ON Semiconductor

Is Now

To learn more about onsemi™, please visit our website at
www.onsemi.com

ON Semiconductor

Design Note – DN05059/D

NCP1077, 12 Vout, 6 Watt, Off-line Buck Regulator Using a Tapped Inductor

Device	Application	Input Voltage	Output Power	Topology	I/O Isolation
NCP1077	Smart Meters Electric Meters, White Goods	85 to 265 Vac	6W at 12Vout 12W peak	Off-Line 100 kHz Buck	Non-isolated

	Output Specification
Output Voltage	3.3 to 28 Vdc depending on selected Z1 zener value
Output Ripple	Less than 1%
Typical Current	500 mA continuous
Max Current	1 amp maximum (several second surge – thermally limited)
Min Current	zero

PFC (Yes/No)	No, Pout < 25 watts
Efficiency	>75% typical at 120Vac
Inrush Limiting / Fuse	Fused input
Operating Temp. Range	0 to +50°C (dependent on U1 heatsinking)
Cooling Method / Supply Orientation	Convection
Signal Level Control	None

Circuit Description

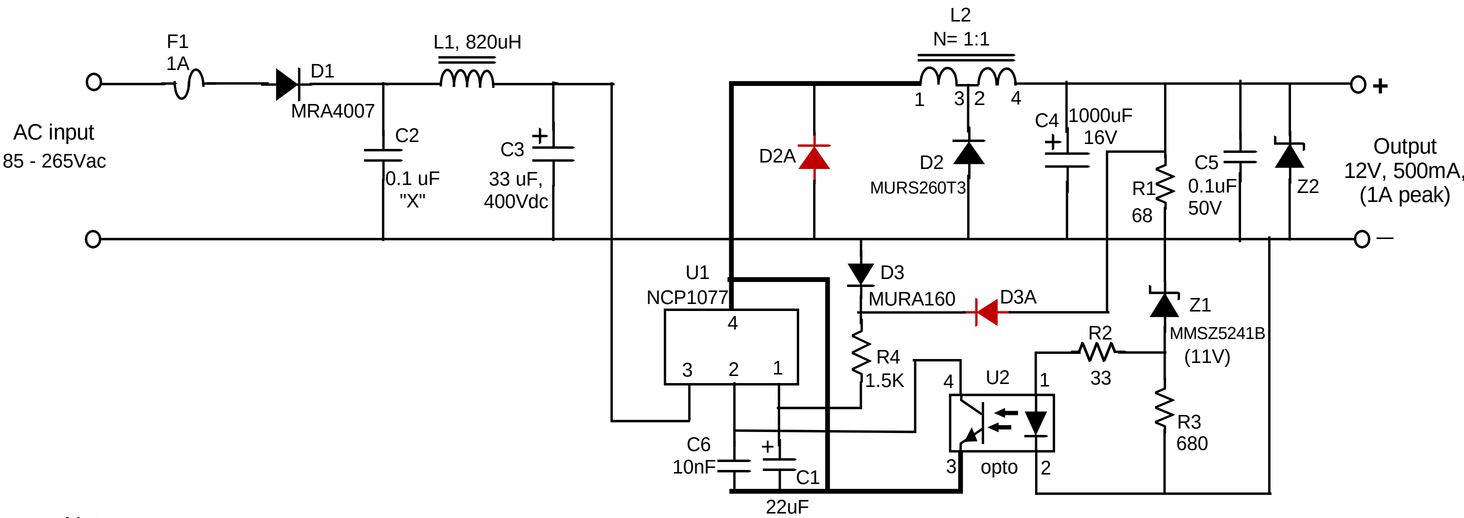
This design note describes a simple, low power, constant voltage output variation of the buck power converter intended for powering electronics for white goods, electrical meters, and industrial equipment where isolation from the AC mains is not required and maximum efficiency is essential. This buck circuit design has been modified by tapping the freewheel diode connection to the inductor to provide several advantages over the conventional buck circuit. ON Semiconductor application note AND8318 provides a detailed discussion of the tapped inductor buck circuit theory which will not be covered in detail in this design note.

One of the major disadvantages of the conventional buck circuit configuration is that for off-line applications, the typical dc input-to-output voltage differential is very high; resulting is a very short operational duty ratio (D) in the power MOSFET. Since the buck's input-to-output voltage transfer function is defined as Vout = D x Vin, we can see that for a rectified input of 165 Vdc and an output of 12 Vdc, D will be 12/165 = 0.07 or 7%. Assuming a switching frequency of 100 kHz (T = 10 us), this results in a typical on-time of 0.7 us. With this short of a duty ratio, the conversion efficiency is not very good and this short of pulse width is approaching the propagation delay time for some control chips which can affect switching stability at light load and higher input voltages. In addition, the maximum dc output load current of the conventional buck cannot be any greater than the peak current limitation of the monolithic switcher, and is typically less due to the magnetizing component of the inductor current.

By tapping the freewheel diode connection to halfway point on the inductor, two advantages are achieved: 1) The output current can be effectively boosted nearly double that possible with the conventional buck configuration because the power MOSFET duty cycle is expanded by a factor of 2 without any increase in peak current; and, 2) The normally high turn-on switching losses caused by the freewheel diode recovery current in the conventional buck are reduced due to the leakage inductance component of the coupled winding in the tapped choke.

The actual tap point on the inductor can be anywhere, and, the closer it is to the output end of the inductor, the greater the current boosting effect and extension of the effective MOSFET duty ratio. For this design note, a center tap inductor was chosen because several commercial vendors provide such a part in a surface mount configuration that can handle up to one amp peak. Typical efficiency improvements of 5% or more over a conventional buck have been achieved with this tapped configuration and it is particularly effective when low output voltages of 12V or less are required with highest efficiency and low standby power.

Schematic



Notes:

1. L1 is Wurth 7447728215
2. L2 is Coilcraft MSD1583-224KE (150 to 220 uH coupled inductor)
3. U2 is Vishay H11A817A or similar opto.
4. U1 is 100 kHz version of NCP1077 in SOT-223 package.
5. R1 is used to trim Vout
6. Crossed lines on schematic are not connected.
7. C4 should be a low-Z electrolytic cap.
8. Vout = Vz1 + 0.9V (approx)
9. For non-tapped Buck configuration move D2 and D3 to "A" (red) positions.
10. Pin 4 of U1 should have heatsink clad pour.

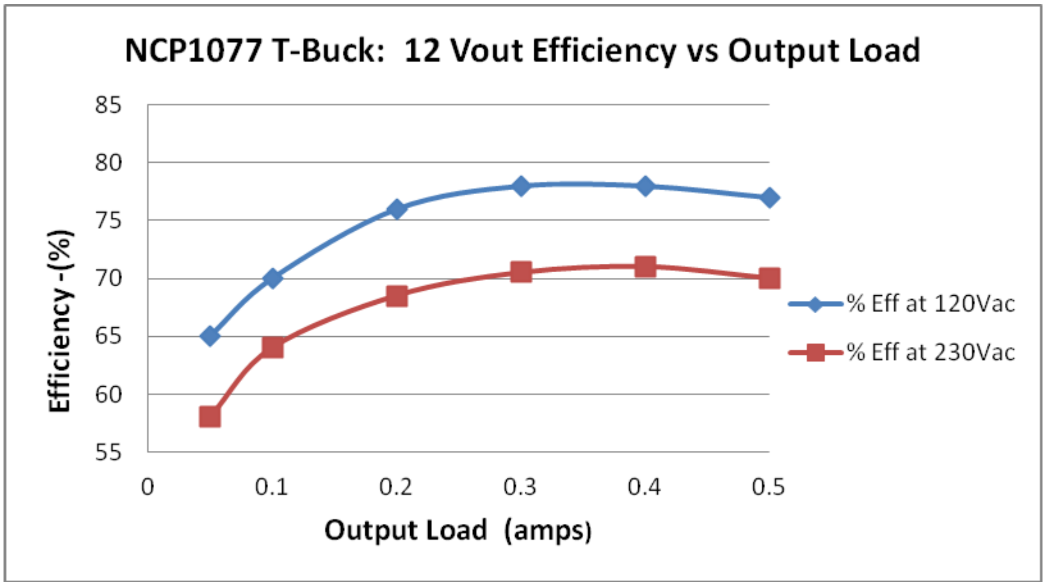
NCP1077 12V, 500 mA Off-line Buck with Tapped Choke (R3)

It should be noted that the efficiency of this tapped inductor buck will depend on the selection of the inductor. Tests have shown that custom made inductors with proper layered winding techniques resulted in the best efficiency, however, the less expensive, off-the-shelf inductors provided by several vendors (Coilcraft, Wurth, PalNova) are usually adequate at the lower current levels where the dc resistance of the windings are sufficient for minimum thermal losses.

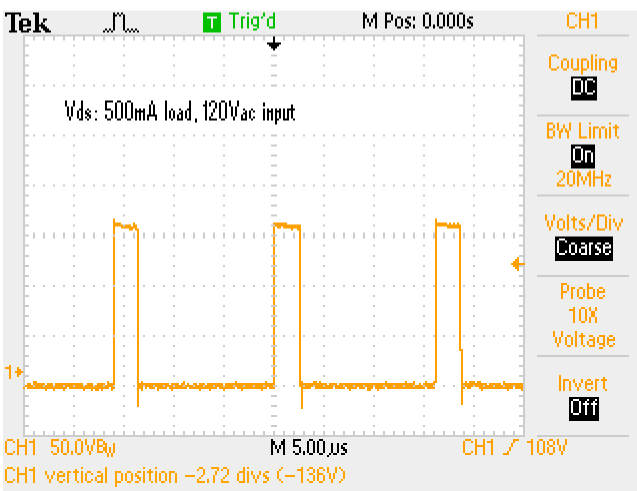
The demo/EVAL board associated with this buck converter can be configured in the standard buck configuration by moving the freewheel diode (D2) and the Vcc bias diode (D3) to the red "A" positions shown in the schematic. The total buck choke inductance will be the series inductance of the two windings on the inductor and will be equal to 4 times that of a single section of the winding. If a smaller capacitance value input bulk cap is desired (C3), a full wave input rectifier should be used instead of the simple, illustrated half-wave rectifier. Depending on the desired output voltage, resistor R4 should be selected for a Vcc current of about 3 to 5 mA assuming approximately 10V on Vcc pin 1. Zener diode Z2 (in conjunction with input fuse F1) is provided for output OVP protection in the event the buck switch would fail shorted. The input EMI filter composed of L1 and C2 should be sufficient to meet Level B for conducted EMI.

For lower output current requirements, the NCP1070, or NCP1075 versions of this monolithic switcher may be used.

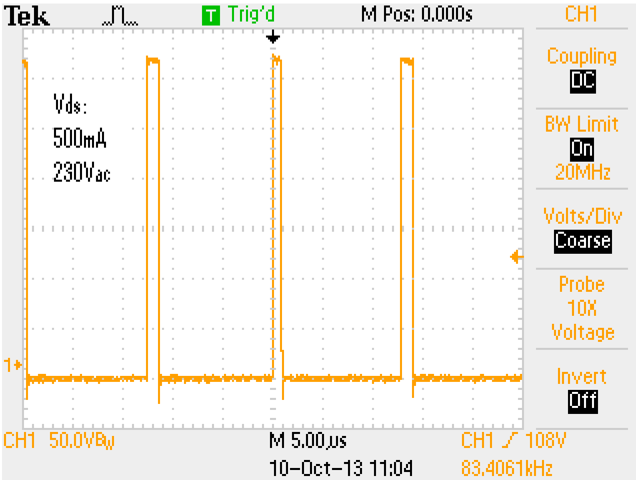
Efficiency vs Load



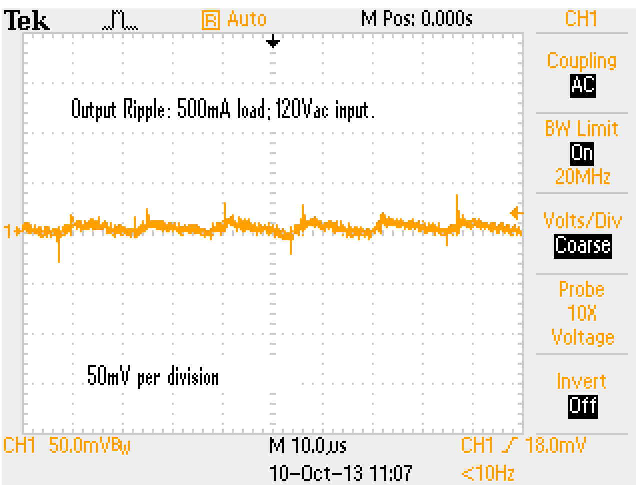
Mosfet Source Voltage – 500 mA Load, 120 Vac Input



Mosfet Source Voltage – 500 mA Load, 230 Vac Input

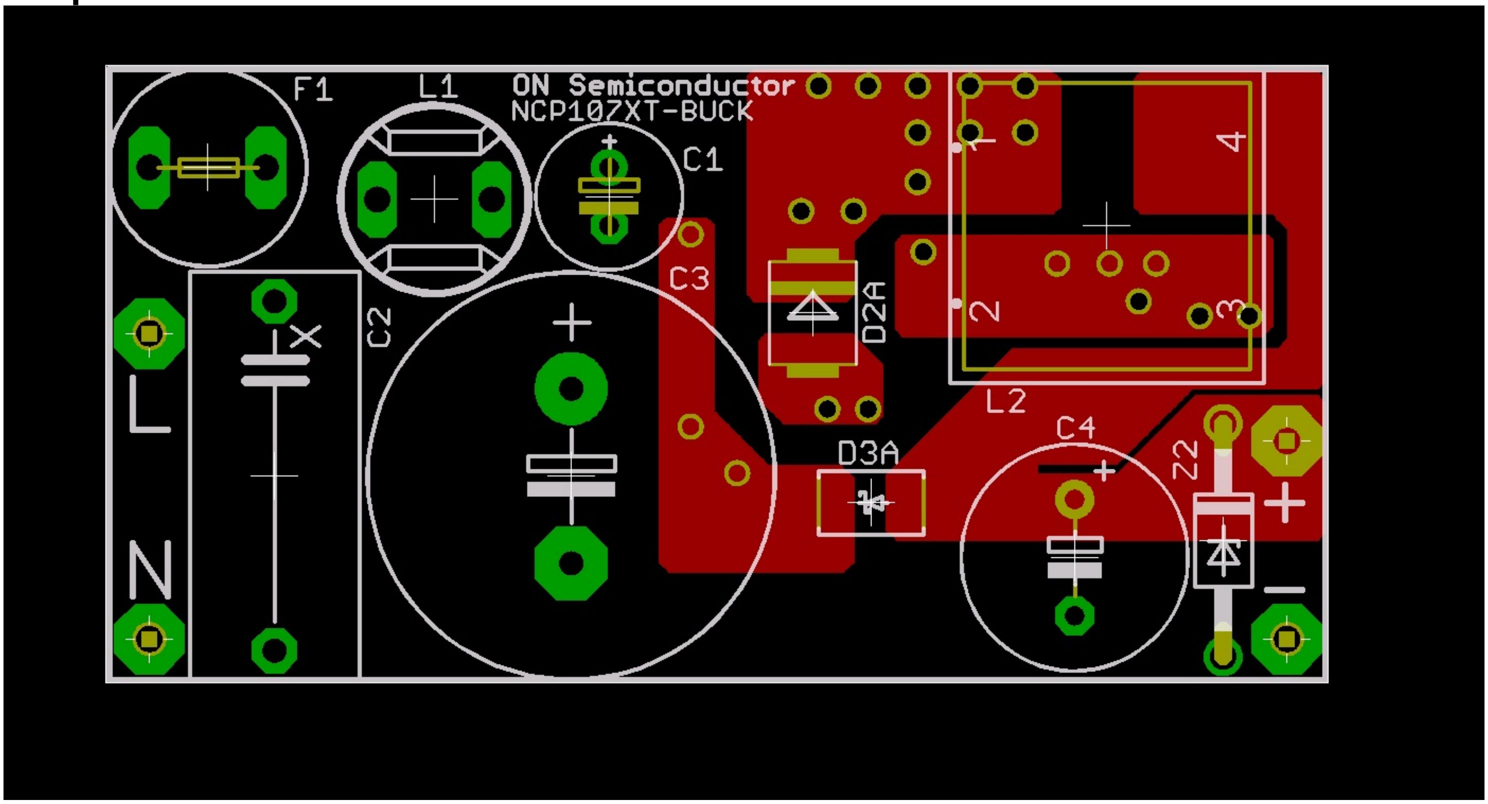


Output Ripple – 500 mA Load, 120 Vac Input

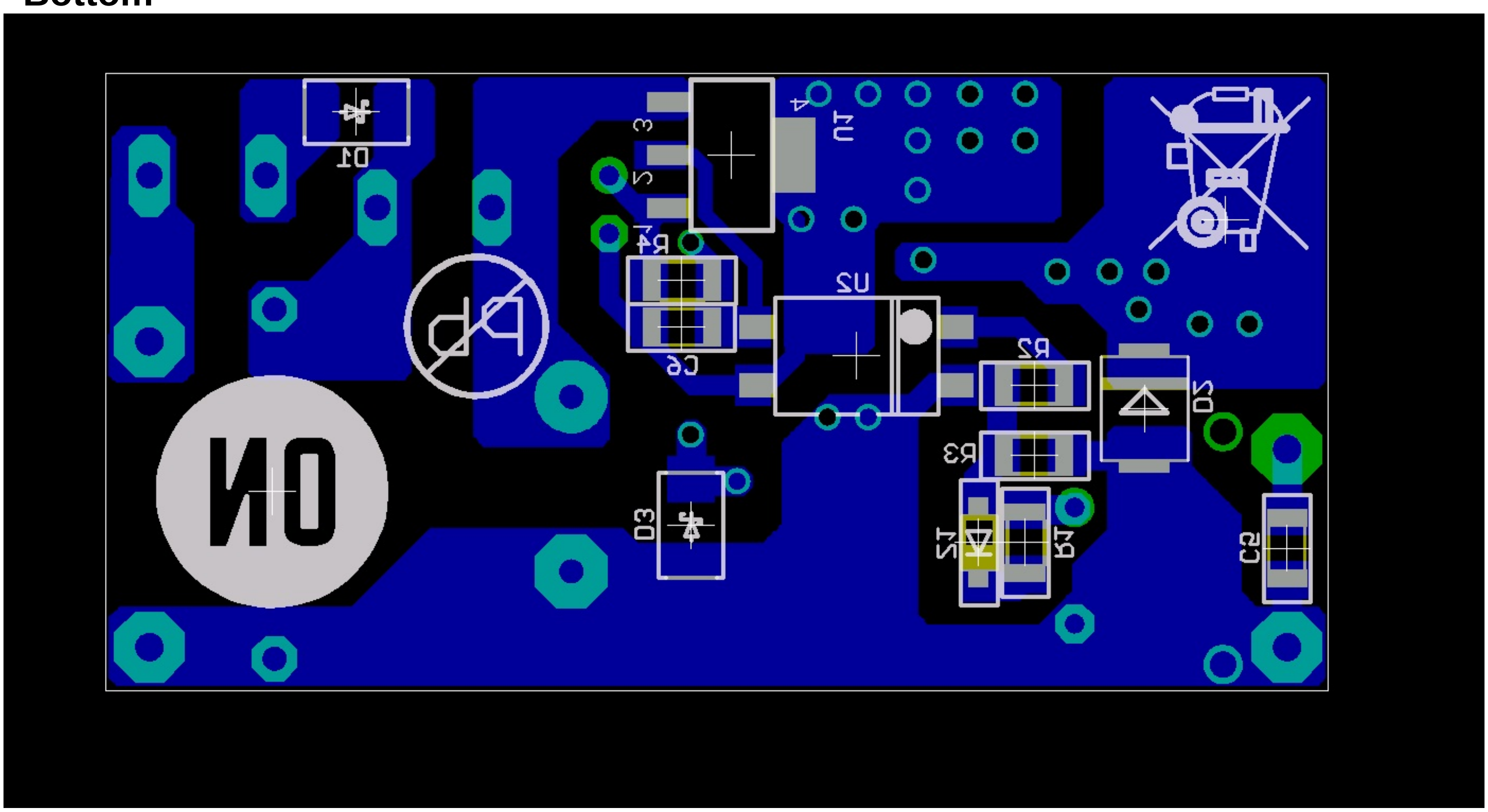


PC Board Layout Details

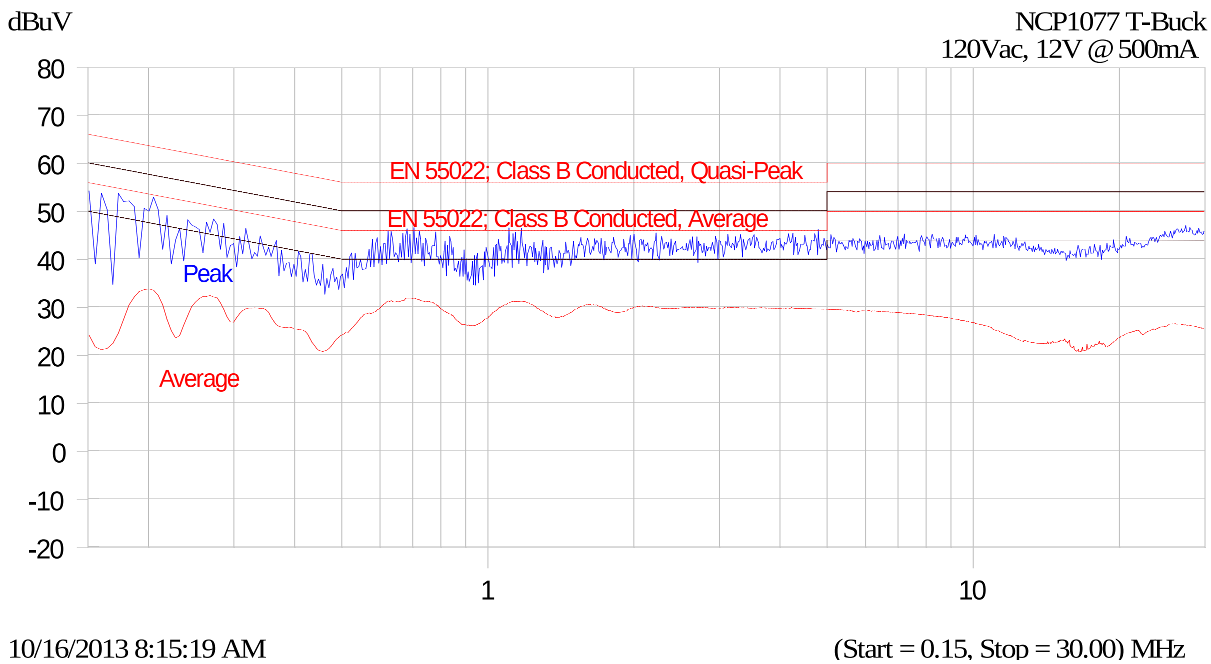
Top



Bottom



Conducted EMI Profile: Peak (blue) and Average (red)



BOM

Designator	Qty	Description	Value	Tolerance	Footprint	Manufacturer	Manufacturer Part Number
D1	1	Diode - 60 Hz,	1A, 800V		SMA	ON Semi	MRA4007
D2 (or D2A)	1	Ultra-fast rectifier	2A, 600V		SMB	ON Semi	MURS260T3
D3 (or D3A)	1	Ultra-fast rectifier	1A, 600V		SMA		
Note: For non-tapped Buck configuration, install D2 and D3 in D2A and D3A positions on PCB							
D3	1	Diode - UFR	1A, 600V		SMA	ON Semi	MURA160
Z1	1	Zener diode	11V		SOD-123	ON Semi	MMSZ5241B
Z2	1	Zener diode	15V/5W		Axial lead	ON Semi	1N5352B or 1N5929B
U2	1	Optocoupler	CTR >/= 0.5		4-pin SMD	Vishay or NEC	SFH6156A-4 or PS2561L-1
U1	1	Controller - NCP1077	100 kHz		SOT223	ON Semi	NCP1077-100
C2	1	"X" cap, box type	100nF, X2		LS = 15 mm	Rifa, Wima	TBD
C6	1	Ceramic cap, monolythic	10 nF, 50V	10%	1206	AVX, Murata	TBD
C5	1	Ceramic cap, monolythic	100nF, 50V	10%	1206	AVX, Murata	TBD
C3	1	Electrolytic cap	33uF, 400V	10%	LS=7.5mm, D=18mm	UCC	TBD
C1	1	Electrolytic cap	22uF, 50Vdc	10%	LS=2.5mm, D=6.3mm	Panasonic - ECG	ECA-1HM220
C4	1	Electrolytic cap	1000uF, 16V	10%	10x20mm, LS=5mm	UCC, Panasonic	TBD
R4	1	Resistor, 1/4W SMD	1.5K	5%	SMD 1206	AVX, Vishay, Dale	TBD
R2	1	Resistor, 1/4W SMD	33 ohms	5%	SMD 1206	AVX, Vishay, Dale	TBD
R3	1	Resistor, 1/4W SMD	680 ohms	5%	SMD 1206	AVX, Vishay, Dale	TBD
R1	1	Resistor, 1/4W SMD	68 ohms	5%	SMD 1206	AVX, Vishay, Dale	TBD
F1	1	Fuse, TR-5 style	1A		TR-5, LS=5mm	Minifuse	TBD
L1	1	Inductor (EMI choke)	820 uH, 500 mA		LS=5mm, Dia=8.5mm	Wurth Magnetics	7447728215
L2	1	Coupled Output Inductor	220uH, 3Apk		15mm x 15mm SMD	Coilcraft	MSD1583-224KE

References:

ON Semiconductor Application Notes: AND8318, AND8328
ON Semiconductor Design Notes: DN05014, DN05023, DN06011, DN06052
ON Semiconductor NCP1077 monolithic switcher data sheet.

Design note created by Frank Cathell, e-mail: f.cathell@onsemi.com