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AND9079/D

Safety Tests on a NCP1612-Based PFC Stage

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APPLICATION NOTE

Introduction

Housed in an SO-10 package, the NCP1612 is an enhanced version of the NCP1611 also designed to drive PFC boost converters. Like the NCP1611, it features the ***Current Controlled Frequency Fold-back*** (***CCFF***) mode and the skip capability to optimize the efficiency of your PFC stage throughout the load range. The NCP1612 is particularly useful in applications where the PFC stage is loaded by converters that like forward or half-bridge ones, take advantage of a narrow input voltage range. In fact, in addition to the NCP1611 *Dynamic Response Enhancer* and *Soft-OVP* functions that help minimize the bulk voltage deviations, the NCP1612 features a pfcOK pin to disable the downstream converter until the bulk voltage has reached its target level and whenever the NCP1612 detects a major fault. In particular, the downstream converter stops operating if the NCP1612 "FOVP/BUV" pin detects that the bulk voltage has dropped below 76% of its regulation level. In addition, the NCP1612 features make the PFC stage extremely robust. Among these protective functions, we can mention the *Brown-Out Detection block* that stops operation when the ac line is too low and the *2-level Current Sensing*, that forces a low duty-ratio operation mode when the MOSFET current happens to exceed 150% of the current limit, for instance, in the event of a short of the bypass or boost diode.

This application note deals with this last aspect, that is, ruggedness and safety considerations. Application note AND9064 [1] describes the behavior of the NCP1611 evaluation board under safety tests. This paper does the same for the NCP1612 evaluation board (NCP1612GEVB – see [2] for details on the boards). The intent is to show how the NCP1612 can ease the compliance with safety requirements. Elements of the PFC stage can be accidentally shorted, badly soldered or damaged as a result of manufacturing or handling incidents, excessive operating stress or other troubles. In particular, adjacent pins of controllers can be shorted together or a pin can be grounded or badly connected. It is common to expect that such open/short situations do not cause fire, smoke nor loud noise. The enhanced functions of the NCP1612 help address such requirements, for instance, in case of an improper pin connection or of a short of the boost or bypass diode. To illustrate this ability, safety tests were performed on the NCP1612 evaluation board. The results are summarized in this application note. For most of the tests, the functions in play are those also embedded in the NCP1611. You can then refer to [1] for further information on their protective efficacy. In this paper, only the NCP1612 specific aspects are detailed. In all cases, you can consult the data sheet [3] for deeper information on the mentioned protecting features.

This report is not intended to guarantee that the part can pass all safety tests in all boards and conditions since the performance can vary with respect to the application and test conditions. The purpose of this application note is to illustrate in detail the typical behavior of the part under particular fault situations using the NCP1612 demo-board, highlighting the protection functions that help pass the safety tests. It remains, nonetheless, the responsibility of the NCP1612 user to check that the system he builds using the NCP1612, properly meets the safety requirements it must be compliant with.

Tests Conditions

The tests were made at a 25°C ambient temperature on the NCP1612 evaluation board (NCP1612GEVB). The schematic of the application is given by Figures 2 and 3. The circuit is separated into two sections for the sake of clarity only. Extremely slim, the NCP1612 evaluation board (shown in Figure 1) is designed to be less than 13 mm high.

This low-profile PFC stage is intended to deliver 160 W under a 390 V output voltage from a wide mains input. This is a PFC boost converter as used in Flat TVs, High Power LED Street Light power supplies, and all-in-one computer supplies. Refer to http://www.onsemi.com/PowerSolutions/product.do?id=NCP1612 for more details.

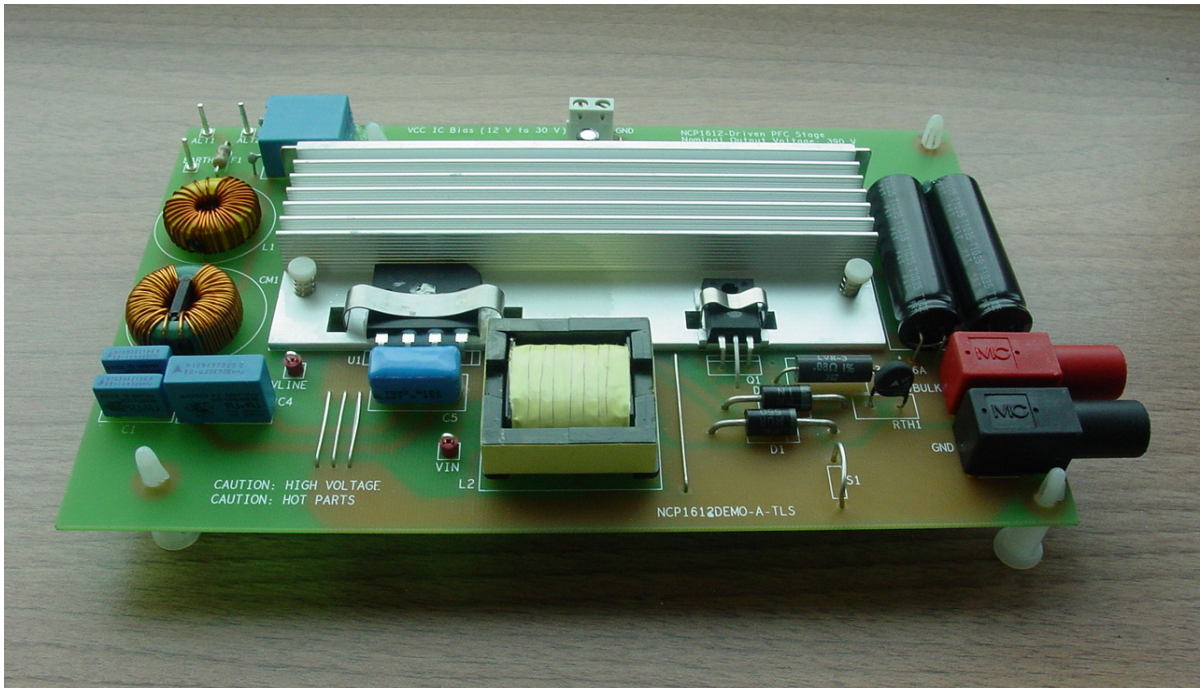

Figure 1. NCP1612 Evaluation Board (NCP1612GEVB)

APPLICATION SCHEMATIC

Power Section

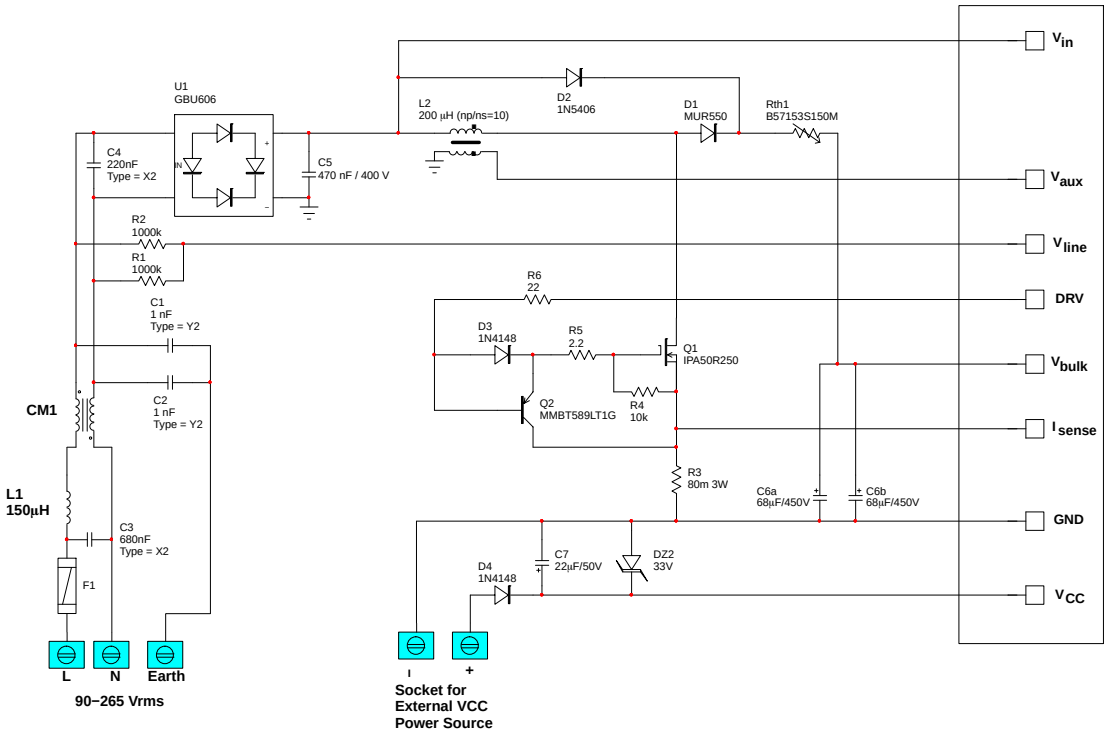

Figure 2. Board Power Section

Control Section

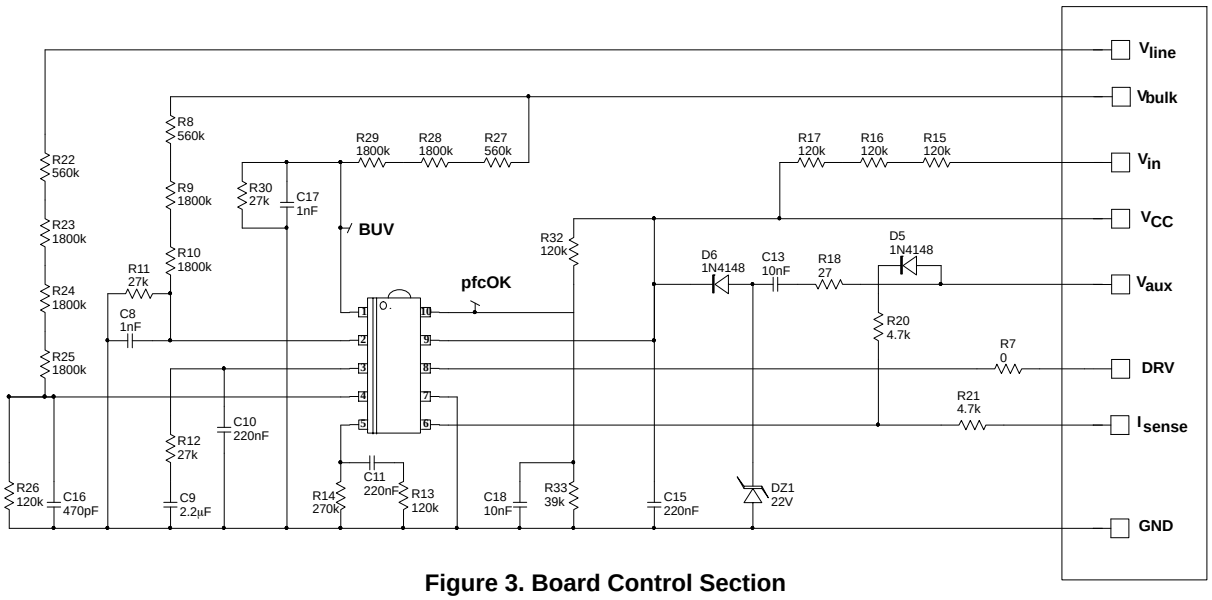

Figure 3. Board Control Section

The circuit V_{CC} was powered by a 17 V external power source featuring a 37 A current capability. Resistor R_{18} was removed to disable the self-powering circuitry using the auxiliary winding.

SHORT faults were created using a switch so that the shorts could be applied before or during operation.

Results Summary Table

The green “OK” label indicates that the fault is not destructive and that the PFC stage recovers operation when the failure source (short for instance) is removed.

The orange “OK” label indicates that the fault can be destructive to some parts of the PFC stage, but the component fails in a safe manner, enabling a pass to usual safety requirements.

Red “NOK” would have indicated an unsafe result like an excessive heating in some part of board.

Mention “Refer to [1]” can be found in the “comments” column. It indicates that the same operation occurs with the NCP1611 and that hence, further information can be found in the “Safety tests on a NCP1611-driven PFC stage” application note [1].

As shown in the table, all the tests made on the NCP1612 evaluation board were “OK”, including ground pin disconnection, bypass and boost diode short.

Table 1. RESULTS SUMMARY TABLE

	Fault Applied before Start-up	Fault Applied in Operation	Comments – What we observe in the evaluation
ADJACENT PIN TO PIN SHORT			
Pins 1 and 2 (FOVP/BUV and FB)	OK	OK	The two pins generally receive the same portion of the output voltage. In this case, shorting them does not alter the PFC stage operation.
Pins 2 and 3 (FB and $V_{CONTROL}$)	OK	OK	The regulation may be lost but the FOVP/BUV function maintains the bulk voltage below 107% of the regulation level.
Pins 3 and 4 ($V_{CONTROL}$ and V_{SENSE})	OK	OK	The PFC stage stops operating when the $V_{CONTROL}$ forces the V_{SENSE} pin below the 0.9-V threshold for brown-out detection (if the short is applied before operation or at light load). If the short is applied in heavy load conditions, the V_{SENSE} pin impedance reduces the loop gain leading the output voltage to stabilize below the target. The system must be able to face a reduced bulk voltage level. Normal operation is recovered when the short is removed. Refer to [1].
Pins 4 and 5 (V_{SENSE} and $FF_{CONTROL}$)	OK	OK	The PFC stage cannot start if the short is applied before operation. A short in operation may cause the brown-out protection to trip and/or the PFC stage to lose regulation (if high-line is improperly detected). Normal operation is recovered when the short is removed. Refer to [1].
Pins 6 and 7 CS/ZCD and GND	OK	OK	The circuit detects the pin grounding and stops operating. Normal operation is recovered when the short is removed. Refer to [1].
Pins 7 and 8 (GND and DRV)	OK	OK	The PFC stage stops operating. No damage is observed. Only the V_{CC} consumption rises from 7 to 24 mA in our example (Refer to [1]). The PFC stage recovers normal operation when the short is removed.
Pins 8 and 9 (DRV and V_{CC})	OK	OK	The MOSFET and the fuse blow up without noise, fire nor smoke. The circuit is not damaged in our case. The PFC stage can restart when the MOSFET and fuse are replaced. Behavior may vary depending on the V_{CC} power source impedance.
Pins 9 and 10 (V_{CC} and pfcOK)	OK	OK	The NCP1612 latches off if the pfcOK pin is pulled up above 7.5 V. This is the case here. The PFC stage remains disabled until it is reset by forcing a brown-out situation or by forcing V_{CC} below its reset level (refer to detailed description for more details).

Table 1. RESULTS SUMMARY TABLE (continued)

	Fault Applied before Start-up	Fault Applied in Operation	Comments – What we observe in the evaluation
SHORT TO VCC			
Pin 1 (FOVP/BUV)	OK	OK	The PFC stage stops operating (fast OVP). The V_{CC} consumption rises. Can be destructive for the part (high V_{CC}).
Pin 2 (FB)	OK	OK	The PFC stage stops operating (soft OVP). The V_{CC} consumption rises. Can be destructive for the part (high V_{CC}). Refer to [1].
Pin 3 ($V_{CONTROL}$)	OK	OK	Even if the high voltage applied to the circuit damaged it, the circuit appeared to nicely stop in our application. However, operation can be erratic and difficult to predict. **A circuitry preventing excessive voltages on pin 3 is necessary to avoid unsafe situations.** Refer to [1].
Pin 4 (V_{SENSE})	OK	OK	The PFC stage operates, but its functionality is degraded: the V_{CC} consumption is increased and there is no frequency foldback, no brown-out detection, no line range detection. Can be destructive for the part (high V_{CC}). Refer to [1].
Pin 5 ($FF_{CONTROL}$)	OK	OK	The PFC stage operates but its functionality is degraded: the V_{CC} consumption is increased and there is no frequency foldback. Possibly destructive for the part (high V_{CC}). Refer to [1].
Pin 6 (CS/ZCD)	OK	OK	The circuit stops operating (OCP). The consumption increases. Possibly destructive for the part (high V_{CC}). Refer to [1].
Pin 7 (GND)	N/A	N/A	May create an issue on the V_{CC} power source, not on the PFC stage itself.
Pin 8 (DRV)	OK	OK	The MOSFET and fuse blow up. The 37-mA V_{CC} current limitation saves the part from being damaged. Refer to [1].
Pin 10 (pfcOK)	OK	OK	The NCP1612 latches off if the pfcOK pin is pulled up above 7.5 V. This is the case here. The PFC stage remains disabled until it is reset by forcing a brown-out situation or by forcing V_{CC} below its reset level (refer to detailed description for more details).
SHORT TO GND			
Pin 1 (FOVP/BUV)	OK	OK	The PFC stage remains off as long as the FOVP/BUV pin is grounded (UVP2)
Pin 2 (FB)	OK	OK	The PFC stage remains off as long as the FB pin is grounded (UVP). Refer to [1].
Pin 3 ($V_{CONTROL}$)	OK	OK	The PFC stage remains off as long as the $V_{CONTROL}$ pin is grounded (staticOVP). Refer to [1].
Pin 4 (V_{SENSE})	OK	OK	The PFC stage remains off as long as the V_{SENSE} pin is grounded (Brown-out protection). Refer to [1].
Pin 5 ($FF_{CONTROL}$)	OK	OK	The PFC stage remains off as long as the FFcontrol pin is grounded (SKIP). Refer to [1].
Pin 6 (CS/ZCD)	OK	OK	The PFC stage remains off as long as the CS/ZCD pin is grounded (CS/ZCD pin short to GND detection). Refer to [1].
Pin 8 (DRV)	OK	OK	The PFC stage does not operate and V_{CC} consumption increases but the circuit is not damaged and recovers operation when the short is removed. Refer to [1].

Table 1. RESULTS SUMMARY TABLE (continued)

	Fault Applied before Start-up	Fault Applied in Operation	Comments – What we observe in the evaluation
SHORT TO GND			
Pin 9 (V_{CC})	N/A	N/A	Independent of the NCP1612. However, it should be checked that the V_{CC} power source can safely face a short to ground. Refer to [1].
Pin 10 (pfcOK)	OK	OK	The pfcOK pin remains in low state. The PFC stage operates normally but if a downstream converter is controlled by this pin, it will remain off. The latching off capability is lost. Refer to detailed description for more details.
FLOATING PINS			
FOVP/UVP	OK	OK	A 250 nA current source maintains the pin in low state and the PFC stage remains off as long as the FOVP/BUV pin is floating (UVP2)
FB	OK	OK	A 250 nA current source maintains the pin in low state and the PFC stage remains off as long as the FB pin is floating (UVP). Refer to [1].
$V_{CONTROL}$ Floating	OK	OK	The PFC stage operates but the power factor is low and the functioning is erratic since the loop bandwidth is not controlled. Refer to [1].
V_{SENSE} Floating	OK	OK	Erratic operation. Refer to [1].
$FF_{CONTROL}$ Floating	OK	OK	The PFC stage operates without frequency foldback. Refer to [1].
CS/ZCD Floating	OK	OK	The PFC stage remains off as long as the CS/ZCD pin remains floating (CS/ZCD pin open state detection). Refer to [1].
GND Floating	OK	OK	The circuit detects that the ground pin is not connected and the PFC stage is maintained off. Refer to [1].
DRV Floating	OK	OK	The PFC stage is off since an external resistor maintains the MOSFET in low state (R_4 10 kΩ resistor of Figure 2). Refer to [1].
V_{CC} Floating	OK	OK	The NCP1612 being not fed, the PFC stage remains off. Refer to [1].
pfcOK Floating	OK	OK	The pfcOK pin is pulled down by the 300 kΩ impedance of the pin. The PFC stage operates normally but obviously, the pin capability to disable/enable a downstream converter and the latching-off capability are lost.
OTHER TESTS			
ZCD External Diode Short (D_5 of Figure 3)	OK	OK	A diode can be placed between the ZCD external diode cathode and ground. If the main diode is shorted, the additional one is destroyed, grounding the auxiliary winding. In the demo-board, the auxiliary winding acts as a fuse. Refer to [1].
Boost Diode Short	OK	OK	The circuit operates in a low duty ratio mode. Refer to [1].
Bypass Diode Short	OK	OK	The circuit operates in a low duty ratio mode. Refer to [1].

NCP1612 SPECIFIC ASPECTS (COMPARED TO NCP1611)

Shorting the FOVP/BUV Pin to Ground

If the FOVP/BUV pin is grounded, the circuit cannot start operation since the under-voltage protection attached to pin 1 (UVP2) trips (The UVP2 function disables the drive as long as the pin1 voltage is below 300 mV typically). The circuit enters operation as soon as the short is removed.

Similarly, when in operation, the circuit stops operation when the pin is grounded and recovers operation as soon as the grounding is removed. This behavior is illustrated by Figure 4.

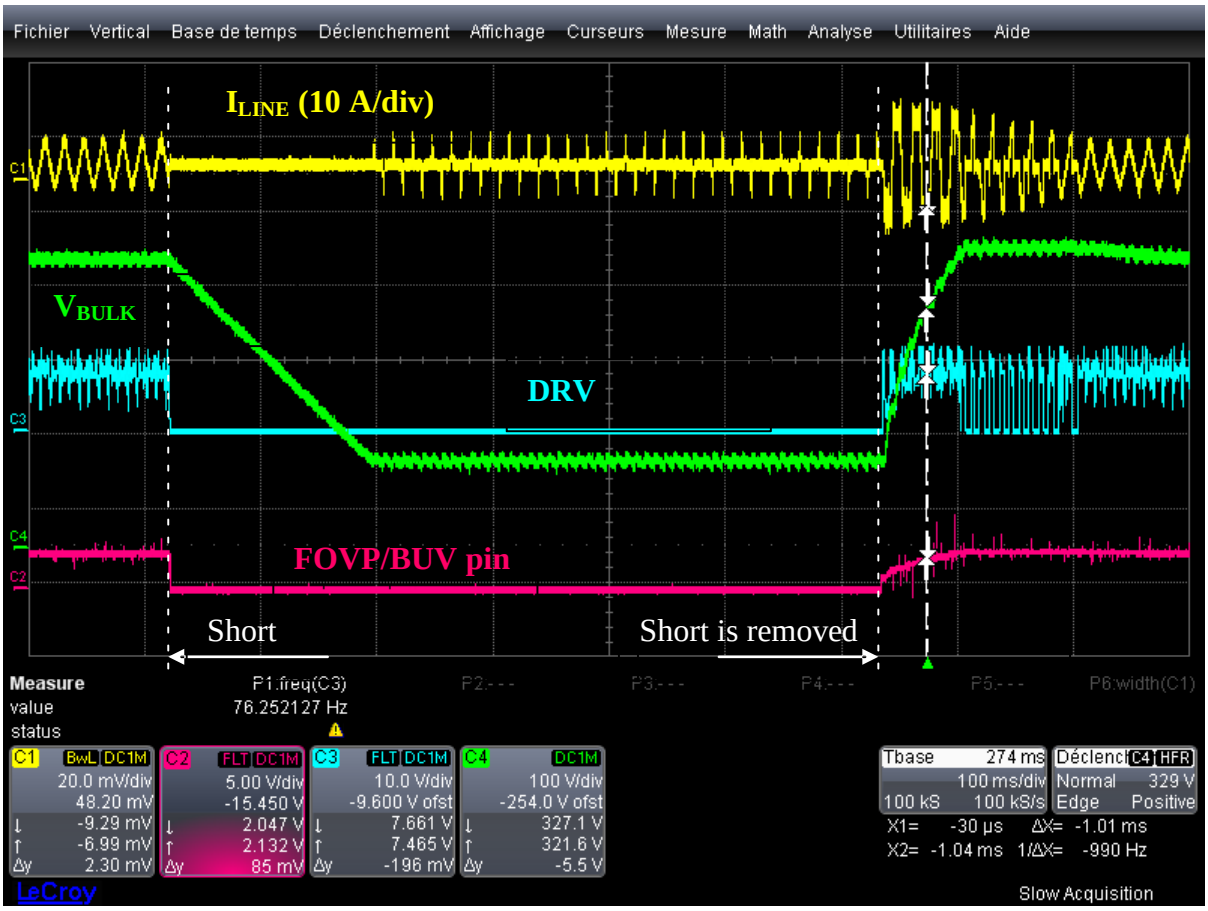

Figure 4. Grounding/No Grounding Sequences of the FOVP/BUV Pin (Test Made @ 115 V, 60 Hz, 0.2 A Load)

Shorting the FOVP/BUV Pin to the FB Pin

In the evaluation board under test, the same portion of the output voltage is applied to the FB and FOVP/BUV pins. As a result, no change in operation is noted. The test was done @ 115 V, 60 Hz, 0.2 A load.

Disconnection of the FOVP/BUV Pin

If the FOVP/BUV pin is floating, an internal 200 nA current pulls down the pin so that the under-voltage protection attached to pin 1 (UVP2) trips (The UVP2 function disables the drive as long as the pin 1 voltage is below 300 mV typically). The circuit is then safely protected.

Shorting the FOVP/BUV Pin to V_{CC}

If the FOVP/BUV pin happens to be shortened to V_{CC} when in operation, the PFC stage immediately stops operating by virtue of the fast Over Voltage Protection (fastOVP). In fact, this NCP1612 protection prevents the circuit from generating drive pulses whenever the FOVP/BUV voltage exceeds 107% of the regulation reference voltage (that is about 2.675 V).

Due to the ESD structure protecting the FOVP/BUV pin, the V_{CC} consumption rises. For instance, I_{CC} is in the range of 18 mA @ 17 V, 30 mA @ 25 V, 36 mA @ 29 V.

The circuit recovers as soon as the short is removed as illustrated by Figure 5.

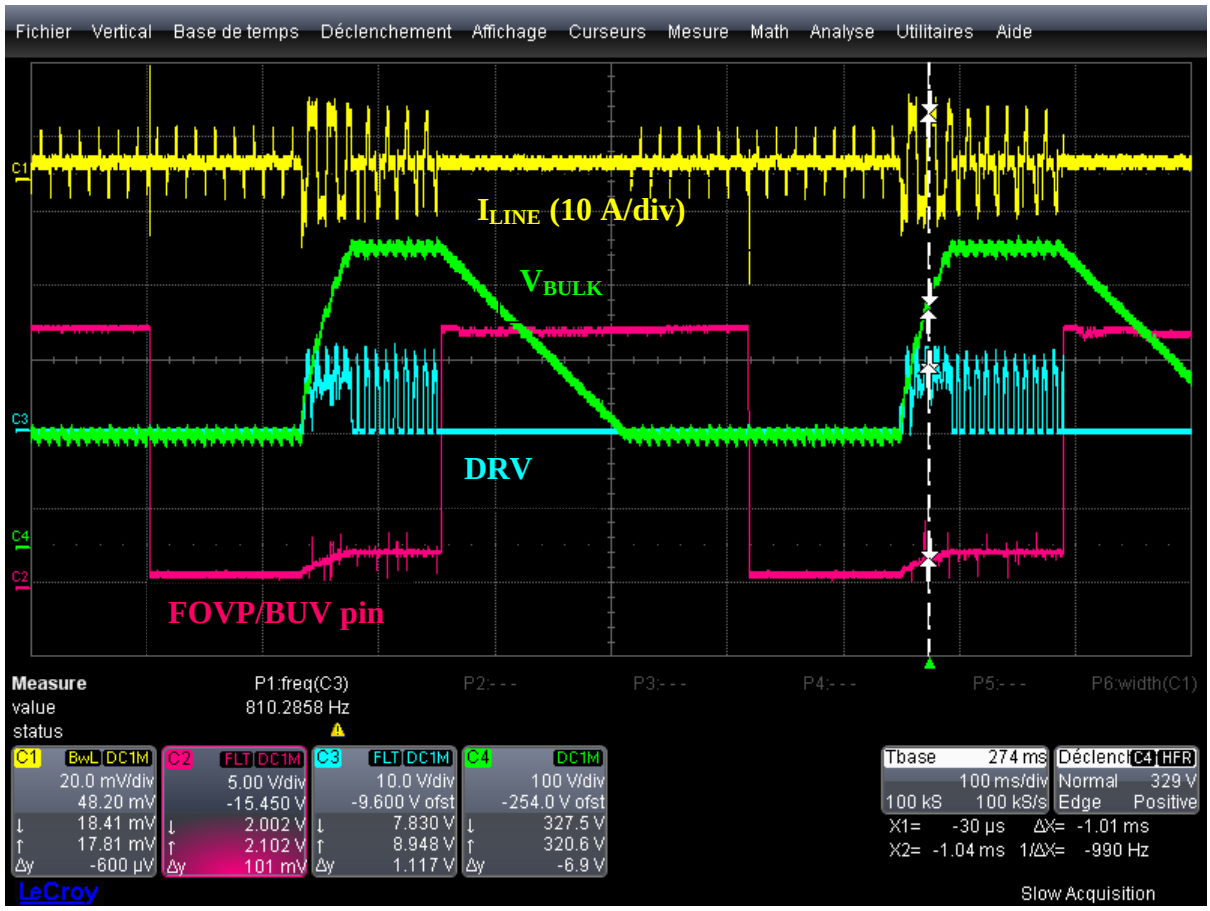

Figure 5. Short/No Short Tests Between the FOVP/BUV Pin and V_{CC} @ 115 V, 60 Hz, 0.2 A Load

Similarly, no start-up is possible in presence of this short because of the fast OVP protection.

Shorting the pfcOK Pin to Ground

No change in operation is noted as illustrated by Figure 6.

The latching-off capability and associated protection are however lost since the pfcOK pin cannot be pulled-up above the 7.5 V latching-off threshold anymore (in the studied application, this happens in the case of an excessive V_{CC} level).

Also, if the pfcOK is used to enable/disable a downstream converter, this downstream converter will be forced off during the short.

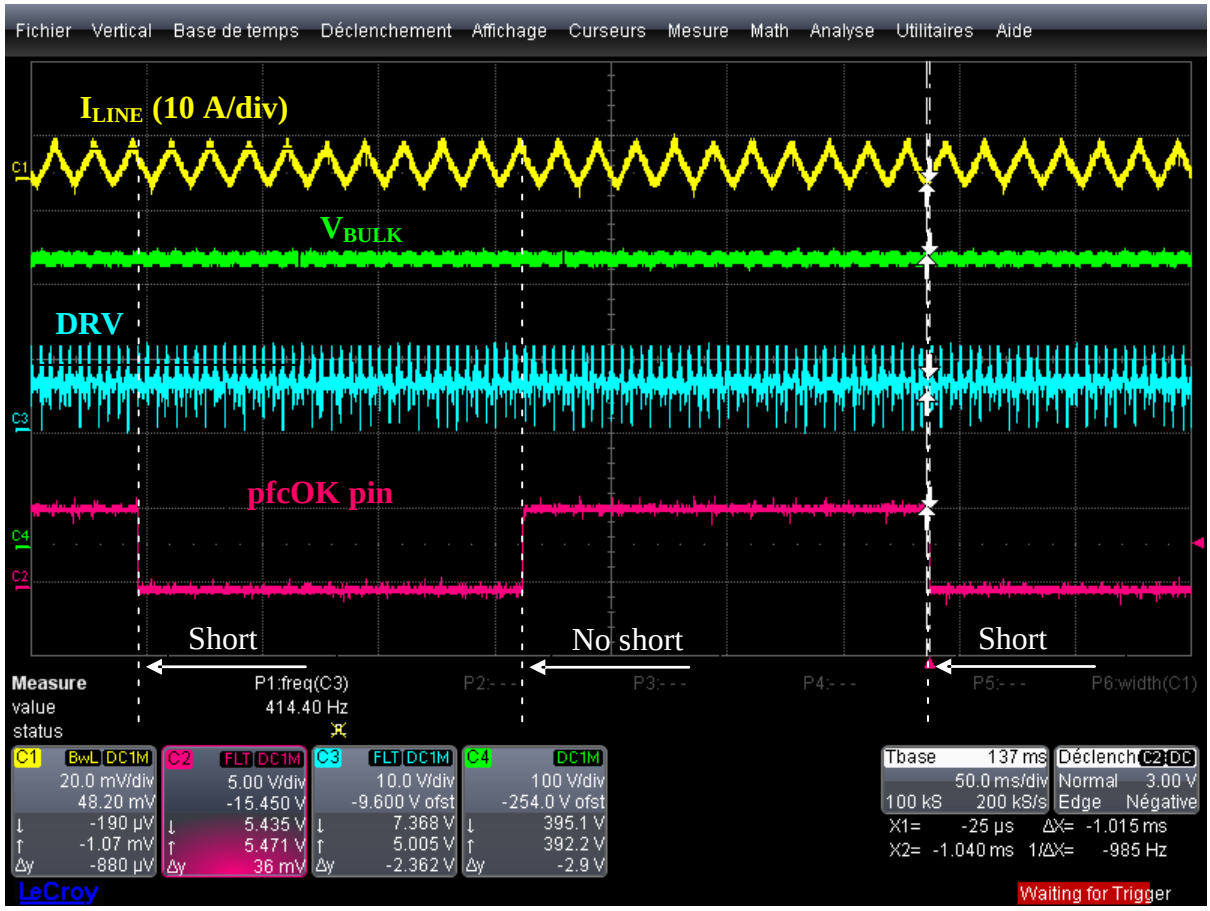

Figure 6. Grounding/No Grounding Tests of the pfcOK Pin @ 115 V, 60 Hz, 0.2 A Load

Shorting the pfcOK Pin to V_{CC}

Let's consider three cases:

- An External Power Source is Applied to the V_{CC} Socket and the Short is Applied between the Power Source and the pfcOK Pin
- No External Power Source is Applied to the V_{CC} Socket and the Short is Applied between the V_{CC} and pfcOK Pins
- An External Power Source is Applied to the V_{CC} Socket and the Short is Applied between the V_{CC} and pfcOK Pins

Let us note that the external V_{CC} power source and the V_{CC} pin are separated by a diode (D_4 of Figure 1).

In the three cases, the V_{CC} start-up resistors (R_{15}, R_{16} and R_{17}) and the V_{CC} charge pump (R_{18}, C_{13}, D_6 and D_{Z1}), are still connected.

<u>An External Power Source is Applied to the V_{CC} Socket and the Short is Applied between the Power Source and the pfcOK Pin</u>

After the pfcOK pin is applied to V_{CC}, we observe the behavior of Figure 7.

Figure 7. pfcOK Shorted to an External V_{CC} Power Source @ 115 V, 60 Hz, 0.2 A Load

The external power source collapses to about 1 V voltage as imposed by the pfcOK pin voltage. Please note that this voltage depends on the power source current capability (37 mA in this case). If the current limit is increased to 84 mA, the V_{CC} voltage is only pulled down to 3.6 V.

In this condition, the circuit stops pulsating. In fact, the short has leaded the pfcOK pin voltage to exceed the 7.5 V latching off threshold. As a result, the NCP1612 has latched off. Hence, the circuit stops pulsating and the pfcOK pin is forced in low state. Due to the external power source current, the pfcOK pin cannot drop below 1 V.

Since the external V_{CC} power source is grounded (but not the circuit V_{CC} pin), the V_{CC} start-up resistors (R_{15}, R_{16} and R_{17}) make the V_{CC} pin voltage swing between the UVLO thresholds. As a result, V_{CC} cannot decay to its reset level (4 V typically) and the NCP1612 stays latched off.

If the short is removed, nothing happens except that the external V_{CC} recovers its normal 17 V value. Thus, the V_{CC} pin voltage does not cycle up and down anymore since the external V_{CC} power source prevents it from dropping. None of the reset conditions being met (brown-out detection or V_{CC} drop below the 4 V reset level), the part remains latched off and hence, maintains the pfcOK pin in low state as shown by Figure 8.

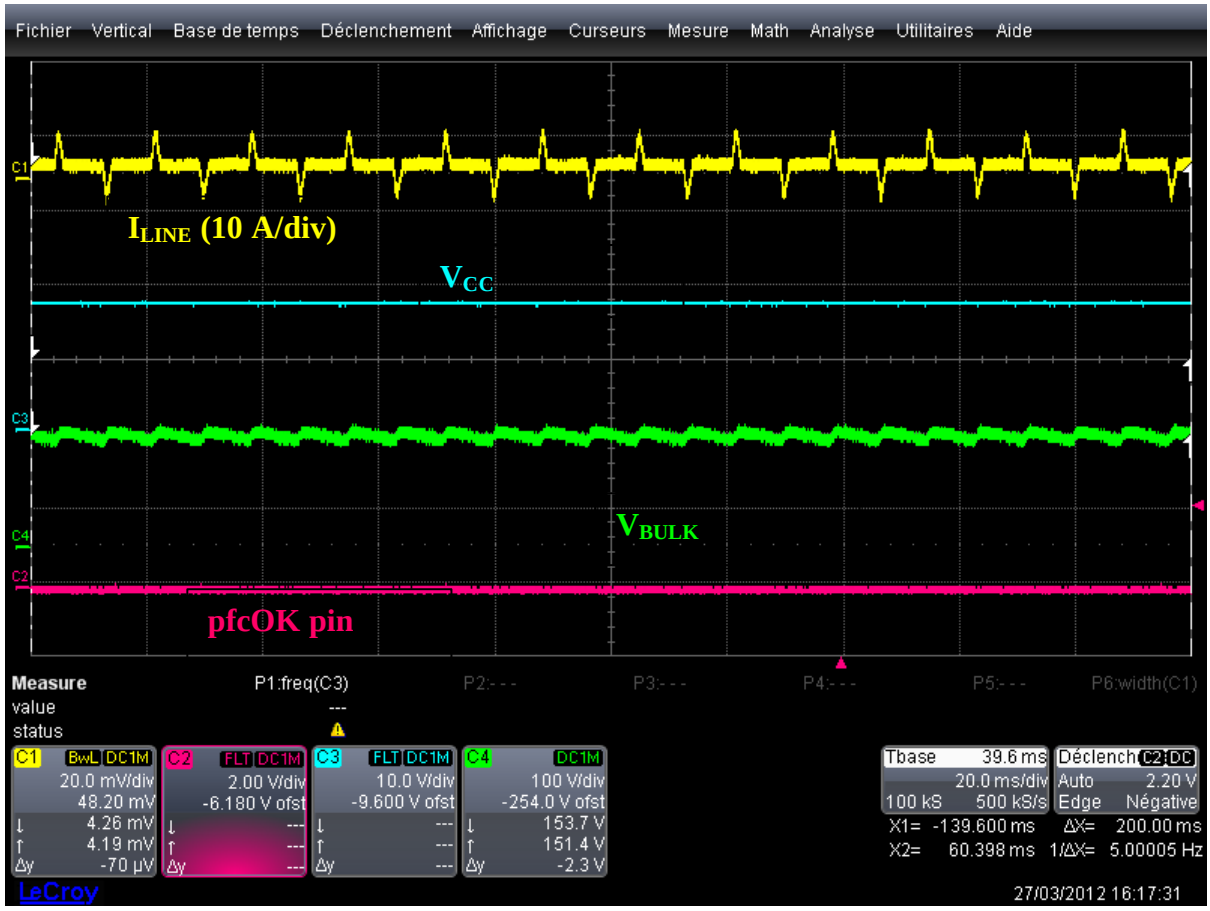

Figure 8. pfcOK Remains in Low State (115 V, 60 Hz, 0.2 A Load)

The circuit remains latched off until the V_{CC} drops below its reset level or until a brown-out situation is created.

If one of these events occurs, the circuit can recover operation. In practice, we generated a mains interruption to produce a brown-out situation and hence, restart the PFC stage.

No External Power Source is Applied to the V_{CC} Socket and the Short is Applied between the V_{CC} and pfcOK Pins

If the V_{CC} and pfcOK pins happen to be shorted, the pfcOK pin voltage exceeds the 7.5 V latching off threshold. As a result, the NCP1612 latches off and hence, grounds the pfcOK pin. Finally, the pfcOK pin grounds V_{CC} as long as the short is present.

Since V_{CC} decays below the 4 V reset level, the circuit is no more latched-off.

However, the pfcOK being in low state, it sinks the start-up current provided by the V_{CC} start-up resistors (R_{15}, R_{16} and R_{17}) and hence, prevents the V_{CC} capacitor from charging. In the absence of a sufficient V_{CC} voltage, the NCP1612 and hence, the PFC stage stay off.

However, as soon as the short is removed, the circuit recovers operation as shown by Figure 9.

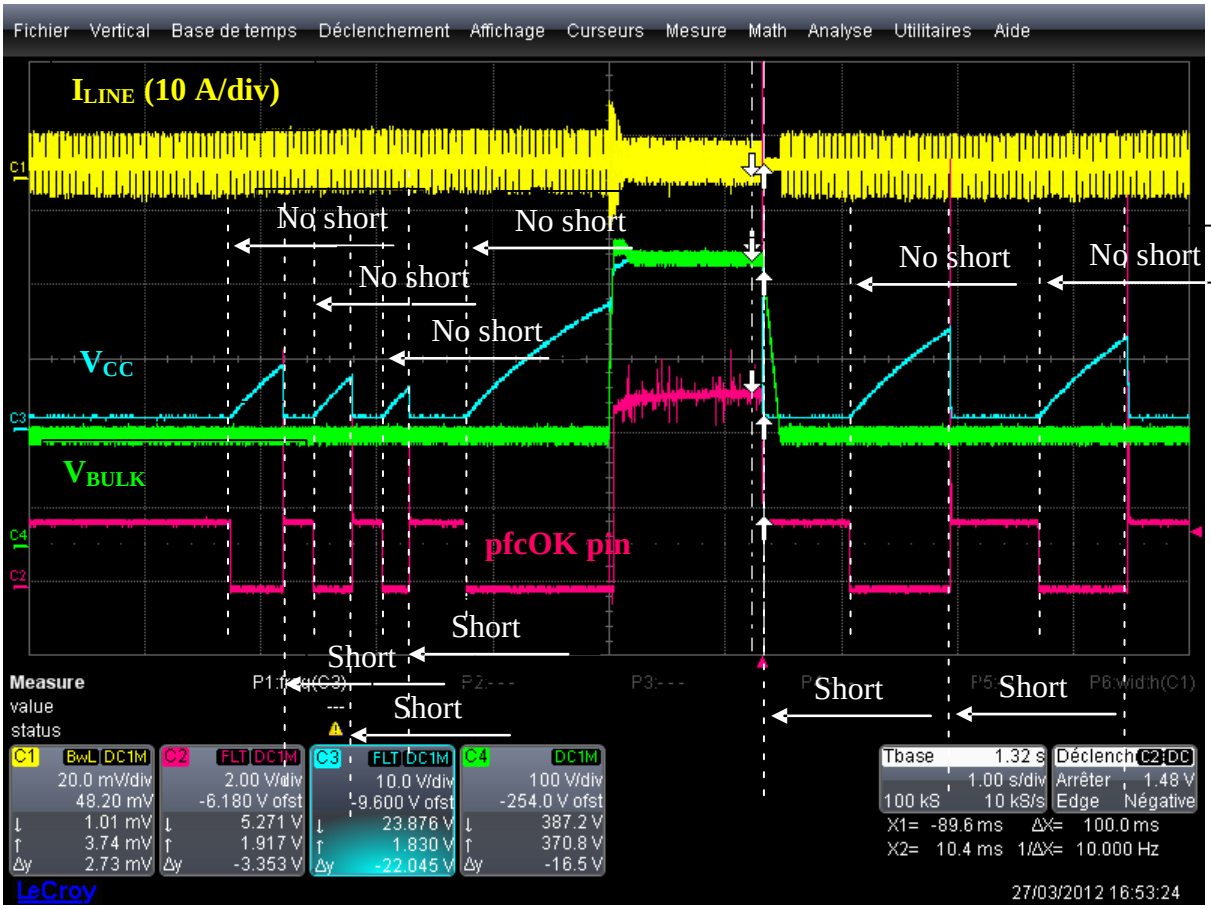

Figure 9. Short/No Short between the V_{CC} and pfcOK Pins without a Power Source Applied to the V_{CC} Socket @ 115 V, 60 Hz, 0.2 A Load

An External Power Source is Applied to the V_{CC} Socket and the Short is Applied between the V_{CC} and pfcOK Pins

Again, if the V_{CC} and pfcOK pins happen to be shorted, the pfcOK pin voltage exceeds the 7.5 V latching off threshold. As a result, the NCP1612 latches off and hence, grounds the pfcOK pin. Finally, the pfcOK pin tends to ground V_{CC} as long as the short is present.

Since V_{CC} decays below the 4 V reset level, the circuit is no more latched-off.

The obtained V_{CC} voltage depends on the current capability of the V_{CC} external power source. In our case, V_{CC} drops to about 4 V with a 40 mA current limitation and down to about 5.5 V if the maximum I_{CC} is set to 80 mA.

So, depending on the current capability of the V_{CC} external power source, V_{CC} decays below the 4 V reset level or not. Practically, with a 40 mA current limitation, the V_{CC} decay is large enough to allow the circuit reset. In this case, the PFC stage recovers operation when the short is removed. If the current capability is 80 mA, the circuit is not reset and then, it remains latched off if the latch is removed. In this case, a brown-out condition is necessarily to have the circuit restart after the short is removed.

Disconnection of the pfcOK Pin

If the pin is floating, the circuit operates normally.

The pfcOK pin is pulled down by the 300 kΩ impedance of the pin.

As shown in Figure 10, the relatively high impedance of the pin leads to noise to be visible on the pin. Depending to the layout and in very stressful conditions, the circuit may happen to latch off, which can be welcome in some applications.

Finally the PFC stage operates normally. However, **the pin ability to disable/enable a downstream converter and the latching-off capability are lost.**

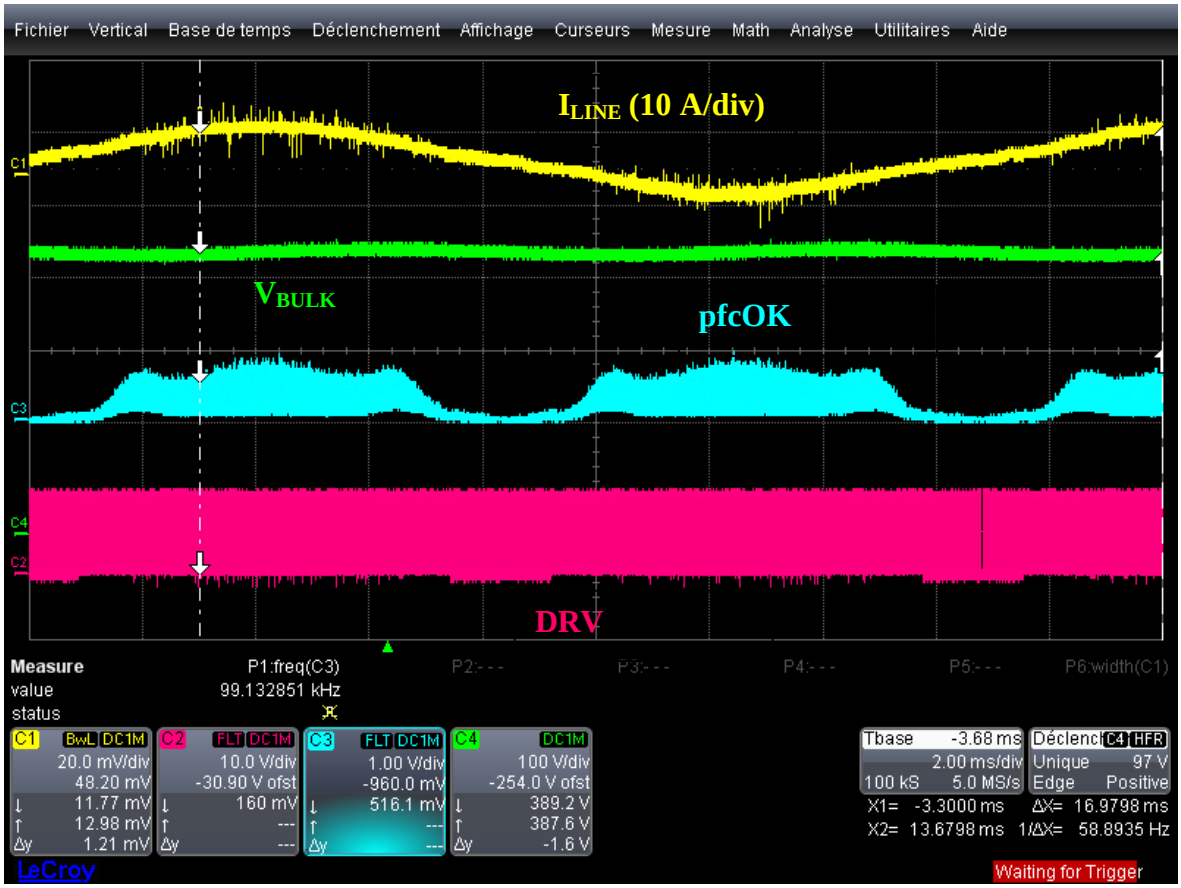

Figure 10. Test with the pfcOK Being Floating @ 115 V, 60 Hz, 0.2 A Load

Conclusion

The paper reports the safety tests applied to the NCP1612 evaluation board. As seen throughout the testing, simulated faults resulted in predicable safety responses and the enhanced safety features built in to the NCP1612 in the majority of causes resulted in events that were recoverable when the fault condition was removed. **As already stated, it remains the responsibility of the NCP1612 user to verify that systems they build, successfully pass the safety tests they must meet.**

References

[1] Joel Turchi, “Safety tests on a NCP1611-driven PFC stage”, Application note AND9064/D, http://www.onsemi.com/pub_link/Collateral/AND9064−D.PDF.

[2] NCP1612 Evaluation Board Documents, http://www.onsemi.com/PowerSolutions/supportDoc.do?type=boards&rpn=NCP1612

[3] NCP1612 Data Sheet, http://www.onsemi.com/pub_link/Collateral/NCP1612−D.PDF

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