TND6286/D

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

ON Semiconductor®

www.onsemi.com

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.

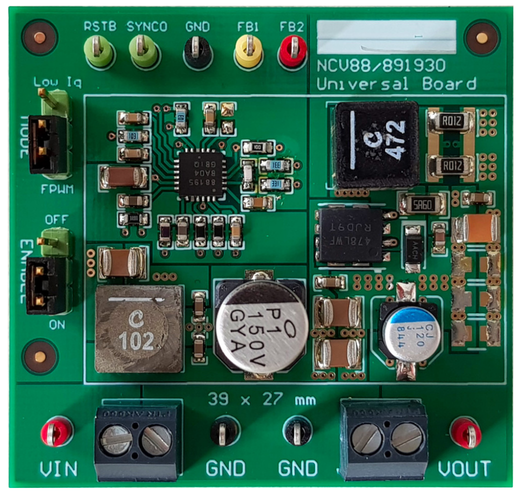

Figure 1. Reference Design Board Image

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

SCHEMATICS

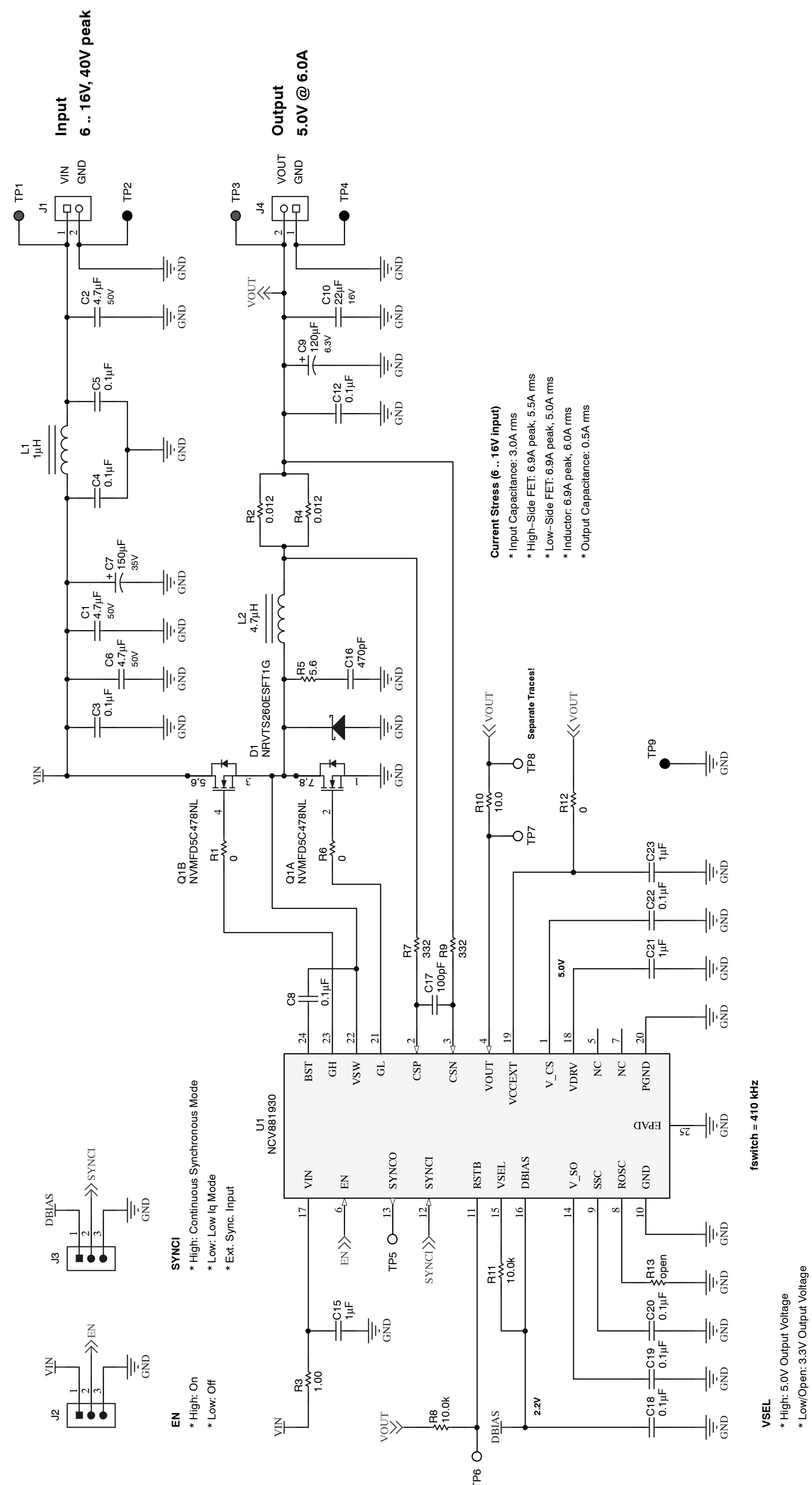

Figure 2. NCV881930 Synchronous Buck Schematic

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.

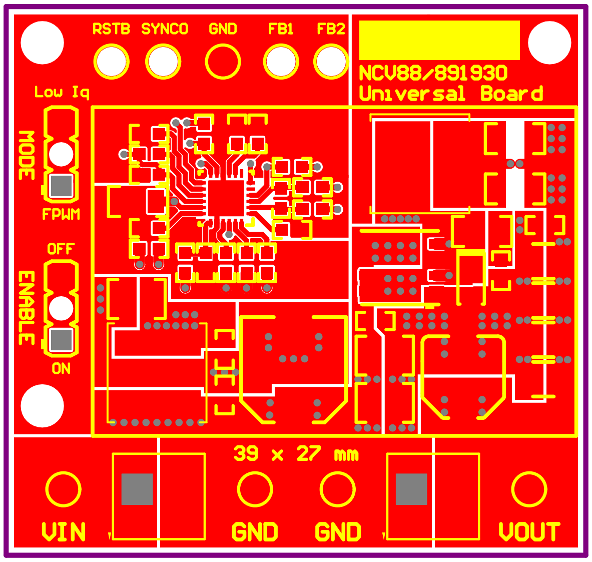

Figure 3. Top Layer and Assembly Drawing

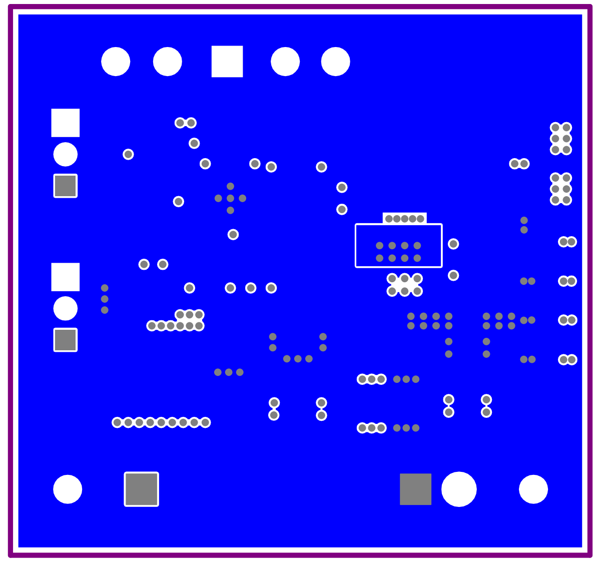

Figure 4. Bottom Layer and Assembly Drawing

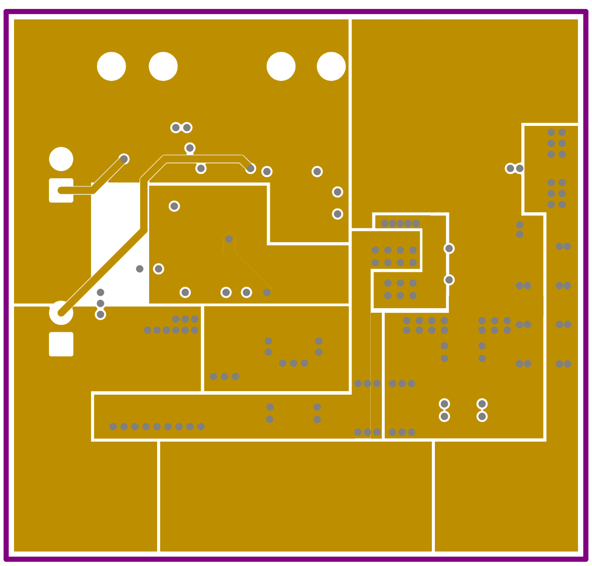

Figure 5. Inner 1 Layer

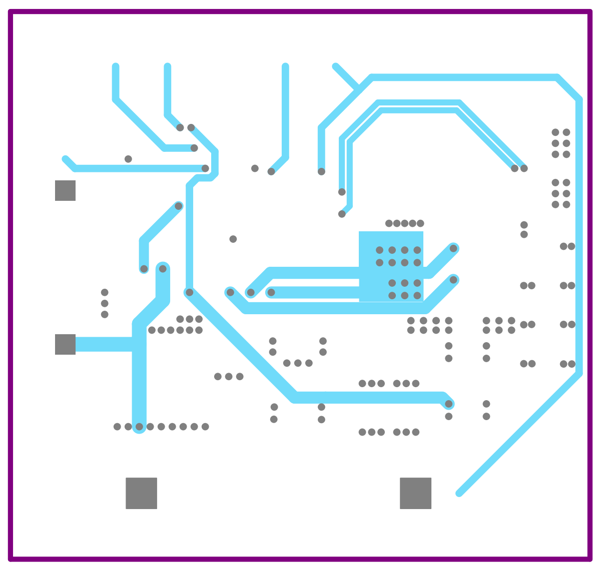

Figure 6. Inner 2 Layer

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).

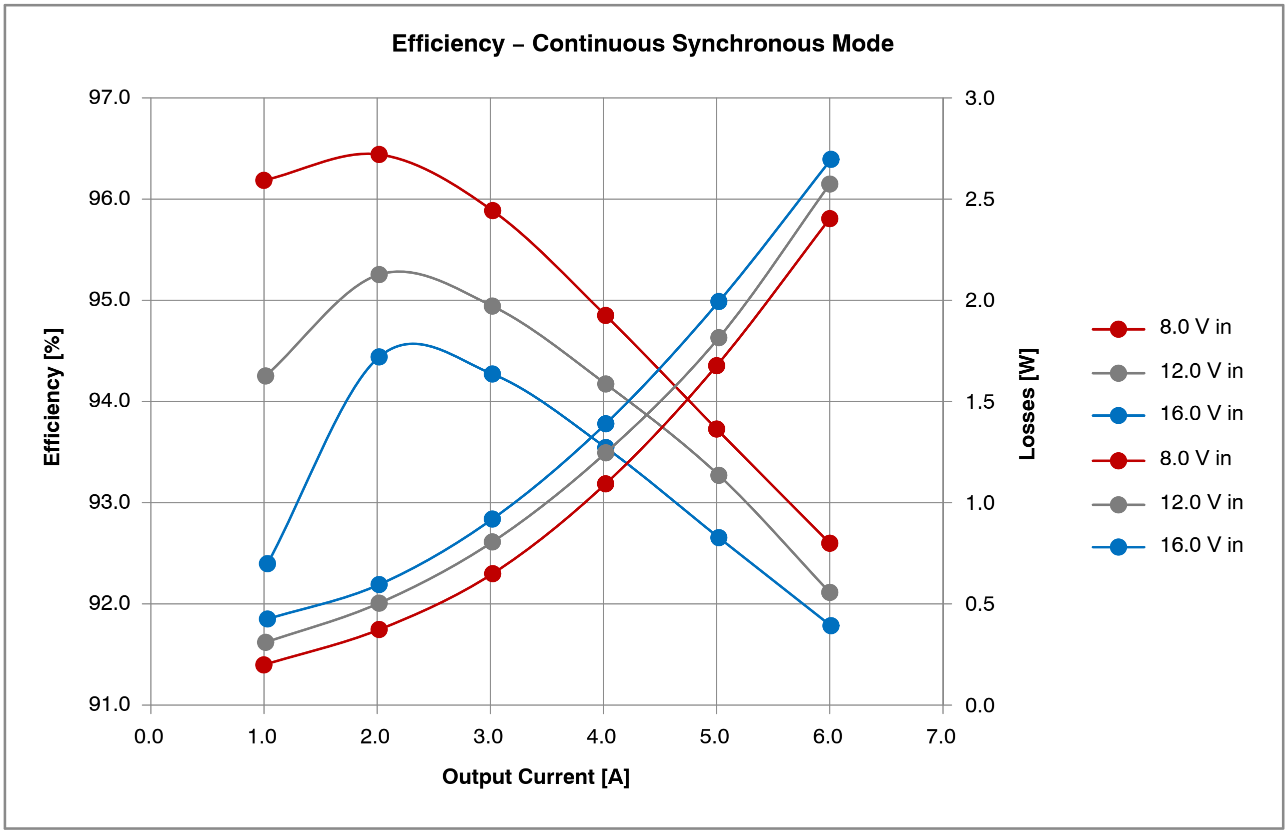

Figure 7. Efficiency for 8.0, 12.0 and 16.0 V Input Voltage

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

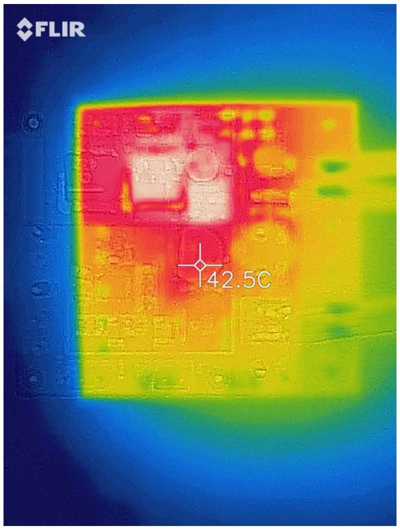

Figure 8. Thermal Image at 3.0 A Load

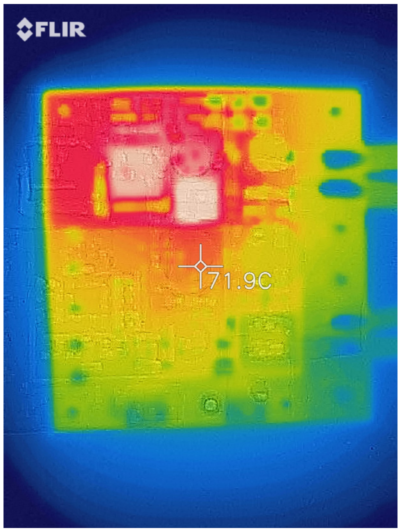

Figure 9. Thermal Image at 6.0 A Load

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

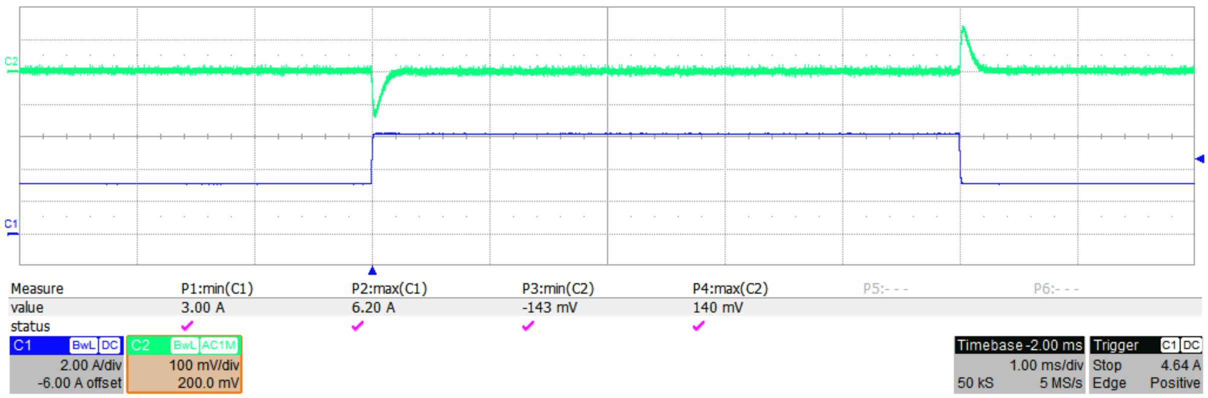

Figure 10. Transient Response on 3.0 A Load Step

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

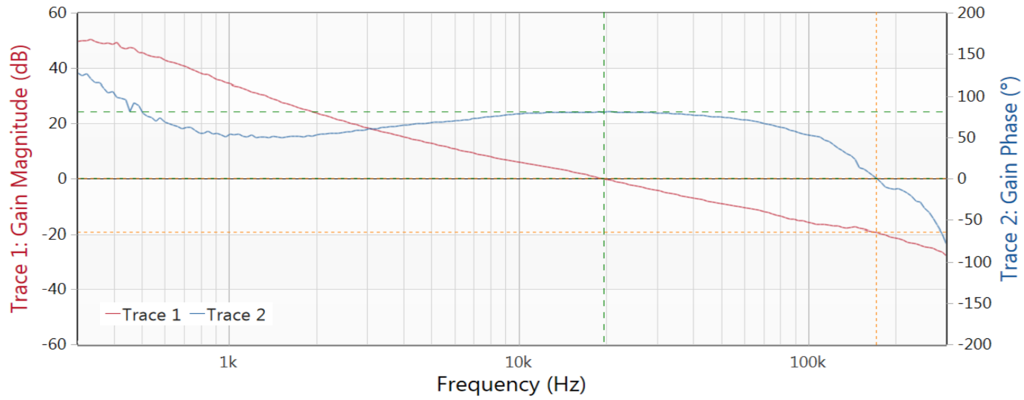

Figure 11. Frequency Response at 6.0 A Load

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	

PUBLICATION ORDERING INFORMATION

LITERATURE FULFILLMENT:
Literature Distribution Center for ON Semiconductor
19521 E. 32nd Pkwy, Aurora, Colorado 80011 USA
Phone: 303−675−2175 or 800−344−3860 Toll Free USA/Canada
Fax: 303−675−2176 or 800−344−3867 Toll Free USA/Canada
Email: orderlit@onsemi.com

N. American Technical Support: 800−282−9855 Toll Free USA/Canada
Europe, Middle East and Africa Technical Support:
Phone: 421 33 790 2910

ON Semiconductor Website: **www.onsemi.com**

Order Literature: http://www.onsemi.com/orderlit

For additional information, please contact your local Sales Representative