TND332/D
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ON Semiconductor®

GreenPoint™
From ON Semiconductor

8 W Power Supply for DTA (Digital−to−Analog Converter Box)

Reference Design Documentation Package

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http://onsemi.com

TECHNICAL NOTE

1 Overview

This reference document describes a built-and-tested, GreenPoint™ solution for an 8 W Digital-to-Analog converter box power supply.

The power supply design is build around ON Semiconductor's NCP1308 Current-Mode Controller, on the primary side, using Free Running Quasi-Resonant.

The secondary side offers three outputs (5 V, 3.3 V and 1.8 V). The 3.3 V and 1.8 V are derived from the 5 V output by using the NCP1595 in a buck (step-down) DC-DC topology with synchronous rectification.

Figure 1 shows a simplified block diagram of the reference design circuit.

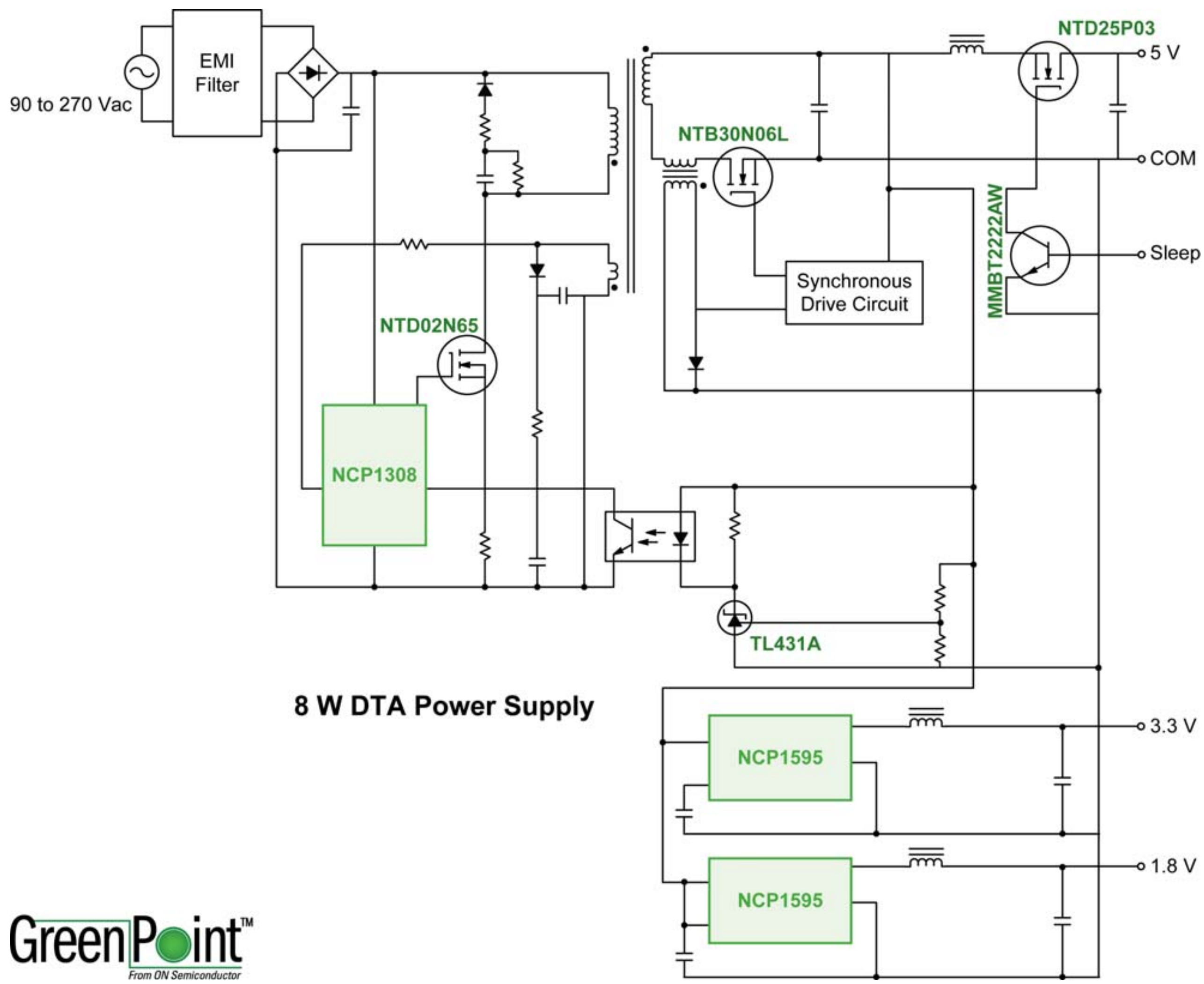


Figure 1. 8 W Power Supply for Digital-to-Analog Converter Box

2 Introduction

As a result of a bill passed in Congress, at midnight on February 17, 2009, all full-power television stations in the United States will stop broadcasting in analog and switch to 100% digital broadcasting. After that date, conventional CRT TVs with analog-NTSC tuners will be unable to receive over-the-air broadcasts. Anyone who watches TV via "rabbit ears" or a rooftop antenna (as opposed to cable or satellite), and whose TV does not have a built-in or separate digital tuner, will stop receiving programs on that TV.

For most owners of new HDTVs, getting over-the-air high-definition programming will be as simple as putting up a high definition antenna. In effect, most TVs that can now display HDTV are sold with built-in ATSC (Advanced Television Systems Committee) tuners and are required to receive high-definition as well as lower-resolution digital broadcasts over the air.

Because the switch-off of analog TV broadcasts would deprive many viewers of their only source of television, Congress also created a subsidy program. Run by the government's National Telecommunications and Information Administration (NTIA), this program will provide coupons which can be used to pay for a Digital-to-Analog (DTA) converter box. A DTA box can receive digital television broadcasts and converts them into standard-definition programming to be viewed on conventional CRT TVs with analog-NTSC tuners.

More information on the over-the-air broadcasting television method from analog to digital can be found at www.dtvtransition.org.

More information on DTAs and the coupon program: www.ntia.doc.gov.

3 AC-DC Power Supply Requirements

3.1 Definitions

The version 1.1 ENERGY STAR® guidelines for DTAs (more details can be found on the web site http://www.energystar.gov/index.cfm?c=dta.pr_dta) provide the following definitions:

- ***DTA***: Stand-alone device that does not contain features or functions except those necessary to enable a consumer to convert any channel broadcast in the digital television service into a format that the consumer can display on television receivers designed to receive and display signals only in the analog television service, but may also include a remote control device. In addition to meeting the requirements laid out in this Version 1.1 ENERGY STAR specification, DTAs must also meet the minimum technical requirements laid out in the Technical Appendices of the National Telecommunications and Information Administration's (NTIA) final rule-making on its Digital Television Converter Box Coupon Program (see http://www.ntia.doc.gov/ for the final rulemaking).
- ***On Mode***: A state in which the DTA is actively delivering its principal functions and some or all of its applicable secondary functions.
- ***Off Mode***: A state in which there is negligible or no power consumption
- ***Sleep Mode***: A state in which the device has greater power consumption, capability, and responsiveness than it does in the Off state, and has less (or similar) power consumption, capability and responsiveness than it does in the On state.

3.2 Energy Efficiency Specification

Mode	Input Power Consumption under Test Conditions Effective Date: Jan. 31, 2007
On Mode	≤ 8 watts
Sleep Mode	≤ 1 watts (NTIA's requirement is 2 W)

1. Source: ENERGY STAR and NTIA

ENERGY STAR requirements have set a maximum input power to the DTA box to be no more than 8 W. This low power requirement puts severe constraints on the DTA's efficiency and obviously on the power supply's efficiency. At single digit low power levels such as this, achieving efficiencies in the 70 percent range is difficult because of the inherent low voltage outputs required for the DTA's ASIC circuitry (typically 5 volts and below), and the significant fraction of the total power that the power supply's internal quiescent current represents.

4 DTA Power Supply Specification

The reference design described in this document provides 5.0 V, 3.3 V, and 1.8 V outputs with universal AC input and an efficiency of greater than 72%. Other output voltages are possible with simple changes in the sensing networks on the 3.3 and 1.8 V outputs. The design also provides an option for inhibiting the 5 V output if “sleep mode” is required. The power supply’s main converter is designed around ON Semiconductor’s NCP1308 current mode controller and an external Mosfet in a quasi−resonant (QR) flyback topology. The 5 volt output utilizes a synchronous rectifier Mosfet and the two lower voltage output converters are implemented using the NCP1595 monolithic, synchronous buck regulator operating at 1 MHz. The 5 V output also functions as a dc source for the two buck regulators. This particular combination of parts provides a simple yet effective triple output switcher with an effective power output of approximately 6 watts depending on the output voltage and current combination and the subsequent overall system efficiency (see efficiency results in Table 1). Typical protection functions such as over−current and over−voltage are included in addition to an input conducted EMI filter.

Input: 90 to 265 Vac, 50/60 Hz, two−wire input (line and neutral)

Input Power (Sleep mode): 8 W max (as specified by Energy Star)

Standby Input Power (no load): Less than 200 mW

Input Fuse: 1 amp

Inrush Limiting: 5 ohms approximately

Input Filter: Common and differential mode conducted EMI filter

Outputs (also see Table 1)

- 5 V @ 1A
- 3.3 V @ 1A
- 1.8 V @ 1A
- Total output power not to exceed approximately 6 watts

Regulation: Better than ±3% for all outputs

Output Ripple (Vpk/pk): 30 mV max on any output

Efficiency: Better than 72%; actual value will depend on output voltage and current combinations (see efficiency results in Table 1)

Protection: Over−current and over−voltage

Temperature Range/Cooling: 0 to 55°C; convection cooled

Control Features: Inhibit of 5 Vout for sleep mode operation (optional)

5 Circuit Operation

Referring to the power supply circuit schematic of Figure 2, the operation of the supply is as follows: Inrush current into the bulk capacitor C3 is limited at supply turn–on by Resistor R1 and the winding resistance of EMI filter inductor L1. This inductor along with “X” capacitors C1 and C2 form a differential mode EMI filter while the winding–to–winding leakage inductance of L1 and C8 comprise a common mode filter. The AC input is full–wave rectified by D1 – D4 and produces a “bulk” dc bus level of 1.4 x Vac rms across C3.

The quasi–resonant flyback converter is implemented using ON Semiconductor’s quasi–resonant NCP1308 current mode controller (U1) and a 2 A, 650 V Mosfet (Q7). This controller contains all the internal circuitry for self–protection from over–current and over–voltage conditions. Although the control chip can be self–powered due to the inclusion of ON’s patented dynamic self supply (DSS) feature, an auxiliary winding on the flyback transformer T1 and the associated components of D7, C5, C6, and R3 provide a “bootstrapped” Vcc supply for the IC. The bootstrapped Vcc significantly lowers dissipation in U1 during normal operation and reduces the standby or no–load power consumption of the supply to less than 200 mW. Resistor R3 limits the Vcc voltage and provides a convenient means for setting the OVP trip level in the chip in the event of an optocoupler or open sense loop failure.

The snubber network of D5, C4, R20 and R21 provides voltage spike suppression for the external Mosfet Q7. This voltage spike is generated by the leakage inductance of the primary winding of T1 and can be destructive if not properly managed. Such snubber networks are essential in simple, single switch flyback circuits such as this one. Note the use of a conventional 50/60 Hz PN diode for D5 and the inclusion of a resistor in series with it. This arrangement, along with C4, not only suppresses the voltage spike at Mosfet turn–off, but also dampens the resonant ringing associated with T1’s leakage inductance and C4.

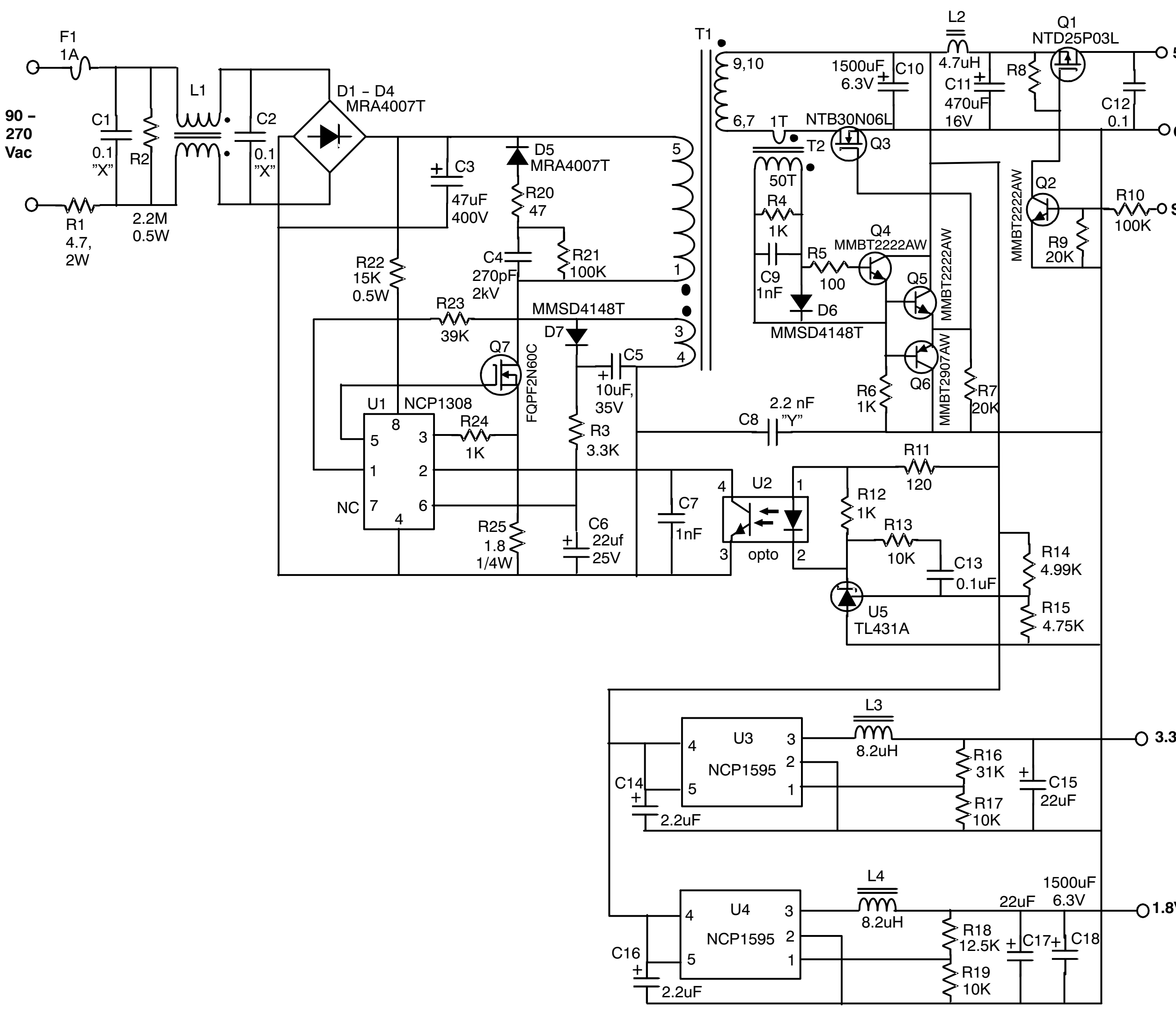


Figure 2.

6 Transformer Design

The design of flyback transformer T1 requires the minimizing of typical transformer parasitic parameters such as leakage inductance and winding capacitance. This becomes increasingly difficult for small transformer core structures due to the required increased primary and secondary turns as the core's cross sectional area decreases with overall core size. The balance between sufficient turns to limit the magnetic flux density (< 3 kilogauss) versus increased leakage inductance can become tricky in small cores. In this design an EF−16 core was used and it was possible to get the primary wound with just 2 layers and the Vcc winding and 5 volt secondary in just one layer each. Tests indicated that the voltage spike generated by the resultant leakage inductance was of minimal energy and the snubber network of D5, C4, R20, and R21 was adequate to suppress the voltage spike with minimal impact on the efficiency. Figure 3 gives the details of the transformer design.

The main secondary output of T1 produces 5 volts with Q3 and the associated circuitry of T2, C9, R4 thru R7, Q4 thru Q6, and D6 comprising a synchronous flyback rectifier for maximum efficiency. When the Mosfet Q7 switches off, the secondary flyback current charging output capacitor C10 is sensed by the small current sense transformer T2 which develops sufficient voltage across R4 to turn on the complementary driver circuit of Q5 and Q6. This driver in turn switches the gate of Q3 on which functions as a very low forward voltage drop rectifier for the 5 volt secondary. When no secondary current flows, Q3 is in an off−state and reverse blocking mode. For reduced output ripple and noise an addition filter composed of inductor L2 and C11 is provided. In addition, P−Mosfet Q1 and driver transistor Q2 are included (optional) to allow shutdown of the 5 volt output for "sleep mode" or similar requirement if needed to reduce power drain to an absolute minimum.

The 5 volt output is regulated by sensing the voltage across primary output capacitor C10 and dividing this voltage down via R14 and R15 to match the 2.5 volt internal reference of programmable zener U5 (TL431A). U5 functions as an error amplifier and provides feedback to the primary side controller U1 through optocoupler U2. Control loop phase and gain compensation is provided by C13 and R13 while C7 provides high frequency noise decoupling for the feedback input of U5.

The other two low voltage outputs (3.3 V and 1.8 V) are derived from the 5 volt output using a couple of NCP1595 monolithic, synchronous buck regulators (U3 and U4). These buck converters switch at 1 MHz, so very small output inductors (L3 and L4) and capacitors (C15 and C17) are needed. Because of the very high input and output ripple frequency of these buck chips, low impedance multilayer ceramic capacitors should be used for C14 through C17. C18 is a standard aluminum electrolytic and was required for minimal output voltage droop when the particular DTA microprocessor that this supply was tested with started up from a sleep mode. A large output capacity was not needed for the 3.3 V output in this test application but is an option to be considered if it is the main power source for the DTA's microprocessor. For voltages other than the selected 3.3 V and 1.8 V levels, one merely needs to modify the voltage sense divider network trim resistor (R17 or R19) to provide the correct feedback level to the buck controller's sense input (see NCP1595 data sheet at www.onsemi.com website for device application details).

MAGNETICS DESIGN DATA SHEET

Project / Customer: ON Semiconductor − DTA power supply, QR Version

Part Description: 6 watt flyback xfmr, QR version − Rev. 1

Schematic ID: T1

Core Type: EF16 (E16/8/5); 3C95 material (Ferroxcube) or similar

Core Gap: Gap for 1.75 mH inductance

Inductance: 1.75 mH +/−10%

Bobbin Type: 8 pin horizontal mount for EF16

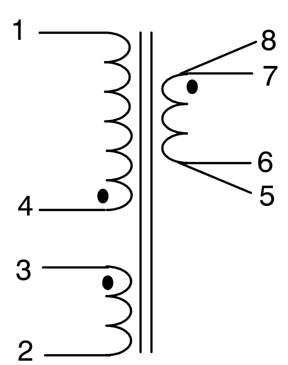
Windings (in order):

Winding # / type	Turns / Material / Gauge / Insulation Data
Vcc/Boost (3 − 2)	10 turns of #34HN spiral wound over 1 layer. Insulate with 1 layer of tape (1000V insulation to next winding)
Primary (4 − 1)	90 turns of #34HN over 2 layers (45 turns/layer); Insulate for 3 kV to the next winding with tape.
5V Secondary (7,8 − 5,6)	6 turns of 2 strands of #26HN wound bifilar over one layer with 2 mm end margins and cuffed ends. Self leads to pins as shown below. Insulate with final layer of tape.

Vacuum varnish assembly

Hipot: 3 kV from boost/primary to secondary

Schematic



Lead Breakout / Pinout

(Bottom View − facing pins)

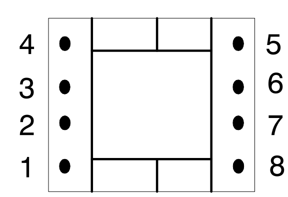


Figure 3.

7 Test Results

7.1 Active Mode Efficiency

Since efficiency and circuit simplicity were the primary goals in this design, and the necessary voltage and current configurations for specific DTA circuit applications will obviously vary, the efficiency was measured at several different load configurations. The results are shown in Table 1. As would be expected the configuration with the greatest amount of loading on the 5 V output resulted in the highest overall efficiency.

Table 1. Power Supply Efficiency versus Loading Configuration

Load Configuration	1.8 V Load	3.3 V Load	5 V Load	P_{out} Total	P_{in} Total	Efficiency
# 1	1.0 A	0.5 A	0.4 A	5.45 W	7.46 W	73%
# 2	0.5 A	1.0 A	0.25 A	5.45 W	7.45 W	73%
# 3	0.5 A	0.25 A	0.75 A	5.47W	7.29 W	75%

7.2 Sleep Mode and Off Mode

- Sleep mode: ≤720 mW input power
- Off mode (no load power): ≤200 mW input power

7.3 Waveforms

The output ripple for a 1 amp load on the 5 volt channel is shown in Figure 4 while Figure 5 displays the ripple on the 1.8 volt output with a load of 1 amp. Although not shown, the ripple on the 3.3 volt output with a 1 amp load was essentially identical to that on the 1.8 volt channel. Measurements were taken at 120 Vac input and a total power load of approximately 5.5 watts. Operating at 240 Vac input had negligible effects on the output ripple and efficiency.

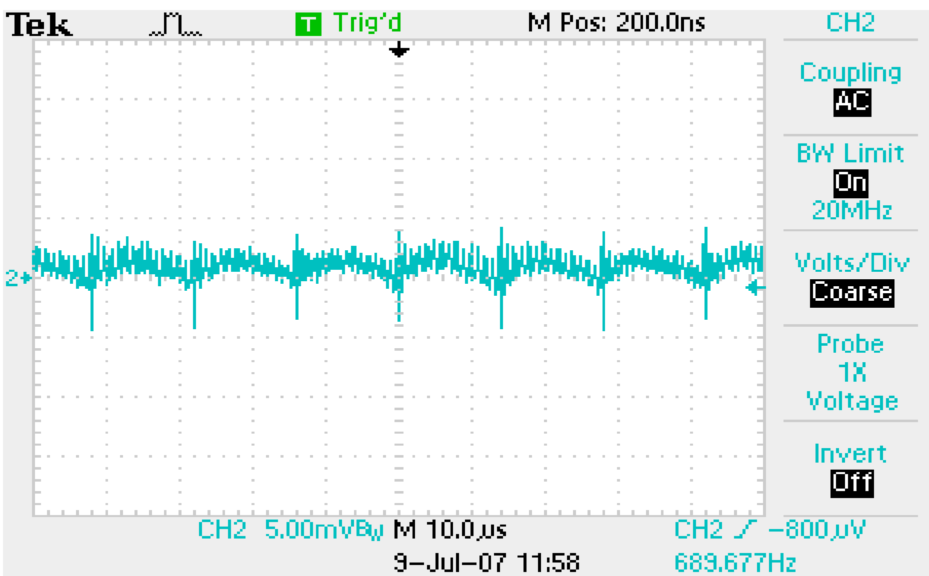


Figure 4. 5.0 Volt Output Ripple @ 1 A

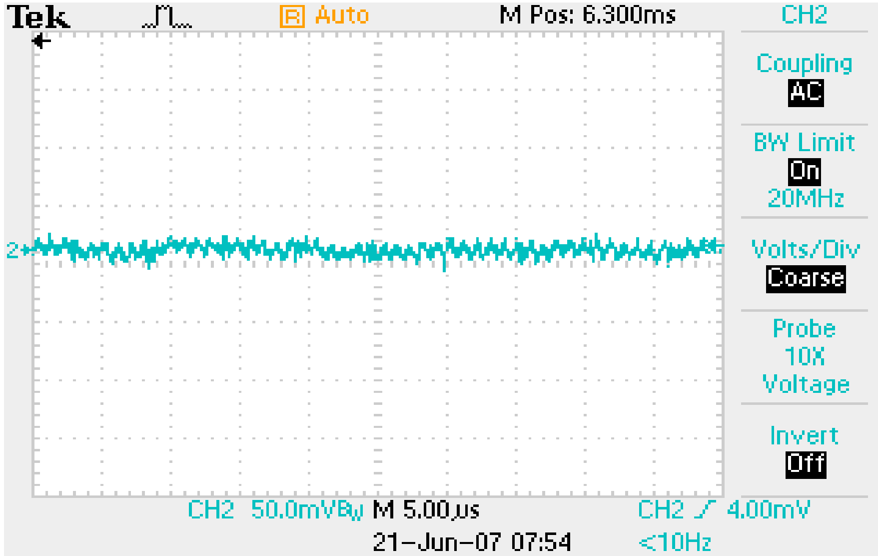


Figure 5. 1.8 Volt Output Ripple @ 1 A

Figure 6 displays the Mosfet's drain voltage profile with 120 Vac input and a total load of 5.5 watts. Note that from the waveform at this particular load, the circuit is operating in discontinuous conduction mode where the Mosfet switches back on in one flyback ring-out cycle after core reset. Note also that the Mosfet turn-on occurs at the 2nd valley point of the ring-out waveform. Switching at this point allows for very efficient quasi-resonant turn-on when the voltage on the Mosfet drain is minimum. The high frequency ringing at the beginning of the flyback pulse is caused by the transformer's leakage inductance resonating with the Mosfet's drain-to-source capacitance and any stray transformer winding capacitance. The snubber network of D5, C4, R20 and R21 acts to suppresses the peak voltage excursion and dampens the residual ringing.

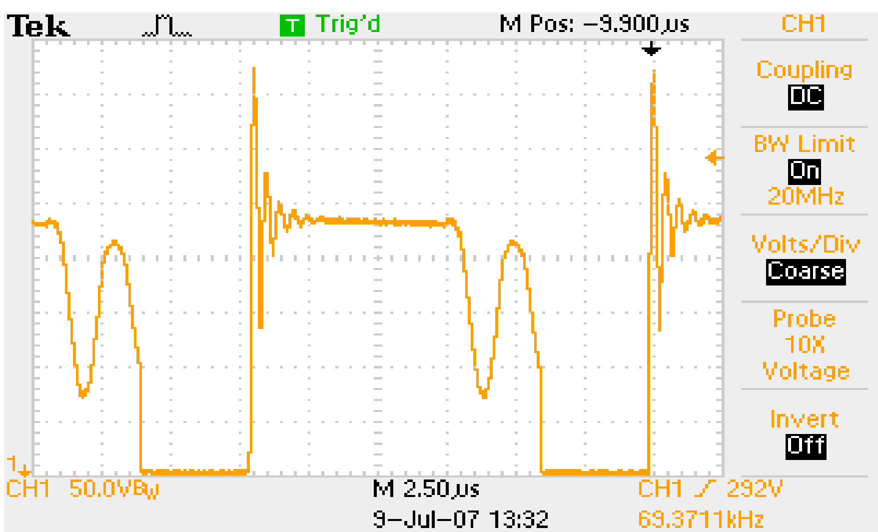


Figure 6. Mosfet Drain – Switching Waveform Profile

8 Additional Comments and Recommendations

Although conducted EMI was not tested on this particular reference design, the same input filter design has been used in other similar ON Semiconductor low power flyback reference designs which do pass FCC Level B for conducted EMI.

For best thermal management, the NCP1595's DFN surface mount packages (U3 & U4) should be properly soldered to extended copper clad areas of the pc board, and this is particularly important for higher current outputs on the NCP1595 buck devices. Consult the respective device data sheets for more information on this.

The design of current sense transformer T2 is not necessarily critical and any small ferrite core with a 30:1 to a 50:1 turns ratio can be utilized. The design of T1, however, the main flyback transformer, is critical to the efficiency and optimum performance of the power supply. Re-designing the transformer in a smaller core structure (smaller core cross sectional area Ae) is not recommended. Using cores with a larger Ae can result in less overall turns and a possible incremental improvement in the efficiency, however the specified inductance value should be maintained for proper circuit operation.

It is recommended that the data sheets for the ON Semiconductor NCP1308 and NCP1595 monolithic controllers be thoroughly studied when applying this reference design.

9 Bill of Materials

Part	Qty	ID	Description	Comments
SEMICONDUCTORS				
MRA4007T3G	5	D1, 2, 3, 4, 5	1 A, 800 V diode	ON Semiconductor
MMSD4148T1	2	D6, D7	100 mA signal diode	ON Semiconductor
MMBT2222AWT1	3	Q2, 4, 5	500 mA, 40 V NPN transistor	ON Semiconductor
MMBT2907AWT1	1	Q6	500 mA, 40 V PNP transistor	ON Semiconductor
NCP1308	1	U1	Ouasi-resonant PWM controller	ON Semiconductor
FQPF2N60C	1	Q7	2 A, 600 V Mosfet	Fairchild
NTD25P03LG	1	Q1	P-channel Mosfet, 30 V	ON Semiconductor
NTB30N06LT4G	1	Q3	N-channel Mosfet, logic level	ON Semiconductor
NCP1595AMNR2G	2	U3, U4	Synchronous buck regulator	ON Semiconductor
Optocoupler	1	U2	SFH6156A-4 (4 pin) or similar	Vishay
TL431ACD (SOIC-8)	1	U5	Programmable zener	ON Semiconductor
CAPACITORS				
“X” cap, (box package)	2	C1, C2	100 nF “X2” capacitor, 270 Vac	Vishay
“Y” cap, disc package	1	C8	2.2 nF “Y2” cap, 270 Vac	Vishay
Ceramic cap, disc	1	C4	270 pF, 2 kV capacitor (snubber)	Vishay
Ceramic cap, monolythic	2	C12, C13	0.1 μF, 50 V ceramic cap	Vishay
Ceramic cap, monolythic	2	C14, C16	2.2 μF, 16 V low impedance ceramic	Vishay
Ceramic cap, monolythic	2	C15, C17	22 μF, 10 V, multilayer	Vishay
Ceramic cap, monolythic	2	C7, C9	1 nF, 50 V ceramic cap	Vishay
Electrolytic cap	1	C11	470 μF, 6.3 V	UCC, Rubycon
Electrolytic cap	1	C3	47 μF, 400 Vdc	UCC, Rubycon
Electrolytic cap	2	C10, C18	1500 μF, 6.3 V (low ESR)	UCC, Rubycon
Electrolytic cap	1	C5	10 μF, 35 V	UCC, Rubycon
Electrolytic cap	1	C6	22 μF, 25 V	UCC, Rubycon
RESISTORS				
Resistor, 2 W	1	R1	4.7 ohm, 2 W ceramic, axial lead	Ohmite
Resistor, 1/2 W	1	R2	1 Meg, 1/2 W, axial lead, metal film	Ohmite
Resistor, 1/2 W	1	R22	15 K, 1/2 W, 1210 SMD	5% SMD (1210)
Resistor, 1/4 W	1	R4	1 K	1% SMD (1206)
Resistor, 1/4 W	1	R25	1.8 ohm, 1/4 W, 1206 SMD	5% SMD (1206)
Resistor, 1/4 W	1	R21	82 K	5% SMD (1206)
Resistor, 1/8 W	3	R6, R12, R24	1 K	1% SMD (1206)
Resistor, 1/8 W	1	R23	39 K	1% SMD (1206)
Resistor, 1/8 W	1	R5	100 ohms	1% SMD (1206)
Resistor, 1/8 W	1	R3	3.3 K	1% SMD (1206)
Resistor, 1/8 W	1	R7, R9	20 K	1% SMD (1206)
Resistor, 1/8 W	1	R11	120 ohms	1% SMD (1206)
Resistor, 1/8 W	2	R8, R10	100 K	1% SMD (1206)
Resistor, 1/8 W	3	R13, 17, 19	10 K	1% SMD (1206)
Resistor, 1/8 W	1	R14	4.99 K	1% SMD (1206)
Resistor, 1/8 W	1	R15	4.75 K	1% SMD (1206)

9 Bill of Materials

Part	Qty	ID	Description	Comments
RESISTORS				
Resistor, 1/8 W	1	R16	31 K	1% SMD (1206)
Resistor, 1/8 W	1	R20	47 ohms	1% SMD (1206)
Resistor, 1/8 W	1	R18	12.5 K	1% SMD (1206)
MISCELLANEOUS				
Fuse (TR5 type)	1	F1	1 to 1.5 A, 250 Vac	Bussmann
MAGNETICS				
EMI Inductor	1	L1	BU16-4530R5BL	Coilcraft
Choke, 4.7 μH, 4A	1	L2	RFB0807-4R7L	Coilcraft
Choke, 8.2 μH, 3 A	2	L3, L4	RFB0807-8R2L	Coilcraft
Flyback Transformer (custom)	1	T1	Primary L = 1.75 mH	See Figure 3
Current sense transformer (1:50)	1	T2	T6522-AL	Coilcraft

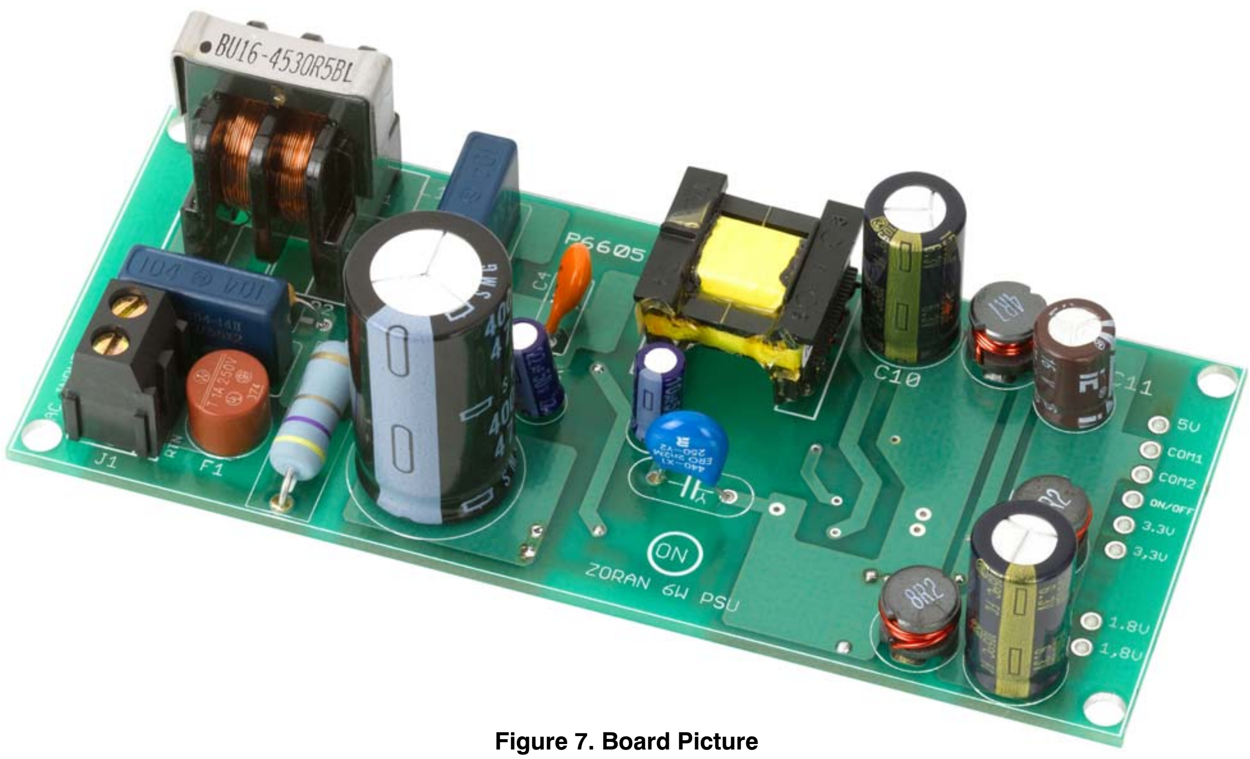


Figure 7. Board Picture

10 Appendix

References:

- ENERGY STAR: Digital-to-Analog Converter Boxes http://www.energystar.gov/index.cfm?c=dta.pr_dta
- National Telecommunications and Information Administration (NTIA): Digital Television Transition and Public Safety Act of 2005 http://www.ntia.doc.gov/otiahome/dtv/index.html http://www.ntia.doc.gov/

Additional Collateral from ON Semiconductor:

- NCP1308: Current-Mode Controller for Free Running Quasi-Resonant Operation
- NCP1595: 1.5 A Synchronous Converter with 5 V input
- MMBT2222AW: General Purpose Transistor NPN
- MMBT2907AW: General Purpose Transistor PNP
- NTD25P03L: Power MOSFET 25 A, 30 V Logic Level P-Channel in DPAK
- NTB30N06L: Power MOSFET 30 Amps, 60 Volts, Logic Level
- TL431A: Programmable Precision Reference
- MMSD4148/D: 100 V Switching Diode
- Design note DN06008/D: NCP1308: ±18 V Dual Output Power Supply
- Design note DN06029/D: NCP1308_LM2575: Universal Input, 50 W, 5 Output quasi-resonant flyback converter
- Application Note AND8112/D: A Quasi-Resonant SPICE Model Eases Feedback Loop Designs
- Application Note AND8127/D: Implementing NCP1207 in QR 24 W AC-DC Converter with Synchronous Rectifier
- Application Note AND8129/D: A 30 W Power Supply Operating in a Quasi-Square Wave Resonant Mode

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