

# NCP10970AGEVB

## Dual Output (with 3.3 V LDO) PSU for High Voltage Input Evaluation Board User's Manual



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### DESCRIPTION

The NCP10970AGEVB evaluation board is a non-isolated buck topology converter which provides adjustable output voltage up to 16 V and fixed linear output voltage 3.3 V. Input voltage range is from ~30 V<sub>rms</sub> up to 440 V<sub>rms</sub>. The board is also ready for DC input voltage up to 620 V.

Nominal output current of the board is 150 mA. This current is divided between switcher output and LDO output, i.e. when LDO provides 100 mA of output current, there is 50 mA on switcher output.

The NCP10970A1 is SOIC-16 power management IC combines HV switcher, LDO, internal circuitry for creating the input voltage for LDO in very effective way and internal comparator circuitry. The switcher works in a DCM mode for better efficiency, EMI and surge robustness. To ensure low no-load standby power and good efficiency at light load, the device is equipped with a skip mode operation.

A dedicated comparator circuitry provides a means to instruct the external control section that an over-temperature or over-current point has been reached. The comparator input is biased by a precise constant current source and output is an open-drain type. The speed of comparator is driven by a voltage value on STBY pin.

### EVAL BOARD USER'S MANUAL

### KEY FEATURES

- Wide Input Voltage Range up to 440 V<sub>rms</sub>
- Adjustable Output Voltage up to 16 V
- Fixed Linear Output Voltage 3.3 V
- High Efficiency
- Complies with CoC5 Tier2
- Low EMI Emissions
- Over-Current Protection
- Over-Voltage Protection
- Internal TSD Protection
- Integrated Comparator

Table 1. GENERAL PARAMETERS

| Device                                    | Applications                                                                   | Input Voltage              | Output Voltage / Current                                                                | V <sub>OUT</sub> Ripple | I/O Isolation |
|-------------------------------------------|--------------------------------------------------------------------------------|----------------------------|-----------------------------------------------------------------------------------------|-------------------------|---------------|
| NCP10970A1                                | White goods, IoT devices, E-metering applications, power sources driven by MCU | Up to 440 V <sub>rms</sub> | 15 V switcher output<br>3.3 V LDO output<br>150 mA shared between 15 V and 3.3 V output | < 100 mV                | Non-isolated  |
| Efficiency                                | No-load Input Power                                                            | Operating Temperature      | Cooling                                                                                 | Topology                | Board Size    |
| see efficiency graphs and table in page 4 | 21 mW @ 115 V <sub>rms</sub><br>30 mW @ 230 V <sub>rms</sub><br>55 mW @ 600 V  | 0 – 50°C                   | Passive cooling                                                                         | Buck                    | 68 x 37 mm    |

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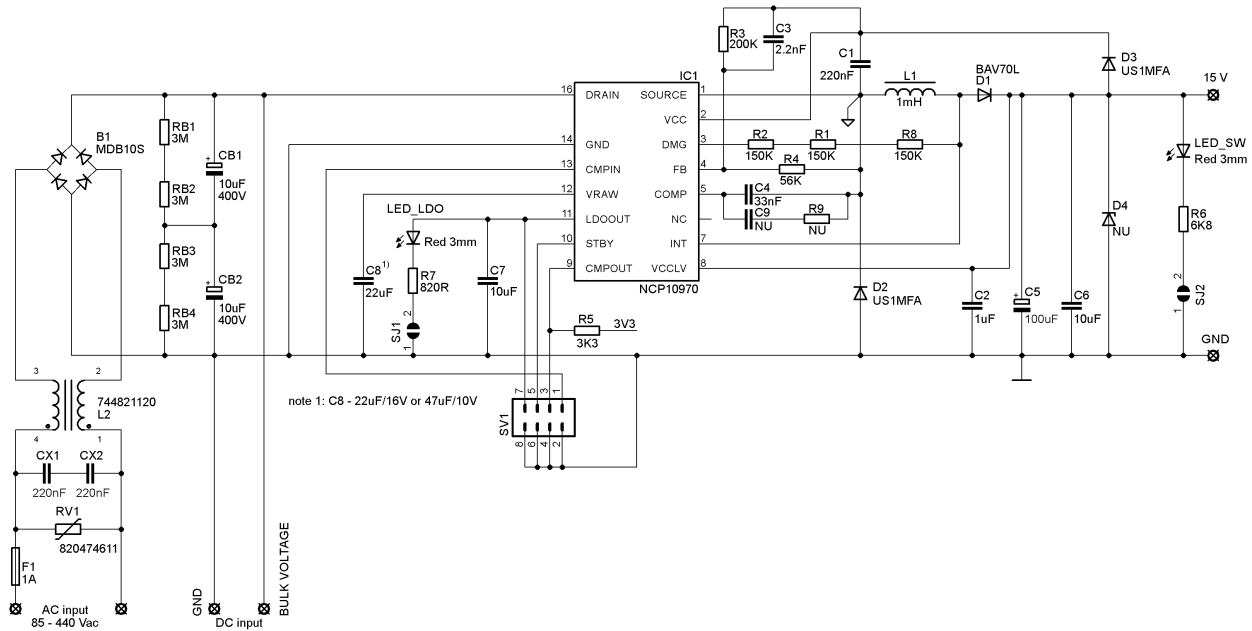


Figure 1. Schematic Diagram of NCP10970AGEVB Board

## DETAILED DESCRIPTIONS OF THE EVALUATION BOARD

The 1 A time-lag fuse, to withstand the inrush current, protects the input of the converter. There is also the varistor  $RV_1$  placed behind the fuse as a differential mode lighting surge protection.

The EMI filter consists from the common-mode power line choke  $L_2$  and X-capacitors  $CX_1$  and  $CX_2$  connected in series to withstand the high input voltage.

The power stage is a buck topology and it consists of the bridge rectifier  $B_1$ , bulk capacitors  $CB_1$  and  $CB_2$  with voltage balancing resistors  $RB_1$ – $RB_4$ , switcher in  $IC_1$ , inductor  $L_1$ , diodes  $D_1$  and  $D_2$  and output capacitors  $C_5$  with decoupling ceramic capacitor  $C_6$ .

The voltages on all pins of switcher  $IC_1$  (pin 1 to 5 and pin 16) are related to SOURCE pin, which is common ground of the switcher.

The output voltage is controlled based on the portion of the output voltage on FB pin from resistor divider  $R_3$  and  $R_4$  through diode  $D_3$ . The voltage on resistor  $R_4$  is compared with internal reference voltage  $V_{REF} = 3.3$  V.

Capacitor  $C_3$  in parallel to resistor  $R_3$  makes the feedback loop faster.

The supply capacitor  $C_1$  connected to VCC pin ensures the stability of the switcher supply voltage. Its value also affects the switching behavior of the switcher. It means, low value bring faster response but causes high output voltage during no-load as well.

The capacitor  $C_4$  connected to COMP pin creates a type I compensation network, i.e. the value affects the gain and phase margin of the feedback loop.

Sensing signal of the end of the inductor demagnetization is connected to DGM pin through resistors  $R_1$ ,  $R_2$  and  $R_8$ . These resistors have to withstand the voltage of input power

source and reduce the maximum current value to 2 mA during on-time. During off-time, these resistors  $R_1$ ,  $R_2$  and  $R_8$  create a resistor divider with 47 k $\Omega$  internal resistor  $R_{int}$ .

The Zener diode  $D_4$  is prepared to clamp output voltage when it is needed, otherwise high output voltage causes Over-Voltage Protection on VCC pin.

The low-voltage part of the  $IC_1$  is supplied via VCCLV pin with connected ceramic capacitor  $C_2$  for better decoupling from output voltage. This capacitor also provides stability of supply voltage when the internal switch connected to VCCLV pin supplies the input of the LDO regulator.

VRAW pin is the input of the LDO regulator. The current is transferred from inductor  $L_1$  through INT pin and internal switch to the capacitor  $C_8$  connected to VRAW pin. The capacitor  $C_8$  determines the ripple of VRAW voltage and provides the energy during skip mode operation of switcher – no switching pulses, i.e. the energy for LDO cannot be transferred through INT switch. Therefore, it is recommended to use capacitor with X7R dielectric and 22  $\mu$ F / 16 V as minimum value or 47  $\mu$ F / 10 V.

The capacitor  $C_7$  connected to LDOOUT pin ensures the stability and performance during normal operation and load transients on LDO rail. The PSRR performance based on capacitor  $C_7$  value is shown in datasheet.

The indication of presence of output voltages providing the red LEDs connected to the outputs through solder jumpers  $SJ_1$  and  $SJ_2$ .

CMPIN pin is the input pin of the integrated comparator. This pin is biased by a precise internal 120  $\mu$ A current source – the over-temperature detection can be realized with PTC thermistor connected to this pin. The 100 nF capacitor can be connected in parallel to PTC thermistor for better behavior of over-temperature detection.

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The output of the comparator CMPOUT pin crosses from High Z state to low state when voltage on CMPIN pin achieves 1 V. The output goes back to High Z state when voltage on CMPIN pin drops below 0.8 V. Detailed explanation of comparator is stated in datasheet.

STBY pin drives the speed of the comparator. The comparator is slow (300 ns delay) when this pin is grounded

and fast (70 ns delay) when 3 V and more is connected to this pin – 5.5 V is maximum allowed voltage. The input of the STBY pin is internally grounded through 100 k $\Omega$  resistor.

### PCB LAYOUT

The PCB is made as a double layer FR4 board with 35  $\mu$ m copper cladding.

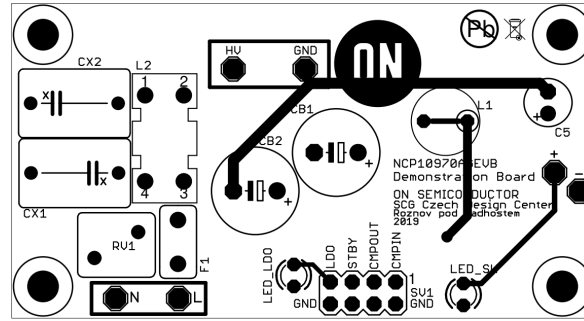
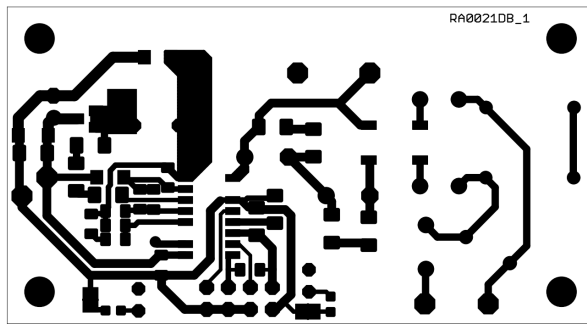
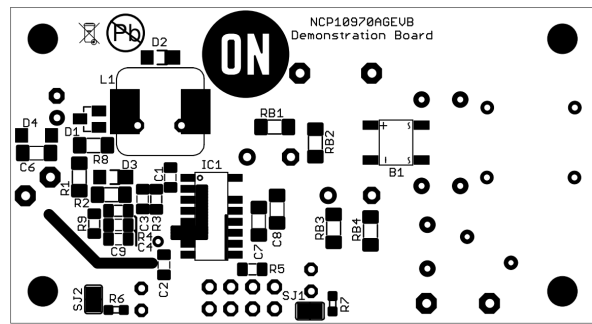


Figure 2. NCP10970AGEVB – Top Side Layer + Components

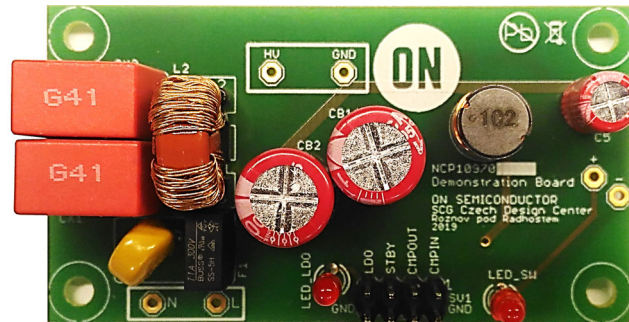


(a)

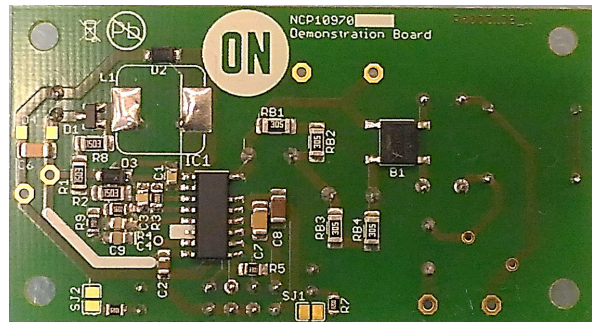


(b)

Figure 3. NCP10970AGEVB – Bottom Side – (a) Layer, (b) Components



(a)



(b)

Figure 4. NCP10970AGEVB Board Photo – (a) Top Side, (b) Bottom Side

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## MEASUREMENTS – GRAPHS AND TABLES

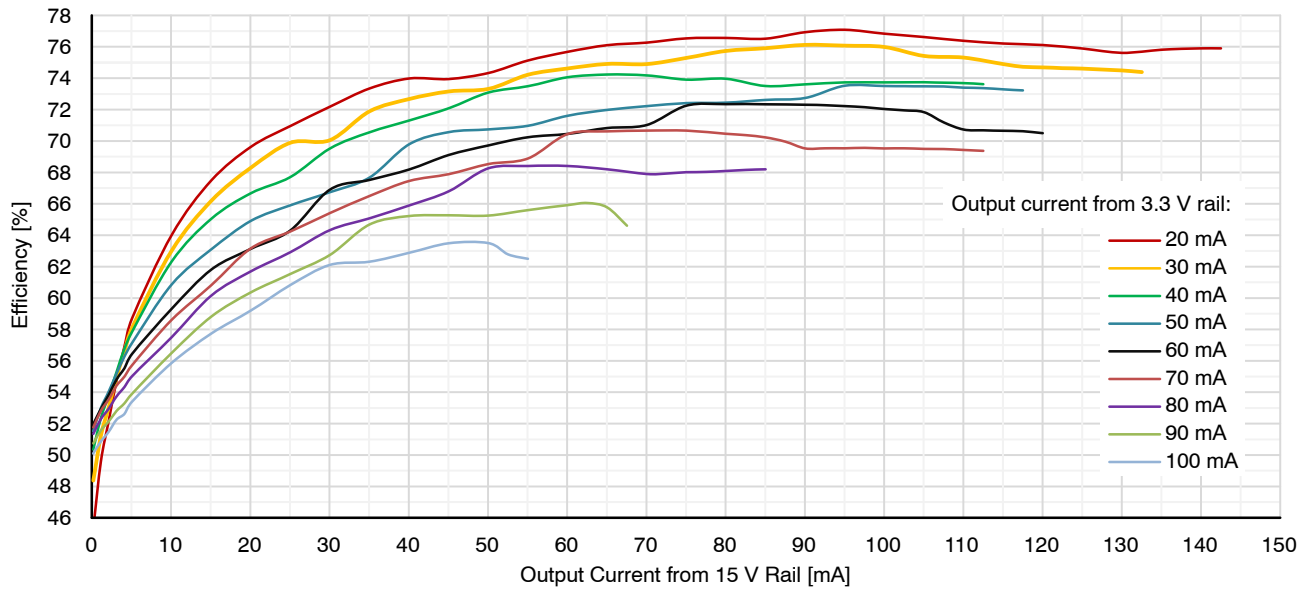


Figure 5. Efficiency Graph of NCP10970AGEVB for 115 V<sub>rms</sub> / 60 Hz

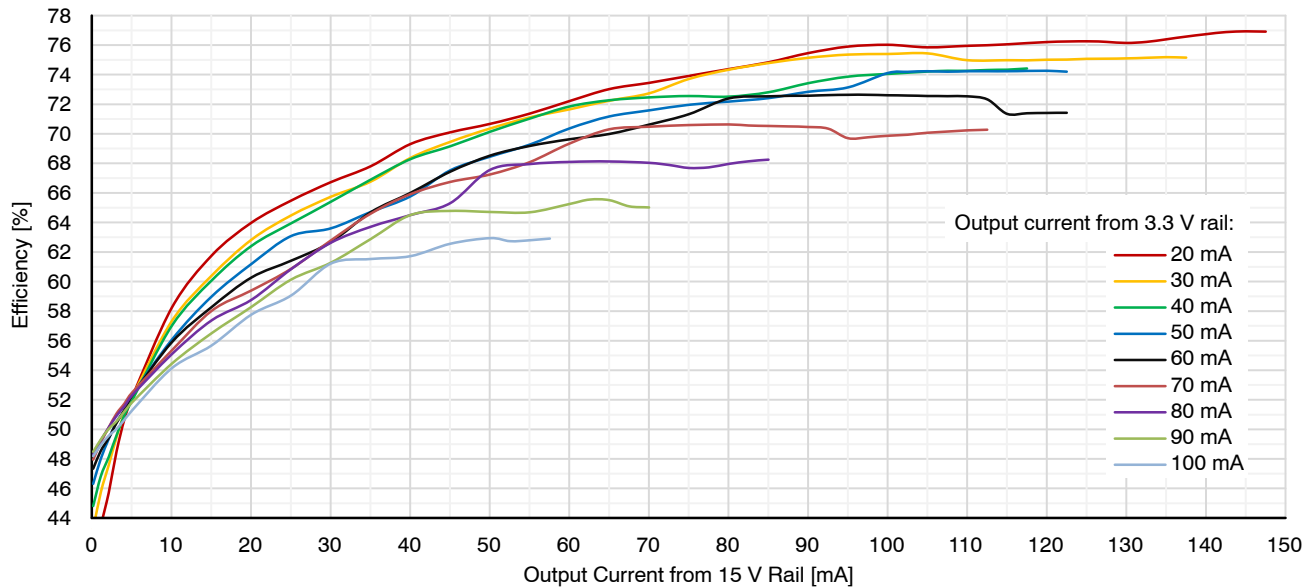
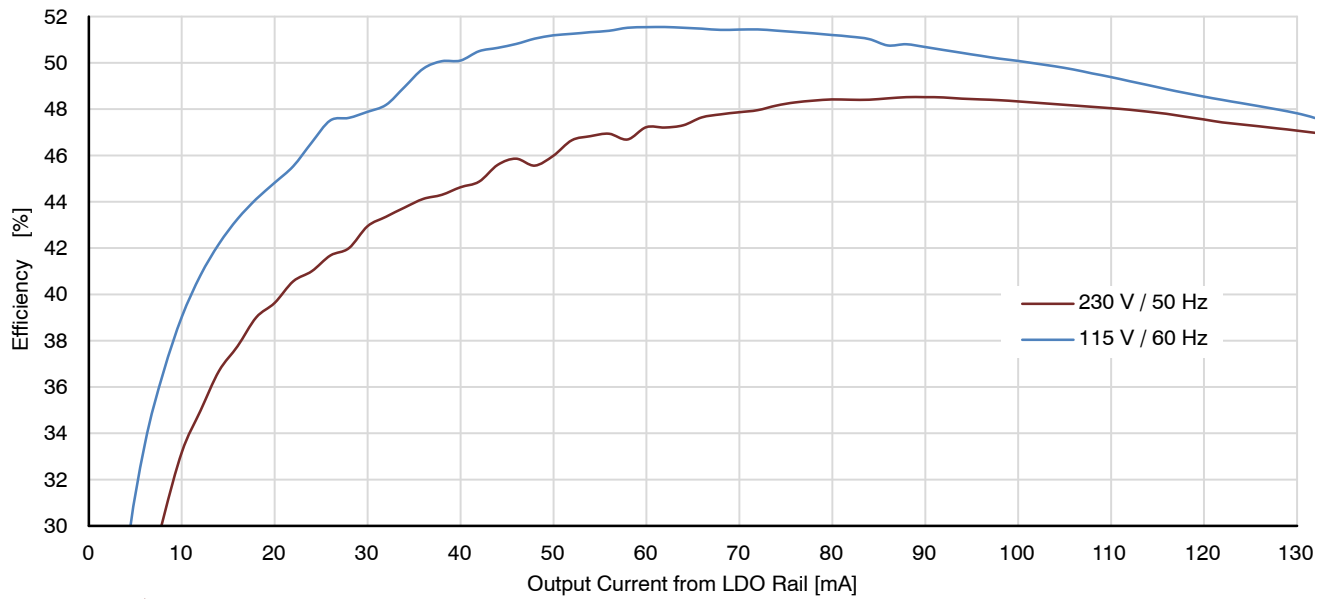


Figure 6. Efficiency Graph of NCP10970AGEVB for 230 V<sub>rms</sub> / 50 Hz

Table 2. EFFICIENCY TABLE

| Output Load                                            | Input Voltage        |                      |       |
|--------------------------------------------------------|----------------------|----------------------|-------|
|                                                        | 115 V <sub>rms</sub> | 230 V <sub>rms</sub> | 600 V |
| I <sub>OUT</sub> = 15 mA, I <sub>LDOOUT</sub> = 30 mA  | 65.5%                | 60.3%                | 53.0% |
| I <sub>OUT</sub> = 15 mA, I <sub>LDOOUT</sub> = 60 mA  | 62.0%                | 57.8%                | 51.5% |
| I <sub>OUT</sub> = 15 mA, I <sub>LDOOUT</sub> = 80 mA  | 59.7%                | 56.8%                | 51.8% |
| I <sub>OUT</sub> = 15 mA, I <sub>LDOOUT</sub> = 100 mA | 57.3%                | 55.8%                | 50.9% |
| I <sub>OUT</sub> = 30 mA, I <sub>LDOOUT</sub> = 100 mA | 61.6%                | 60.9%                | 57.5% |
| I <sub>OUT</sub> = 50 mA, I <sub>LDOOUT</sub> = 100 mA | 62.5%                | 62.5%                | 59.3% |

## NCP10970AGEVB

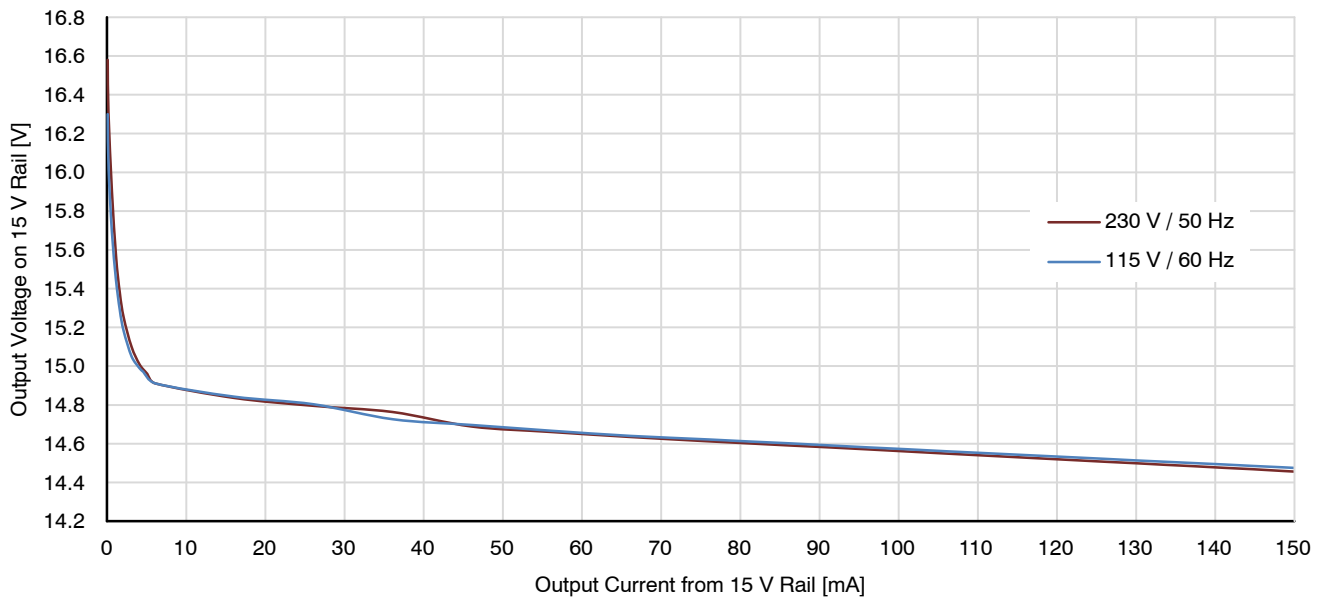


**Figure 7. Efficiency Graph of NCP10970AGEVB as HV LDO – the 15 V Rail is not Loaded**

**Table 3. NO-LOAD INPUT POWER TABLE**

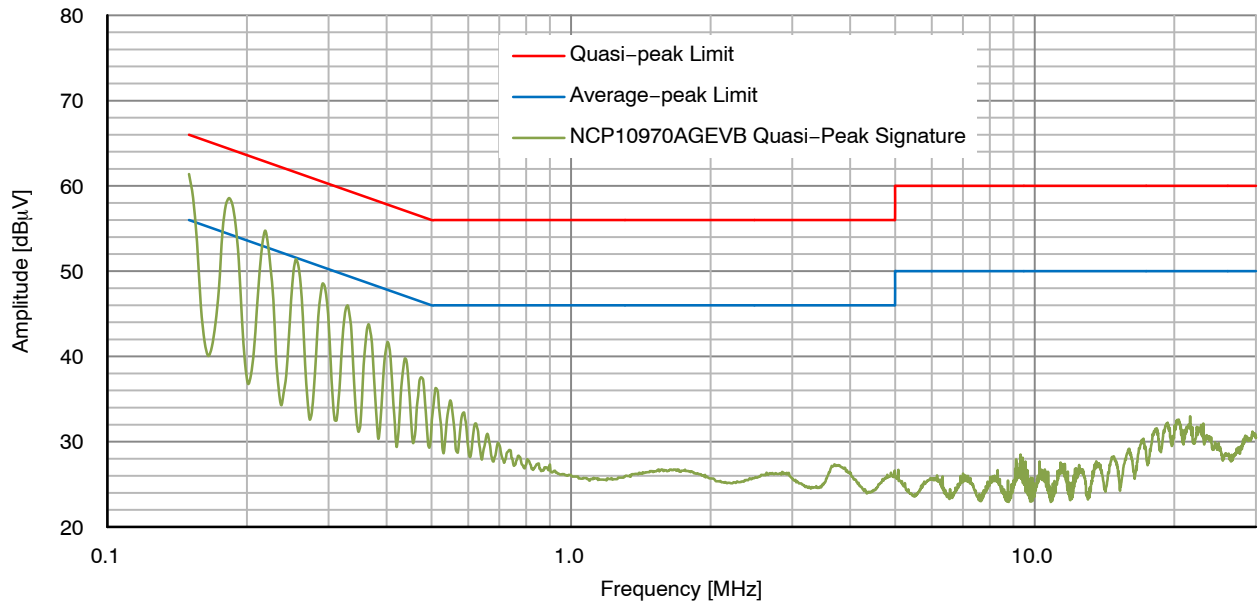
| Input Voltage        | No-load Input Power<br>$I_{OUT} = \text{Unloaded}$<br>$I_{LDOOUT} = \text{Unloaded}$ | Application Standby<br>$I_{OUT} = 0.5 \text{ mA}$<br>$I_{LDOOUT} = 3 \text{ mA}$ |
|----------------------|--------------------------------------------------------------------------------------|----------------------------------------------------------------------------------|
| 115 V <sub>rms</sub> | 21 mW                                                                                | 46 mW                                                                            |
| 230 V <sub>rms</sub> | 30 mW                                                                                | 58 mW                                                                            |
| 400 V                | 34 mW                                                                                | 60 mW                                                                            |
| 600 V                | 55 mW                                                                                | 82 mW                                                                            |

\*115/230 V<sub>rms</sub> was applied on AC input terminals, 400/600 V was applied on DC input terminals

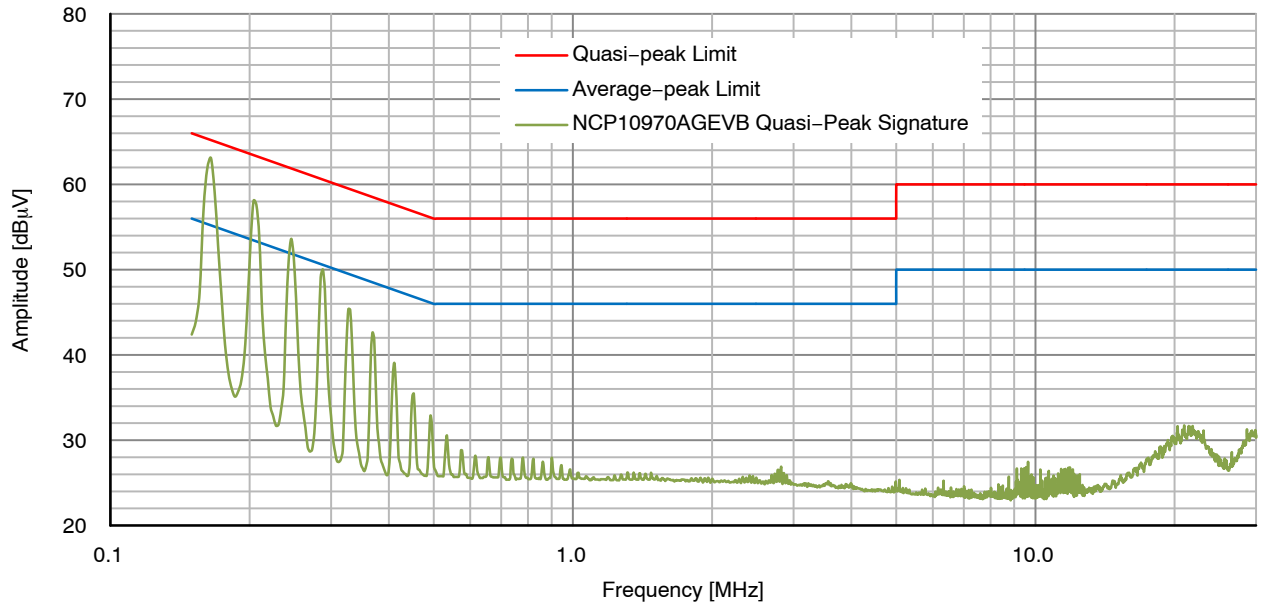


**Figure 8. Output Voltage Regulation of NCP10970AGEVB**

## NCP10970AGEVB



**Figure 9. Quasi-Peak EMI Measurement NCP10970AGEVB,  $V_{IN} = 230 V_{rms}$ ,  $I_{OUT} = 44 mA$ ,  $I_{LDOUT} = 94 mA$**



**Figure 10. Quasi-Peak EMI Measurement NCP10970AGEVB,  $V_{IN} = 115 V_{rms}$ ,  $I_{OUT} = 44 mA$ ,  $I_{LDOUT} = 94 mA$**

MEASUREMENTS – WAVEFORMS

Startup and Power-down Behavior

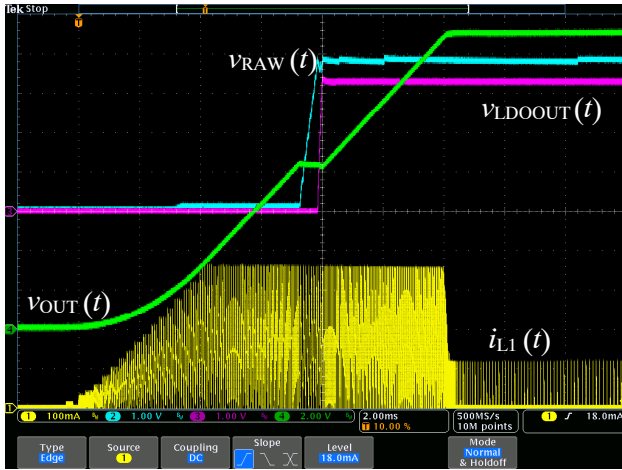


Figure 11. Startup at  $V_{IN} = 115\text{ V}$ ,  $I_{OUT} = I_{LDOOUT} = \text{Unloaded}$

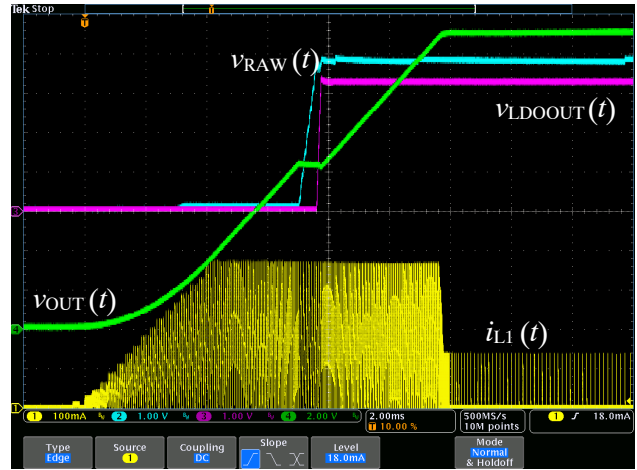


Figure 12. Startup at  $V_{IN} = 230\text{ V}$ ,  $I_{OUT} = I_{LDOOUT} = \text{Unloaded}$

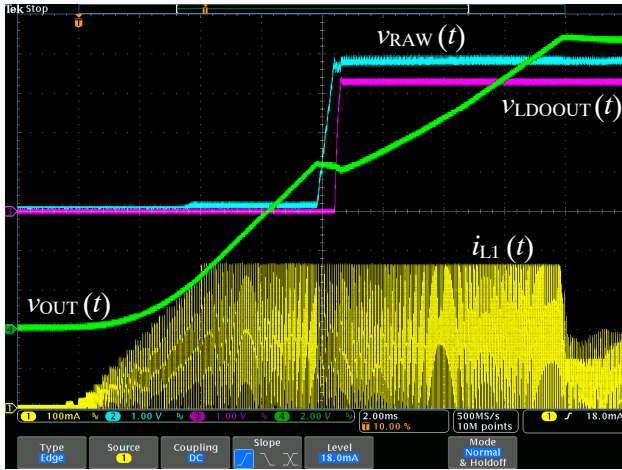


Figure 13. Startup at  $V_{IN} = 115\text{ V}$ ,  $I_{OUT} = 15\text{ mA}$ ,  $I_{LDOOUT} = 60\text{ mA}$

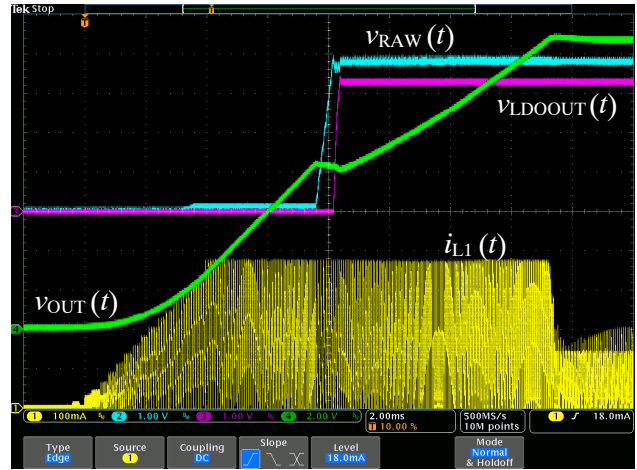


Figure 14. Startup at  $V_{IN} = 230\text{ V}$ ,  $I_{OUT} = 15\text{ mA}$ ,  $I_{LDOOUT} = 60\text{ mA}$

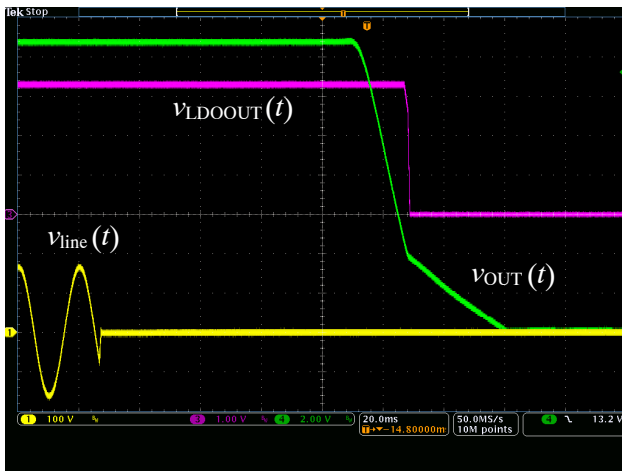


Figure 15. Power-down at  $V_{IN} = 115\text{ V}$ ,  $I_{OUT} = 15\text{ mA}$ ,  $I_{LDOOUT} = 60\text{ mA}$ ; Outputs are in Regulation for 80 ms

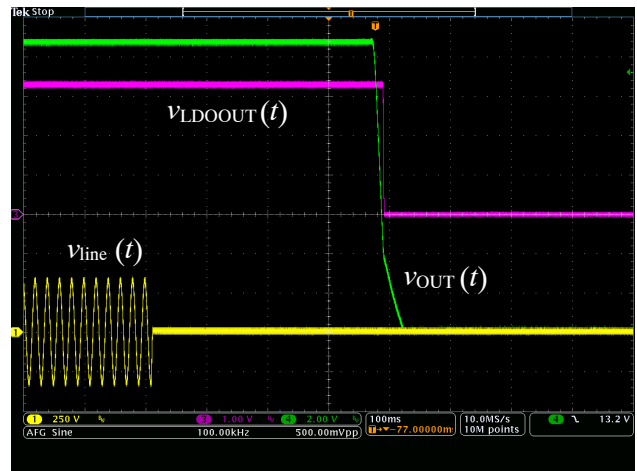


Figure 16. Power-down at  $V_{IN} = 230\text{ V}$ ,  $I_{OUT} = 15\text{ mA}$ ,  $I_{LDOOUT} = 60\text{ mA}$ ; Outputs are in Regulation for 350 ms

## Output Voltage Ripple

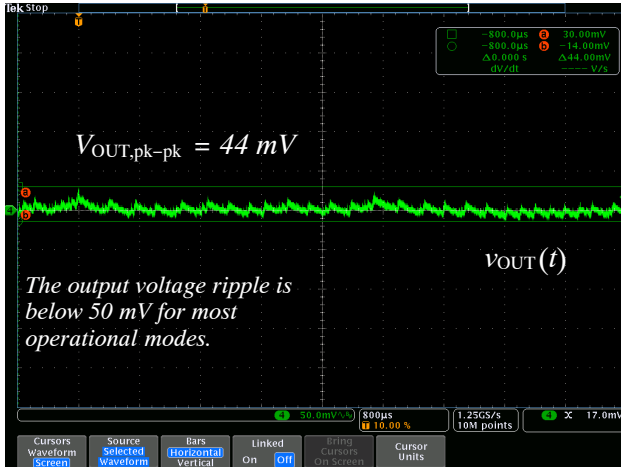


Figure 17.  $V_{OUT}$  Ripple for  $V_{IN} = 115\text{ V}$ ,  $I_{OUT} = 5\text{ mA}$ ,  $I_{LDOOUT} = 30\text{ mA}$

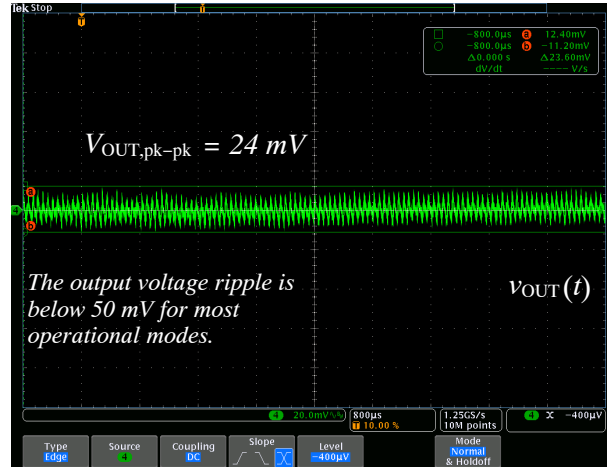


Figure 18.  $V_{OUT}$  Ripple for  $V_{IN} = 230\text{ V}$ ,  $I_{OUT} = 15\text{ mA}$ ,  $I_{LDOOUT} = 60\text{ mA}$

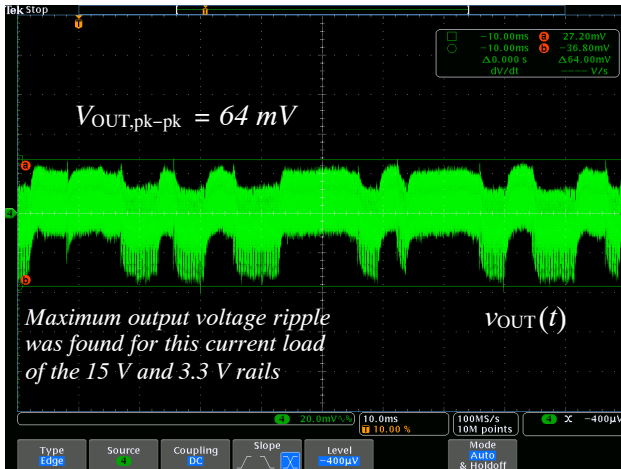


Figure 19.  $V_{OUT}$  Ripple for  $V_{IN} = 115\text{ V}$ ,  $I_{OUT} = 88\text{ mA}$ ,  $I_{LDOOUT} = 52\text{ mA}$

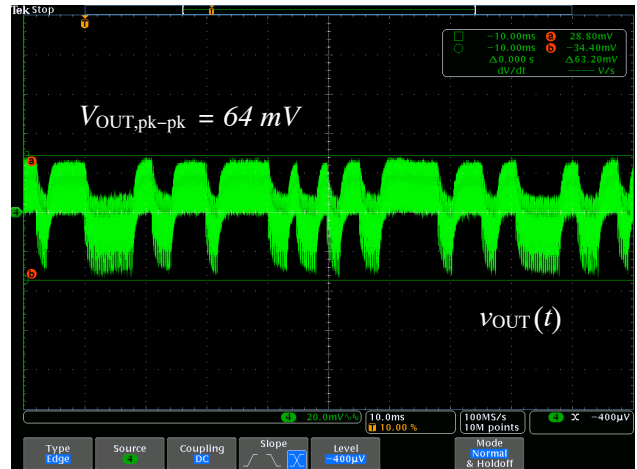


Figure 20.  $V_{OUT}$  Ripple for  $V_{IN} = 230\text{ V}$ ,  $I_{OUT} = 53\text{ mA}$ ,  $I_{LDOOUT} = 77\text{ mA}$

## Load Transient Response

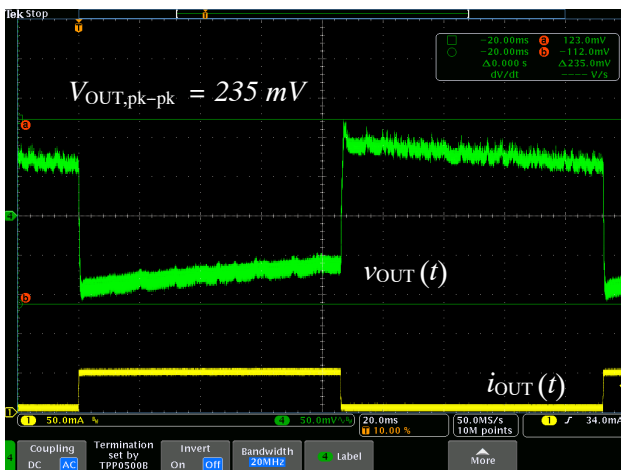


Figure 21. Response at  $I_{OUT} = 5\text{ mA}$  to  $50\text{ mA}$ ,  $I_{LDOOUT} = 30\text{ mA}$ ,  $V_{IN} = 115\text{ V}$ , Slew Rate  $0.5\text{ A}/\mu\text{s}$

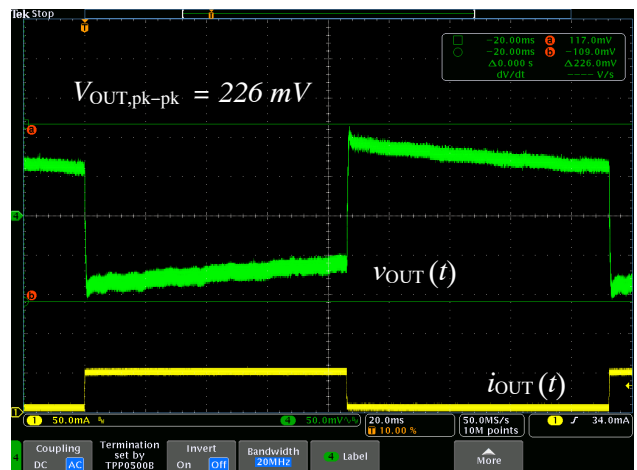


Figure 22. Response at  $I_{OUT} = 5\text{ mA}$  to  $50\text{ mA}$ ,  $I_{LDOOUT} = 30\text{ mA}$ ,  $V_{IN} = 230\text{ V}$ , Slew Rate  $0.5\text{ A}/\mu\text{s}$

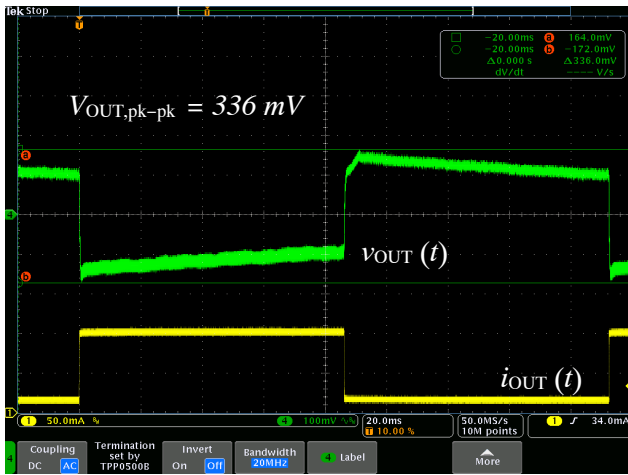


Figure 23. Response at  $I_{OUT} = 15\text{ mA}$  to  $100\text{ mA}$ ,  $I_{LDOOUT} = 30\text{ mA}$ ,  $V_{IN} = 115\text{ V}$ , Slew Rate  $0.5\text{ A}/\mu\text{s}$

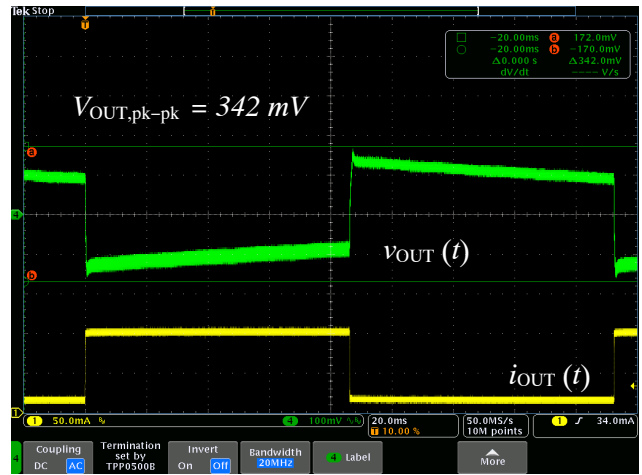


Figure 24. Response at  $I_{OUT} = 15\text{ mA}$  to  $100\text{ mA}$ ,  $I_{LDOOUT} = 30\text{ mA}$ ,  $V_{IN} = 230\text{ V}$ , Slew Rate  $0.5\text{ A}/\mu\text{s}$

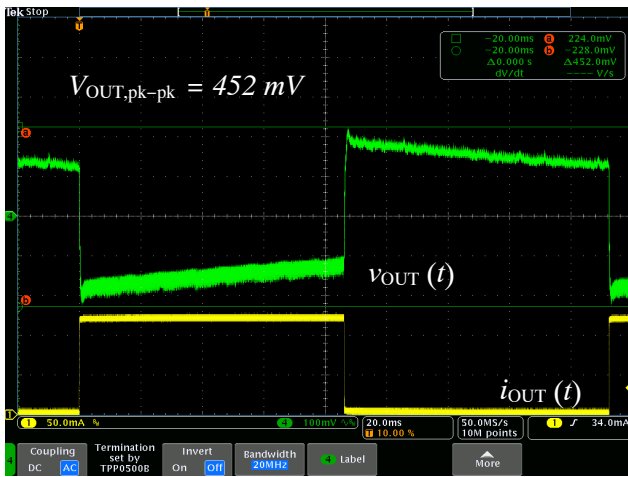


Figure 25. Response at  $I_{OUT} = 2\text{ mA}$  to  $120\text{ mA}$ ,  $I_{LDOOUT} = 30\text{ mA}$ ,  $V_{IN} = 115\text{ V}$ , Slew Rate  $0.5\text{ A}/\mu\text{s}$

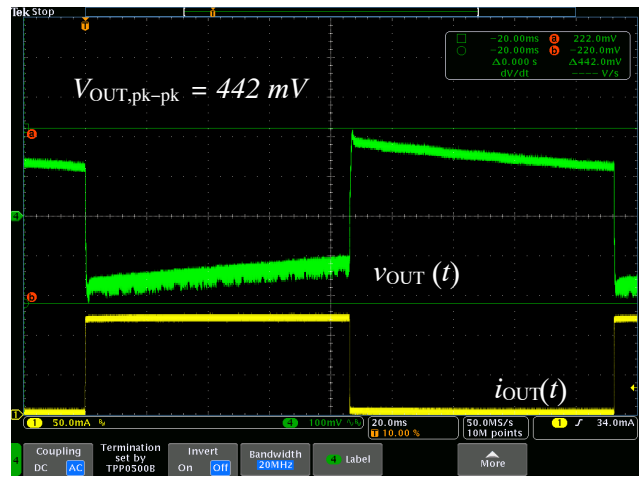


Figure 26. Response at  $I_{OUT} = 2\text{ mA}$  to  $120\text{ mA}$ ,  $I_{LDOOUT} = 30\text{ mA}$ ,  $V_{IN} = 230\text{ V}$ , Slew Rate  $0.5\text{ A}/\mu\text{s}$

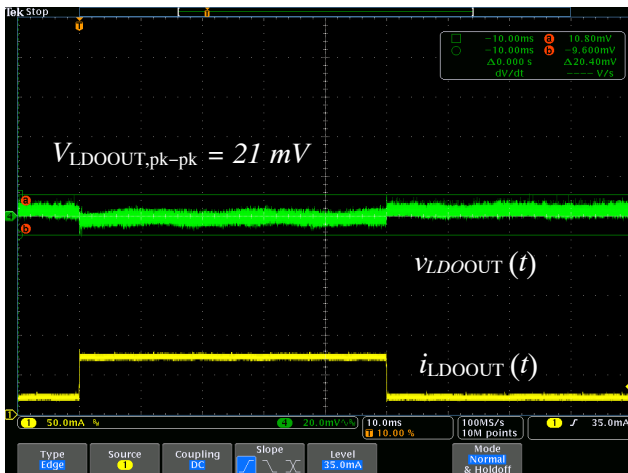


Figure 27. Response at  $I_{LDOOUT} = 20\text{ mA}$  to  $75\text{ mA}$ ,  $I_{OUT} = 5\text{ mA}$ ,  $V_{IN} = 230\text{ V}$ , Slew Rate  $0.5\text{ A}/\mu\text{s}$

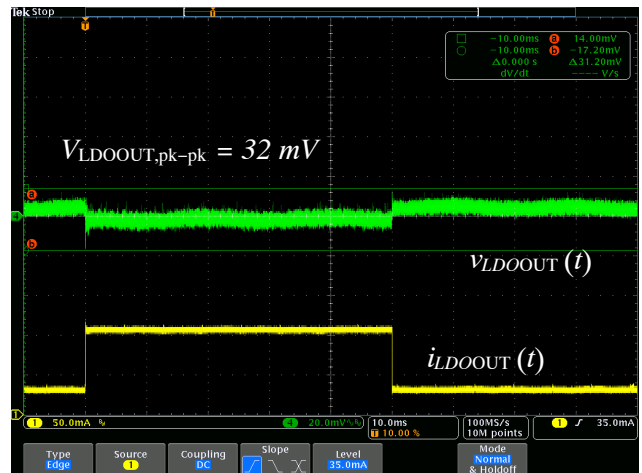


Figure 28. Response at  $I_{LDOOUT} = 30\text{ mA}$  to  $108\text{ mA}$ ,  $I_{OUT} = 5\text{ mA}$ ,  $V_{IN} = 230\text{ V}$ , Slew Rate  $0.5\text{ A}/\mu\text{s}$

Protections

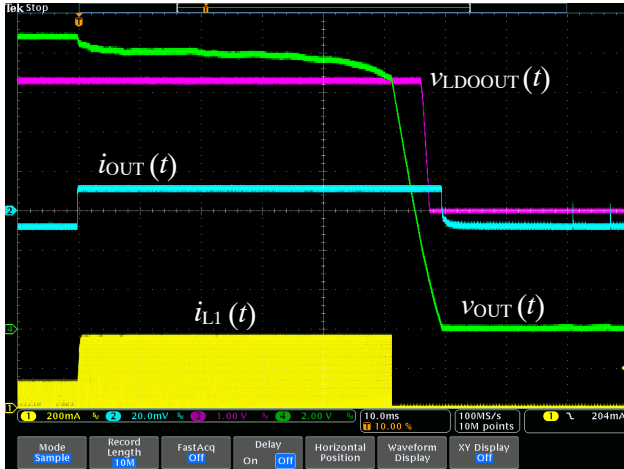


Figure 29. Timer-based Over-current Protection,  $I_{OUT} = 5\text{mA}$  to  $150\text{mA}$ ,  $I_{LDOOUT} = 30\text{mA}$ ,  $V_{IN} = 230\text{V}$

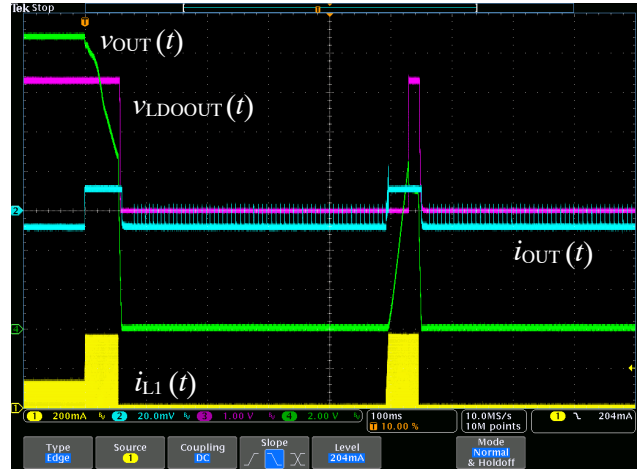


Figure 30. Auto-recovery Over-current Protection,  $I_{OUT} = 150\text{mA}$ ,  $I_{LDOOUT} = 30\text{mA}$ ,  $V_{IN} = 230\text{V}$

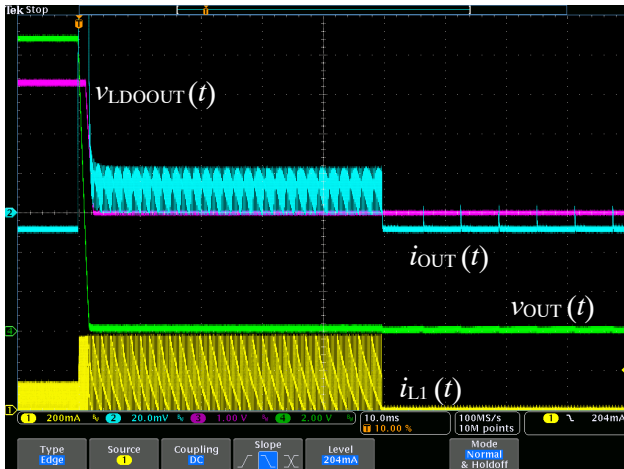


Figure 31. Timer-based Over-current Protection – Short Circuit,  $I_{OUT} = \text{Short}$ ,  $I_{LDOOUT} = 30\text{mA}$ ,  $V_{IN} = 230\text{V}$

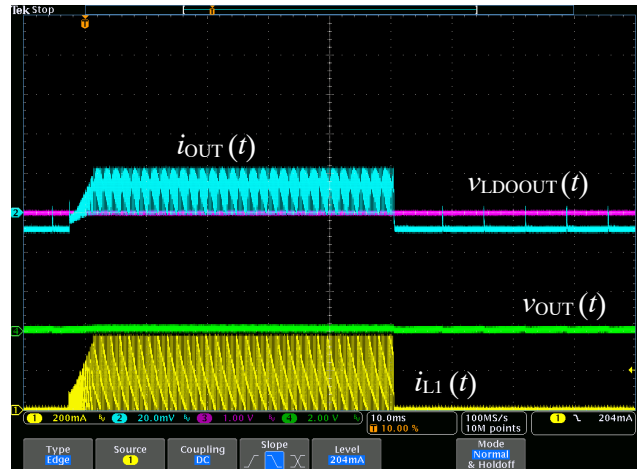


Figure 32. Short Circuit During Startup,  $I_{OUT} = \text{Short}$ ,  $I_{LDOOUT} = 30\text{mA}$ ,  $V_{IN} = 230\text{V}$

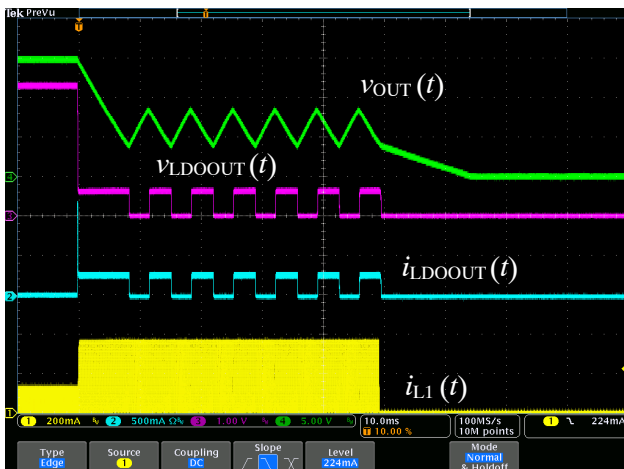


Figure 33. LDO Over-current Protection – Short Circuit on LDO Rail,  $I_{OUT} = 30\text{mA}$ ,  $I_{LDOOUT} = \text{Short}$ ,  $V_{IN} = 230\text{V}$

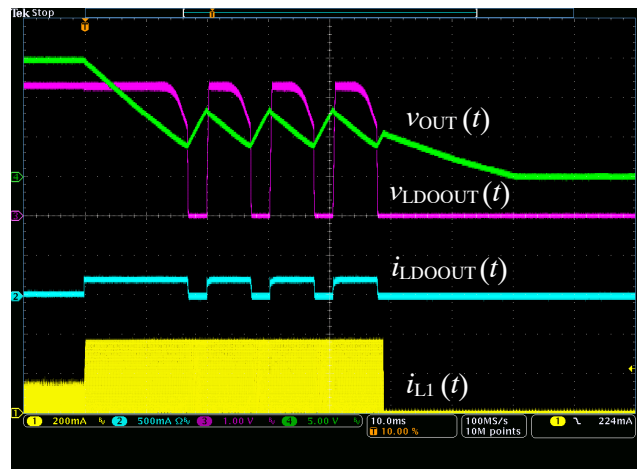
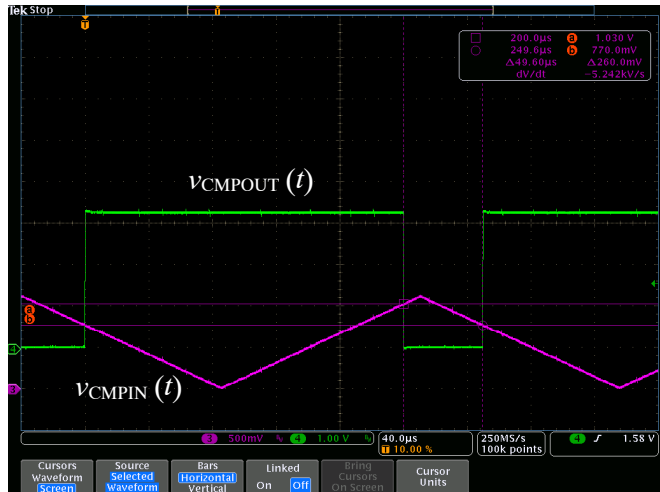


Figure 34. LDO Over-current Protection – Over-loaded LDO Rail,  $I_{OUT} = 30\text{mA}$ ,  $I_{LDOOUT} = 30$  to  $200\text{mA}$ ,  $V_{IN} = 230\text{V}$

## Comparator Behavior



**Figure 35. Comparator Behavior in Standby Mode, STBY Pin is Grounded**

# NCP10970AGEVB

**Table 4. BILL OF MATERIALS**

| QTY | Parts                 | Value                  | Tolerance | Package    | Description                                | Manufacturer     | Manufacturer part       | Substitution Allowed |
|-----|-----------------------|------------------------|-----------|------------|--------------------------------------------|------------------|-------------------------|----------------------|
| 1   | B1                    | MDB10S                 | –         | TSSOP–4    | Bridge Rectifier 1A, 1kV                   | ON Semiconductor | MDB10S                  | Yes                  |
| 1   | C1                    | 220 nF                 | 20%       | 0805       | Capacitor MLCC, SMD                        | Various          | Various                 | Yes                  |
| 1   | C2                    | 1 $\mu$ F / 25 V       | 20%       | 0805       | Capacitor MLCC, SMD                        | Various          | Various                 | Yes                  |
| 1   | C3                    | 2.2 nF                 | 20%       | 0805       | Capacitor MLCC, SMD                        | Various          | Various                 | Yes                  |
| 1   | C4                    | 33 nF                  | 20%       | 0805       | Capacitor MLCC, SMD                        | Various          | Various                 | Yes                  |
| 1   | C5                    | 100 $\mu$ F / 25 V     | 20%       | TH         | Electrolytic Capacitor                     | Wurth Elektronik | 860080473006            | Yes                  |
| 2   | C6, C7                | 10 $\mu$ F / 25 V, X7R | 20%       | 1206       | Capacitor MLCC, SMD                        | Various          | Various                 | Yes                  |
| 1   | C8                    | 22 $\mu$ F / 16 V, X7R | 20%       | 1206       | Capacitor MLCC, SMD                        | Murata           | GRM31CZ71C226ME15L      | Yes                  |
| 0   | C9                    | NU                     | 20%       | 0805       | Capacitor MLCC, SMD                        | Various          | Various                 | Yes                  |
| 2   | CB1, CB2              | 10 $\mu$ F / 400 V     | 20%       | TH         | Electrolytic Capacitor                     | Wurth Elektronik | 860021375011            | Yes                  |
| 2   | CX1, CX2              | 220 nF / 275 Vac       | –         | TH         | X Capacitor                                | Wurth Elektronik | 890324023028            | Yes                  |
| 1   | D1                    | BAV70L                 | –         | SOT–23–3   | Switching Diode                            | ON Semiconductor | BAV70LT1G               | Yes                  |
| 2   | D2, D3                | US1MFA                 | –         | SOD–123 FL | Superfast Rectifier                        | ON Semiconductor | US1MFA                  | Yes                  |
| 0   | D4                    | NU                     | –         | SOD–123    | Zener Diode                                | ON Semiconductor | –                       | Yes                  |
| 1   | F1                    | T1A                    | –         | TH         | Fuse                                       | Bel Fuse         | RST1                    | Yes                  |
| 1   | IC1                   | NCP10970A1             | –         | SOIC–16    | Dual Output Controller                     | ON Semiconductor | NCP10970A1DR2G          | No                   |
| 1   | L1                    | 1 mH                   | –         | TH<br>SMD  | Inductor 1 mH, 0.5A<br>Inductor 1 mH, 0.4A | Wurth Elektronik | 768772102<br>7687714102 | Yes                  |
| 1   | L2                    | 2 x 10 mH              | –         | TH         | Common Mode Choke                          | Wurth Elektronik | 744821110               | Yes                  |
| 2   | LED_SW,<br>LED_LDO    | Red 3 mm               | –         | TH         | Red LED 3mm                                | Various          | Various                 | Yes                  |
| 3   | R1, R2, R8            | 150 k $\Omega$         | 1%        | 1206       | Resistor, SMD                              | Various          | Various                 |                      |
| 1   | R3                    | 200 k $\Omega$         | 1%        | 0805       | Resistor, SMD                              | Various          | Various                 | Yes                  |
| 1   | R4                    | 56 k $\Omega$          | 1%        | 0805       | Resistor, SMD                              | Various          | Various                 | Yes                  |
| 1   | R5                    | 3.3 k $\Omega$         | 1%        | 0603       | Resistor, SMD                              | Various          | Various                 | Yes                  |
| 1   | R6                    | 6.8 k $\Omega$         | 1%        | 0603       | Resistor, SMD                              | Various          | Various                 | Yes                  |
| 1   | R7                    | 820 $\Omega$           | 1%        | 0603       | Resistor, SMD                              | Various          | Various                 | Yes                  |
| 0   | R9                    | NU                     | 1%        | 0805       | Resistor, SMD                              | Various          | Various                 | Yes                  |
| 4   | RB1, RB2, RB3,<br>RB4 | 3 M $\Omega$           | 1%        | 1206       | Resistor, SMD                              | Various          | Various                 | Yes                  |
| 0   | RV1                   | NU                     | –         | TH         | Varistor                                   | Wurth Elektronik | 820474611               | Yes                  |

NOTES: All parts are Lead-free  
TH = Through Hole

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