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Design Note – DN05109/D

High Efficiency DC-DC Converter Module

Device	Application	Input Voltage	Output Power	Topology	I/O Isolation
NCP12700	Module	18 to 160 Vdc	Up to 15 W	DCM Flyback	Isolated

	Output Specification
Output Voltage	12 Vdc nominal
Nominal Current	1.25 A
Full Load Efficiency	> 85%
Startup Time	< 20 ms
Over Power Protection	115 % - 155 %
Over Voltage Protection	16 Vdc

Circuit Description

The NCP12700 is fixed frequency, peak current mode PWM controller for single-ended switch mode power supplies (SMPS). Among its many features are a best-in-class startup linear regulator; programmability of switching frequency, soft start, and over-power protection; fully integrated slope compensation, and multiple protection functions necessary for designing efficient industrial, telecom, and transportation DC-DC power supplies with a minimum number of external components.

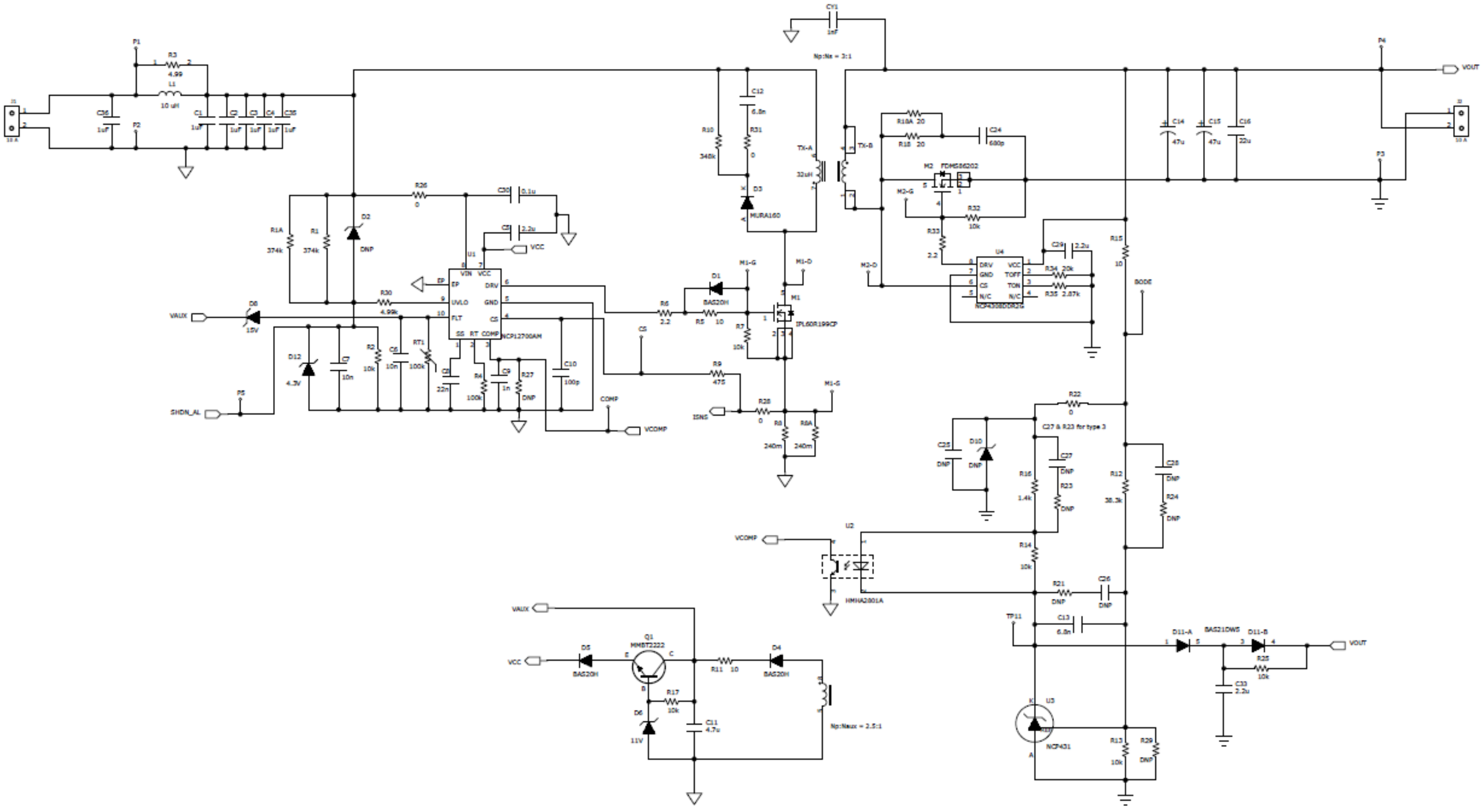
This design note describes a 12 V, 15 W flyback SMPS developed with the NCP12700BMTTXG controller. The SMPS operates from an input voltage range of 18 – 160 V while achieving greater than 85% full load efficiency. The SMPS was designed to operate in discontinuous conduction mode and implements secondary side synchronous rectification for improved efficiency, utilizing the NCP4308.

A full circuit schematic, bill of materials, transformer design details, and PCB artwork are provided. The design note also contains multiple operational waveforms and performance data highlighting the features and capabilities of the NCP12700 in this DC-DC application.

Key Features

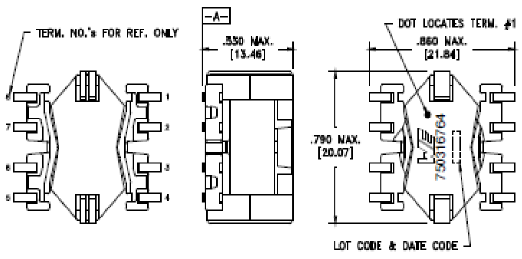
- Wide Input Range (9 – 120/200 V; MSOP10/WQFN10) Startup Regulator
- Startup Regulator Circuit capable of sourcing a minimum of 15 mA
- Programmable Over-Power Protection
- Integrated Slope Compensation
- Fault Input for Over Temperature and Output Over Voltage Fault Conditions, NTC Compatible
- 1 A / 2.8 A Source / Sink Gate Driver
- Programmable Soft Start
- Overload Protection with 30 ms Timer and 1 s Auto-recovery
-

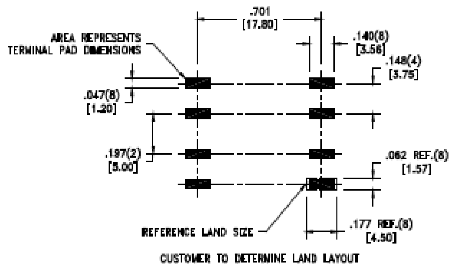
Circuit Schematic

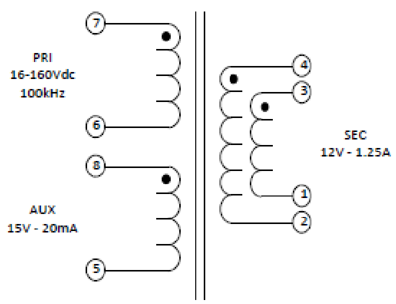


Magnetics Design – Flyback Transformer

CUSTOMER TERMINAL	RoHS	LEAD(Pb)–FREE
Sn 96%, Ag 4%	Yes	Yes







Application of the transformer allows for the leadwires between terminals 1&2 and 3&4 to solder bridge.

Customer to tie terminals 1&2 and 3&4 on PC board.

ELECTRICAL SPECIFICATIONS @ 25° C unless otherwise noted:

PARAMETER		TEST CONDITIONS	VALUE
D.C. RESISTANCE	1-4	tie(1+2, 3+4), @20°C	0.014 ohms ±20%
D.C. RESISTANCE	5-8	@20°C	0.069 ohms ±10%
D.C. RESISTANCE	6-7	@20°C	0.049 ohms ±20%
INDUCTANCE	7-6	10kHz, 100mV, Ls	32.0µH ±10%
SATURATION CURRENT	7-6	20% rolloff from initial	5.6A
LEAKAGE INDUCTANCE	7-6	tie(1+2+3+4, 5+8),100kHz, 100mV, Ls	500nH typ., 750nH max.
DIELECTRIC	1-8	tie(3+4, 5+6), 2250VAC, 1 second	1800VAC, 1 minute
DIELECTRIC	5-7	625VAC, 1 second	
TURNS RATIO		(7-6):(8-5)	2.5:1, ±1%
TURNS RATIO		(7-6):(4-1), tie(1+2, 3+4)	3:1, ±1%

GENERAL SPECIFICATIONS:

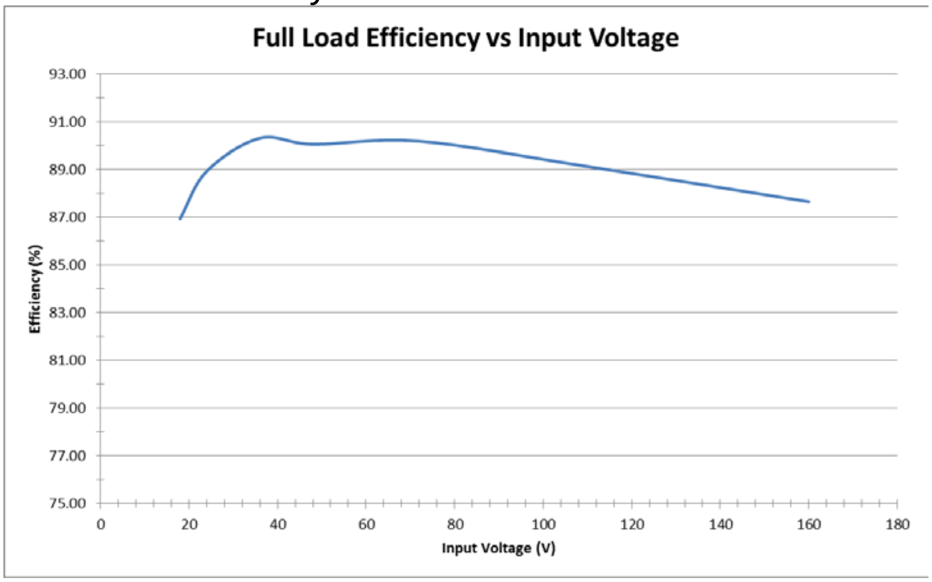
OPERATING TEMPERATURE RANGE: -40°C to +125°C including temp rise.

Designed to comply with the following requirements as defined by IEC60950-1, EN60950-1, UL60950-1/CSA60950-1 and AS/NZS60950.1:

- Functional insulation for a primary circuit at a working voltage of 265Vrms, 400Vpeak, Overvoltage Category II.

Efficiency Plots

Full Load Efficiency

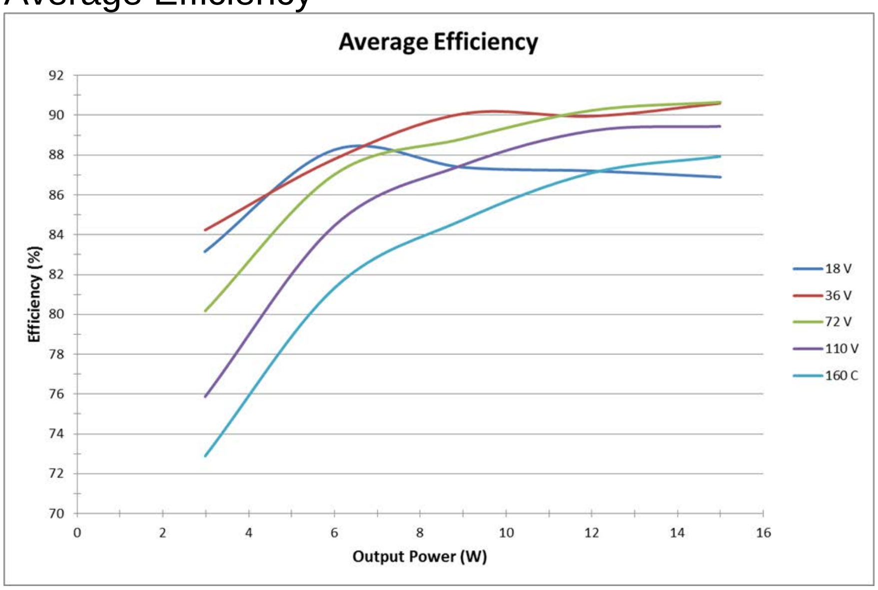


Vin (V)	Pin (W)	Po (W)	Efficiency (%)
18	17.25	15.00	86.94
24	16.85	14.99	88.93
36	16.60	14.99	90.31
48	16.65	15.00	90.06
72	16.63	15.00	90.19
110	16.83	15.00	89.13
160	17.12	15.00	87.65

Full Load Efficiency > 86%

Figure 1: Full Load Efficiency vs. Input Voltage

Average Efficiency



Vin (V)	Pin (W)	Po (W)	Efficiency (%)
18	17.26	15.00	86.89
18	13.77	12.01	87.20
18	10.30	9.00	87.38
18	6.80	6.00	88.27
18	3.58	2.98	83.15
36	16.54	14.99	90.60
36	13.35	12.00	89.95
36	9.98	8.98	90.07
36	6.84	6.00	87.80
36	3.54	2.98	84.23
72	16.55	15.00	90.65
72	13.30	12.00	90.24
72	10.12	8.99	88.81
72	6.90	6.00	87.03
72	3.72	2.98	80.17
110	16.76	14.99	89.44
110	13.46	12.01	89.22
110	10.27	8.99	87.49
110	7.11	6.00	84.47
110	3.93	2.98	75.87
160	17.05	14.99	87.93
160	13.78	12.01	87.11
160	10.61	8.99	84.74
160	7.38	6.01	81.34
160	4.10	2.99	72.89

Figure 2: Average Efficiency vs Output Power

Typical Performance Waveforms

18 V_{IN} | 160 V_{IN}

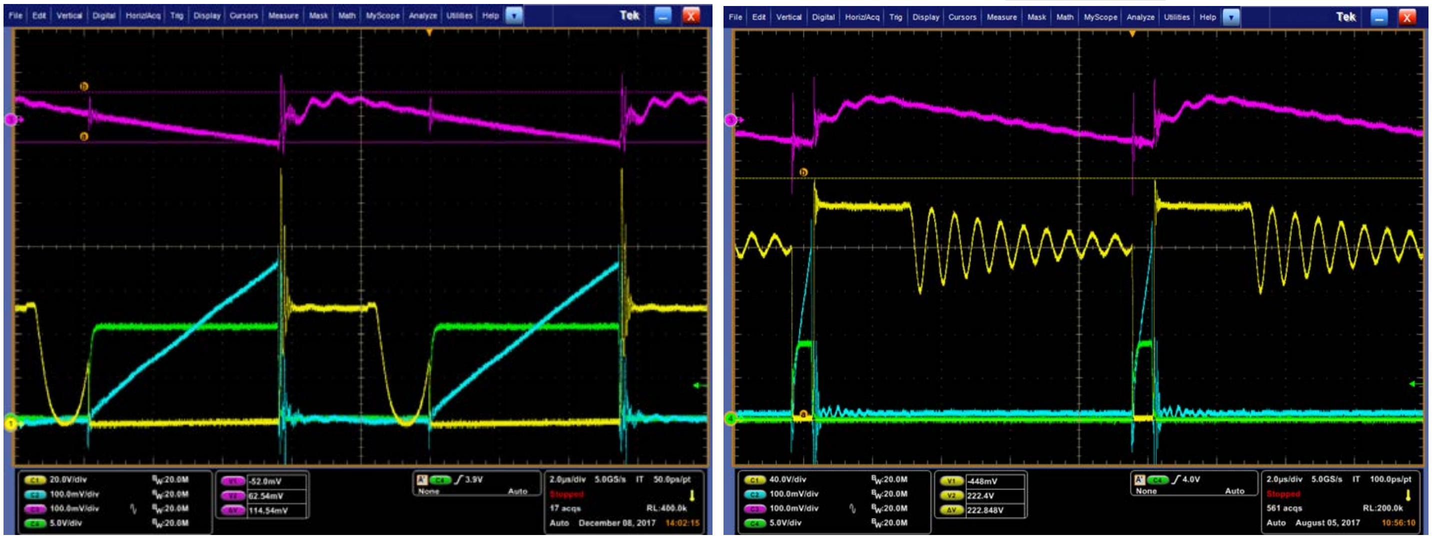


Figure 3: Typical Operating Waveforms

Ch. 1 (Yellow): Primary V_{DS}
Ch. 2 (Blue): CS
Ch. 3 (Purple): V_{OUT} (ac coupled)
Ch. 4 (Green): DRV

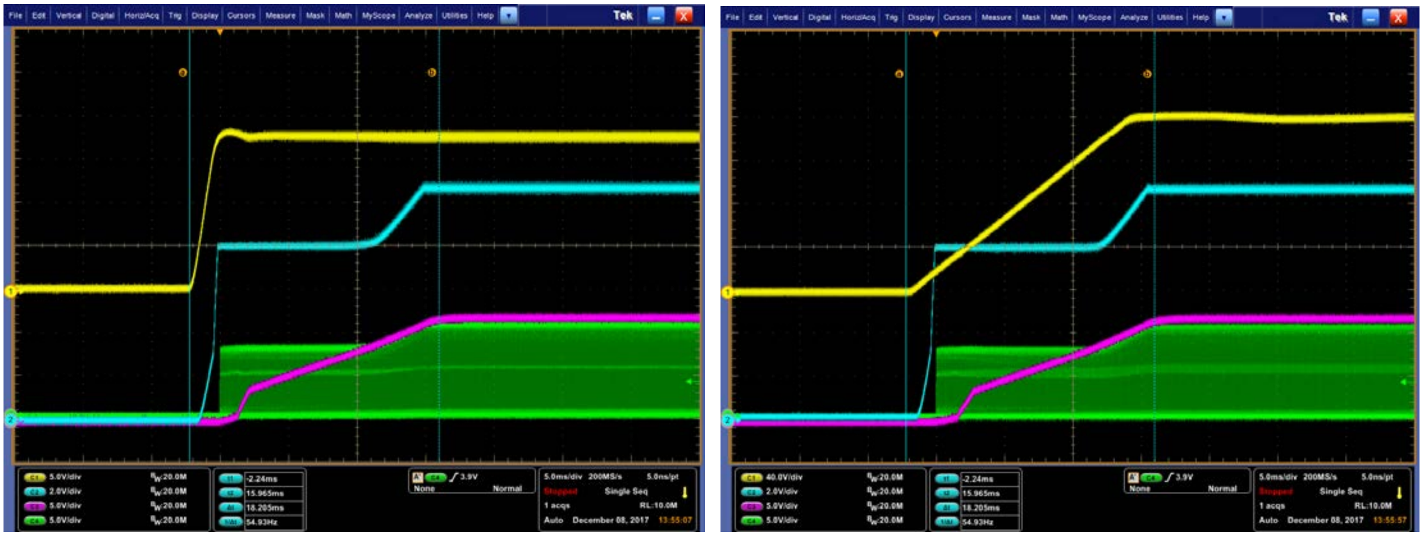
The waveforms in Figure 3 show typical full load operation of the SMPS at 18 and 160 V_{IN}. Characteristic of discontinuous mode operation, the peak current and demagnetization period are approximately equal for a given load condition, regardless of input voltage. The wide input range capability is made possible with a minimum of external components due to the capability of the high voltage startup regulator and the integration of over-power protection. The SMPS design also operates at 100 kHz and utilizes much of the duty cycle capability of the NCP12700 to achieve regulation across the wide input range without being subjected to issues of minimum on times.

Also worth noting is the use of secondary side synchronous rectification (SR) which is evident from the oscilloscope capture in Figure 3 by the inflection on the primary V_{DS} waveform just prior to the end of the demagnetization period. This is the point at which the SR turns off, demonstrating that the conduction period of the SR is sustained for much of the demagnetization period for optimum efficiency.

Description of Key Features

1. High Voltage Startup Regulator

18 V_{IN} 160 V_{IN}



Figures 4: Startup Regulator Operation

Startup Regulator Operation
Ch. 1 (Yellow): VIN
Ch. 2 (Blue): VCC
Ch. 3 (Purple): VOUT
Ch. 4 (Green): DRV

The NCP12700 features a high voltage startup regulator capable of operating from input voltage ranging from 9 – 200 V. The regulator is capable of sourcing > 15 mA with as little as 2 V of overhead. A capacitor in the range 1 – 10 µF at the V_{CC} pin is recommended to ensure stability of the regulator. The input operating range, source current capability, and stability requirements of the regulator were designed for best-in-class performance providing the user with fast startup capability and requiring no additional components for ease of design. The regulator's drive capability ensures that the device can continue to self-bias for the duration of the startup period easing the design of the auxiliary winding. Once the application is in regulation it is recommended that an auxiliary winding from the power transformer be utilized for biasing of the supply to reduce the thermal stress on the controller.

The startup waveforms for the DC-DC Module at 18 and 160 V are shown in Figure 4. The V_{CC} voltage is quickly charged to 8 V, enabling switching of the application within 2.5 ms of the input power being applied. The application module reaches regulation in less than 20 ms and no voltage drop is observed on V_{CC} demonstrating the source capability of the regulator.

2. Input Over-Power Compensation

In wide input range power supplies the power delivery capability tends to increase at higher line voltages presenting thermal challenges for the supply designer. The NCP12700 features an integrated input over-power protection feature for limiting the output power capability of the application at higher line voltages. Shown in the Figure 5, the controller tracks an image of the input line voltage through the UVLO pin and sources current out of the current sense pin as the UVLO pin voltage increases. A series resistor between the CS pin at the controller and the current sensing element creates an offset voltage reducing the available peak current in the power supply and thereby reducing the power delivery capability. The current out of the CS pin has been limited to 200 µA allowing the designer to utilize the series resistor commonly included for high frequency filtering of the CS signal.

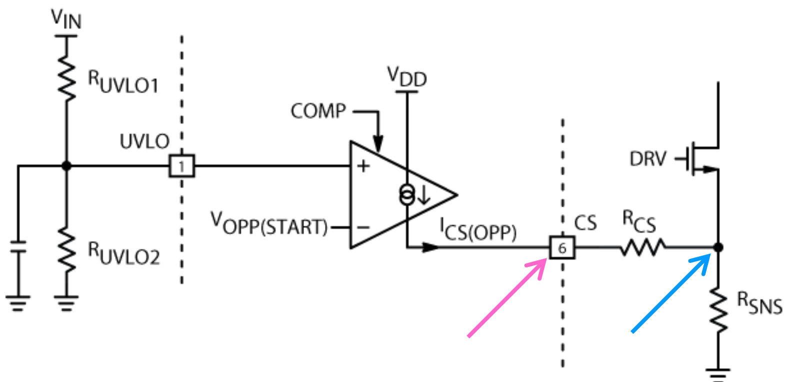


Figure 5: Over Power Protection Circuit

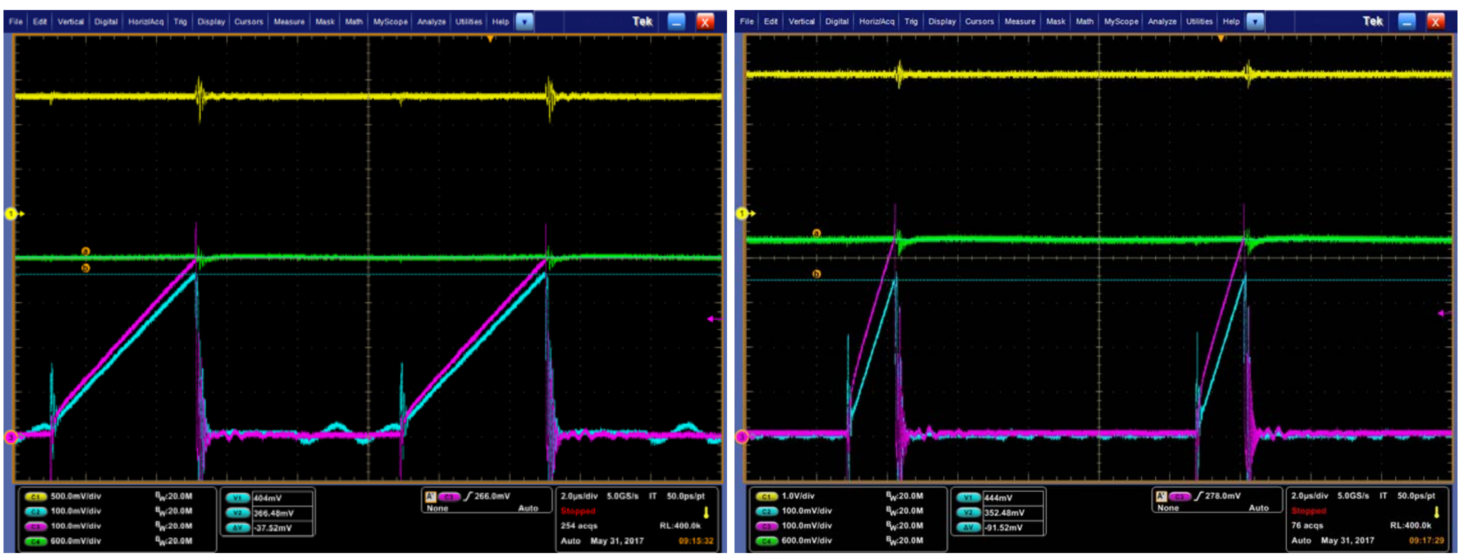


Figure 6: Over Power Protection Waveform

Ch. 1 (Yellow): V_{UVLO}
Ch. 2 (Blue): CS @ R_{SNS}
Ch. 3 (Purple): CS @ Pin
Ch. 4 (Green): COMP

The waveforms in Figure 6 demonstrate the offset voltage and reduced peak current capability in the demonstration board applied at two different input voltages. The divided down image of the input voltage is sensed at the UVLO voltage on the yellow trace. The waveform in purple shows how the current sense voltage at the controller is increased relative to the voltage across the current sensing element.

The plot in Figure 7 shows the power supply overload current as a function of input voltage. The available overload current is practically constant across an input voltage range of about 5:1 and remains below 55% throughout the input voltage range.

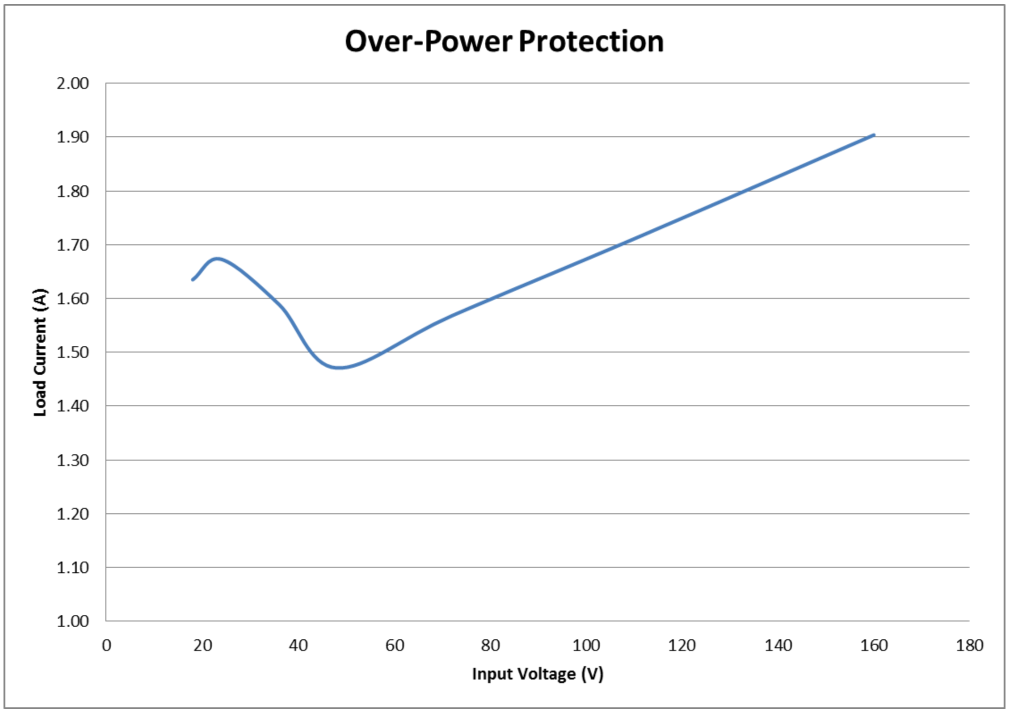
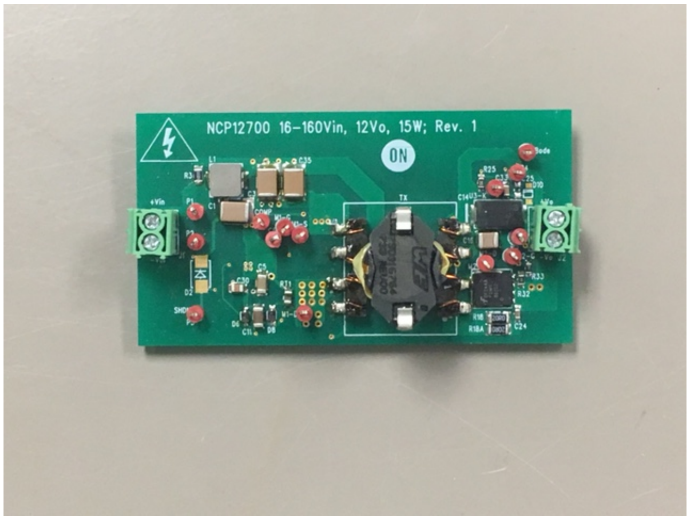


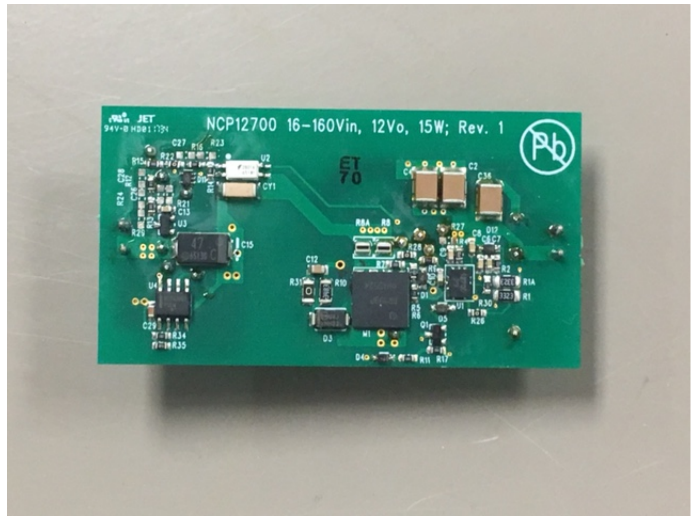
Figure 7: Overload Current vs Input Voltage

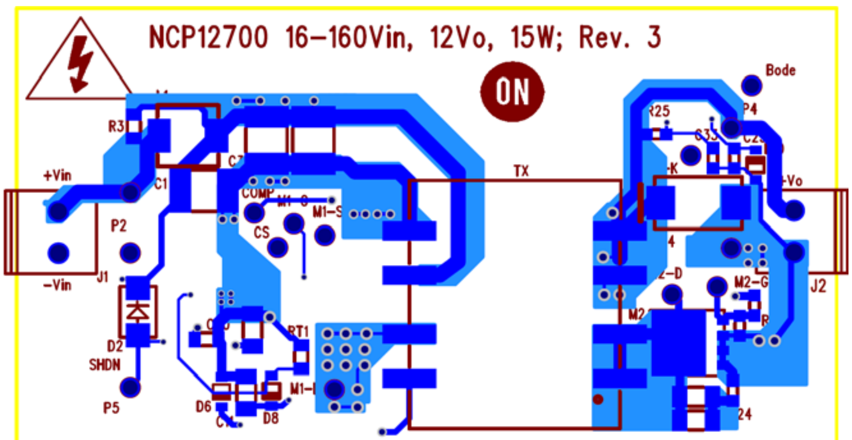
Bill of Materials

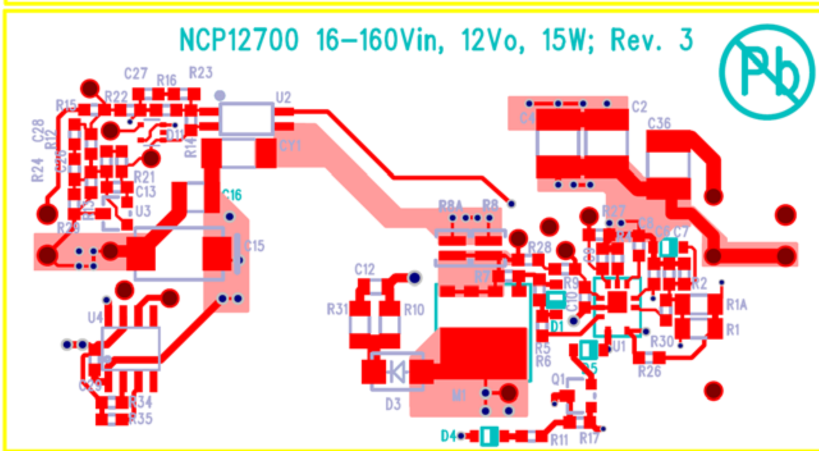
REF DES	QTY	Description	Value	Tolerance	Footprint	Manufacturer	Manufacturer PN	Substitution
C1, C2, C3, C4, C35, C36	6	Capacitor, Ceramic, X7T	1 uF, 250 V	20%	SMD, 1812	TDK	C4532X7T2E105M250KA	Yes
C5	1	Capacitor, Ceramic, X7R	2.2 uF, 50 V	10%	SMD, 1206	Samsung	CL31B225KBHNNNE	Yes
C6, C7	2	Capacitor, Ceramic, X7R	10 nF, 50 V	10%	SMD, 0603	Yageo	CC0603KRX7R9BB103	Yes
C8	1	Capacitor, Ceramic, X7R	22 nF, 50 V	10%	SMD, 0603	Yageo	CC0603KRX7R9BB223	Yes
C9	1	Capacitor, Ceramic, X7R	1 nF, 50 V	10%	SMD, 0603	Yageo	CC0603KRX7R9BB102	Yes
C10	1	Capacitor, Ceramic, C0G	100 pF, 50 V	5%	SMD, 0603	Yageo	CC0603JRNPO9BN101	Yes
C11	1	Capacitor, Ceramic, X7R	4.7 uF, 50 V	10%	SMD, 1206	Murata	GRM31CR71H475KA12L	Yes
C12	1	Capacitor, Ceramic, X7R	6800 pF, 630 V	10%	SMD, 0805	Kemet	C0805C682KBRACTU	Yes
C13	1	Capacitor, Ceramic, X7R	6.8 nF, 50 V	10%	SMD, 0603	Yageo	CC0603KRX7R9BB682	Yes
C14 , C15	2	Capacitor, Ceramic, X7R	47 uF, 16 V	10%	SMD, 2917	Panasonic	EEF-CX1C470R	Yes
C16	1	Capacitor, Ceramic, X7R	22 uF, 25 V	10%	SMD, 1210	Murata	GRM32ER71E226KE15L	Yes
C24	1	Capacitor, Ceramic, X7R	680p, 250 V	5%	SMD, 0603	Kemet	C0603C681JAGACAUTO	Yes
C25, C26, C27, C28	4	DNP	DNP					
C29, C33	2	Capacitor, Ceramic, X7R	2.2 uF, 50 V	10%	SMD, 0603	Murata	GRM188R61H225KE11D	Yes
C30	1	Capacitor, Ceramic, X7T	0.1 uF, 250 V	10%	SMD, 0805	TDK	C2012X7T2E104K125AA	Yes
CY1	1	Capacitor, Ceramic, X7R	1 nF, 250 Vac	10%	SMD, 1808	Johanson Dielectric	502R29W102KV3E-X1Y2-SC	Yes
D1, D4, D5	3	Diode, Switching	200 V, 0.2 A		SMD, SOD-323	ON Semiconductor	BAS20HT1G	No
D2, D10	2	DNP	DNP					
D3	1	Diode, Fast recovery	600 V, 1 A		SMD, SMA	ON Semiconductor	MURA160T3G	No
D6	1	Diode, Zener	11 V, 300 mW		SMD, SOD-323	ON Semiconductor	MM3Z11VT1G	No
D8	1	Diode, Zener	15 V, 300 mW		SMD, SOD-323	ON Semiconductor	MM3Z15VT1G	No
D11	1	Diode, Switching	250 V, 0.2 A, Dual		SMD, SC-88A	ON Semiconductor	BAS21DW5T1G	No
D12	1	Diode, Zener	4.3 V, 300 mW		SMD, SOD-323	ON Semiconductor	MM3Z4V3T1G	No
J1, J2	2	Terminal Block, 2 pos, in-line	300 V, 10 A		TH, 2POS, LS3.5MM	Phoenix Contact	1984617	Yes
L1	1	Power Inductor, Shielded	10 uH, 2.25 A	20%	IHLP_2020	Vishay	IHLP2020CZER100M1	Yes
M1	1	Transistor, MOSFET, Power	600 V, 12 A		4VSON / Power88	Infineon	IPL60R199CP	No
M2	1	Transistor, MOSFET, Power	120 V, 32 A		SMD, DFN5_5x6	Fairchild	FDMS86202	No
P1 - P5	5	Printed Circuit Pin	8 A		TH, 1POS, D1.02mm	Mill-Max	1179-0-00-15-00-00-33-0	Yes
Q1	1	Transistor, NPN, General Purpose	40 V, 0.6 A		SOT-23	ON Semiconductor	MMBT2222ALT1G	No
R1, R1A	2	Resistor, 1/4 W	374 kΩ	1%	SMD, 1206	Stackpole	RMCF1206FT374K	Yes
R2, R7, R13, R14, R17, R25, R32	7	Resistor 1/10 W	10 kΩ	1%	SMD, 0603	Stackpole	RMCF0603FT10K0	Yes
R3	1	Resistor, 1/8 W	4.99 Ω	1%	SMD, 0805	Stackpole	RMCF0805FT4R99	Yes
R4	1	Resistor, 1/10 W	100 kΩ	1%	SMD, 0603	Stackpole	RMCF0603FT100K	Yes
R5, R11, R15	3	Resistor, 1/10 W	10 Ω	1%	SMD, 0603	Stackpole	RMCF0603FT10R0	Yes
R6, R33	2	Resistor, 1/10 W	2.2 Ω	1%	SMD, 0603	Stackpole	RMCF0603FT2R20	Yes
R8, R8A	2	Resistor, 1/2 W	240 mΩ	1%	SMD, 0805 Wide	Rohm	LTR10EVHFLR240	No
R9	1	Resistor, 1/10 W	475	1%	SMD, 0603	Stackpole	RMCF0603FT475R	Yes
R10	1	Resistor, 1/4 W	348 kΩ	1%	SMD, 1206	Stackpole	RMCF1206FT348K	Yes
R12	1	Resistor, 1/10 W	38.3 kΩ	1%	SMD, 0603	Stackpole	RMCF0603FT38K3	Yes
R16	1	Resistor, 1/10 W	1.4 kΩ	1%	SMD, 0603	Stackpole	RMCF0603FT1K40	Yes
R18, R18A	2	Resistor, 1/4 W	20 Ω	1%	SMD, 1206	Stackpole	RMCF1206FT20R0	Yes
R21, R23, R24, R27, R29	5	DNP	DNP					
R22, R26, R28	3	Resistor, 1/10 W	0 Ω	1%	SMD, 0603	Stackpole	RMCF0603ZT0R00	Yes
R30	1	Resistor, 1/10 W	4.99 kΩ	1%	SMD, 1206	Stackpole	RMCF1206FT4K99	Yes
R31	1	Resistor, 1/4 W	0 Ω	1%	SMD, 1206	Stackpole	RMCF1206ZT0R00	Yes
R34	1	Resistor, 1/10 W	20 kΩ	1%	SMD, 0603	Stackpole	RMCF0603FT20K0	Yes
R35	1	Resistor, 1/10 W	2.87 kΩ	1%	SMD, 0603	Stackpole	RMCF0603FT2K87	Yes
RT1	1	NTC Thermistor	100 kΩ	5%	SMD, 0805	Murata	NCP21WF104J03RA	Yes
TP1 - 5, 8 - 11	9	Testpoint, Red, 40 mil			TH, 1POS, D1.02mm	Keystone Electronics	5000	Yes
TX	1	Flyback Transformer	32 uH, 4.75 A, Np:Ns = 3:1		SMD, RM6-8P	Wurth Electronics	750316764	No
U1	1	PWM Controller			SMD, WQFN-10, 3X4 mm	ON Semiconductor	NCP12700BMTTXG	No
U2	1	Optocoupler	50 mA, 80-160%		SMD, SSOP-4	Fairchild	HMHA2801A	No
U3	1	Shunt Regulator	36 V, 100 mA		SOT-23	ON Semiconductor	NCP431AVSNT1G	No
U4	1	SR Gate Driver			SMD, SOIC8	ON Semiconductor	NCP4308DDR2G	No

Demo Board









References

NCP12700 Datasheet
NCP4308 Datasheet
NCP431 Datasheet