	40	V
Line Level Detection Threshold	$V_{BO/HV}$ increasing	1	$V_{lineselect}$	216	240	264	V
High to Low Line Mode Selector Timer	$V_{BO/HV}$ decreasing	1	$t_{high\ to\ low\ line}$	43	54	65	ms
Low to High Line Mode Selector Timer	$V_{BO/HV}$ increasing	1	$t_{low\ to\ high\ line}$	200	350	450	$\mu\text{s}$
Brownout Pin Off State Leakage Current	$V_{BO/HV} = 500\text{ V}$	1	$I_{BO/HV(off)}$	–	–	42	$\mu\text{A}$
<b>PFC MAXIMUM OFF TIME TIMER</b>							
Maximum Off Time	$V_{PCS/PZCD} > V_{PILIM2}$	13	$t_{PFC(off1)}$ $t_{PFC(off2)}$	100 700	200 1000	300 1300	$\mu\text{s}$
<b>PFC CURRENT SENSE</b>							
Fixed Cycle by Cycle Current Sense Threshold		14	$V_{PILIM1}$	1.35	1.5	1.65	V
Cycle by Cycle Leading Edge Blanking Duration		14	$t_{PCS(LEB1)}$	250	325	400	ns
Cycle by Cycle Current Sense Propagation Delay		14	$t_{PCS(delay1)}$	–	100	400	ns
Abnormal Overcurrent Fault Threshold		14	$V_{PILIM2}$	1.8	2	2.2	V
Abnormal Overcurrent Fault Leading Edge Blanking Duration		14	$t_{PCS(LEB2)}$	100	175	250	ns
Abnormal Overcurrent Fault Propagation Delay		14	$t_{PCS(delay2)}$	–	100	200	ns

Product parametric performance is indicated in the Electrical Characteristics for the listed test conditions, unless otherwise noted. Product performance may not be indicated by the Electrical Characteristics if operated under different conditions.



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**Table 4. ELECTRICAL CHARACTERISTICS:** ( $V_{CC} = 12\text{ V}$ ,  $V_{BO/HV} = 120\text{ V}$ ,  $V_{Fault} = \text{open}$ ,  $V_{PFB} = 1.9\text{ V}$ ,  $V_{PControl} = 4\text{ V}$ ,  $V_{PCS/PZCD} = 0\text{ V}$ ,  $V_{QFB} = 3\text{ V}$ ,  $V_{PONOFF} = 4\text{ V}$ ,  $V_{QCS} = 0\text{ V}$ ,  $V_{QZCD} = 0\text{ V}$ ,  $C_{MULT} = 2\text{ nF}$ ,  $C_{VCC} = 100\text{ nF}$ ,  $C_{QCT} = 220\text{ pF}$ ,  $C_{PDRV} = 1\text{ nF}$ ,  $C_{QDRV} = 1\text{ nF}$ , for typical values  $T_J = 25^\circ\text{C}$ , for min/max values,  $T_J$  is  $-40^\circ\text{C}$  to  $125^\circ\text{C}$ , unless otherwise noted)

Characteristics	Conditions	Pin	Symbol	Min	Typ	Max	Unit
<b>PFC CURRENT SENSE</b>							
Multiplier Cycle by Cycle Current Sense Offset	$BO = 180$ , $PFB = 1.5\text{ V}$	14	$V_{PILIM\_MULT}$	-12	-	10	mV
Multiplier Cycle by Cycle Current Sense Propagation Delay	$BO = 180\text{ V}$ , $PFB = 1.5\text{ V}$	14	$t_{PCS(\text{delay\_mult})}$	10	100	200	ns
Pull-up Current Source	$V_{PCS/PZCD} = 2.5\text{ V}$	14	$I_{PCS/PZCD}$	0.7	1.0	1.3	$\mu\text{A}$
<b>PFC REGULATION BLOCK</b>							
PFC Reference Voltage See Table 2 for Options	$V_{BO/HV} > V_{BO(\text{lineselect})}$ $V_{BO/HV} < V_{BO(\text{lineselect})}$	16	$V_{PREF(HL)}$ $V_{PREF(LL)}$	3.47 3.92 1.95 3.92	3.55 4.00 2 4	3.62 4.08 2.05 4.08	V
Error Amplifier Current Source Sink Source Sink	PFC Enabled $V_{PFB} = 0.96 \times V_{PREF(HL)}$ $V_{PFB} = 1.04 \times V_{PREF(HL)}$ $V_{PFB} = 0.96 \times V_{PREF(LL)}$ $V_{PFB} = 1.04 \times V_{PREF(LL)}$	4	$I_{EA(SRCHL)}$ $I_{EA(SNKHL)}$ $I_{EA(SRCLL)}$ $I_{EA(SNKLL)}$	16 16 10 10	32 32 20 20	48 48 30 30	$\mu\text{A}$
Open Loop Error Amplifier Transconductance	$V_{PFB} = V_{PREF(LL)} \pm 4\%$ $V_{PFB} = V_{PREF(HL)} \pm 4\%$	4	$g_m$ $g_{m\_HL}$	100 100	200 200	300 300	$\mu\text{S}$
Maximum Control Voltage	$V_{PFB} \times K_{LOW(PFCxL)}$ , $C_{PControl} = 10\text{ nF}$	4	$V_{PControl(MAX)}$	-	4.5	-	V
Minimum Control Voltage (Lower clamp)	$V_{PFB} \times K_{POVP(xL)}$ , $C_{PControl} = 10\text{ nF}$	4	$V_{PControl(MIN)}$	-	0.6	-	V
EA Output Control Voltage Range	$V_{PControl(MAX)} - V_{PControl(MIN)}$	4	$\Delta V_{PControl}$	3.7	3.9	4.1	V
Ratio between the $V_{out}$ Low Detect Threshold and the Regulation Level	$V_{PFB}$ decreasing, $V_{BOOST} / V_{PREF(HL)}$ $V_{PFB}$ decreasing, $V_{BOOST} / V_{PREF(LL)}$	16	$K_{LOW(PFCHL)}$ $K_{LOW(PFCLL)}$	0.940 0.940	0.945 0.945	0.950 0.950	
Ratio between the $V_{out}$ Low Exit Threshold and the Regulation Level	$V_{PFB}$ increasing	16	$K_{LOW(HYSHL)}$ $K_{LOW(HYSSL)}$	0.950 0.950	0.960 0.960	0.965 0.965	
Source Current During $V_{out}$ Low Detect		4	$I_{PControl(boost)}$	190	240	290	$\mu\text{A}$
PFC In Regulation Threshold	$V_{PControl}$ increasing	4	$I_{In\_Regulation}$	-6.5	-	0	$\mu\text{A}$
Resistance of Internal Pull Down Switch	$I_{PControl} = 5\text{ mA}$	4	$R_{PControl}$	4	25	50	$\Omega$
<b>PFC SKIP MODE</b>							
Delta Between Skip Level and Lower Clamp PControl Voltages	$V_{PControl}$ decreasing, measured from $V_{PControl(MIN)}$	4	$\Delta V_{PSKIP}$	5	25	50	mV
PFC Skip Hysteresis	$V_{PControl}$ increasing	4	$V_{PSKIP(HYS)}$	25	50	75	mV
Delay Exiting Skip Mode	Apply 1 V step from $V_{PControl(MIN)}$	4	$t_{\text{delay}(PSKIP)}$	-	50	60	$\mu\text{s}$
<b>PFC FAULT PROTECTION</b>							
Ratio between the Hard Overvoltage Protection Threshold and Regulation Level	$V_{PFB}$ increasing $K_{POVP(LL)} = V_{PFB}/V_{PREF(LL)}$ $K_{POVP(HL)} = V_{PFB}/V_{PREF(HL)}$	16	$K_{POVP(LL)}$ $K_{POVP(HL)}$	1.06 1.05	1.08 1.06	1.10 1.08	
Soft Overvoltage Protection Threshold	$V_{PSOVP(LL)}$ = soft overvoltage level $\Delta_{POVP(LL)} = K_{POVP} \times V_{PREF(LL)} - V_{PSOVP(LL)}$ $\Delta_{POVP(HL)} = K_{POVP} \times V_{PREF(HL)} - V_{PSOVP(HL)}$	16	$\Delta_{POVP(LL)}$ $\Delta_{POVP(HL)}$	20 20	- -	55 55	mV
PFC Feedback Pin Disable Threshold	$V_{PFB}$ decreasing	16	$V_{PFB(\text{disable})}$	0.225	0.30	0.35	V
PFC Feedback Pin Enable Threshold	$V_{PFB}$ increasing	16	$V_{PFB(\text{enable})}$	0.275	0.35	0.40	V
PFC Feedback Pin Hysteresis	$V_{PFB}$ increasing	16	$V_{PFB(HYS)}$	25	50	-	mV
PFC Feedback Disable Delay		16	$t_{\text{delay}(PFB)}$	20	30	40	$\mu\text{s}$
<b>PFC ON TIME CONTROL</b>							
PFC Maximum On	$V_{PControl} = V_{PControl(MAX)}$ $V_{BO/HV} = 163\text{ V}$ $V_{BO/HV} = 325\text{ V}$	13	$t_{on1a}$ $t_{on1b}$	12.5 4.25	15 5.00	17.5 5.75	$\mu\text{s}$

Product parametric performance is indicated in the Electrical Characteristics for the listed test conditions, unless otherwise noted. Product performance may not be indicated by the Electrical Characteristics if operated under different conditions.

# NCL30030

**Table 4. ELECTRICAL CHARACTERISTICS:** ( $V_{CC} = 12\text{ V}$ ,  $V_{BO}/HV = 120\text{ V}$ ,  $V_{Fault} = \text{open}$ ,  $V_{PFB} = 1.9\text{ V}$ ,  $V_{PControl} = 4\text{ V}$ ,  $V_{PCS}/PZCD = 0\text{ V}$ ,  $V_{QFB} = 3\text{ V}$ ,  $V_{PONOFF} = 4\text{ V}$ ,  $V_{QCS} = 0\text{ V}$ ,  $V_{QZCD} = 0\text{ V}$ ,  $C_{MULT} = 2\text{ nF}$ ,  $C_{VCC} = 100\text{ nF}$ ,  $C_{QCT} = 220\text{ pF}$ ,  $C_{PDRV} = 1\text{ nF}$ ,  $C_{QDRV} = 1\text{ nF}$ , for typical values  $T_J = 25^\circ\text{C}$ , for min/max values,  $T_J$  is  $-40^\circ\text{C}$  to  $125^\circ\text{C}$ , unless otherwise noted)

Characteristics	Conditions	Pin	Symbol	Min	Typ	Max	Unit
<b>PFC DISABLE</b>							
Voltage to Current Conversion Ratio	$V_{QFB} = 3\text{ V}$ , Low Line $V_{QFB} = 3\text{ V}$ , High Line	5	$I_{ratio1(QFB/PON)}$ $I_{ratio2(QFB/PON)}$	13 13	15 15	17 17	$\mu\text{A}$
PFC Disable Threshold	$V_{PONOFF}$ decreasing	5	$V_{POFF}$	1.9	2.0	2.1	V
PFC Enable Hysteresis	$V_{QFB}$ = increasing	5	$V_{PONHYS}$	0.135	0.160	0.185	V
PONOFF Operating Mode Voltage	$t_{demag}/T = 70\%$ , $R_{PONOFF} = 191\text{ k}\Omega$ , $C_{PONOFF} = 1\text{ nF}$ $V_{QFB} = 1.8\text{ V}$ (decreasing) $V_{QFB} = 3\text{ V}$ (decreasing)	5	$V_{PONOFF1}$ $V_{PONOFF2}$	1.08 1.8	1.20 2.0	1.32 2.2	V
PFC Disable Timer	Disable Timer	5	$t_{pdisable}$	450	500	550	ms
PFC Enable Filter Delay		5	$t_{penable(filter)}$	50	100	150	$\mu\text{s}$
PFC Enable Timer	PONOFF Increasing	5	$t_{penable}$	200	–	500	$\mu\text{s}$
<b>PFC MULTIPLIER</b>							
Multiplier maximum BO=180V	PControl = open, BO = 180 V	3	MULT_max_180	0.85	1	1.15	V
Multiplier maximum BO = 360V	PControl = open, BO = 360 V	3	MULT_max_360	0.425	0.5	0.575	V
Multiplier output	PControl = 2.5 V, BO = 180 V	3	$V_{multLL}$	0.425	0.5	0.575	V
Multiplier output	PControl = 2.5 V, BO = 360 V	3	$V_{multHL}$	0.2125	0.25	0.2875	V
Multiplier linearity with respect to BO at low line. ( $V_{MULT180}/180\text{V}$ )/( $V_{MULT120}/120\text{V}$ )	PControl = 2.5 V, BO = 180 V and BO = 120 V	3	Mult_linearityLL	0.98	1	1.02	
Multiplier linearity with respect to BO at high line. ( $V_{MULT360}/360\text{V}$ )/( $V_{MULT300}/300\text{V}$ )	PControl = 2.5 V, BO = 360 V and BO = 300 V	3	Mult_linearityHL	0.99	1	1.01	
<b>PFC GATE DRIVE</b>							
Rise Time (10–90%)	$V_{PDRV}$ from 10% to 90% of $V_{CC}$	13	$t_{PDRV(rise)}$	–	40	80	ns
Fall Time (90–10%)	90% to 10% of $V_{PDRV}$	13	$t_{PDRV(fall)}$	–	20	40	ns
Driver Resistance Source Sink		13	$R_{PDRV(SRC)}$ $R_{PDRV(SNK)}$	– –	13 7	– –	$\Omega$
Current Capability Source Sink	$V_{PDRV} = 2\text{ V}$ $V_{PDRV} = 10\text{ V}$	13	$I_{PDRV(SRC)}$ $I_{PDRV(SNK)}$	– –	500 800	– –	mA
High State Voltage	$V_{CC} = V_{CC(off)} + 0.2\text{ V}$ , $R_{PDRV} = 10\text{ k}\Omega$ $V_{CC} = 26\text{ V}$ , $R_{PDRV} = 10\text{ k}\Omega$	13	$V_{PDRV(high1)}$ $V_{PDRV(high2)}$	8 10	– 12	– 14	V
Low State Voltage	$V_{Fault} = 4\text{ V}$	13	$V_{PDRV(low)}$	–	–	0.25	V
<b>PFC ZERO CURRENT DETECTION</b>							
Zero Current Detection Threshold	$V_{PCS}/PZCD$ rising $V_{PCS}/PZCD$ falling	14	$V_{PZCD(rising)}$ $V_{PZCD(falling)}$	675 200	750 250	825 300	mV
Hysteresis on Voltage Threshold	$V_{PZCD(rising)} - V_{PZCD(falling)}$	14	$V_{PZCD(HYS)}$	375	500	625	mV
Propagation Delay	Measure from $V_{PCS}/PZCD = V_{PZCD(falling)}$ to PDRV rising	14	$t_{PZCD}$	50	100	170	ns
Input Voltage Excursion Upper Clamp Negative Clamp	$I_{PCS}/PZCD = 1\text{ mA}$ $I_{PCS}/PZCD = -2\text{ mA}$	14	$V_{PCS}/PZCD(MAX)$ $V_{PCS}/PZCD(MIN)$	6.5 –0.9	7 –0.7	7.5 0	V
Minimum detectable ZCD Pulse Width	Between $V_{PZCD(rising)}$ and $V_{PZCD(falling)}$ to PDRV	14	$t_{SYNC}$	–	70	200	ns
ZCD blanking time	Measured DRV off to DRV on	14	$T_{Pzcd\_blank}$	450	700	1000	ns
<b>QR FLYBACK GATE DRIVE</b>							
Rise Time (10–90%)	$V_{QDRV}$ from 10 to 90%	12	$t_{QDRV(rise)}$	–	40	80	ns

Product parametric performance is indicated in the Electrical Characteristics for the listed test conditions, unless otherwise noted. Product performance may not be indicated by the Electrical Characteristics if operated under different conditions.

# NCL30030

**Table 4. ELECTRICAL CHARACTERISTICS:** ( $V_{CC} = 12\text{ V}$ ,  $V_{BO}/HV = 120\text{ V}$ ,  $V_{Fault} = \text{open}$ ,  $V_{PFB} = 1.9\text{ V}$ ,  $V_{PControl} = 4\text{ V}$ ,  $V_{PCS}/PZCD = 0\text{ V}$ ,  $V_{QFB} = 3\text{ V}$ ,  $V_{PONOFF} = 4\text{ V}$ ,  $V_{QCS} = 0\text{ V}$ ,  $V_{QZCD} = 0\text{ V}$ ,  $C_{MULT} = 2\text{ nF}$ ,  $C_{VCC} = 100\text{ nF}$ ,  $C_{QCT} = 220\text{ pF}$ ,  $C_{PDRV} = 1\text{ nF}$ ,  $C_{QDRV} = 1\text{ nF}$ , for typical values  $T_J = 25^\circ\text{C}$ , for min/max values,  $T_J$  is  $-40^\circ\text{C}$  to  $125^\circ\text{C}$ , unless otherwise noted)

Characteristics	Conditions	Pin	Symbol	Min	Typ	Max	Unit
<b>QR FLYBACK GATE DRIVE</b>							
Fall Time (90–10%)	90 to 10% of $V_{QDRV}$	12	$t_{QDRV(\text{fall})}$	–	20	40	ns
Driver Resistance Source Sink		12	$R_{QDRV(\text{SRC})}$ $R_{QDRV(\text{SNK})}$	– –	13 7	– –	$\Omega$
Current Capability Source Sink	$V_{QDRV} = 2\text{ V}$ $V_{QDRV} = 10\text{ V}$	12	$I_{QDRV(\text{SRC})}$ $I_{QDRV(\text{SNK})}$	– –	500 800	– –	mA
High State Voltage	$V_{CC} = V_{CC(\text{off})} + 0.2\text{ V}$ , $R_{QDRV} = 10\text{ k}\Omega$ $V_{CC} = 26\text{ V}$ , $R_{QDRV} = 10\text{ k}\Omega$	12	$V_{QDRV(\text{high1})}$ $V_{QDRV(\text{high2})}$	8 10	– 12	– 14	V
Low State Voltage	$V_{Fault} = 4\text{ V}$	12	$V_{QDRV(\text{low})}$	–	–	0.25	V
<b>QR FLYBACK FEEDBACK</b>							
Internal Pull-Up Current Source		8	$I_{QFB}$	46.75	50	53.25	$\mu\text{A}$
Feedback Input Open Voltage		8	$V_{QFB(\text{open})}$	4.5	5.0	5.5	V
$V_{QFB}$ to Internal Current Setpoint Division Ratio		8	$K_{QFB}$	3.8	4.0	4.2	
QFB Pull Up Resistor	$V_{QFB} = 0.4\text{ V}$	8	$R_{QFB}$	340	400	460	$\text{k}\Omega$
Valley Thresholds Transition from 1 <sup>st</sup> to 2 <sup>nd</sup> valley Transition from 2 <sup>nd</sup> to 3 <sup>rd</sup> valley Transition from 3 <sup>rd</sup> to 4 <sup>th</sup> valley Transition from 4 <sup>th</sup> valley to VCO Transition from VCO to 4 <sup>th</sup> valley Transition from 4 <sup>th</sup> to 3 <sup>rd</sup> valley Transition from 3 <sup>rd</sup> to 2 <sup>nd</sup> valley Transition from 2 <sup>nd</sup> to 1 <sup>st</sup> valley	$V_{QFB}$ decreasing $V_{QFB}$ decreasing $V_{QFB}$ decreasing $V_{QFB}$ decreasing $V_{QFB}$ increasing $V_{QFB}$ increasing $V_{QFB}$ increasing $V_{QFB}$ increasing	8	$V_{H2D}$ $V_{H3D}$ $V_{H4D}$ $V_{HVCOI}$ $V_{HVCOI}$ $V_{H4I}$ $V_{H3I}$ $V_{H2I}$	1.316 1.128 0.846 0.752 1.316 1.504 1.692 1.880	1.400 1.200 0.900 0.800 1.400 1.600 1.800 2.000	1.484 1.272 0.954 0.848 1.484 1.696 1.908 2.120	V
Skip Threshold	$V_{QFB}$ decreasing	8	$V_{QSKIP}$	0.35	0.40	0.45	V
Skip Hysteresis	$V_{QFB}$ increasing	8	$V_{QSKIP(\text{HYS})}$	25	50	75	mV
Delay Exiting Skip Mode to 1 <sup>st</sup> QDRV Pulse	Apply 1 V step from $V_{QSKIP}$	8	$t_{\text{delay}(\text{QSKIP})}$	–	–	10	$\mu\text{s}$
Maximum On Time		12	$t_{\text{onQR}(\text{MAX})}$	26	32	38	$\mu\text{s}$
<b>QR FLYBACK TIMING CAPACITOR</b>							
QCT Operating Voltage Range	$V_{QFB} = 0.5\text{ V}$	6	$V_{QCT(\text{peak})}$	3.815	4.000	4.185	V
On Time Control Source Current	$V_{QCT} = 0\text{ V}$	6	$I_{QCT}$	18	20	22	$\mu\text{A}$
Minimum voltage on QCT Input		6	$V_{QCT(\text{min})}$	–	–	90	mV
Minimum Operating Frequency in VCO Mode	$V_{QCT} = V_{QCT(\text{peak})} + 100\text{ mV}$	6	$f_{VCO(\text{MIN})}$	23.5	27	30.5	kHz
<b>QR FLYBACK DEMAGNETIZATION INPUT</b>							
QZCD threshold voltage	$V_{QZCD}$ decreasing	9	$V_{QZCD(\text{th})}$	35	55	90	mV
QZCD hysteresis	$V_{QZCD}$ increasing	9	$V_{QZCD(\text{HYS})}$	15	35	55	mV
Demagnetization Propagation Delay	$V_{QZCD}$ step from 4.0 V to $-0.3\text{ V}$	9	$t_{\text{DEM}}$	–	150	250	ns
Input Voltage Excursion Upper Clamp Negative Clamp	$I_{QZCD} = 5.0\text{ mA}$ $I_{QZCD} = -2.0\text{ mA}$	9	$V_{QZCD(\text{MAX})}$ $V_{QZCD(\text{MIN})}$	12.4 –0.9	12.7 –0.7	13.5 0	V
Blanking Delay After Turn-Off		9	$t_{ZCD(\text{blank})}$	2	3	4	$\mu\text{s}$
Timeout After Last Demagnetization Detection	During soft-start After soft-start	12	$t_{Q(\text{tout1})}$ $t_{Q(\text{tout2})}$	80 5.1	100 6	120 6.9	$\mu\text{s}$
<b>QR FLYBACK CURRENT SENSE</b>							
Current Sense Voltage Threshold	$V_{QCS}$ increasing $V_{QCS}$ increasing, $V_{QZCD} = 1\text{ V}$	11	$V_{QILIM1a}$ $V_{QILIM1b}$	0.760 0.760	0.800 0.800	0.840 0.840	V

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# NCL30030

**Table 4. ELECTRICAL CHARACTERISTICS:** ( $V_{CC} = 12\text{ V}$ ,  $V_{BO}/HV = 120\text{ V}$ ,  $V_{Fault} = \text{open}$ ,  $V_{PFB} = 1.9\text{ V}$ ,  $V_{PControl} = 4\text{ V}$ ,  $V_{PCS}/PZCD = 0\text{ V}$ ,  $V_{QFB} = 3\text{ V}$ ,  $V_{PONOFF} = 4\text{ V}$ ,  $V_{QCS} = 0\text{ V}$ ,  $V_{QZCD} = 0\text{ V}$ ,  $C_{MULT} = 2\text{ nF}$ ,  $C_{VCC} = 100\text{ nF}$ ,  $C_{QCT} = 220\text{ pF}$ ,  $C_{PDRV} = 1\text{ nF}$ ,  $C_{QDRV} = 1\text{ nF}$ , for typical values  $T_J = 25^\circ\text{C}$ , for min/max values,  $T_J$  is  $-40^\circ\text{C}$  to  $125^\circ\text{C}$ , unless otherwise noted)

Characteristics	Conditions	Pin	Symbol	Min	Typ	Max	Unit
<b>QR FLYBACK CURRENT SENSE</b>							
Cycle by Cycle Leading Edge Blanking Duration	Minimum on time minus $t_{\text{delay(ILIM\_QR)}}$	11	$t_{\text{QCS(LEB1)}}$	220	275	350	ns
Cycle by Cycle Current Sense Propagation Delay		11	$t_{\text{QCS(delay1)}}$	–	125	175	ns
Immediate Fault Protection Threshold	$V_{\text{QCS}}$ increasing, $V_{\text{QFB}} = 4\text{ V}$	11	$V_{\text{QILIM2}}$	1.125	1.200	1.275	V
Abnormal Overcurrent Fault Leading Edge Blanking Duration		11	$t_{\text{QCS(LEB2)}}$	90	120	150	ns
Abnormal Overcurrent Fault Propagation Delay		11	$t_{\text{QCS(delay2)}}$	–	125	175	ns
Number of Consecutive Abnormal Overcurrent Detections to Enter Fault Mode		11	$n_{\text{QILIM2}}$	–	4	–	
Minimum Peak Current Level in VCO Mode	$V_{\text{QFB}} = 0.4\text{ V}$ , $V_{\text{QCS}}$ increasing	11	$I_{\text{peak(VCO)}}$	11	12.5	14	%
Set point decrease for $V_{\text{QZCD}} = -250\text{ mV}$	$V_{\text{QCS}}$ Increasing, $V_{\text{QFB}} = 4\text{ V}$	11	$V_{\text{OPP(MAX)}}$	28	31.25	33	%
Overpower Protection Delay		11	$t_{\text{QOPP(delay)}}$	–	125	175	ns
Pull-up Current Source	$V_{\text{QCS}} = 1.5\text{ V}$	11	$I_{\text{QCS}}$	0.7	1.0	1.3	$\mu\text{A}$
<b>QR FLYBACK FAULT PROTECTION</b>							
Soft-Start Period	Measured from 1 <sup>st</sup> QDRV pulse to $V_{\text{QCS}} = V_{\text{QILIM1}}$	11	$t_{\text{SSTART}}$	2.8	4.0	5.0	ms
Flyback Overload Fault Timer	$V_{\text{QCS}} = V_{\text{QILIM1}}$	11	$t_{\text{QOVL D}}$	60	80	100	ms
<b>COMMON FAULT PROTECTION</b>							
Overvoltage Protection (OVP) Threshold	$V_{\text{Fault}}$ increasing	7	$V_{\text{Fault(OVP)}}$	2.79	3.00	3.21	V
Delay Before Fault Confirmation Used for OVP Detection Used for OTP Detection	$V_{\text{Fault}}$ increasing $V_{\text{Fault}}$ decreasing	7	$t_{\text{delay(Fault\_OVP)}}$ $t_{\text{delay(Fault\_OTP)}}$	22.5 22.5	30.0 30.0	37.5 37.5	$\mu\text{s}$
Overtemperature Protection (OTP) Threshold (Note 7)	$V_{\text{Fault}}$ decreasing	7	$V_{\text{Fault(OTP\_in)}}$	0.38	0.40	0.42	V
Overtemperature Protection (OTP) Exiting Threshold (Note 7)	$V_{\text{Fault}}$ increasing, B version	7	$V_{\text{Fault(OTP\_out)}}$	0.874	0.920	0.966	V
OTP Pull-up Current Source (Note 7)	$V_{\text{Fault}} = V_{\text{Fault(OTP\_in)}} + 0.2\text{ V}$	7	$I_{\text{Fault(OTP)}}$	42.5	45.5	48.5	$\mu\text{A}$
Fault Input Clamp Voltage	$V_{\text{Fault}} = \text{open}$	7	$V_{\text{Fault(clamp)}}$	1.5	1.75	2.0	V
Fault Input Clamp Series Resistor		7	$R_{\text{Fault(clamp)}}$	1.32	1.55	1.82	$\text{k}\Omega$

7. NTC with  $R_{110} = 8.8\text{ k}\Omega$  (TTC03-474)]

## THERMAL PROTECTION

Thermal Shutdown	Temperature increasing	N/A	$T_{\text{SHDN}}$	–	150	–	$^\circ\text{C}$
Thermal Shutdown Hysteresis	Temperature decreasing	N/A	$T_{\text{SHDN(HYS)}}$	–	40	–	$^\circ\text{C}$

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DETAILED OPERATING DESCRIPTION

INTRODUCTION

The NCL30030 is a combination critical mode (CrM) power factor correction (PFC) and quasi-resonant (QR) flyback controller optimized for high performance LED driver applications.

HIGH VOLTAGE STARTUP CIRCUIT

The NCL30030 integrates a high voltage startup circuit accessible by the BO/HV pin. The BO/HV input is also used for monitoring the ac line voltage and detecting brown-out faults. The startup circuit is rated at a maximum voltage of 700 V to support higher voltages used in commercial lighting such as 277 and 347 VAC.

A startup regulator consists of a constant current source that supplies current from the ac input terminals ( $V_{in}$ ) to the supply capacitor on the  $V_{CC}$  pin ( $C_{CC}$ ). The startup circuit current ( $I_{start2A}$ ) is typically 3.75 mA.  $I_{start2A}$  is disabled if the  $V_{CC}$  pin is below  $V_{CC(inhibit)}$ . In this condition the startup current is reduced to  $I_{start1A}$ , typically 0.5 mA. The internal high voltage startup circuit eliminates the need for external startup components. In addition, the startup regulator helps increase the system efficiency as it uses negligible power in the normal operation mode.

Once  $C_{CC}$  is charged to the startup threshold,  $V_{CC(on)}$ , typically 17 V, the startup regulator is disabled and the controller is enabled. The startup regulator will remain disabled until  $V_{CC}$  falls below the minimum operating voltage threshold,  $V_{CC(off)}$ , typically 8.8 V. Once reached, the PFC and flyback controllers are disabled reducing the bias current consumption of the IC. The startup circuit is then are then enabled allowing  $V_{CC}$  to charge back up.

A dedicated comparator monitors  $V_{CC}$  when the QR stage is enabled and latches off the controller if  $V_{CC}$  exceeds  $V_{CC(OVP)}$ , typically 28 V.

The controller is disabled once a fault is detected. The controller will restart the next time  $V_{CC}$  reaches  $V_{CC(on)}$  and all non-latching faults have been removed.

The supply capacitor provides power to the controller during power up. The capacitor must be sized such that a  $V_{CC}$  voltage greater than  $V_{CC(off)}$  is maintained while the auxiliary supply voltage is building up. Otherwise,  $V_{CC}$  will collapse and the controller will turn off. The operating IC bias current,  $I_{CC4}$ , and gate charge load at the drive outputs

must be considered to correctly size  $C_{CC}$ . The increase in current consumption due to external gate charge is calculated using Equation 1.

$$I_{CC(gatecharge)} = f \cdot Q_G \quad (\text{eq. 1})$$

where  $f$  is the operating frequency and  $Q_G$  is the gate charge of the external MOSFETs.

LINE VOLTAGE SENSE

The BO/HV pin provides access to the brown-out and line voltage detectors. The brown-out detector detects mains interruptions and the line voltage detector determines the presence of either 120 V or 230 V ac mains. Depending on the detected input voltage range device parameters are internally adjusted to optimize the system performance.

This pin can connect after the rectifier bridge to achieve full wave rectification as shown in Figure 3. A diode is used to prevent the pin from going below ground. A low value resistor in series with the BO/HV pin can be used for protection. A low value resistor is needed to reduce the voltage offset while sensing the line voltage.

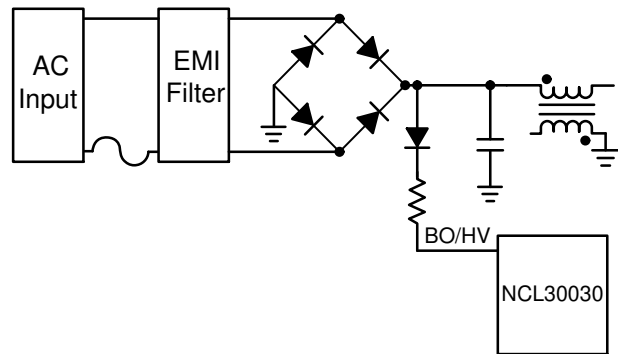


Figure 3. Brown-out and Line Voltage Detectors Configuration

The flyback stage is enabled once  $V_{BO/HV}$  is above the brown-out threshold,  $V_{BO(start)}$ , typically 111 V, and  $V_{CC}$  reaches  $V_{CC(on)}$ . The high voltage startup is immediately enabled when the voltage on  $V_{BO/HV}$  crosses over the brown-out start threshold,  $V_{BO(start)}$ , to ensure that device is enabled quickly upon exiting a brown-out state. Figure 4 shows typical power up waveforms.



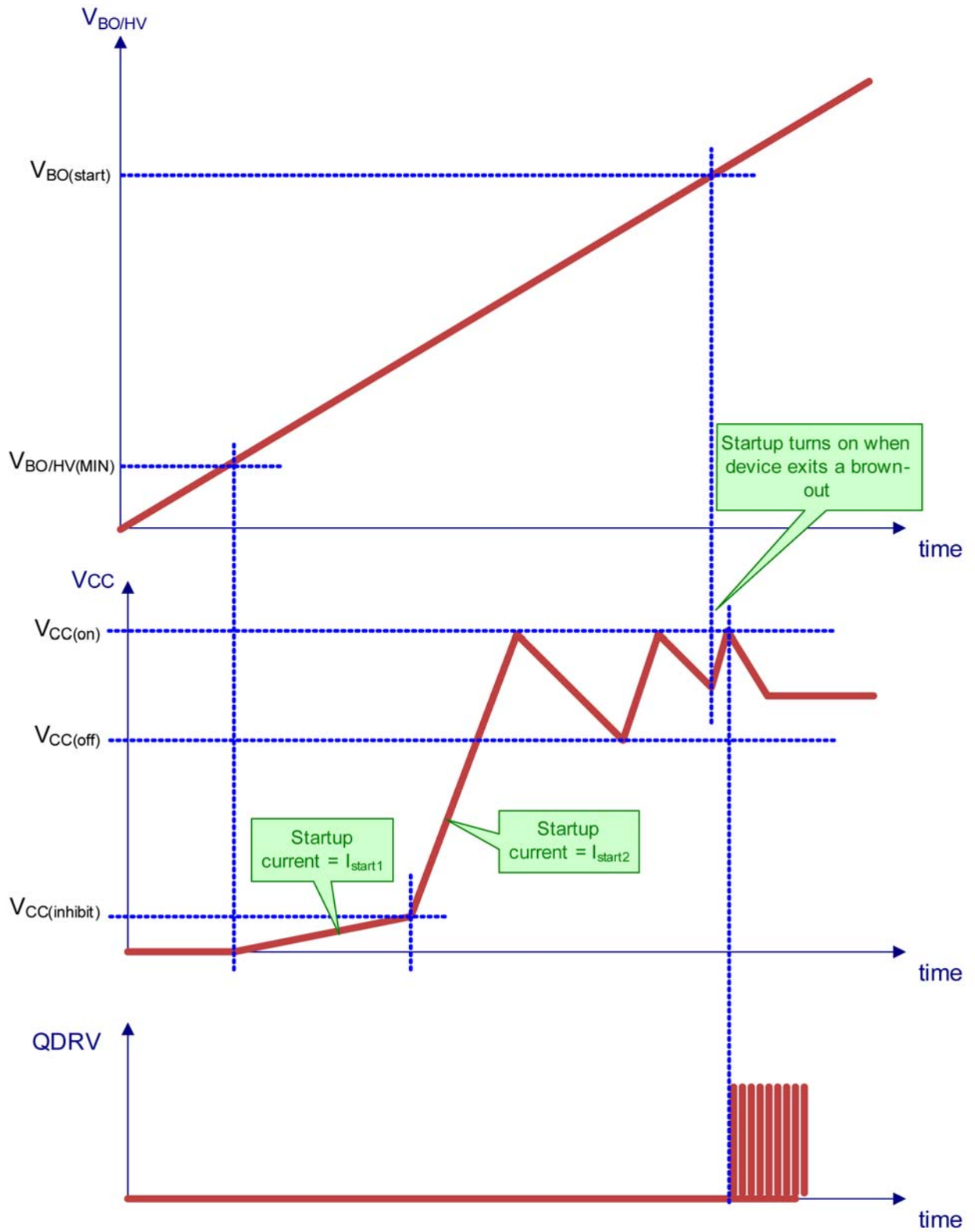


Figure 4. Startup Timing Diagram

A timer is enabled once  $V_{BO/HV}$  drops below its stop threshold,  $V_{BO(stop)}$ , typically 101 V. If the timer,  $t_{BO}$ , expires the device will begin monitoring the voltage on  $V_{BO/HV}$  and disable the PFC and flyback stages when that voltage is below the Brown-out Drive Disable threshold,  $V_{BO(DRV\_disable)}$ , typically 30 V. This ensures that device switching is stopped in a low energy state which minimizes inductive voltage kick from the EMI components and ac mains. The timer,  $t_{BO}$ , typically 54 ms, is set long enough to ignore a single cycle drop-out.

**LINE VOLTAGE DETECTOR**

The input voltage range is detected based on the peak voltage measured at the BO/HV pin. Discrete values are selected for the PFC stage gain (feedforward) depending on the input voltage range. The controller compares  $V_{BO/HV}$  to an internal line select threshold,  $V_{BO(lineselect)}$ , typically 240 V. Once  $V_{BO/HV}$  exceeds  $V_{BO(lineselect)}$ , the PFC stage operates in “high line” (Commercial US – 277 Vac) or “230 Vac” mode. In high line mode the maximum on time is

reduced by a factor of 3, resulting in a maximum output power independent of input voltage.

The default power-up mode of the controller is low line. The controller switches to “high line” mode if  $V_{BO/HV}$  exceeds the line select threshold for longer than the low to high line timer,  $t_{(low\ to\ high\ line)}$ , typically 300  $\mu$ s, as long as it was not previously in high line mode. If the controller has switched from “high line” to “low line” mode, the low to high line timer,  $t_{(low\ to\ high\ line)}$ , is inhibited until  $V_{BO/HV}$  falls below  $V_{BO(stop)}$ . This prevents the controller from toggling back to “high line” until at least one  $V_{BO(stop)}$  transition has occurred. The timer and logic is included to prevent unwanted noise from toggling the operating line level.

In “high line” mode the high to low line timer,  $t_{(high\ to\ low\ line)}$ , (typically 54 ms) is enabled once  $V_{BO/HV}$  falls below  $V_{BO(lineselect)}$ . It is reset once  $V_{BO/HV}$  exceeds  $V_{BO(lineselect)}$ . The controller switches back to “low line” mode if the high to low line timer expires.

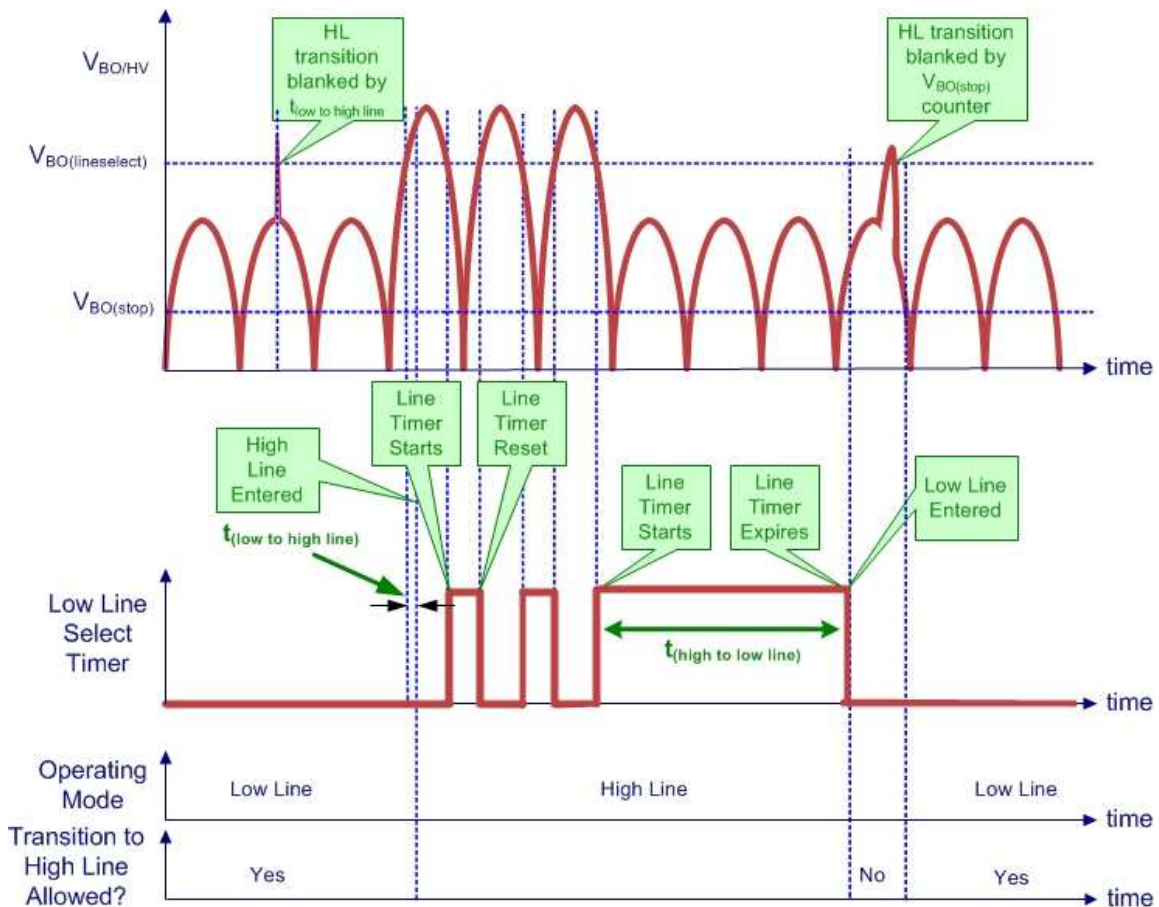


Figure 5. Line Detector Waveforms

**FAULT INPUT**

The NCL30030 includes a dedicated fault input accessible via the Fault pin. The controller will enter triple hiccup mode when the pin is pulled above the upper fault threshold,  $V_{Fault(OVP)}$ , typically 3.0 V. The controller is disabled if the Fault pin voltage,  $V_{Fault}$ , is pulled below the lower fault threshold,  $V_{Fault(OTP\_in)}$ , typically 0.4 V. The lower threshold is normally used for detecting an overtemperature fault. The controller operates normally while the Fault pin voltage is maintained within the upper and lower fault thresholds. Figure 6 shows the architecture of the Fault input.

The lower fault threshold is intended to be used to detect an overtemperature fault using an NTC thermistor. A pull up current source  $I_{Fault(OTP)}$ , (typically 45.5  $\mu$ A) generates a voltage drop across the thermistor. The resistance of the NTC thermistor decreases at higher temperatures resulting in a lower voltage across the thermistor. The controller detects a fault once the thermistor voltage drops below  $V_{Fault(OTP\_in)}$ . Part option A latches off the controller after an overtemperature fault is detected. For part option B the controller is re-enabled once the fault is removed such that  $V_{Fault}$  increases above  $V_{Fault(OTP\_out)}$  and  $V_{CC}$  reaches  $V_{CC(on)}$ . Figure 7 shows typical waveforms related to the latch option where as Figure 8 shows waveforms of the auto-recovery option.

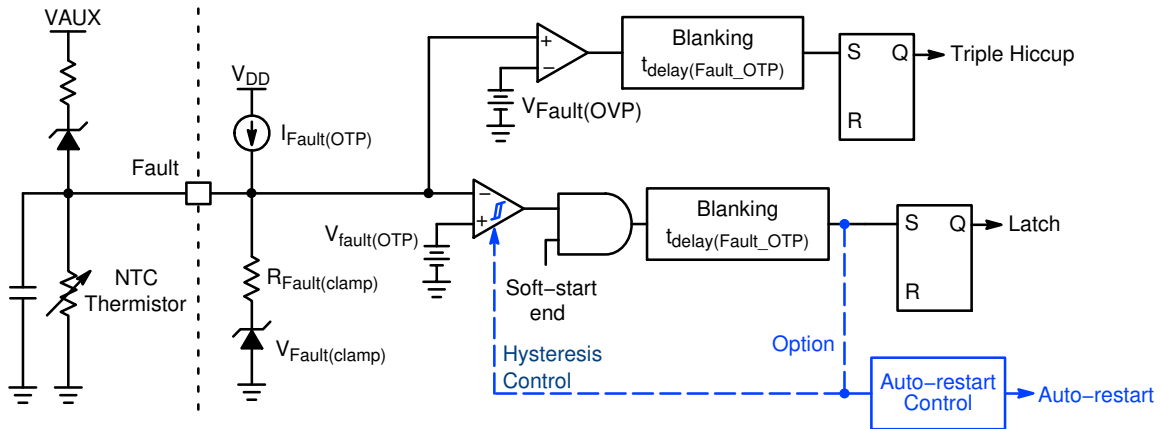
An active clamp prevents the Fault pin voltage from reaching the upper latch threshold if the pin is open. To reach

the upper threshold, the external pull-up current has to be higher than the pull-down capability of the clamp (set by  $R_{Fault(clamp)}$  at  $V_{Fault(clamp)}$ ). The upper fault threshold is intended to be used for an overvoltage fault using a Zener diode and a resistor in series from the auxiliary winding voltage,  $V_{AUX}$ . The controller goes into a triple hiccup once  $V_{Fault}$  exceeds  $V_{Fault(OVP)}$ .

The Fault input signal is filtered to prevent noise from triggering the fault detectors. Upper and lower fault detector blanking delays,  $t_{delay(Fault\_OVP)}$  and  $t_{delay(Fault\_OTP)}$  are both typically 30  $\mu$ s. A fault is detected if the fault condition is asserted for a period longer than the blanking delay.

A bypass capacitor is usually connected between the Fault and GND pins and it will take some time for  $V_{Fault}$  to reach its steady state value once  $I_{Fault(OTP)}$  is enabled. Therefore, a lower fault (i.e. overtemperature) is ignored during soft-start. In Option B,  $I_{Fault(OTP)}$  remains enabled while the lower fault is present independent of  $V_{CC}$  in order to provide temperature hysteresis. The upper OVP fault detection is enabled and remains active as long as the QR flyback is enabled.

Once the controller is latched, it is reset if a brown-out condition is detected or if  $V_{CC}$  is cycled down to its reset level,  $V_{CC(reset)}$ . In the typical application these conditions occur only if the ac voltage is removed from the system. Prior to reaching  $V_{CC(reset)}$ ,  $V_{fault(clamp)}$  is set at 0 V.



**Figure 6. Fault Detection Schematic**

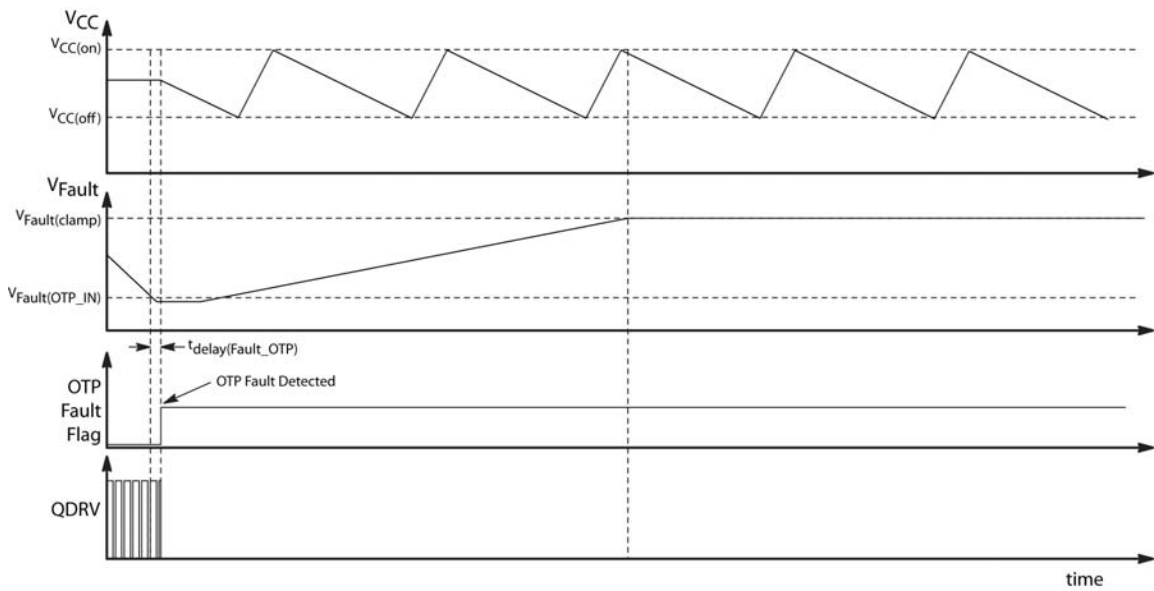


Figure 7. Latch-off Function Timing Diagram

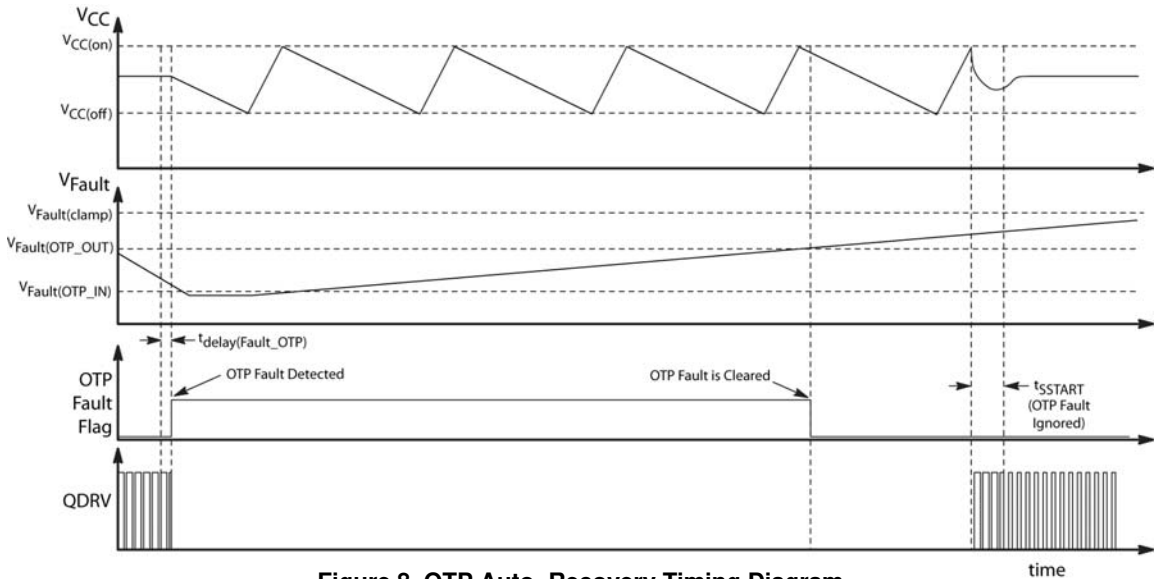


Figure 8. OTP Auto-Recovery Timing Diagram

**QR FLYBACK VALLEY LOCKOUT**

The NCL30030 integrates a quasi-resonant (QR) flyback controller. The power switch turn-off of the QR converter is determined by the peak current set by the feedback loop. The switch turn-on is determined by the transformer demagnetization. The demagnetization is detected by monitoring the transformer auxiliary winding voltage.

Turning on the power switch once the transformer is demagnetized or reset reduces switching losses. Once the transformer is demagnetized, the drain voltage starts ringing at a frequency determined by the transformer magnetizing inductance and the drain lump capacitance eventually settling at the input voltage. A QR controller takes advantage of the drain voltage ringing and turns on the power switch at the drain voltage minimum or “valley” to

reduce switching losses and electromagnetic interference (EMI).

The operating frequency of a traditional QR flyback controller is inversely proportional to the system load. That is, a load reduction increases the operating frequency. This traditionally requires a maximum frequency clamp to limit the operating frequency. This causes the controller to become unstable and jump (or hesitate) between two valleys generating audible noise. The NCL30030 incorporates a patent pending valley lockout circuitry to eliminate valley jumping. Once a valley is selected, the controller stays locked in this valley until the output power changes significantly. Like a traditional QR flyback controller, the frequency increases when the load decreases. Once a higher valley is selected the frequency decreases very rapidly. It

will continue to increase if the load is further reduced. This technique extends QR operation over a wider output power range while maintaining good efficiency and limiting the maximum operating frequency. Figure 9 shows a qualitative frequency vs output power relationship.

Figure 10 shows the internal arrangement of the valley detection circuitry. An internal counter increments each time a valley is detected. The operating valley (1<sup>st</sup>, 2<sup>nd</sup>, 3<sup>rd</sup> or 4<sup>th</sup>) is determined by the QFB voltage. As  $V_{QFB}$  decreases

or increases, the valley comparators toggle one after another to select the proper valley. The activation of an “n” valley comparator blanks the “n-1” or “n+1” valley comparator output depending if  $V_{QFB}$  decreases or increases, respectively.

A valley is detected once  $V_{QZCD}$  falls below the QR flyback demagnetization threshold,  $V_{QZCD(th)}$ , typically 55 mV. The controller will switch once the valley is detected or increment the valley counter depending on QFB voltage.

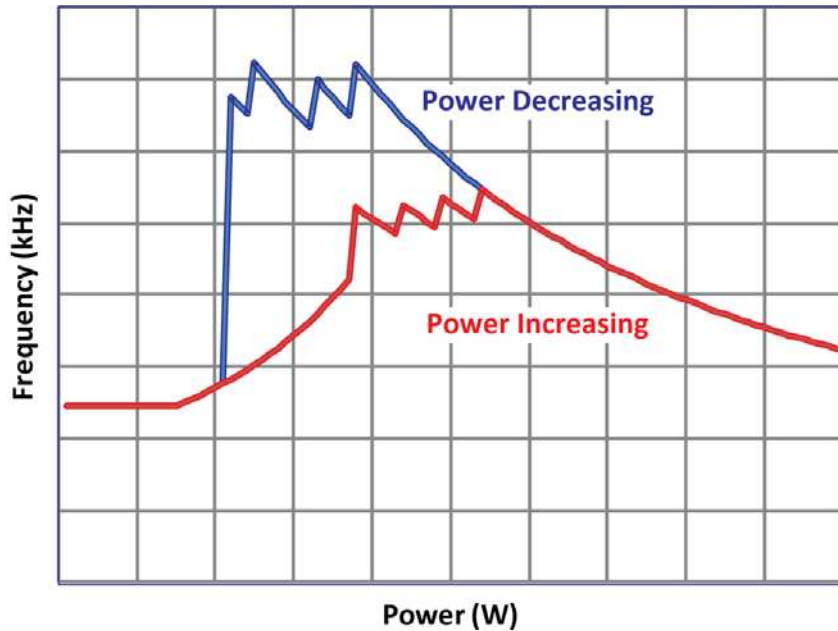


Figure 9. Valley Lockout Frequency vs Output Power Relationship

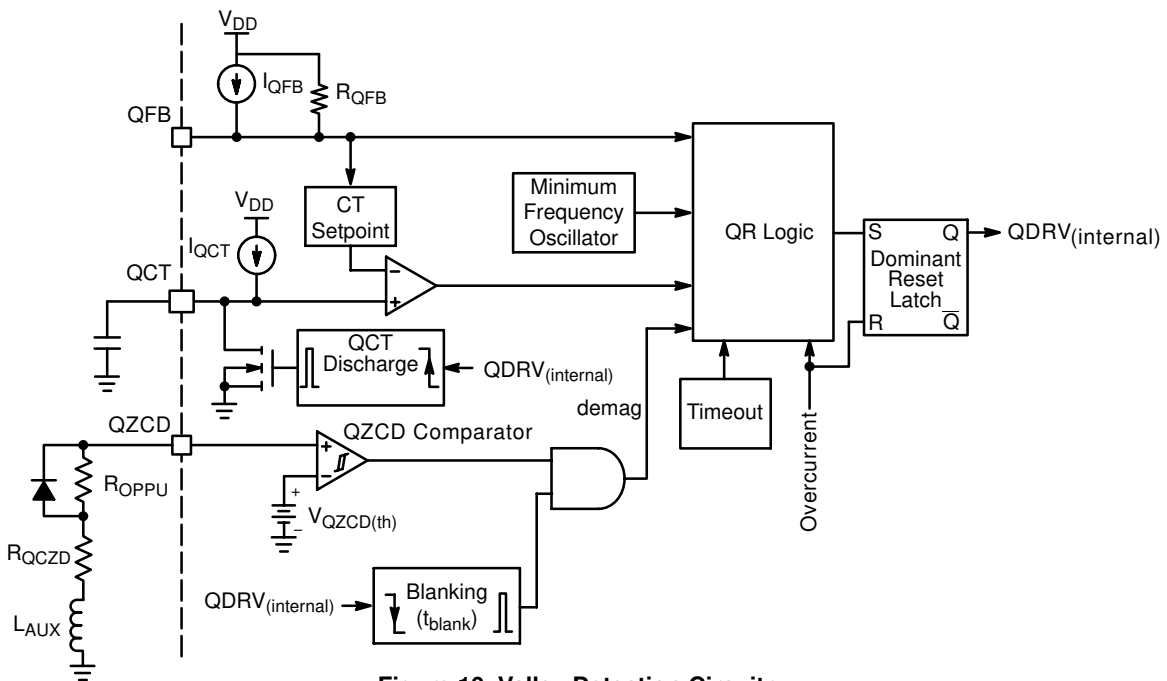


Figure 10. Valley Detection Circuitry



Figure 11 shows the operating valley versus  $V_{QFB}$ . Once a valley is asserted by the valley selection circuitry, the controller is locked in this valley until  $V_{QFB}$  decreases or increases such that  $V_{QFB}$  reaches the next valley threshold. A decrease in output power causes the controller to switch from “n” to “n+1” valley until reaching the 4<sup>th</sup> valley.

A further reduction of output power causes the controller to enter the voltage control oscillator (VCO) mode once

$V_{QFB}$  falls below  $V_{HVCOI}$ . In VCO mode the peak current is set to  $V_{QILIM1} * KI_{peak(VCO)}$  as shown in Figure 12. The operating frequency in VCO mode is adjusted to deliver to required output power.

A hysteresis between valleys provides noise immunity and helps stabilize the valley selection in case of small perturbations on  $V_{QFB}$ .

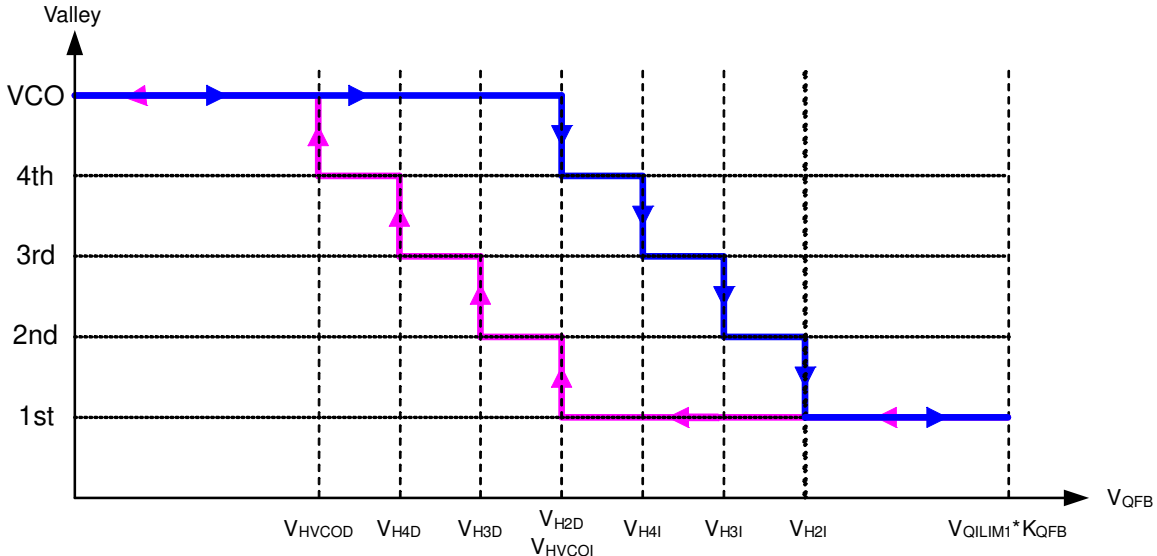


Figure 11. Selected Operating Valley versus  $V_{QFB}$

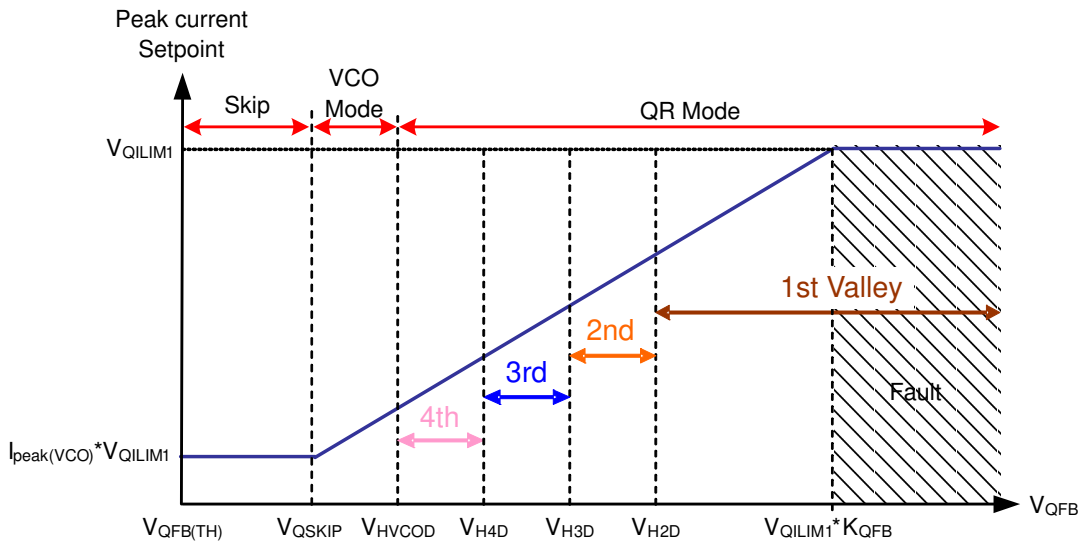


Figure 12. Operating Valley versus  $V_{QFB}$

Figures 13 through 16 show drain voltage,  $V_{QFB}$  and  $V_{QCT}$  simulation waveforms for a reduction in output power. The transitions between 2<sup>nd</sup> to 3<sup>rd</sup>, 3<sup>rd</sup> to 4<sup>th</sup> and 4<sup>th</sup>

valley to VCO mode are observed without any instabilities or valley jumping.

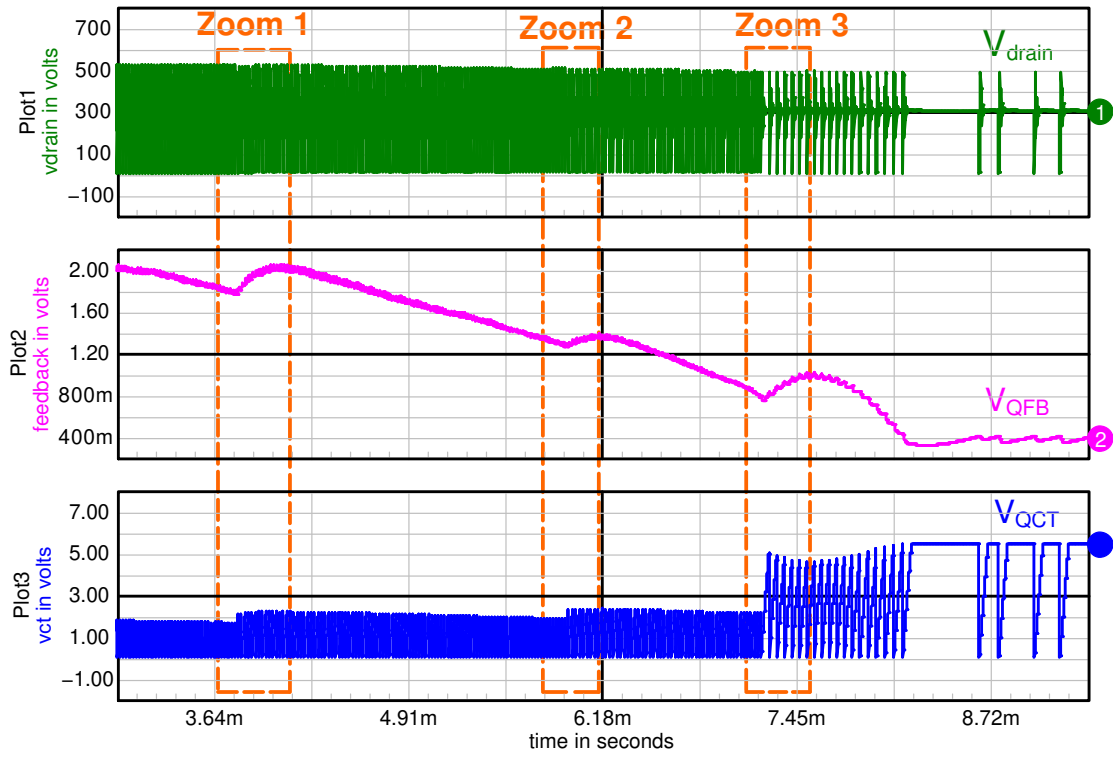


Figure 13. Operating Mode Transitions Between 2<sup>nd</sup> to 3<sup>rd</sup>, 3<sup>rd</sup> to 4<sup>th</sup> and 4<sup>th</sup> Valley to VCO Mode

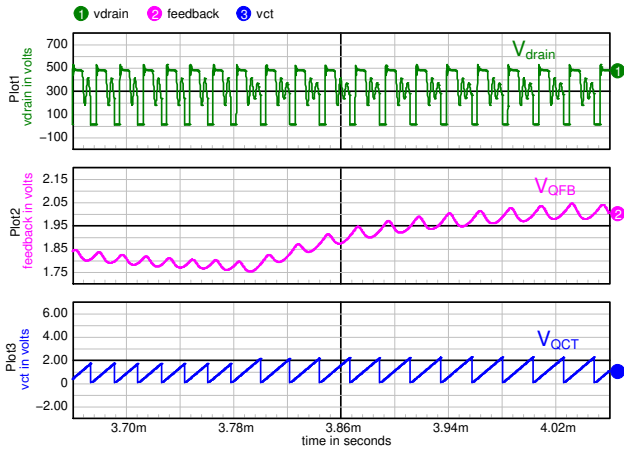


Figure 14. Zoom 1: 2<sup>nd</sup> to 3<sup>rd</sup> Valley Transition

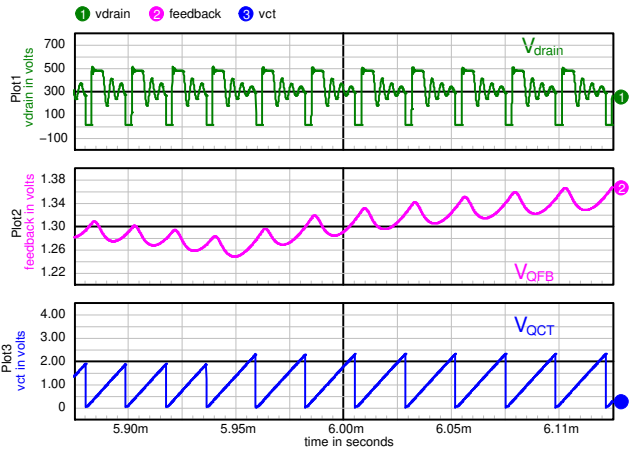


Figure 15. Zoom 2: 3<sup>rd</sup> to 4<sup>th</sup> Valley Transition

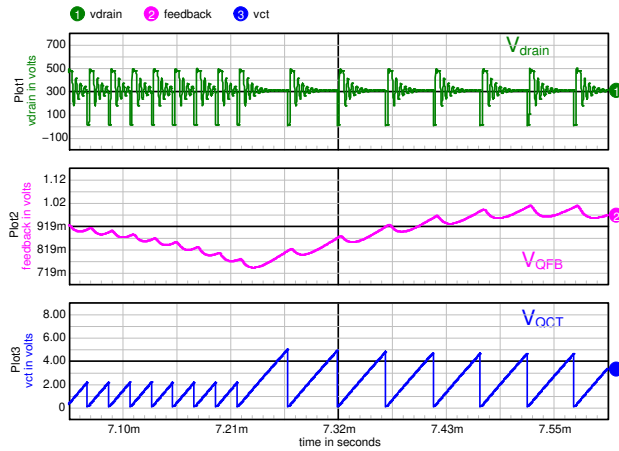


Figure 16. Zoom 3: 4<sup>th</sup> Valley to VCO Mode Transition

### VCO MODE

The controller enters VCO mode once  $V_{QFB}$  falls below  $V_{HVCOD}$  and remains in VCO until  $V_{QFB}$  exceeds  $V_{HVCOI}$ . In VCO mode the peak current is set to  $V_{QILIMI} * I_{peak}(VCO)$  and the operating frequency is linearly dependent on  $V_{QFB}$ . The product of  $V_{QILIMI} * I_{peak}(VCO)$  is typically 12.5%. A minimum frequency clamp,  $f_{VCO(MIN)}$ , typically 27 kHz, prevents operation in the audible range. Further reduction in output power causes the controller to enter skip operation. The minimum frequency clamp is only enabled when operating in VCO mode.

The VCO mode operating frequency is set by the timing capacitor connected between the QCT and GND pins. This

capacitor is charged with a constant current source,  $I_{QCT}$ , typically 20  $\mu A$ .

The capacitor voltage,  $V_{QCT}$ , is compared to an internal voltage level,  $V_{f(QFB)}$ , inversely proportional to  $V_{QFB}$ . The relationship between  $V_{f(QFB)}$  and  $V_{QFB}$  is given by Equation 2).

$$V_{f(QFB)} = 5 - 2 \cdot V_{QFB} \quad (\text{eq. 2})$$

A drive pulse is generated once  $V_{QCT}$  exceeds  $V_{f(QFB)}$  followed by the immediate discharge of the timing capacitor. The timing capacitor is also discharged once the minimum frequency clamp is reached. Figure 17 shows simulation waveforms of  $V_{f(QFB)}$ ,  $V_{QDRV}$  and output current while operating in VCO mode.

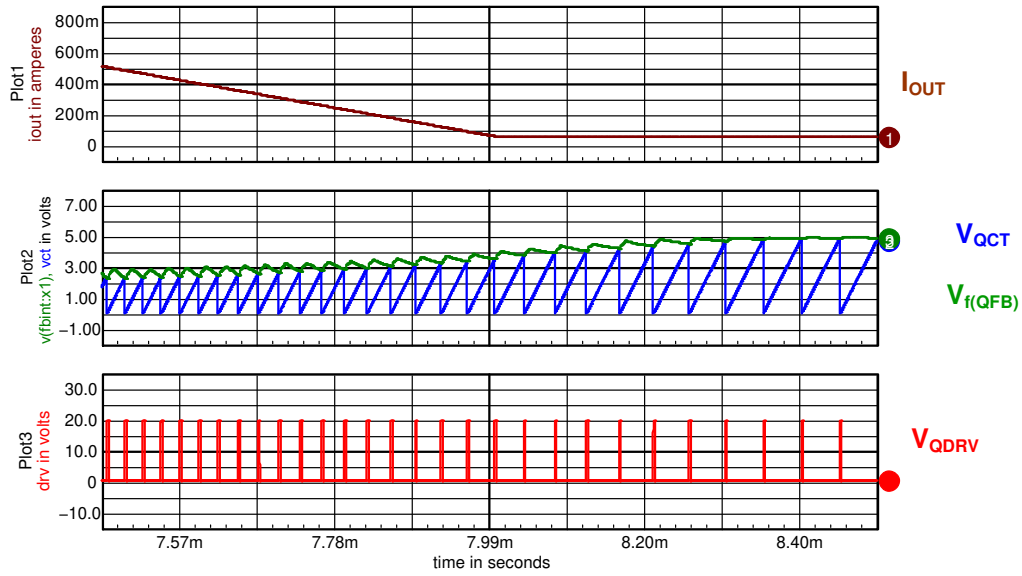


Figure 17. VCO Mode Operating Waveforms

**FLYBACK TIMEOUT**

In case of extremely damped oscillations, the QZCD comparator may be unable to detect the valleys. In this condition, drive pulses will stop waiting for the next valley or ZCD event. The NCL30030 ensures continued operation by incorporating a maximum timeout period after the last demagnetization detection. The timeout signal is a substitute for the ZCD signal for the valley counter. Figure 18 shows the timeout period generator circuit schematic. The steady state timeout period,  $t_{Q(tout2)}$ , is set at 6  $\mu s$  to limit the frequency step.

During startup, the voltage offset added by the overpower compensation diode,  $D_{OPP}$  prevents the QZCD Comparator from accurately detecting the valleys. In this condition, the steady state timeout period will be shorter than the inductor demagnetization period causing continuous current mode (CCM) operation. CCM operation lasts for a few cycles until the voltage on the QZCD pin is high enough to detect the valleys. A longer timeout period,  $t_{Q(tout1)}$ , (typically 100  $\mu s$ ) is set during soft-start to limit CCM operation. Figures 19 and 20 show the timeout period generator related waveforms.

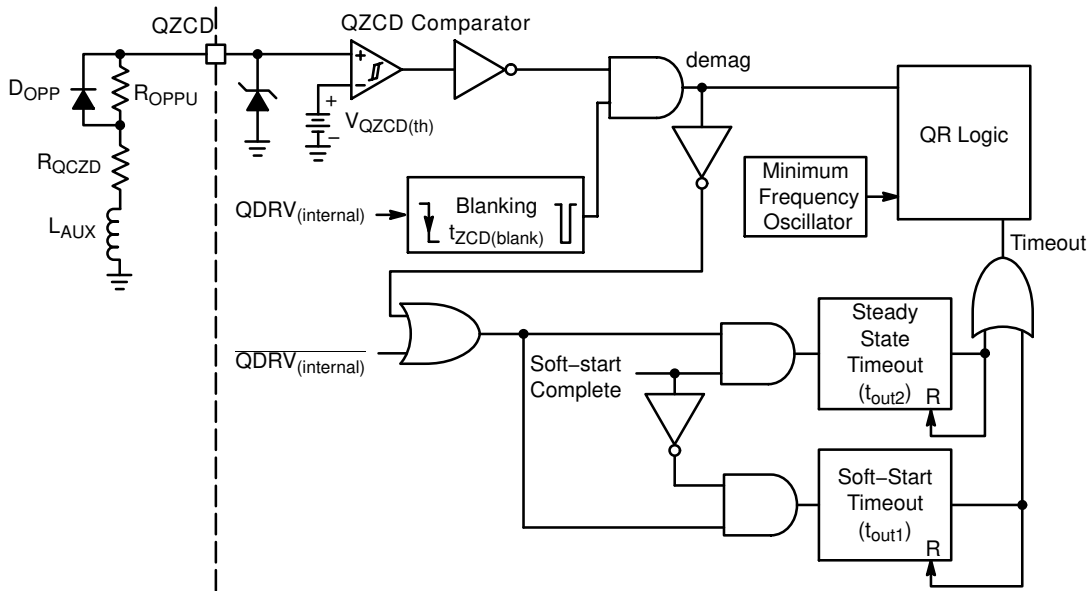


Figure 18. Timeout Period Generator Circuit Schematic

# NCL30030

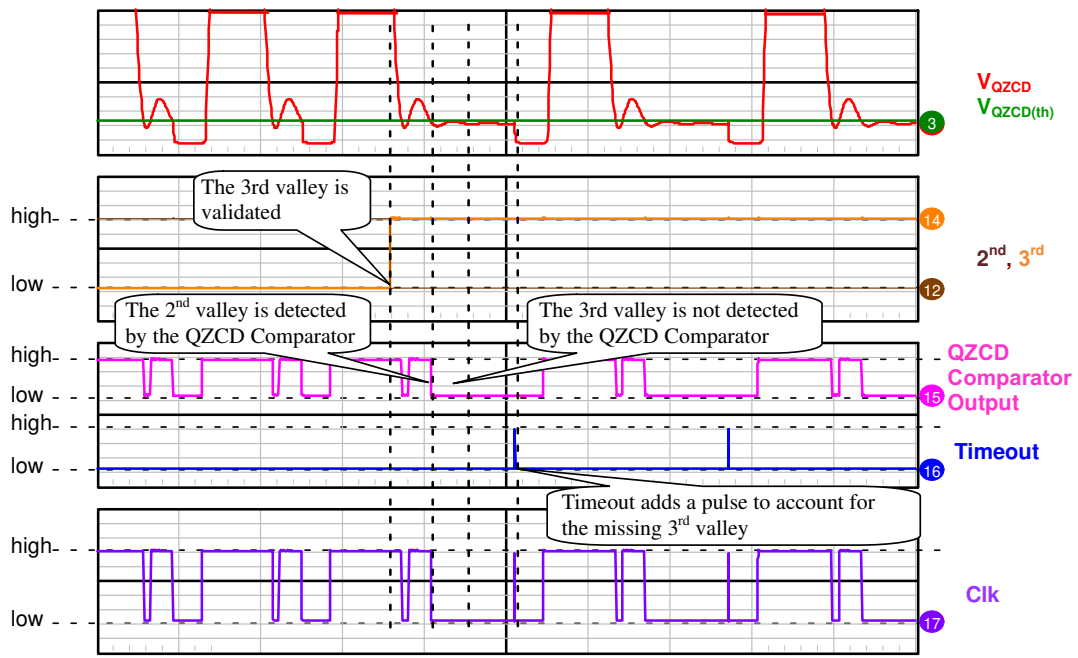


Figure 19. Timeout Operation With a Missing 3<sup>rd</sup> Valley

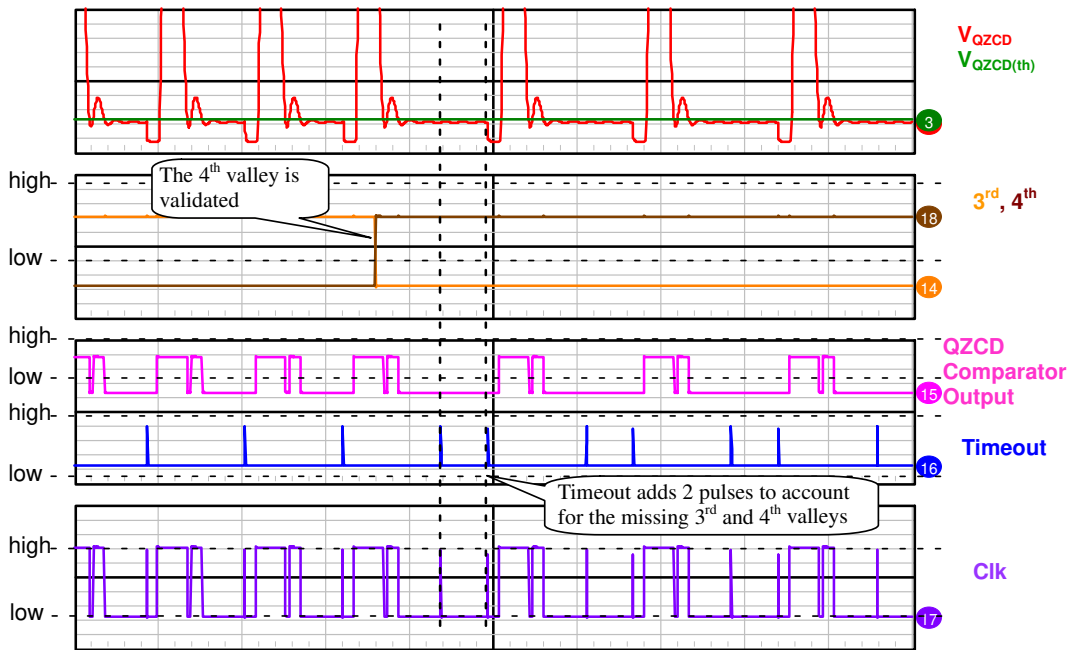


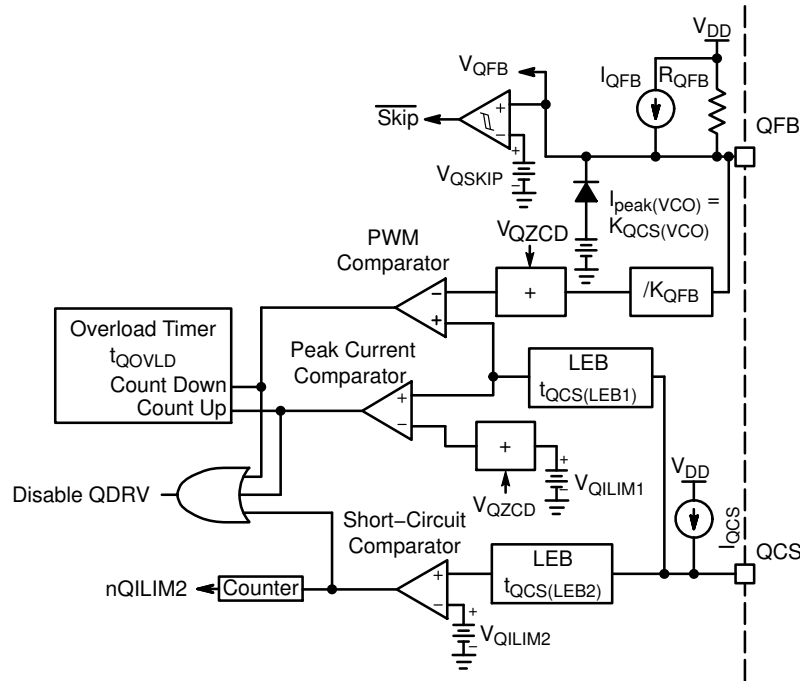
Figure 20. Timeout Operation With Missing 3<sup>rd</sup> and 4<sup>th</sup> Valleys



**QR FLYBACK CURRENT SENSE AND OVERLOAD**

The power switch on time is modulated by comparing a ramp proportional to the switch current to  $V_{QFB}/K_{QFB}$  using the PWM Comparator. The switch current is sensed across a current sense resistor,  $R_{SENSE}$ , and the resulting voltage is applied to the QCS pin. The current signal is blanked by a leading edge blanking (LEB) circuit. The blanking period eliminates the leading edge spike and high frequency noise during the switch turn-on event. The LEB period,  $t_{QCS(LEB1)}$ , is typically 275 ns. The drive pulse terminates once the current sense signal exceeds  $V_{QFB}/K_{QFB}$ .

The Maximum Peak Current Comparator compares the current sense signal to a reference voltage to limit the maximum peak current of the system. The maximum peak current reference voltage,  $V_{QILIM1}$ , is typically 0.8 V. The maximum peak current setpoint is reduced by the overpower compensation circuitry. An overload condition causes the output of the Maximum Peak Current Comparator to transition high and enable the overload timer. Figure 21 shows the implementation of the current sensing circuitry.

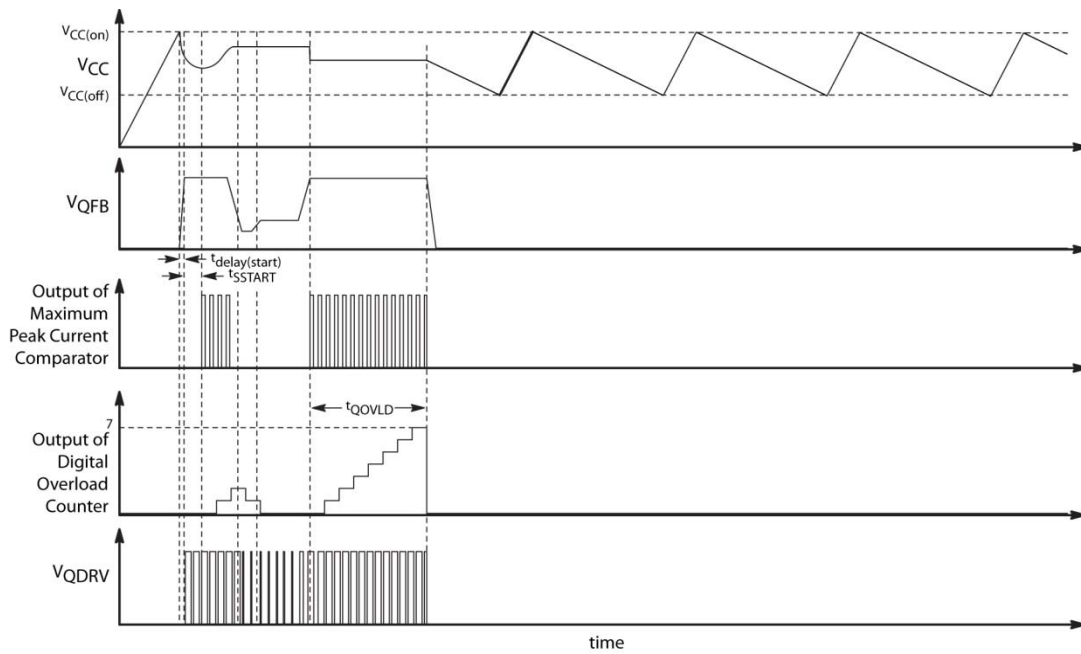


**Figure 21. Current Sensing Circuitry Schematic**

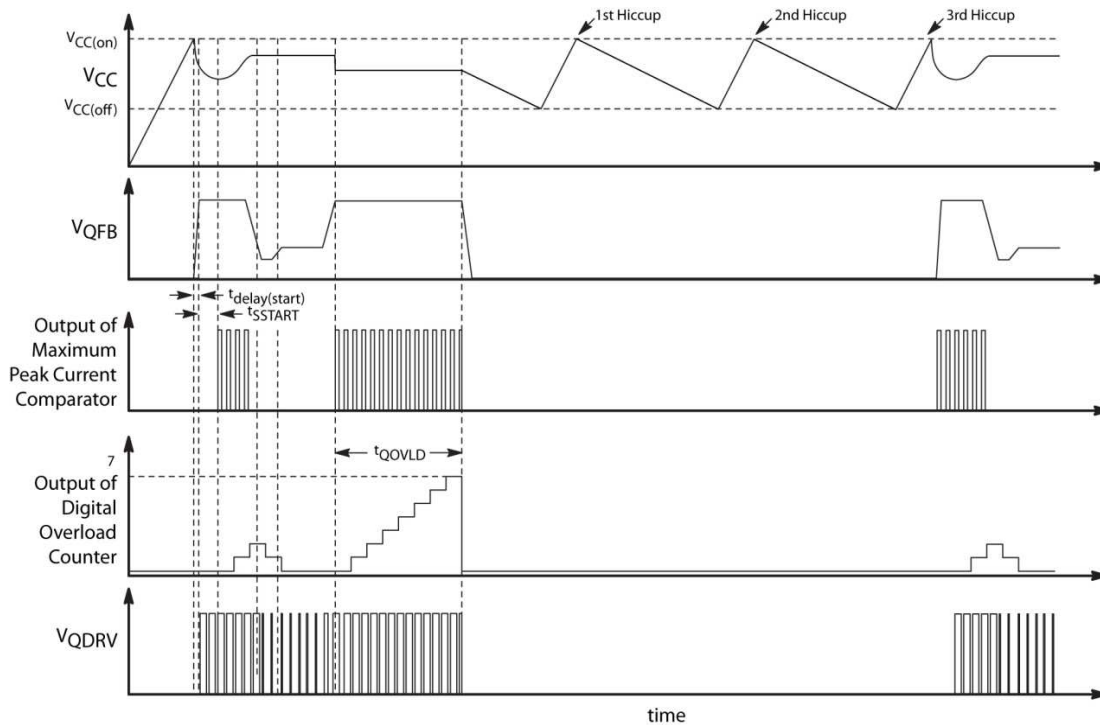
The overload timer integrates the duration of the overload fault. That is, the timer count increases while the fault is present and reduces its count once it is removed. The overload timer duration,  $t_{QOVL}$ , is typically 80 ms. If both the PWM and Maximum Peak Current Comparators toggle at the same time, the PWM Comparator takes precedence

and the overload timer counts down. The controller can latch (option A) or allow for auto-recovery (option B) once the overload timer expires. Auto-recovery requires a  $V_{CC}$  triple hiccup before the controller restarts. Figures 22 and 23 show operating waveforms for latched and auto-recovery overload conditions.

# NCL30030



**Figure 22. Latched Overload Operation**



**Figure 23. Auto-Recovery Overload Operation**

A severe overload fault like a secondary side winding short-circuit causes the switch current to increase very rapidly during the on-time. The current sense signal significantly exceeds  $V_{QILIM1}$ . But, because the current sense signal is blanked by the LEB circuit during the switch turn on, the system current can get extremely high causing system damage.

The NCL30030 protects against this fault by adding an additional comparator, Fault Overcurrent Comparator. The current sense signal is blanked with a shorter LEB duration,  $t_{QCS(LEB2)}$ , typically 120 ns, before applying it to the Fault Overcurrent Comparator. The voltage threshold of the comparator,  $V_{QILIM2}$ , typically 1.2 V, is set 50% higher than  $V_{QILIM1}$ , to avoid interference with normal operation. Four

consecutive faults detected by the Fault Overcurrent Comparator causes the controller to enter triple-hiccup auto-recovery mode. The count to 4 provides noise immunity during surge testing. The counter is reset each time a QDRV pulse occurs without activating the Fault Overcurrent Comparator. A 1 μA (typically) pull-up current source, I<sub>QCS</sub>, pulls up the QCS pin to disable the controller if the pin is left open.

**QR FLYBACK SOFT-START**

Soft-start is achieved by ramping up an internal reference, V<sub>SSTART</sub>, and comparing it to current sense signal. V<sub>SSTART</sub> ramps up from 0 V once the controller powers up. The soft-start duration, t<sub>SSTART</sub>, is typically 4 ms.

During soft-start the timeout duration is extended and the lower latch or OTP Comparator signal (typically for

overtemperature) is blanked. Soft-start ends once V<sub>SSTART</sub> exceeds the peak current sense signal threshold.

**QR FLYBACK OVERPOWER COMPENSATION**

The input voltage of the QR flyback stage varies with the line voltage and operating mode of the PFC converter. At low line the PFC bulk voltage is 220 V and at high line it will be 390 V or 440 V, depending on the version of the part. Additionally, the PFC can be disabled at which point the PFC bulk voltage is set by the rectified peak line voltage.

An integrated overpower circuit provides a relative constant output power across PFC bulk voltage, V<sub>bulk</sub>. It also reduces the variation on V<sub>QFB</sub> during the PFC stage enable or disable transitions. Figure 24 shows the circuit schematic for the overpower detector.

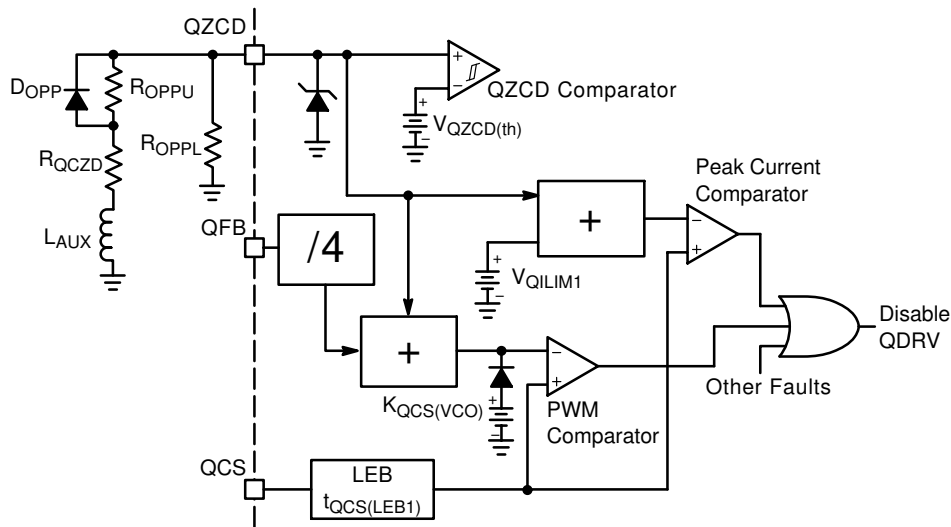


Figure 24. Overpower Compensation Circuit Schematic

The auxiliary winding voltage during the power switch on time is a reflection of the input voltage scaled by the primary to auxiliary winding turns ratio, N<sub>P,AUX</sub>, as shown in Figure 25.

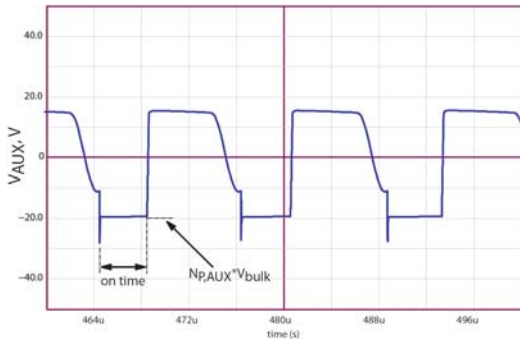


Figure 25. Auxiliary Winding Voltage Waveform

Overpower compensation is achieved by scaling down the on-time reflected voltage and applying it to the QZCD pin.

The voltage is scaled down using R<sub>OPPU</sub> and R<sub>OPPL</sub>. The negative voltage applied to the pin is referred to as V<sub>OPP</sub>.

The internal current setpoint is the sum of V<sub>OPP</sub> and peak current sense threshold, V<sub>QILIM1</sub>. V<sub>OPP</sub> is also subtracted from V<sub>QFB</sub> to compensate for the PWM Comparator delay and improve the PFC on/off accuracy.

The current setpoint is calculated using Equation 3. For example, a V<sub>OPP</sub> of -0.15 V results in a current setpoint of 0.65 V.

$$\text{Current setpoint} = V_{QILIM1} + V_{OPP} \quad (\text{eq. 3})$$

To ensure optimal zero-crossing detection, a diode is needed to bypass R<sub>OPPU</sub> during the off-time. Equation 4 is used to calculate R<sub>OPPU</sub> and R<sub>OPPL</sub>.

$$\frac{R_{QZCD} + R_{OPPU}}{R_{OPPL}} = - \frac{N_{P,AUX} \cdot V_{bulk} - V_{OPP}}{V_{OPP}} \quad (\text{eq. 4})$$

R<sub>OPPU</sub> is selected once a value is chosen for R<sub>OPPL</sub>. R<sub>OPPL</sub> is selected large enough such that enough voltage is available for the zero crossing detection during the off-time.