ON Semiconductor

Design Note – DN06049/D

24 Volt, Off-line Flyback Converter for Motor and Solenoid Applications

Device	Application	Input Voltage	Output Power	Topology	I/O Isolation
NCP1216, MBR30H100	Motors and Solenoids	120 Vac with 240 Vac option	100 W nominal (230W peak)	Flyback	Yes – 3 kV

	Output 1
Output Voltage	24 V
Nominal Current	4.5 A
Peak Current	~ 25 A

PFC (Yes/No)	No
Inrush Limiting / Fuse	6 A fuse, Thermistor inrush limiter
Operating Temp. Range	0 to +60°C
Cooling Method / Supply Orientation	Convection
Signal Level Control	None

Others	High output surge current capability for several seconds.

Circuit Description

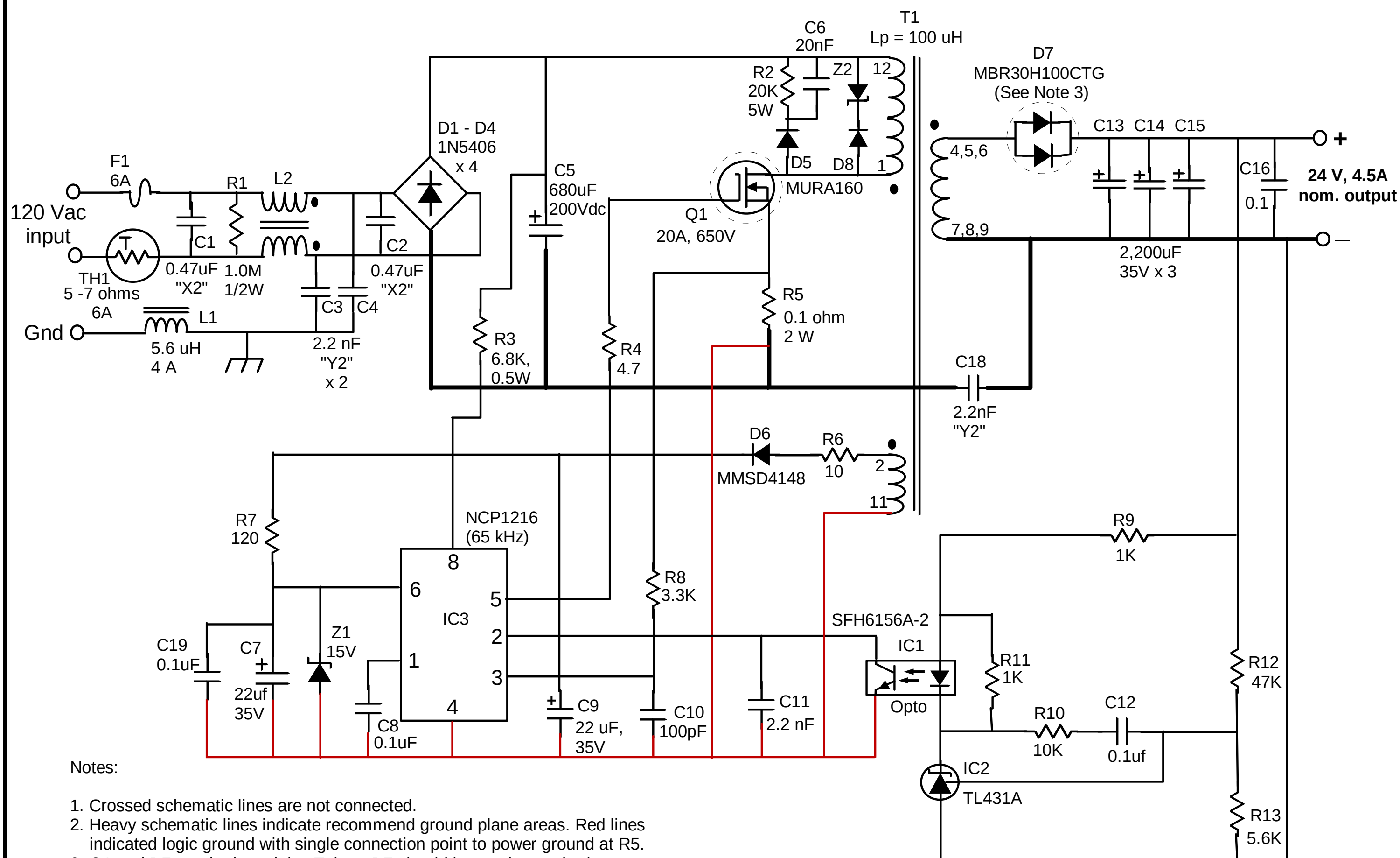
This application note evolved from a custom power supply design intended for driving a 24 V dc high torque motor. The motor required a 20+ amp start-up surge current with a 4 to 5 amp running current at 24 Vdc nominal. The starting surge duration was several seconds and an output droop of 15 V was acceptable during the peak of the surge. This required the supply to be able to supply a peak power of over 230 watts during the start-up surge. Although the power topology choice would have typically been a forward converter for this application, the short duration, high surge followed by a 100 W running power allowed the use of a less complex flyback topology. The flyback circuit operates in continuous conduction mode (CCM) during the motor starting surge period and reverts to discontinuous conduction mode (DCM) operation during normal steady state running operation.

This power supply design is applicable to similar motor and solenoid applications where a large momentary surge current is required followed by a lower level, steady state running current. In similar applications where the initial surge is only several milliseconds long, extra output capacitance can usually be added to the supply to handle the surge. In this case, however, the surge duration of several seconds would require excessive output capacitance and is not practical, so the main converter must be designed to handle the surge level.

Key Features

- 4.5 A continuous output with over 20 A surge capability with adjustability on the latter threshold
- Overcurrent protection and optional over temperature protection (see description)
- Input EMI filter for conducted emissions attenuation
- Thermistor input surge current limiting at turn-on
- Measured efficiency of 85% at 120 Vac at 4.5 A load
- Extremely simple design

Schematic



Notes:

1. Crossed schematic lines are not connected.
2. Heavy schematic lines indicate recommend ground plane areas. Red lines indicated logic ground with single connection point to power ground at R5.
3. Q1 and D7 require heatsinks. Tab on D7 should be used as cathode connection throught heatsink in addition to center pin.
4. R8 sets ramp compensation for IC3 during CCM operation.
5. R12 sets Vout.
6. D8 and Z2 is for optional ZVS clamp (not used on proto).
7. L1 is Coilcraft RFB0807-5R6L or equivalent.
8. L2 is Coilcraft F5593-AL or equivalent (1.2 mH, 4 A).

Figure 1: Schematic

Circuit Design

The schematic of the power supply circuit is shown in Figure 1. The design is a single-ended flyback topology using ON Semiconductor's NCP1216 current mode controller with a switching frequency of 65 kHz. Although this controller incorporates an internal dynamic self supply (DSS), which allows it to run directly from the high voltage dc bulk via R3 and Vcc capacitor C7, an auxiliary winding on T1 along with rectifier D6 and C9 is implemented to reduce quiescent input current when the supply is idling and/or at no load. Resistor R7 and zener Z1 protects the Vcc from potential transients during abrupt load steps on the output. The design of Figure 1 was intended for 120 Vac nominal input, however, universal input (90 – 270 Vac) is possible if Mosfet Q1 is replaced with a similar 800 volt rated device. It may also be advisable to place a small RC snubber network across output rectifier D7 and use a 150 volt rated Schottky diode to compensate for the increased voltage stress associated with the universal input voltage range.

The ac input section includes a common and differential mode EMI filter (C1 through C4, C18, L1 and L2), and NTC inrush limiting thermistor TH1. Conducted EMI emissions tests on the power supply prototype operating at the normal motor running current of 4 A demonstrated compliance with FCC Level A.

A voltage clamp network composed of C6, R2 and D5 was implemented to protect the main Mosfet Q1 from voltage spikes resulting from the leakage inductance of T1's primary, particularly during the surge period. The pc board layout also allowed for the use of an optional TVS clamp Z2 (and D8); however, for this particular design it was not required but is recommended to accommodate tolerance variations in the design of the flyback transformer and the associated leakage inductance. It should be noted that, for universal input, this additional clamping network will definitely be necessary, particularly during the high current surge interval. Needless to say, Q1 requires a small heat sink for both normal and surge operation. As long as the current surge interval is 5 seconds or less, the thermal time constant of the heatsink utilized for 100 watt operation will suffice. If extended surge operation is anticipated, or the surge interval is a significant fraction of the overall operational duty cycle, it is advisable to utilize a larger heatsink and/or implement a thermal sensor mounted on the heatsink to shut the supply down if a given temperature is exceeded. A close-on-rise thermostat connected across the optocoupler phototransistor (pins 3 and 4) would easily accomplish this.

Peak current sensing for the NCP1216's current mode control algorithm and overcurrent protection is implemented by sensing the peak Mosfet current across R5. The maximum current through the Mosfet is limited to 10 A using a 0.1 ohm value. This is the peak current level during the surge interval. During the normal motor running period, the peak current was measured at 3.75 A. Since the operational mode of the transformer becomes CCM (Continuous Conduction Mode) during the surge interval, it is necessary to provide slope compensation to the current sense signal to avoid the classic sub-harmonic instabilities associated with CCM when the duty cycle exceeds 50%, as it would in this case at a low input line of 90 Vac. This is accomplished by the simple addition of resistor R8 in the current sense line. C10 is added as a noise filter. The constant power characteristic of the CCM flyback circuit can be seen in the linearly decreasing overload slope of Figure 3 which displays the V/I output characteristic of the supply. Note that there is no actual provision for an extended "hard" short circuit, so the addition of the thermal switch mentioned above should suffice for protection. Another option would be to use the NCP1217 controller in lieu of the specified NCP1216. The NCP1217 does not contain DSS circuitry and solely requires the auxiliary Vcc winding on T1 for internal power. This feature can be used to compensate for excessive current at a chosen point on the V/I curve by adjusting the value of resistor R7 and the turns on the auxiliary winding of T1 such that, when the Vcc decays below IC3's undervoltage level during an overload (Vcc will track the output voltage), the control chip (and converter) will shut down and begin a re-start sequence. In this way, extreme overloads or short circuits will allow the circuit to protect itself in a "hiccup" overload mode when a certain point is reached on the V/I curve. With the NCP1217 implementation, it is essential that the maximum surge current of the load does not pull the Vcc to this level, otherwise unreliable motor starting will obviously occur.

The output rectifier section utilizes a 30 A, 100 V, TO-220 Schottky rectifier for D7 which is mounted on the same kind of heatsink as Q1. Sufficient output capacity (C13, 14, 15) is needed to keep the high capacitive ripple currents under control during the surge interval, and maintain reasonable output ripple during the normal running mode.

Output voltage sensing and regulation is accomplished by the "standard" TL431 programmable zener used as an error amplifier along with an optocoupler to interface with IC3's feedback pin 2. The output voltage is set by dividing the output down so as to achieve 2.5 V at the R12/R13 node when the output is at 24 volts. Feedback loop phase gain is set by C12 and R10.

Flyback Transformer Design

The design details of flyback transformer T1 are shown in Figure 2. Construction is on a common EE21 (lamination size) ferrite core with standard magnet wire. The key to optimum performance is strict adherence to the winding structure for minimal primary-to-secondary leakage inductance. Low leakage inductance will minimize voltage spikes and ringing and assure maximum power transfer during the surge interval. Since flyback transformers must be designed to handle the peak output power regardless of how short the duration may be, the primary inductance is necessarily quite low for this transformer to allow for the necessary peak current during the surge interval. Overall wire sizing and current handling capability were based on the 4 A normal steady state running mode. Since the surge was limited to a few seconds, the transformer's thermal time constant was sufficient to withstand the momentary high surge currents with little additional heating and minimal dc resistance loss. It should be noted that the flyback transformer could have been design for CCM operation throughout typical operating range, however, this would have required a higher inductance primary and hence more turns on both primary and secondary windings. The consequential higher copper loss, not to mention a more complex winding scheme and possibly larger ferrite core structure was judged unnecessary.

Project: 250 Watt high surge flyback power supply for motor/solenoid drive

Part Description: 24 Vout, 250 Watt flyback transformer (65 kHz)

Schematic ID: T1

Core Type: Ferroxcube E41/17/12 or Mag Inc #44317 (E21); 3C95 or P material

Core Gap: Gap for 105 uH nominal

Inductance: 95 to 115 uH across primary (pins 1 to 12)

Bobbin Type: Ferroxcube E21PCB1-12 or equivalent (horizontal pc mount, 12 pin)

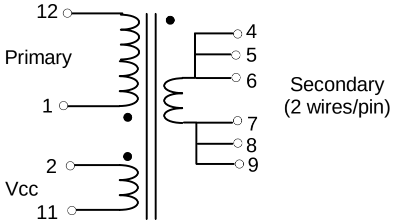
Windings (in order):

Winding # / type	Turns / Material / Gauge / Insulation Data
Primary (1 - 12)	25 turns of #24 HN magnet wire over one layer with winding ends cuffed with tape and 2 mm end margins. Insulate for 3 kV hipot to next winding. Self-leads to pins.
24 V Secondary (4,5,6 - 7,8,9)	4 turns of 6 strands of #24 HN flatwound over 1 layer (hexifilar) with 2 mm approximate end margins. Insulate for 3 kV hipot to next winding. Self-leads to pins with 2 wires per pin.
Vcc Winding (2 - 11)	3 turns #24 HN spiral wound over secondary with 6 mm end margins approximately (center winding). Add final tape insulation. Self-leads to pins.

Vacuum varnish final assembly.

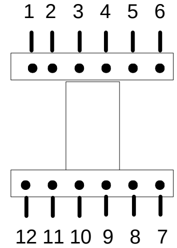
Hipot: 3 kV from Primary/Vcc to 24V Secondary for 1 minute

Schematic



Lead Breakout / Pinout

(bottom view facing pins)



Mesa Power Systems part # 13-1330
1-800-515-8540 (Escondido, CA)

Figure 2: Flyback Transformer Design Data

Prototype Performance

The prototype successfully handled the motor start-up and running conditions with power to spare. Momentarily stalled rotor tests indicated output currents over 30 A with no issues. Figure 3 shows the characteristic V/I curve of the supply with actual overcurrent limiting starting in the neighborhood of 8 A. The normal 4 A running efficiency at 120 Vac input was measured at 85%. As mentioned previously, conducted EMI compliance was consistent with FCC level A during the motor's normal run mode.

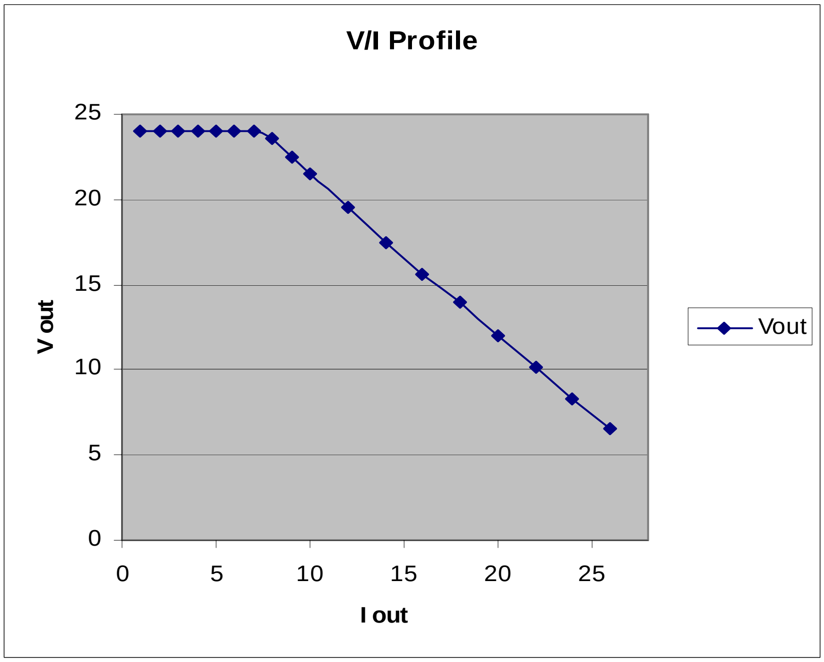


Figure 3: Output Voltage versus Current Profile

Additional collateral from ON Semiconductor

- NCP1216: Current Mode Controller Fixed Frequency Operation
- NCP1217: Current Mode Controller Fixed Frequency Operation
- TL431A: Programmable Precision Reference
- MURA160: 1A, 600 V Surface Mount Ultrafast Power Rectifier
- MBR30H100**:** 30A 100V H-Series Schottky Rectifier
- MMSD4148 (1N4148): 100 V Switching Diode
- Application Note AND8023: Implementing the NCP1200 in Low-Cost AC/DC Converters
- Application Note AND8069: Tips and Tricks to Build Efficient Circuits with NCP1200
- Design Note DN06038/D: NCP1217, 18 to 24 V, 85 W, Off-line PSU with Short Term, High Surge Current Capability

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