

30 W Automotive 2 MHz Pre-Regulator, Non-Isolated, Synchronous Buck, NCV891930-Based Reference Design



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TND6287/D

REFERENCE DESIGN

Overview

This reference design describes the operation and performance of the NCV891930 automotive synchronous buck controller with a NVMFD5C478NL 40 V dual N-channel FET. The design demonstrates the NCV891930 controller capabilities as well as a complete design for an automotive pre-regulator for broad range of applications.

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 NCV891930. 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.

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
- 2 MHz Switching Frequency to Minimize Inductor Size
- NCV891930 Low Quiescent Current Automotive Synchronous Buck Converter and NVMFD5C478NL 40 V Dual N-channel FET
- Small Form Factor PCB with Four Layers

Specifications

Table 1. SPECIFICATIONS TABLE

Device	NCV891930
Application	Automotive Pre-Regulator
Input Voltage	6 V to 16 V DC, 40 V Peak
Output Power	Up to 15 W Average, Up to 30 W Peak
Topology	Synchronous Buck
Isolation	Non-Isolated
Output Voltage	5.0 V
Nominal Current	3.0 A Average 6.0 A Peak

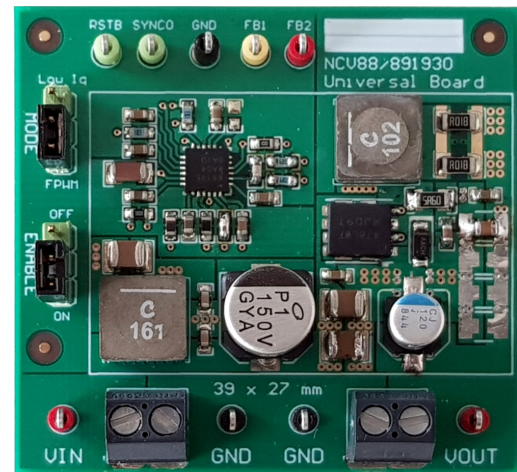


Figure 1. Reference Design Board Image

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SCHEMATICS

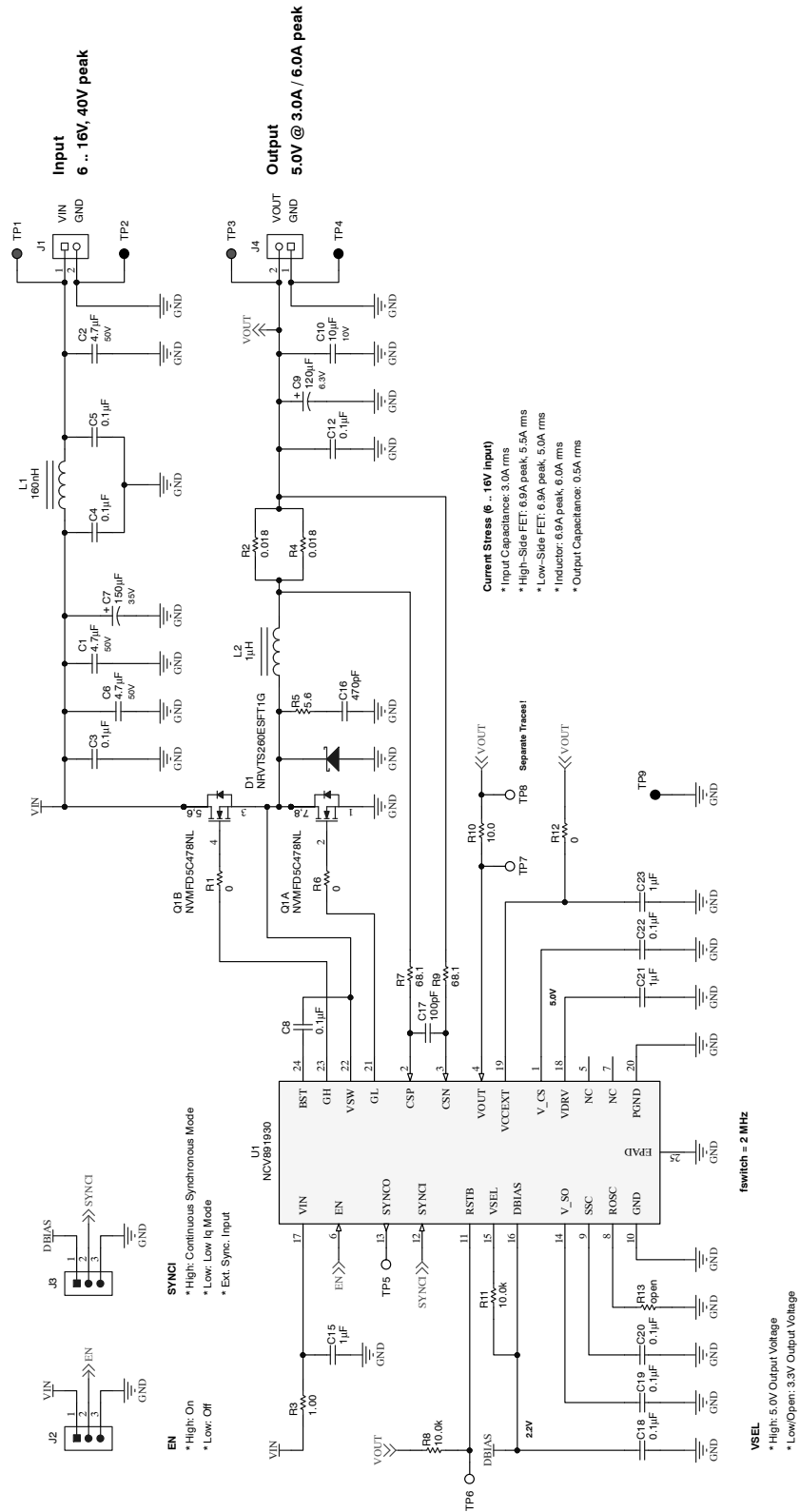


Figure 2. NCV891930 Synchronous Buck Schematic

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.

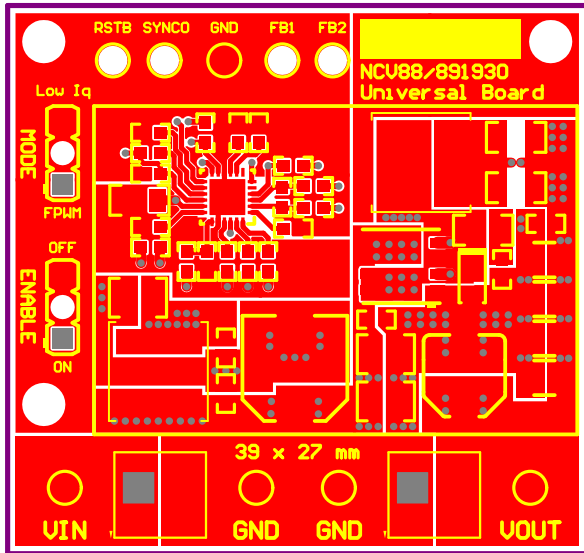


Figure 3. Top Layer and Assembly Drawing

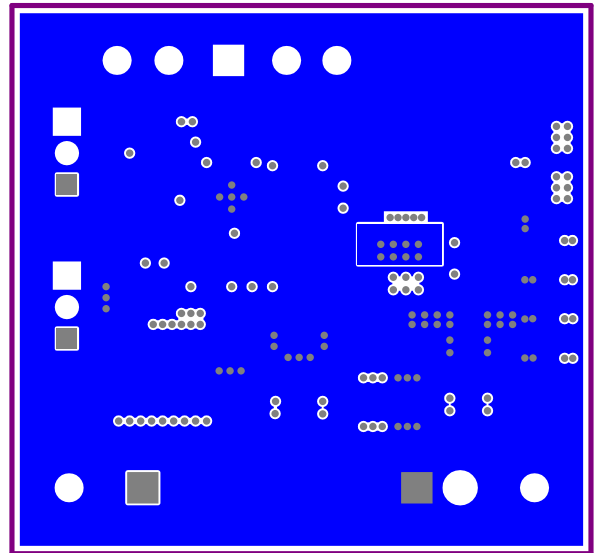


Figure 4. Bottom Layer and Assembly Drawing

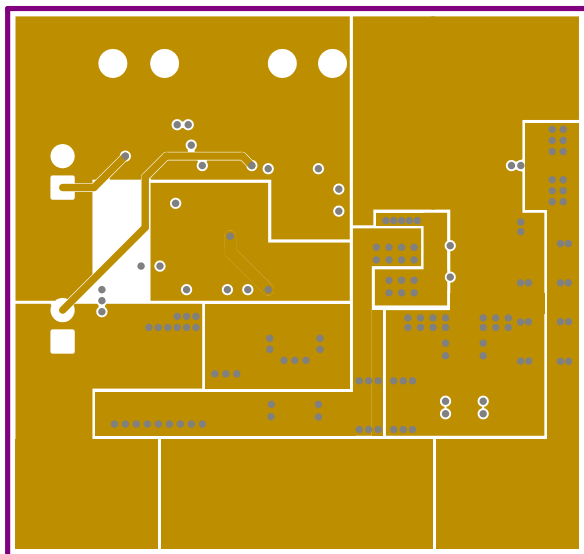


Figure 5. Inner 1 Layer

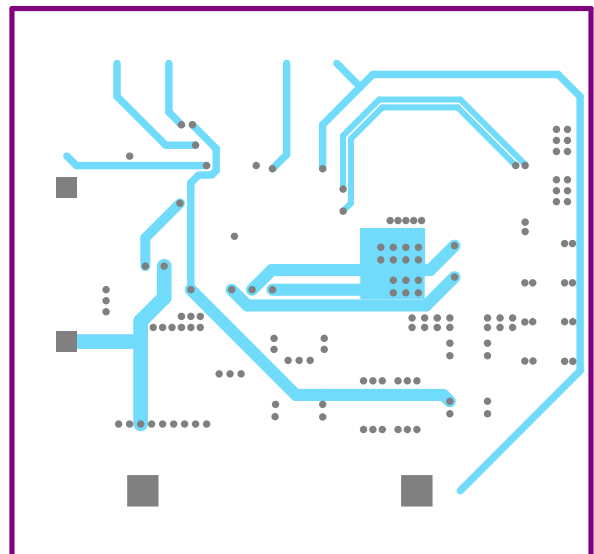


Figure 6. Inner 2 Layer

PERFORMANCE SUMMARY

Output Voltage

NCV891930 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 1 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).

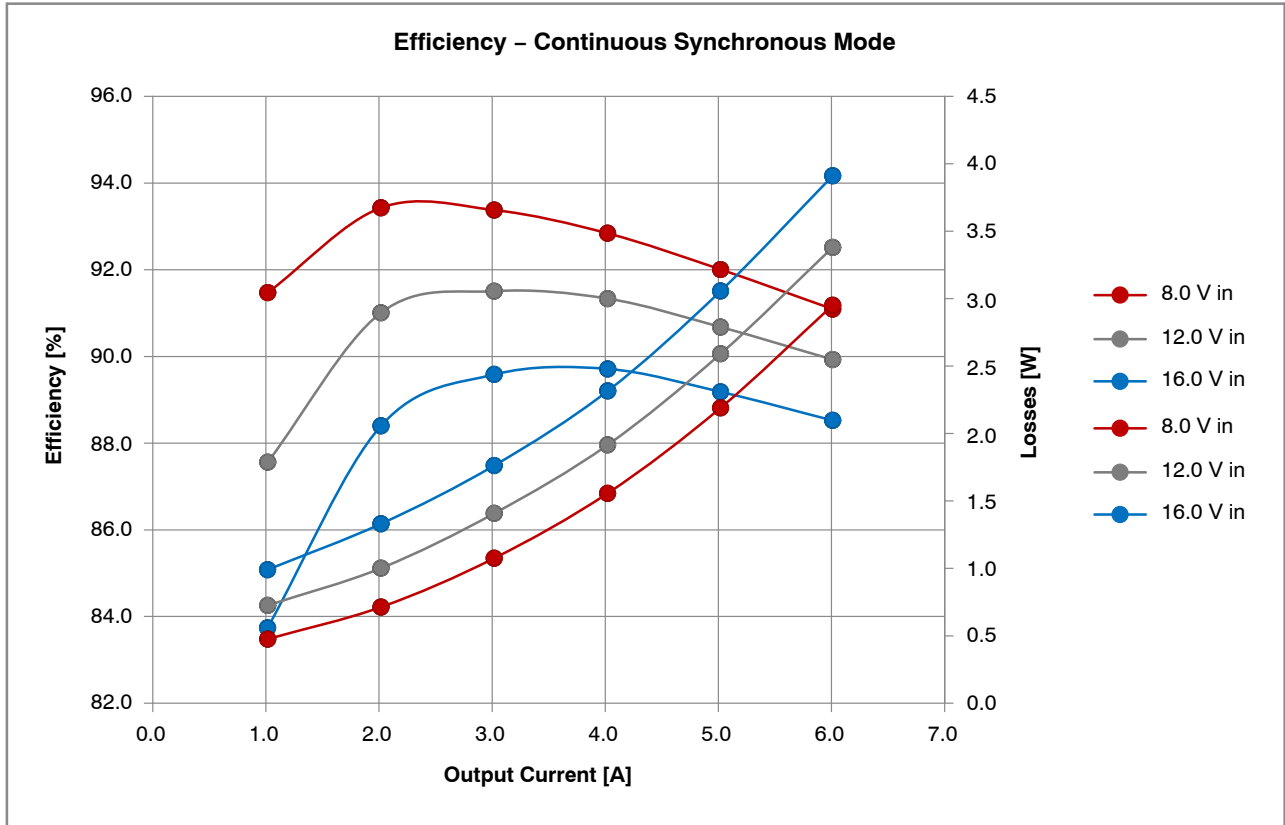


Figure 7. Efficiency for 8.0, 12.0 and 16.0 V Input Voltage

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Thermal Image

The thermal image (Figure 8) shows the circuit at an ambient temperature of 21°C with an input voltage of 12.0 V and 3.0 A load.

- 3.0 A Load
- ◆ FET Q1: 69°C
- ◆ Inductor L2: 57°C

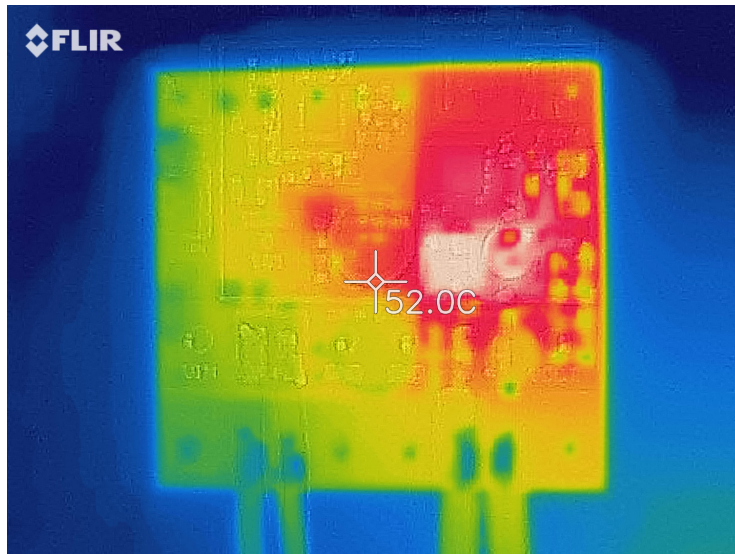


Figure 8. Thermal Image at 3.0 A Load

Transient Response

The response to a load step from 3.0 A to 6.0 A and vice versa at 12.0 V input voltage is shown in Figure 9.

- Channel 1
 - ◆ Output current, load step 3.0 to 6.0 A
 - ◆ 2 A/div, 1 ms/div
- Channel 2
 - ◆ Output voltage, -120 mV (-2.4%) undershoot, +117 mV (2.3%) overshoot
 - ◆ 100 mV/div, 1 ms/div, AC coupled

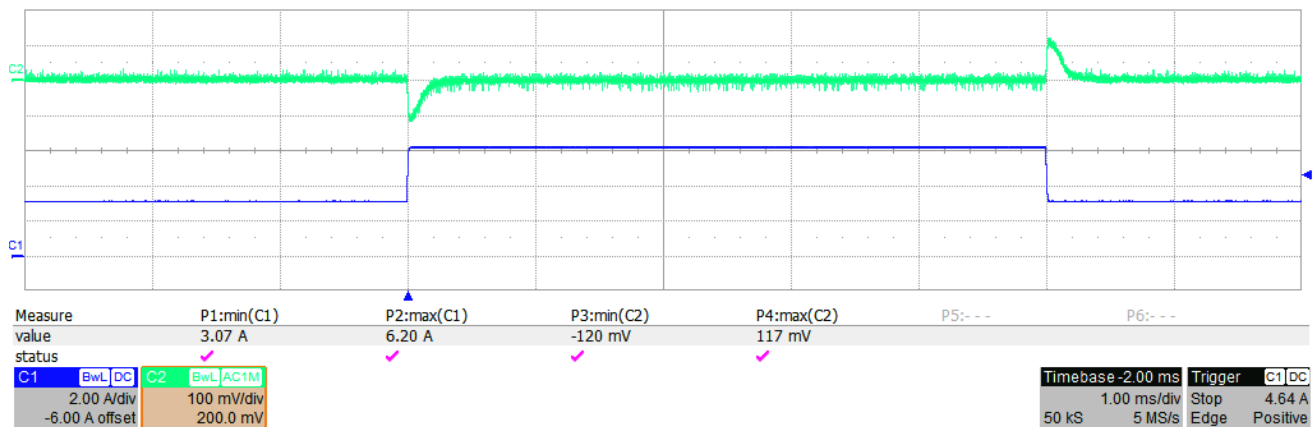


Figure 9. Transient Response on 3.0 A Load Step

Frequency Response

The frequency response at 12.0 V input voltage and 6.0 A load is shown in Figure 10.

Trace 1

- ◆ 31.5 kHz bandwidth
- ◆ -22 dB gain margin

Trace 2

- ◆ 82° phase margin

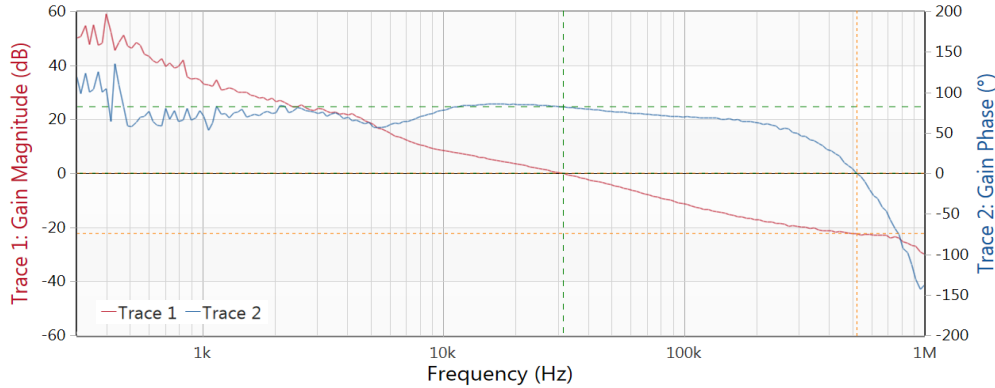


Figure 10. Frequency Response at 6.0 A Load

Impact of Output Capacitance Configuration on Performance

The datasheet of NCV891930 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
- 10 μF ceramic, 10 V, 0805, X7R
muRata GCM21BR71A106KE22L
6 μF @ 5.0 V DC, 4 mΩ ESR @ 2 MHz
- 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

- Using only a polymer capacitor results in relatively high output voltage ripple around 90...100 mV (2 %). Adding a single high capacitance ceramic capacitor (10 μF or more) in parallel reduces the output voltage ripple heavily by a factor of almost ten.
- 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 118 mV (2.4%) and 163 mV (3.3%). 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:

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

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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: 10 μF, 10 V	0	1	2	3	# of caps
Output Ripple, peak-peak	107	8	5	3	[mV]
Output Ripple, peak-peak	2.1	0.2	0.1	0.1	[%]
Transient Response, peak-peak	324	258	255	253	[mV]
Transient Response, peak	162	129	128	127	[mV]
	3.2	2.6	2.6	2.5	[%]
Bandwidth	16.7	17.0	16.0	15.3	[kHz]
Phase Margin	92	92	91	90	[deg]
Gain margin	-26	-21	-20	-20	[dB]

Polymer: 120 μF, 6.3 V	1	1	1	1	# of caps
Ceramic: 10 μF, 10 V	0	1	2	3	# of caps
Output Ripple, peak-peak	89	11	6	5	[mV]
Output Ripple, peak-peak	1.8	0.2	0.1	0.1	[%]
Transient Response, peak-peak	313	246	236	244	[mV]
Transient Response, peak	157	123	118	122	[mV]
	3.1	2.5	2.4	2.4	[%]
Bandwidth	32.3	31.5	31.0	30.2	[kHz]
Phase Margin	82	82	82	82	[deg]
Gain margin	-27	-22	-22	-22	[dB]

Polymer: 100 μF, 6.3 V	1	1	1	1	# of caps
Ceramic: 10 μF, 10 V	0	1	2	3	# of caps
Output Ripple, peak-peak	92	11	7	5	[mV]
Output Ripple, peak-peak	1.8	0.2	0.1	0.1	[%]
Transient Response, peak-peak	325	259	277	262	[mV]
Transient Response, peak	163	130	139	131	[mV]
	3.3	2.6	2.8	2.6	[%]
Bandwidth	33.2	31.4	30.2	30.0	[kHz]
Phase Margin	80	81	80	80	[deg]
Gain margin	-27	-22	-22	-22	[dB]

Ceramic: 22 μF, 16 V	3	4	5	6	# of caps
Output Ripple, peak-peak	8	6	5	4	[mV]
Output Ripple, peak-peak	0.2	0.1	0.1	0.1	[%]
Transient Response, peak-peak	275	265	265	258	[mV]
Transient Response, peak	138	133	133	129	[mV]
	2.8	2.7	2.7	2.6	[%]
Bandwidth	59.0	49.3	40.7	35.6	[kHz]
Phase Margin	49	54	60	64	[deg]
Gain margin	-14	-17	-21	-24	[dB]

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BILL OF MATERIALS (BOM)


Table 3. BILL OF MATERIALS

Designator	Qty.	Value	Part Number	Manufacturer	Description	Package
C1, C2, C6	3	4.7 μ F	GCM32ER71H475KA55	MuRata	CAP, CERM, 4.7 μ F, 50 V, 10%, X7R, 1210	1210
C3, C4, C5, C8, C12, C18, C19, C20, C22	9	0.1 μ F	GCM155R71H104KE02D	MuRata	CAP, CERM, 0.1 μ F, 50 V, \pm 10%, X7R, AEC-Q200 Grade 1, 0402	0402
C7	1	150 μ F	GYA1V151MCQ1GS	Nichicon	CAP, Hybrid Polymer, 150 μ F, 35 V, \pm 20%, 0.027 Ω , SMD	D8xL10mm
C9	1	120 μ F	PCJ0J121MCL1GS	Nichicon	CAP, Aluminum Polymer, 120 μ F, 6.3 V, \pm 20%, 0.024 Ω , SMD	D5.0xL6.0mm
C10	1	10 μ F	GCM21BR71A106KE22L	MuRata	CAP, CERM, 10 μ F, 10 V, 10%, X7R, AEC-Q200 Grade 1, 0805	0805
C15	1	1 μ F	GCM21BR71H105KA03	MuRata	CAP, CERM, 1 μ F, 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 μ F	GCM188R71E105KA64D	MuRata	CAP, CERM, 1 μ F, 25 V, \pm 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	7.0x8.2x6.5mm
J2, J3	2		61300311121	Würth Elektronik	Header, 2.54 mm, 3x1, Gold, TH	Header, 2.54mm, 3x1, TH
L1	1	160 nH	XAL7030-161MEB	Coilcraft	Inductor, Shielded, Composite, 160 nH, 32.5 A, 0.00115 Ω , SMD	7.5x7.5x3.1mm
L2	1	1 μ H	XAL7030-102MEB	Coilcraft	Inductor, Shielded, Composite, 1 μ H, 21.8 A, 0.00455 Ω , SMD	7.5x7.5x3.1mm
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	0.018 Ω	ERJ-8CWFR018V	Panasonic	RES, 0.018 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

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Table 3. BILL OF MATERIALS (continued)

Designator	Qty.	Value	Part Number	Manufacturer	Description	Package
R5	1	5.6 Ω	CRCW12065R60JNEA	Vishay-Dale	RES, 5.6 Ω, 5%, 0.25 W, 1206	1206
R7, R9	2	68.1 Ω	CRCW060368R1FKEA	Vishay-Dale	RES, 68.1 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		NCV891930MW00R2G	ON Semiconductor	Low Quiescent Current 2 MHz Automotive Synchronous Buck Controller	

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