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# 30 W Automotive 410 kHz Pre-Regulator, Non-Isolated, Synchronous Buck, NCV881930-Based Reference Design

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## REFERENCE DESIGN

### Overview

This reference design describes the operation and performance of a 30 W non-isolated synchronous buck automotive pre-regulator, based on the NCV881930 synchronous buck controller with a NVMFD5C478NL 40 V dual N-channel MOSFET. The reference design shows a complete design for an automotive pre-regulator for a broad range of applications, and highlights the capabilities of the NCV881930 controller.

It is intended for the power supply designer to adopt the circuit directly into a typical system design, making only minimal component changes based on system requirements.

The design is meant to be a complete solution, but it also provides access to key features of the NCV881930. These include integrated compensation, low $I_Q$ and continuous synchronous mode, wide input range, overcurrent protection, external synchronization, adaptive non-overlap drivers, integrated spread-spectrum, and undervoltage lockout.

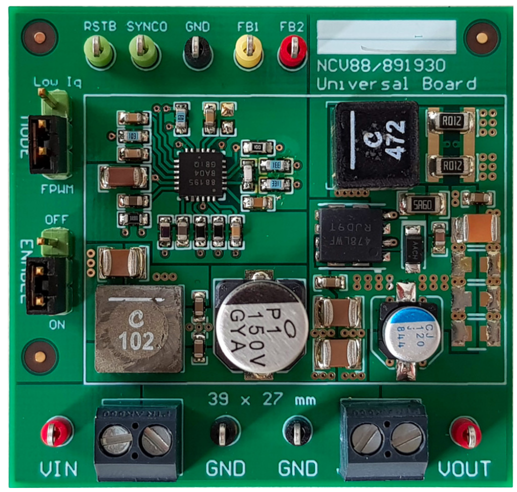


**Figure 1. Reference Design Board Image**

### Key Features

- Complete Automotive Reference Design
- Synchronous Buck Converter with an Input Voltage Range of 5.0 to 16.0 V, Handles Peaks up to 40 V
- 410 kHz Switching Frequency for Maximum Efficiency
- NCV881930 Low Quiescent Current Automotive Synchronous Buck Converter and NVMFD5C478NL 40 V Dual N-channel MOSFET
- Small Form Factor PCB with Four Layers

### Specifications

**Table 1. SPECIFICATIONS TABLE**

| | |
|---|---|
| **Device** | NCV881930 |
| **Application** | Automotive Pre-Regulator |
| **Input Voltage** | 6 V to 16 V DC, 40 V peak |
| **Output Power** | Up to 30 W |
| **Topology** | Synchronous Buck |
| **Isolation** | Non-Isolated |
| **Output Voltage** | 5.0 V |
| **Nominal Current** | 6.0 A |

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## SCHEMATICS

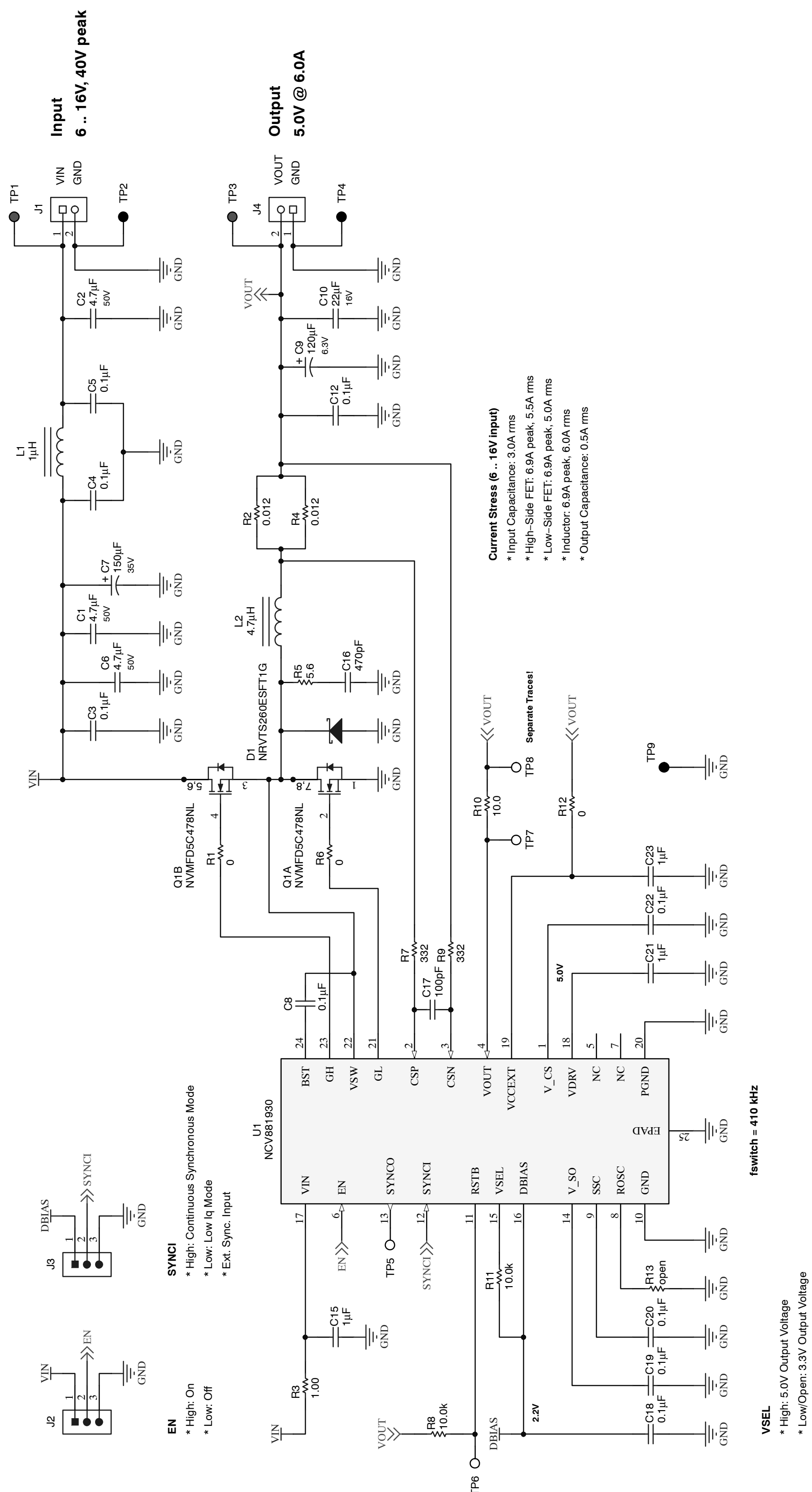


**Figure 2. NCV881930 Synchronous Buck Schematic**

## BOARD LAYOUT

Figure 3, 4, 5 and 6 shows the top and bottom assembly and the four layers of the PCB. The PCB is 47 mm × 44 mm (length × width) where the height of the PCB is approximately 11 mm.

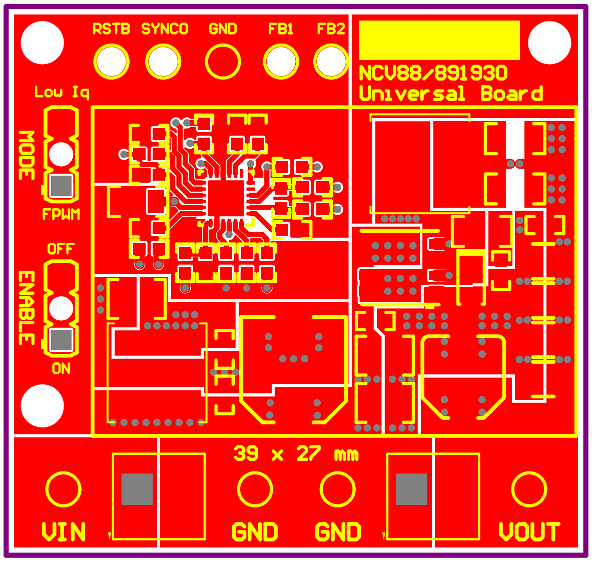


**Figure 3. Top Layer and Assembly Drawing**

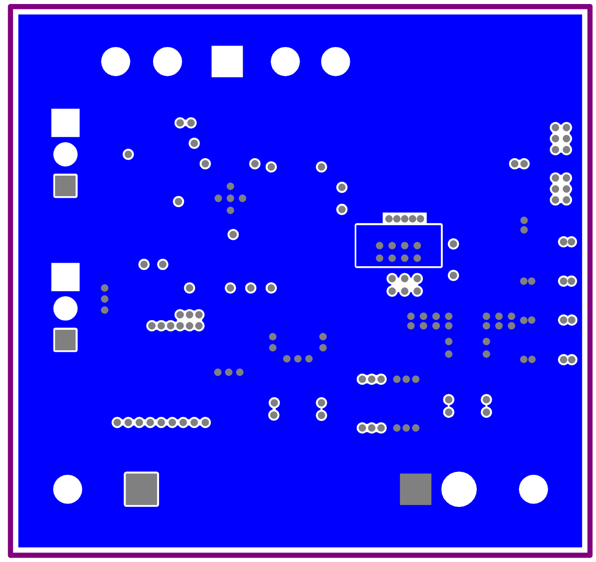

**Figure 4. Bottom Layer and Assembly Drawing**

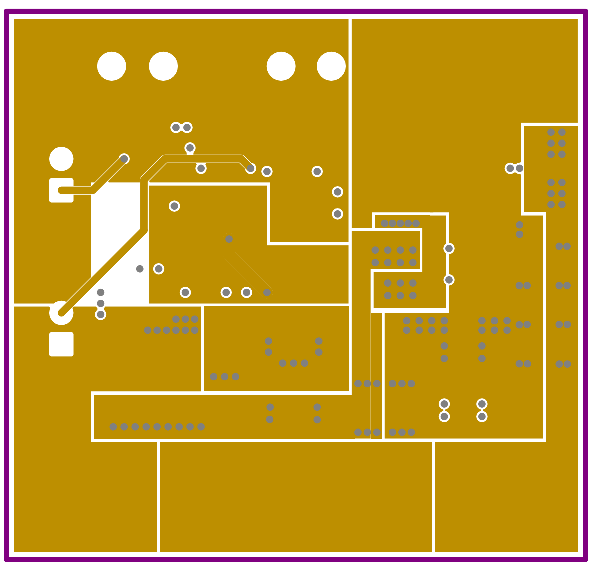

**Figure 5. Inner 1 Layer**

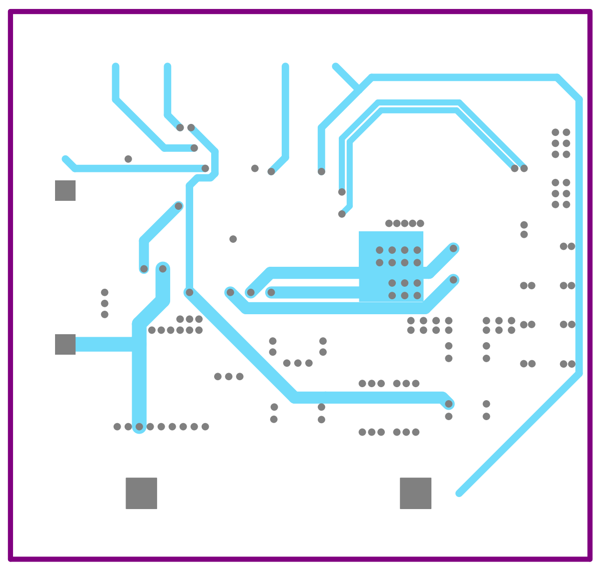

**Figure 6. Inner 2 Layer**

## PERFORMANCE SUMMARY

### Output Voltage

NCV881930 has two fixed output voltage options, 3.3 V and 5.0 V. By pulling pin VSEL to DBIAS by a 10 kΩ resistor, the output voltage is set to 5.0 V. Leaving VSEL floating or connecting to GND, the output voltage is set to 3.3 V.

Dependent on the output current, a modification of the power stage (inductor, shunt, output capacitance) might be necessary. Please consult therefore Table 6 in the datasheet.

### Efficiency

The efficiency for continuous synchronous mode is shown in Figure 7. This measurement doesn't take into account losses of the input filter (inductor L1).

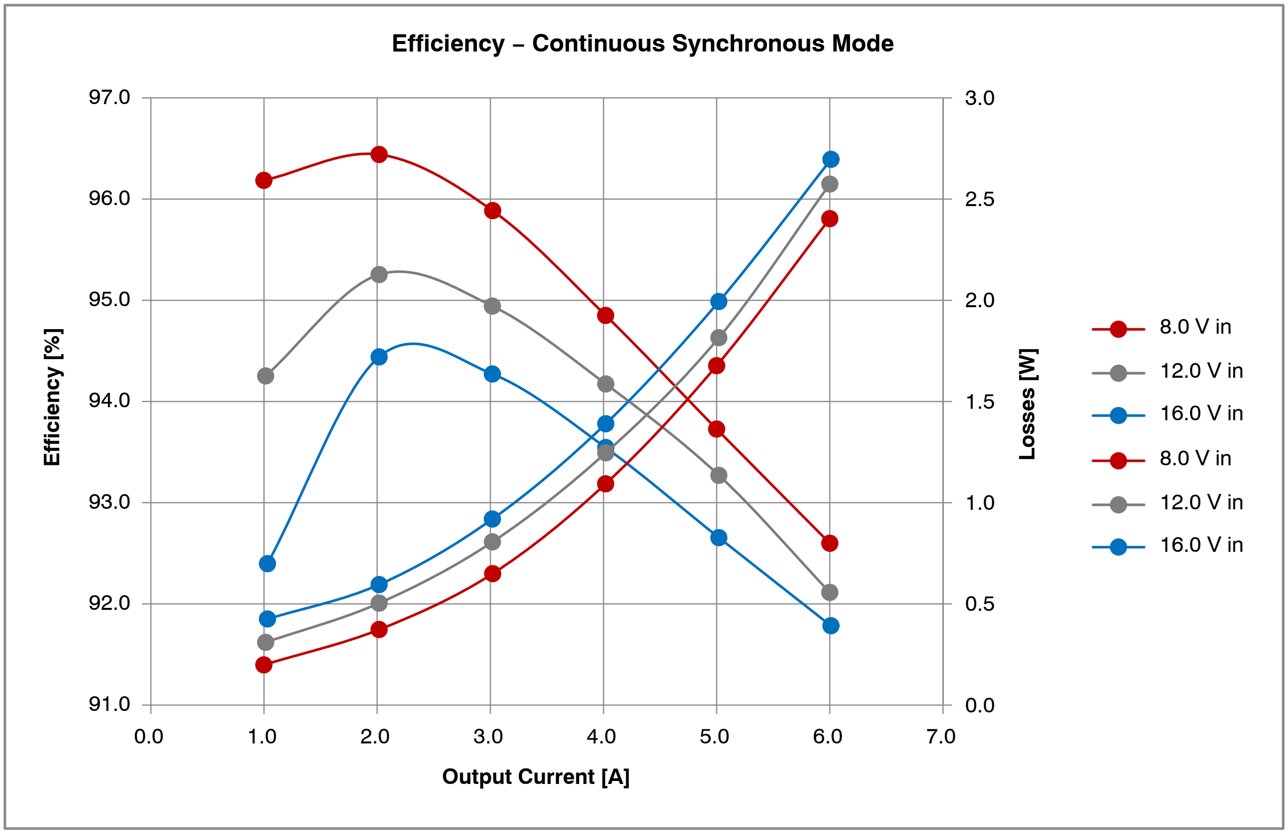


**Figure 7. Efficiency for 8.0, 12.0 and 16.0 V Input Voltage**

### Thermal Image

The thermal images show the circuit at an ambient temperature of 21°C with an input voltage of 12.0 V, 3.0 A (Figure 8) and 6.0 A (Figure 9) load.

3.0 A Load

- FET Q1: 51°C
- Inductor L2: 49°C

6.0 A Load

- FET Q1: 110°C
- Inductor L2: 101°C

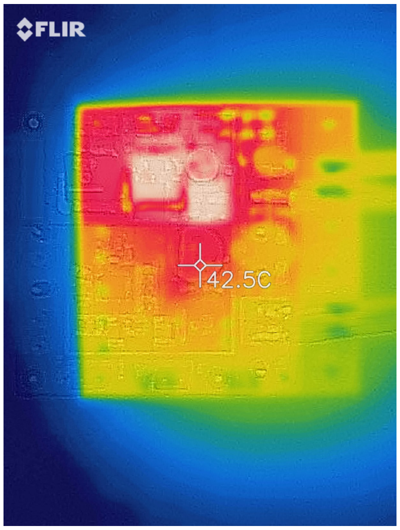


**Figure 8. Thermal Image at 3.0 A Load**

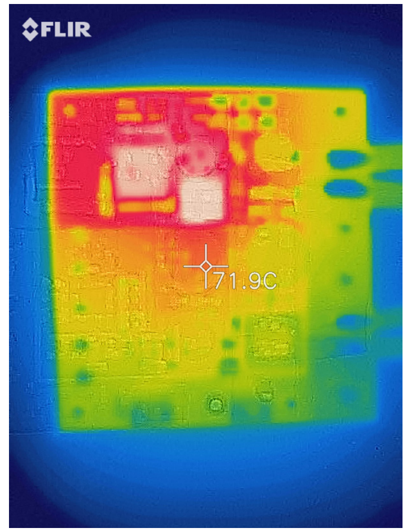


**Figure 9. Thermal Image at 6.0 A Load**

### Transient Response

The response to a load step from 3.0 A to 60 A and vice versa at 12.0 V input voltage is shown in Figure 10.

Channel 1

- Output current, load step 3.0 to 6.0 A
- 2 A/div, 1 ms/div

Channel 2

- Output voltage, −143 mV (−2.9%) undershoot, +140 mV (2.8%) overshoot
- 100 mV/div, 1 ms/div, AC coupled

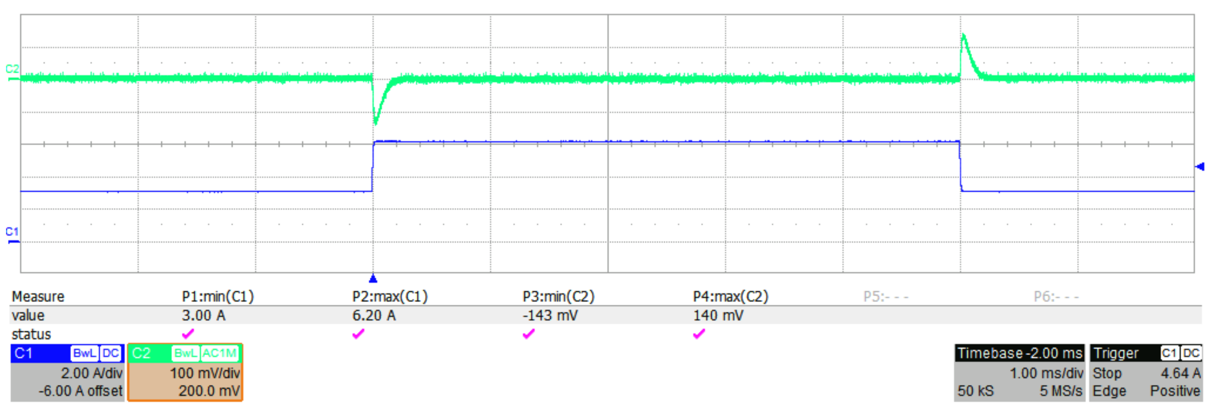


**Figure 10. Transient Response on 3.0 A Load Step**

### Frequency Response

The frequency response at 12.0 V input voltage and 6.0 A load is shown in Figure 11.

Trace 1

- 19.7 kHz bandwidth
- −19 dB gain margin

Trace 2

- 81° phase margin

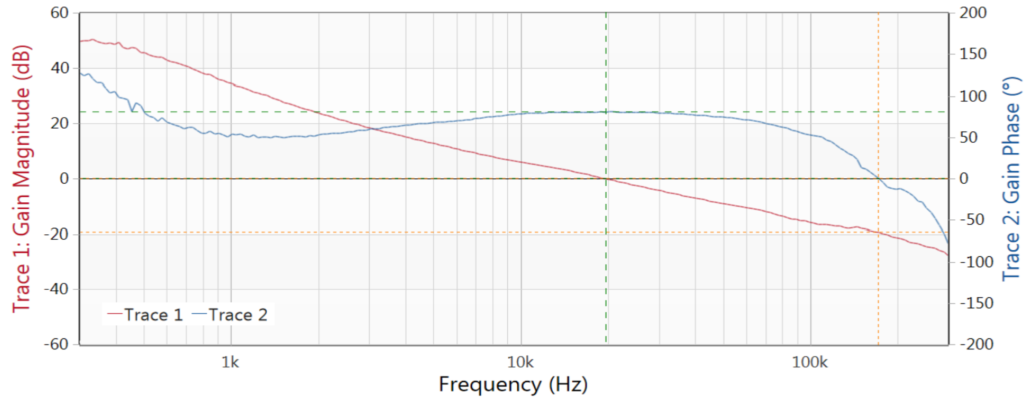


**Figure 11. Frequency Response at 6.0 A Load**

### Impact of Output Capacitance Configuration on Performance

The datasheet of NCV881930 gives detailed recommendations for the output filter configuration (inductance, shunt resistance, output capacitance) dependent on the output voltage and current. A detailed test series with different output capacitance configurations showed, that different configurations are possible without decreasing performance or causing stability issues.

Table 2 shows the measurement results for various output capacitor configurations and their corresponding performance regarding ripple, transient response and phase/gain margin.

Different sets of high capacitance ceramic and polymer capacitors were used for the measurements.

- 1x 100 nF, 50 V, 0603, X7R, always populated
  muRata GCJ188R71H104KA12D
- 22 μF ceramic, 16 V, 1210, X7R
  muRata GCM32ER71C226ME19L
  18 μF @ 5.0 V DC, 2 mΩ ESR @ 410 kHz
- 100 μF polymer
  Nichicon PCJ0J101MCL1GS
  24 mΩ ESR @ 100 kHz
- 120 μF polymer
  Nichicon PCJ0J121MCL1GS
  24 mΩ ESR @ 100 kHz
- 220 μF polymer
  Nichicon PCJ0J221MCL1GS
  15 mΩ ESR @ 100 kHz

### Outcome

- Even with only a polymer capacitor the output voltage ripple is well below 1% of the output voltage (max. is 31 mV which equals 0.6%).
  If one or more high capacitance ceramic capacitors are added, the ripple voltage decreases significantly. Roughly by a factor of two for each additional 22 μF ceramic capacitor.
  If only ceramic capacitors are used, the voltage ripple is in the single digit range.
- The phase and gain margin shows very good values over a broad range of output capacitance and is independent of the type of capacitor (ceramic, polymer or a mix). Basically any value between 54 μF (3x 22 μF ceramic taking DC-biasing into account) and 274 μF (1x 220 μF polymer + 3x 22 μF ceramic) can be used.
  Even higher output capacitance should be no problem, lower capacitance will degrade phase and gain margin too much.
- The transient response is almost identical for all measurements and independent of the output capacitance. The voltage drop / overshoot is between 143 mV (2.9%) and 173 mV (3.5%).
  With low output capacitance the bandwidth increases and with higher output capacitance it decreases. Therefore a lower bandwidth is compensated by larger capacitance and vice versa.
  As the device is internally compensated, the reason for that behavior is the shift of the load pole:

$$f_{Pole_{Load}} = \frac{1}{2 \cdot \pi \cdot C_{out} \cdot R_{load}} = \frac{1}{2 \cdot \pi \cdot C_{out} \cdot \frac{V_{out}}{I_{out}}} \quad \text{(eq. 1)}$$

## Output Ripple, Transient Response & Frequency Response Measurements

**Table 2. MEASUREMENT RESULTS FOR VARIOUS OUTPUT CAPACITOR CONFIGURATIONS**

| | | | | | |
|---|---|---|---|---|---|
| **Polymer: 220 μF, 6.3 V** | 1 | 1 | 1 | 1 | # of caps |
| **Ceramic: 22 μF, 16 V** | 0 | 1 | 2 | 3 | # of caps |
| Output Ripple, peak-peak | 31 | 20 | 9 | 4 | [mV] |
| Output Ripple, peak-peak | 0.6 | 0.4 | 0.2 | 0.1 | [%] |
| Transient Response, peak-peak | 315 | 305 | 285 | 285 | [mV] |
| Transient Response, peak | 158 | 153 | 143 | 143 | [mV] |
| | 3.2 | 3.1 | 2.9 | 2.9 | [%] |
| Bandwidth | 10.6 | 9.8 | 9.0 | 9.2 | [kHz] |
| Phase Margin | 84 | 82 | 79 | 79 | [deg] |
| Gain margin | –24 | –21 | –21 | –21 | [dB] |

| | | | | | |
|---|---|---|---|---|---|
| **Polymer: 120 μF, 6.3 V** | 1 | 1 | 1 | 1 | # of caps |
| **Ceramic: 22 μF, 16 V** | 0 | 1 | 2 | 3 | # of caps |
| Output Ripple, peak-peak | 29 | 15 | 8 | 4 | [mV] |
| Output Ripple, peak-peak | 0.6 | 0.3 | 0.2 | 0.1 | [%] |
| Transient Response, peak-peak | 340 | 315 | 321 | 308 | [mV] |
| Transient Response, peak | 170 | 158 | 161 | 154 | [mV] |
| | 3.4 | 3.2 | 3.2 | 3.1 | [%] |
| Bandwidth | 23.9 | 19.7 | 16.4 | 15.0 | [kHz] |
| Phase Margin | 82 | 81 | 80 | 79 | [deg] |
| Gain margin | –23 | –19 | –20 | –21 | [dB] |

| | | | | | |
|---|---|---|---|---|---|
| **Polymer: 100 μF, 6.3 V** | 1 | 1 | 1 | 1 | # of caps |
| **Ceramic: 22 μF, 16 V** | 0 | 1 | 2 | 3 | # of caps |
| Output Ripple, peak-peak | 31 | 16 | 9 | 4 | [mV] |
| Output Ripple, peak-peak | 0.6 | 0.3 | 0.2 | 0.1 | [%] |
| Transient Response, peak-peak | 345 | 335 | 312 | 315 | [mV] |
| Transient Response, peak | 173 | 168 | 156 | 158 | [mV] |
| | 3.5 | 3.4 | 3.1 | 3.2 | [%] |
| Bandwidth | 22.7 | 18.8 | 17.3 | 15.8 | [kHz] |
| Phase Margin | 81 | 80 | 79 | 78 | [deg] |
| Gain margin | –23 | –20 | –20 | –20 | [dB] |

| | | | | | |
|---|---|---|---|---|---|
| **Ceramic: 22 μF, 16 V** | 3 | 4 | 5 | 6 | # of caps |
| Output Ripple, peak-peak | 9 | 6 | 4 | 3 | [mV] |
| Output Ripple, peak-peak | 0.2 | 0.1 | 0.1 | 0.1 | [%] |
| Transient Response, peak-peak | 335 | 330 | 330 | 330 | [mV] |
| Transient Response, peak | 168 | 165 | 165 | 165 | [mV] |
| | 3.4 | 3.3 | 3.3 | 3.3 | [%] |
| Bandwidth | 41.0 | 32.4 | 25.9 | 22.7 | [kHz] |
| Phase Margin | 60 | 66 | 69 | 71 | [deg] |
| Gain margin | –12 | –16 | –18 | –19 | [dB] |

## BILL OF MATERIALS (BOM)

**Table 3. BILL OF MATERIALS**

| Designator | Qty. | Value | Part Number | Manufacturer | Description | Package |
|---|---|---|---|---|---|---|
| C1, C2, C6 | 3 | 4.7 μF | GCM32ER71H475KA55 | MuRata | CAP, CERM, 4.7 μF, 50 V, ±10%, X7R, 1210 | 1210 |
| C3, C4, C5, C8, C12, C18, C19, C20, C22 | 9 | 0.1 μF | GCM155R71H104KE02D | MuRata | CAP, CERM, 0.1 μF, 50 V, ±10%, X7R, AEC−Q200 Grade 1, 0402 | 0402 |
| C7 | 1 | 150 μF | GYA1V151MCQ1GS | Nichicon | CAP, Hybrid Polymer, 150 μF, 35 V, ±20%, 0.027 Ω, SMD | D8xL10 mm |
| C9 | 1 | 120 μF | PCJ0J121MCL1GS | Nichicon | CAP, Aluminum Polymer, 120 μF, 6.3 V, ±20%, 0.024 Ω, SMD | D5.0xL6.0 mm |
| C10 | 1 | 22 μF | GCM32ER71C226KE19L | MuRata | CAP, CERM, 22 μF, 16 V, ±10%, X7R, 1210 | 1210 |
| C15 | 1 | 1 μF | GCM21BR71H105KA03 | MuRata | CAP, CERM, 1 μF, 50 V, ±10%, X7R, 0805 | 0805 |
| C16 | 1 | 470 pF | GCM155R71H471KA37D | MuRata | CAP, CERM, 470 pF, 50 V, ±10%, X7R, AEC−Q200 Grade 1, 0402 | 0402 |
| C17 | 1 | 100 pF | GCM1555C1H101JA16 | MuRata | CAP, CERM, 100 pF, 50 V, ±5%, C0G/NP0, 0402 | 0402 |
| C21, C23 | 2 | 1 μF | GCM188R71E105KA64D | MuRata | CAP, CERM, 1 μF, 25 V, ±10%, X7R, AEC−Q200 Grade 1, 0603 | 0603 |
| D1 | 1 | 60 V | NRVTS260ESFT1G | ON Semiconductor | Diode, Schottky, 60 V, 2 A, AEC−Q101, SOD−123FL | SOD−123FL |
| FID1, FID2, FID3 | 3 | | N/A | N/A | Fiducial mark. There is nothing to buy or mount. | N/A |
| J1, J4 | 2 | | ED555/2DS | On−Shore Technology | Terminal Block, 3.5 mm Pitch, 2x1, TH | 7.0x8.2x6.5 mm |
| J2, J3 | 2 | | 61300311121 | Wurth Elektronik | Header, 2.54 mm, 3x1, Gold, TH | Header, 2.54 mm, 3x1, TH |
| L1 | 1 | 1 μH | XAL7030−102MEB | Coilcraft | Inductor, Shielded, Composite, 1 μH, 21.8 A, 0.00455 Ω, SMD | 7.5x7.5x3.1 mm |
| L2 | 1 | 4.7 μH | XAL7070−472MEB | Coilcraft | Inductor, Shielded, Composite, 4.7 μH, 13.6 A, 0.01 Ω, SMD | 7.2x7x7.5 mm |
| Q1 | 1 | 40 V | NVMFD5C478NLWFT1G | ON Semiconductor | MOSFET, 2-CH, N-CH, 40 V, 29 A, DFN8 5x6 | DFN8, 5x6 |
| R1, R6, R12 | 3 | 0 Ω | CRCW06030000Z0EA | Vishay−Dale | RES, 0 Ω, 5%, 0.1 W, 0603 | 0603 |
| R2, R4 | 2 | 0.012 Ω | ERJ−8CWFR012V | Panasonic | RES, 0.012 Ω, 1%, 1 W, AEC−Q200 Grade 0, 1206 | 1206 |
| R3 | 1 | 1.00 Ω | CRCW06031R00FKEA | Vishay−Dale | RES, 1.00 Ω, 1%, 0.1 W, 0603 | 0603 |
| R5 | 1 | 5.6 Ω | CRCW12065R60JNEA | Vishay−Dale | RES, 5.6 Ω, 5%, 0.25 W, 1206 | 1206 |

**Table 3. BILL OF MATERIALS** (continued)

| Designator | Qty. | Value | Part Number | Manufacturer | Description | Package |
|---|---|---|---|---|---|---|
| R7, R9 | 2 | 332 Ω | CRCW0603332RFKEA | Vishay−Dale | RES, 332 Ω, 1%, 0.1 W, 0603 | 0603 |
| R8, R11, R13 | 3 | 10.0 kΩ | CRCW060310K0FKEA | Vishay−Dale | RES, 10.0 kΩ, 1%, 0.1 W, 0603 | 0603 |
| R10 | 1 | 10.0 Ω | CRCW060310R0FKEA | Vishay−Dale | RES, 10.0 Ω, 1%, 0.1 W, 0603 | 0603 |
| TP1, TP3 | 2 | | 5000 | Keystone | Test Point, Miniature, Red, TH | Red Miniature Testpoint |
| TP2, TP4, TP9 | 3 | | 5001 | Keystone | Test Point, Miniature, Black, TH | Black Miniature Testpoint |
| TP5, TP6, TP7, TP8 | 4 | | 5002 | Keystone | Test Point, Miniature, White, TH | White Miniature Testpoint |
| U1 | 1 | | NCV881930MW00R2G | ON Semiconductor | Low Quiescent Current 410 kHz Automotive Synchronous Buck Controller | |

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