TND329/D
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5 W Cellular Phone CCCV (Constant Current Constant Voltage) AC−DC Adapter

Reference Design Documentation Package

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ON Semiconductor®

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TECHNICAL NOTE

1 Overview

This reference document describes a built-and-tested, GreenPoint™ solution for a cellular phone Constant Current Constant Voltage (CCCV) AC-DC adapter. This design is intended for isolated, low power, universal input off-line applications where a constant current/constant voltage output (CCCV) is required for charging NiCd, NiMH, Lithium-ion or similar batteries. Typical applications would include cell phone chargers or cordless phone chargers.

The reference design circuit consists of one single-sided printed circuit board designed to fit into a standard cell phone adapter plastic case.

As shown in Figure 1, the reference design offers a simplified cell phone adapter power supply solution, where by judicious choice of design tradeoffs, optimum performance is achieved at minimum cost.

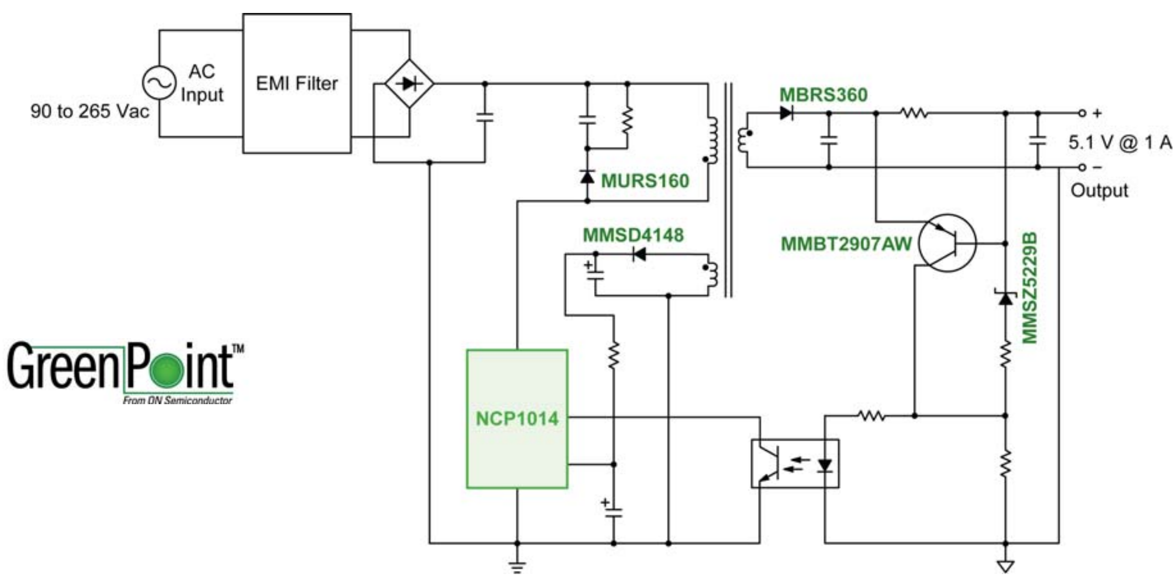


Figure 1. 5 W CCCV AC-DC Adapter

2 Introduction

Cell phones have become an ubiquitous device in our life. In some developed countries, the percentage of penetration of cell phones has reached almost 100% of the population. With the growth of cell phones has come the proliferation of small wall plug-in ac-dc adapters required for charging the batteries (NiCd, NiMH, or Lithium-ion) of the cell phone. A typical household will have anywhere from 4 to 10 ac-dc adapters. In most households, these adapters remain plugged in the socket continuously drawing power from the mains, even though no phone may be attached to the adapter. For this reason, the ac-dc adapter must be designed in such a way that its power consumption in standby (no-load) mode is very low. It is estimated that, on average, 25% of the energy that passes through power supplies does so during standby-mode (Source: NRDC).

3 Cell Phone AC–DC Adapter Requirements

The above paragraph showed the importance of reducing the standby power. Not only the power consumption of a cell phone ac–dc adapter in standby mode has to be very low but the efficiency of the adapter, when it is charging the cell phone batteries, has to be very high. High activemode efficiency saves energy when electronic devices are 'active', which are the times when they consume the most energy. (Examples: TV is turned on; computer is being used to play a video game.) It is estimated that 75% of the energy that passes through power supplies does so during active–mode (Source: NRDC).

3.1 Regulatory Requirements for Standby (no–load) Power Consumption and Active Mode Efficiency

Several regulatory bodies around the world address low standby power consumption and efficiency in active mode for external power supply (EPS). These requirements target two issues:

- Get rid of the losses in a no–load situation (e.g.: when the ac–dc adapter is plugged in even when it is not connected to the cell phone).
- Achieve good average active mode efficiency during various active mode load conditions (25%, 50%, 75% and 100%).

Many regulations have been proposed around the world. Hereafter is the list of some of the most important ones:

ENERGY STAR®: applicable in the US and international partners
http://www.energystar.gov/index.cfm?c=ext_power_supplies.power_supplies_consumers

Nameplate Output Power (P_{no})	**Minimum Average Efficiency in Active Mode** (expressed as decimal)
ENERGY EFFICIENCY CRITERIA FOR ACTIVE MODE	
0 to < 1 Watt	≥ 0.49 * P_{no}
> 1 and ≤ 49 Watts	≥ [0.09 * Ln(P_{no})] + 0.49
> 49 Watts	≥ 0.84
ENERGY CONSUMPTION CRITERIA FOR NO LOAD	
0 to <10 Watts	≤ 0.5 Watt
≥ 10 to ≤ 250 Watts	≤ 0.75 Watt

California Energy Commission: Effective January 1, 2007

Nameplate Output	Minimum Efficiency in Active Mode
0 to < 1 Watt	0.49 * Nameplate Output
> 1 and ≤49 Watts	[0.09 * Ln(Nameplate Output)] + 0.49
> 49 Watts	0.84
	Maximum Energy Consumption in No–Load Mode
0 to <10 Watts	0.5 Watt
≥10 to ≤ 250 Watts	0.75 Watt

Where Ln (Nameplate Output) = Natural Logarithm of the nameplate output expressed in Watts

Effective July 1, 2008

Nameplate Output	Minimum Efficiency in Active Mode
0 to < 1 Watt	0.5 * Nameplate Output
> 1 and ≤ 51 Watts	[0.09 * Ln(Nameplate Output)] + 0.5
> 51 Watts	0.85
	Maximum Energy Consumption in No–Load Mode
Any output	0.5 Watt

Where Ln (Nameplate Output) = Natural Logarithm of the nameplate output expressed in Watts

European Union's Code of Conduct, version 2, November 24, 2004

No–load Power Consumption

Rated Output Power	No–load Power Consumption	
	Phase 1 (Jan. 1, 2005)	**Phase 2** (Jan. 1, 2007)
> 0.3 W and < 15 W	0.30 W	0.30 W
> 15 W and < 50 W	0.50 W	0.30 W
> 50 W and < 60 W	0.75 W	0.30 W
> 60 W and < 150 W	1.00 W	0.50 W

Energy–Efficiency Criteria for Active Mode for Phase 1 (for the period January 1, 2005 to December 31, 2006)

Rated Output Power	Minimum Four Point Average (see Annex) or 100 % Load Efficiency in Active Mode
0 < W < 1.5	30
1.5 < W < 2.5	40
2.5 < W < 4.5	50
4.5 < W < 6.0	60
6.0 < W < 10.0	70
10.0 < W < 25.0	75
25.0 < W < 150.0	80

Energy–Efficiency Criteria for Active Mode for Phase 2 (valid after January 1, 2007)

Nameplate Output Power (P_{no})	**Minimum Four Point Average (see Annex) or 100 % Load Efficiency in Active Mode** (expressed as a decimal) (Note 1)
0 < W < 1	$\geq 0.49 * P_{no}$
1 < W < 49	$\geq [0.09 * Ln(P_{no})] + 0.49$
49 < W < 150	≥ 0.84 (Note 2)

1. "Ln" refers to the natural logarithm. The algebraic order of operations requires that the natural logarithm calculation be performed first and then multiplied by 0.09, with the resulting output added to 0.49. An efficiency of 0.84 in decimal form corresponds to the more familiar value of 84% when expressed as a percentage.
2. Power supplies that have a power factor correction (PFC) to comply with IEC61000–3–2 (above 75 W input power) have a 0.04 (4%) allowance, accordingly the minimum on mode load efficiency (100% or averaged) is relaxed to 0.80 (80%).

Korea:

- External Power Supply – No load: 0.8 W
- Battery Charger – No load: 0.8 W

Worldwide legislation for EPS (external power supplies)

Regulatory Agency/ Organization	Country/State Affected	Implementation Date	Compliance Required (Mandatory or Voluntary)	Comments
ENERGY STAR	United States	January 1, 2005	Voluntary	http://www.energystar.gov/index.cfm?c=ext_power_supplies.power_supplies_consumers
European Union	Europe	January 1, 2005	Voluntary	http://re.jrc.ec.europa.eu/energyefficiency/html/standby_initiative_External%20Power%20Supplies.htm
China Standard Certification Center (CSC, ex–CECP)	China	January 1, 2005	Voluntary	Harmonized with ENERGY STAR, http://www.cecp.org.cn/englishhtml/hlproductlist1.asp
California Energy Commission	California	January 1, 2007	Mandatory	http://www.energy.ca.gov/appliances/index.html
Australia Green-house Office (AGO)	Australia, New Zealand	October 1, 2008	Mandatory	Harmonized with ENERGY STAR, http://www.energyrating.gov.au/eps2.html
Arizona	Arizona	January 2008	Mandatory	Source: http://www.standardsasap.org
Massachusetts	Massachusetts	January 2008	Mandatory	Source: http://www.standardsasap.org
New York	New York	January 2008	Mandatory	Source: http://www.standardsasap.org
Oregon	Oregon	January 2008	Mandatory	Source: http://www.standardsasap.org
Rhode Island	Rhode Island	January 2008	Mandatory	Source: http://www.standardsasap.org
Vermont	Vermont	January 2008	Mandatory	Source: http://www.standardsasap.org
Washington	Washington	January 2008	Mandatory	Source: http://www.standardsasap.org

3. Sources: www.psma.com, www.standardsasap.org

4 Cell Phone AC–DC Adapter Specification

For cell phone OEM manufacturers, the ac–dc adapter is a commodity. So, they impose their own stringent specifications and de–rating guidelines while requiring low costs. The key performance criteria for adapters are:

- Power density (driven by package size requirements)
- Safety
- Low case temperature

Also, since business travelers carry their cell phones around the world, all of the ac–dc adapters for cell phones are designed to cope with universal mains voltage: 90 Vac to 270 Vac, 47–63 Hz.

Input: 90 to 270 Vac, 50/60 Hz

Output: 5 Vdc ±2% at 1.0 A continuous (5 W); constant voltage/constant current

Voltage Regulation: < 2% line and load combined

Current Regulation: < 10% I_{in} and load combined

Output Ripple: Less than 100 mV p/p

Average Efficiency: > 0.09 * Ln (5) + 0.09 = 63.5% (per ENERGY STAR)

Standby (no-load) power consumption < 300 mW

Operating Temperature: 0 to 50°C

Cooling: Convection

Input Protection: 18 ohm inrush limiting resistor

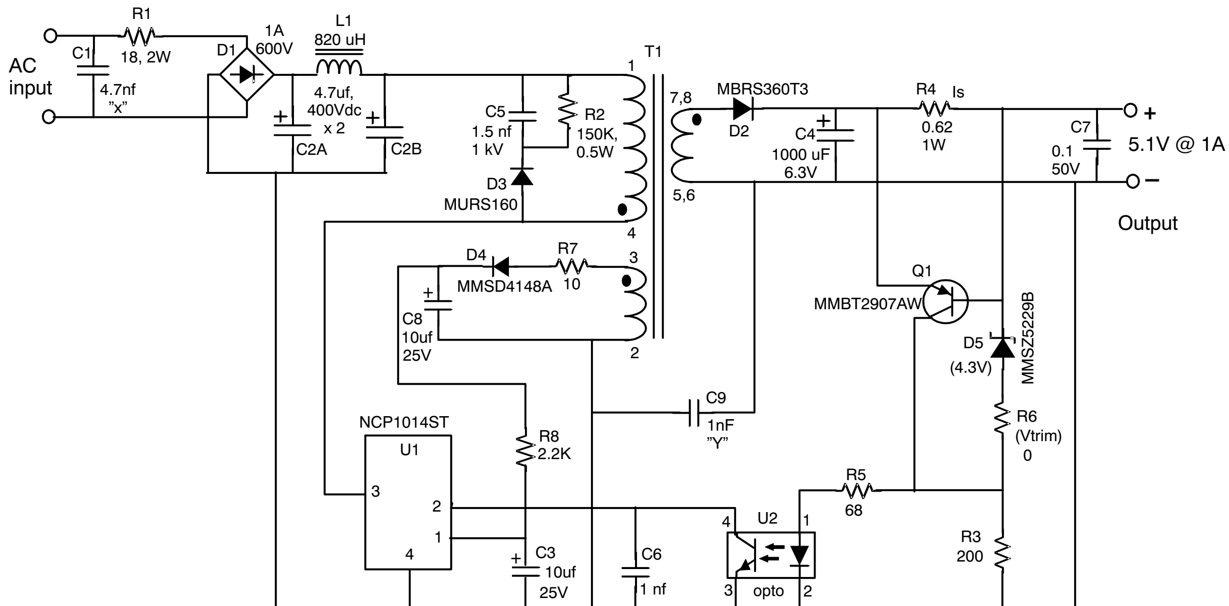
Output Protection: Over–current, over–voltage, and over–temperature

Safety Compliance: 3 kV I/O isolation

EMI Compliance: FCC Part 15 conducted EMI (Level B)

5 Circuit Operation

Referring to the schematic in Figure 2, the charger is designed around a simple flyback converter topology with optocoupler feedback for both output voltage and current sensing. The ac input is full-wave rectified by D1 and filtered by C2A and C2B to provide a dc “bulk” bus to the converter stage. R1 provides inrush current limiting at initial supply turn-on while C1, L1, and C9 comprise a simple, yet effective conducted EMI filter network.



NOTES:

1. L1 is Coilcraft part RFB0807- 821L (820 uH @ 300 mA)
2. U2 is 4 pin optocoupler with CTR of 50% minimum
3. See Magnetics Data Sheet for T1 construction details
4. U1 is 100 kHz version
5. D7 zener sets Vout: Vout = Vz + 0.85V
6. R4 set max current: Imax = 0.65/R4
7. R6 allows for Vout trimming (increase only)
8. Fuse resistor recommended for R1
9. Crossed lines on schematic are not connected

Figure 2. 5 V / 1 A CC/CV Power Supply with Universal AC Input (Rev 3)

The flyback converter is comprised of the NCP1014 controller/MOSFET U1, flyback transformer T1, and output rectifier/filter D2 and C4 respectively. An auxiliary winding on T1 and associated components D4, C8, C3, R8, and R7 provide an operating bias (V_{CC}) for the control chip and allow for very low input standby power when the supply is in a no-load or standby mode. Since the voltage produced by the auxiliary winding tracks the main output voltage it is also used to sense for overvoltage conditions in the event the feedback loop opens. The OVP trip level can be adjusted by the turns on the auxiliary winding and the value of R8. The main secondary voltage is rectified (peak detected) by D2 and filtered to a relatively smooth dc level by C4, the main output capacitor. Capacitor C7 provides for additional high frequency noise filtering for the output. A snubber network composed of C5, R2 and D3 is implemented to clamp voltage spikes caused by the primary leakage inductance of T1. This network prevents potential damage to the MOSFET drain terminal (pin 3) of U1 by limiting the peak voltage.

Constant output voltage and current regulation are achieved by the combination of components Q1, D5, and R3 through R6. For output currents less than 1 A the circuit performs as a constant voltage source. When the output voltage reaches approximately 5.1 V, zener D5 conducts and when sufficient current flows through R3 to produce the 0.9 V necessary to turn the optocoupler diode on, the voltage feedback loop closes and the output will be regulated. The use of R3 forces the reference zener’s current to be in a stable part of the device’s characteristic V/I curve such that temperature effects are minimized. R6 can be used as an option to trim the charger’s output voltage up (only).

When the output current exceeds approximately 1 A, the voltage drop across current sense resistor R4 is sufficient to turn on PNP transistor Q1 and zener D5 is now bypassed and the current level now activates the optocoupler and controls the feedback loop. Although very simple, this current sense circuit will provide a constant current output of approximately 1 A all the way down to an output voltage of 1 V. Beyond this the current will rise some but any output cable resistance will prevent the current from exceeding about 1.5 A maximum. Feedback loop compensation and bandwidth is provided by capacitor C6.

Under constant current operation that would be typical of a heavily discharged battery, the voltage on the auxiliary winding could be sufficiently low that it is unable to adequately power U1. In this case the NCP1014 derives its operating bias from the internal DSS circuit (see device data sheet for details of this feature). Although the output current is limited via R4, the NCP1014 controller also has peak current limiting internally. The controller employs current mode control which limits the peak MOSFET current based on the feedback signal from the optocoupler.

6 Transformer Design

For low power applications it is desirable to have as small a transformer as possible, however, as the transformer gets smaller so does the core's cross sectional area. This forces more primary turns in order to maintain an acceptable magnetic flux density limit and can cause excessive turns buildup in the bobbin such that effective primary to secondary insulation becomes prohibitive. A large number of primary turns also increase the primary leakage inductance, not to mention the dc resistance of the windings in general. Both of these factors contribute to lower efficiency in the converter. In this design an EF16 ferrite core (sometimes referred to as an E16/8/5) was used with a satisfactory compromise with respect to the above mentioned parametric issues. The transformer design is shown in Figure 3. In this design there are sufficient primary turns to allow operation with either the 65 kHz or 100 kHz version of the NCP1014 controller. The turns ratio will also allow flexible operation with outputs from 4 to 9 V. The design shown in Figure 3 should be sufficient for any magnetics fabrication house to produce the transformer. Exact pinouts will depend on the specific layout, however, the core selection, wire sizing, inductance value and turns ratio should be adhered to for proper operation.

MAGNETICS DESIGN DATA SHEET

Project / Customer: ON Semiconductor − NCP1011/1014 Generic CP charger

Part Description: 5 watt flyback transformer, 4 − 9 volts out (REV 3)

Schematic ID: T1

Core Type: EF16 (E16/8/5); 3C90 material or similar

Core Gap: Gap for 3.5 mH

Inductance: 3.5 mH +/−5%

Bobbin Type: 8 pin horizontal mount for EF16

Windings (in order):

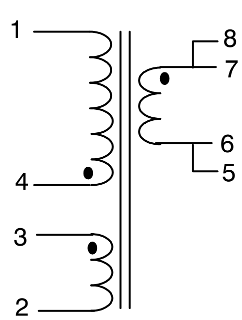
Winding # / type	Turns / Material / Gauge / Insulation Data
Vcc/Boost (2 − 3)	28 turns of #35HN spiral wound over 1 layer. Insulate with 1 layer of tape (500V insulation to next winding)
Primary (1 − 4)	150 turns of #35HN over 3 layers. Insulate for 3 kV to the next winding.
5V Secondary (5, 6 − 7, 8)	14 turns of #25HN spiral wound over one layer with 0.050” (1.3mm) end margins.

Vacuum varinish assembly.

Hipot: 3 kV from boost/primary to secondary for 1 minute.

Vendor for xfmr: Mesa Power Systems (Escondido, CA) part # 131296

Schematic



Lead Breakout / Pinout

(Bottom View − facing pins)

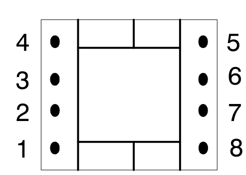


Figure 3.

7 Test Results

7.1 Active Mode Efficiency

The efficiency curves with output loading at 25%, 50%, 75% and 100% for 120 and 230 Vac inputs are shown in Figure 4.

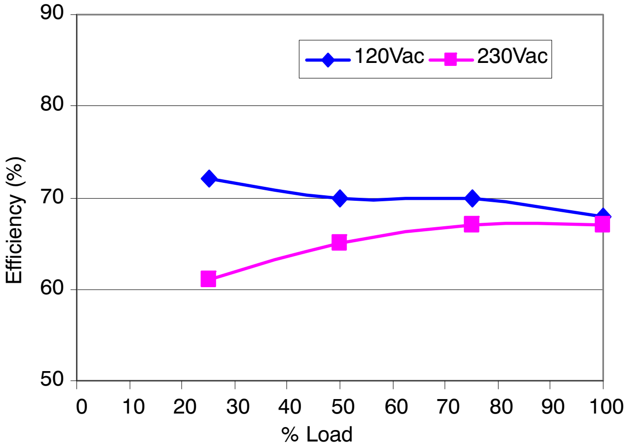


Figure 4. 5 Watt CCCV Charger Efficiency

% Load	Efficiency (%)	
	120 Vac	230 Vac
25	72	61
50	70	65
75	70	67
100	68	67
Avg Eff. =	70%	65%
ENERGY STAR Min =	63.5%	63.5%

Note that the average efficiency for both ranges meets the ENERGY STAR minimum requirement of 63.5% at this particular power level. In the 230 Vac input case the efficiency degradation occurs at light loading due to increased circuit quiescent power, mainly due to higher MOSFET switching losses at this input level.

7.2 Standby (no load) Input Power Consumption

Input Power:
90 mW @ 230 Vac
75 mW @ 120 Vac

7.3 Output V/I Load Line Profiles

Figures 5 and 6 show the output V/I load line profiles for 25°C and 50°C ambient temperatures.

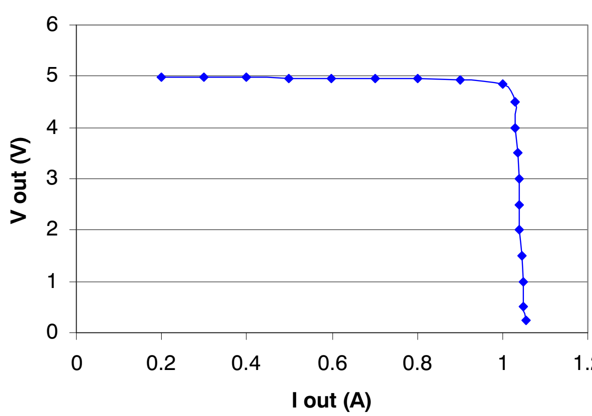


Figure 5. 5 Watt Cell Phone Charger V/I Profile @ 25°C

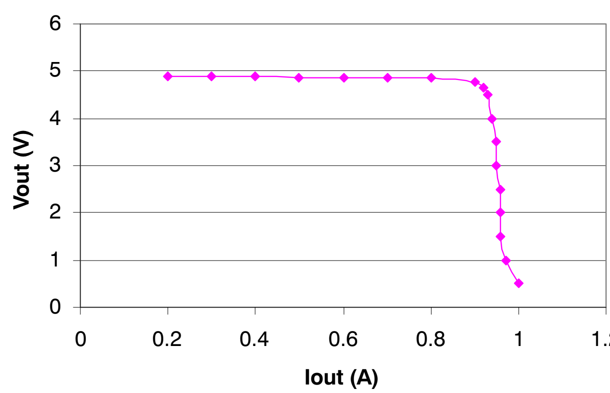


Figure 6. 5 Watt Cell Phone Charger V/I Profile @ 50°C

Note that despite the extremely simple current and voltage feedback circuit design, the voltage set point dropped approximately 50 mV and the constant current level was less than 75 mA at the higher temperature. This temperature coefficient variation is entirely acceptable for most applications, and is actually advantageous if the battery itself is in the same ambient environment also.

7.4 EMI Profile

The charger circuit was also tested at a local certified EMI/EMC test facility for conducted EMI on the AC input mains. The plot of Figure 7 shows the conducted EMI profile for 120 Vac input with an output load of 1 A with the converter operating just at the constant voltage/constant current “knee”. Note that the conducted emissions are below the Level B average limit.

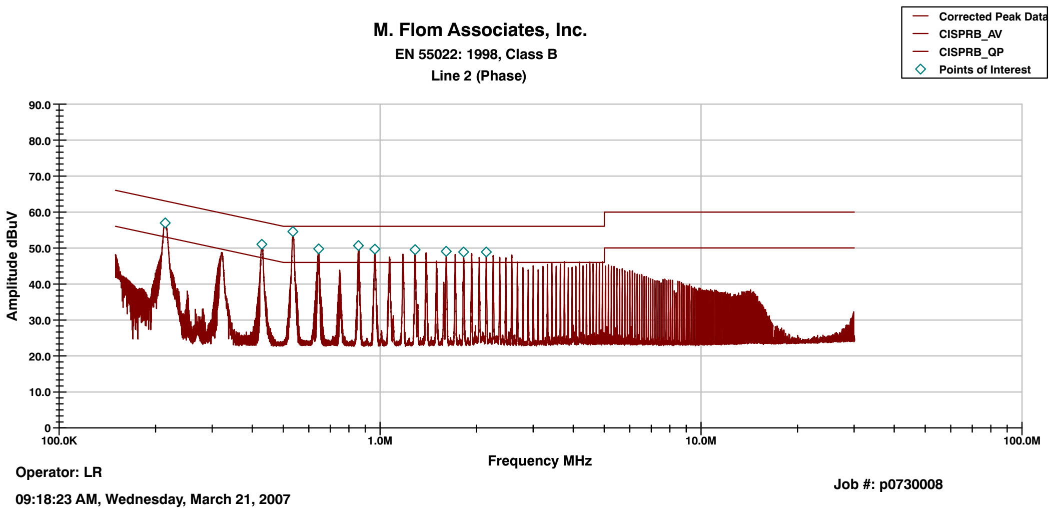


Figure 7.

7.5 Other Results

Figures 8 and 9 show the typical flyback voltage waveforms on U1’s internal MOSFET drain for 120 and 230 Vac inputs respectively and 75% output loading. Note that above approximately 50% load the flyback circuit operates in continuous conduction mode (CCM).

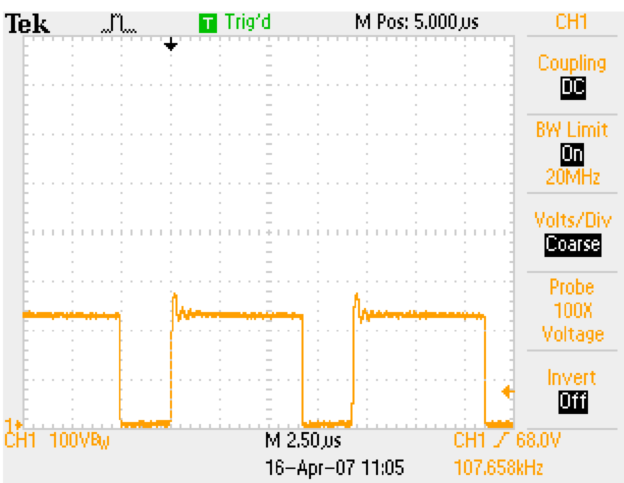


Figure 8.

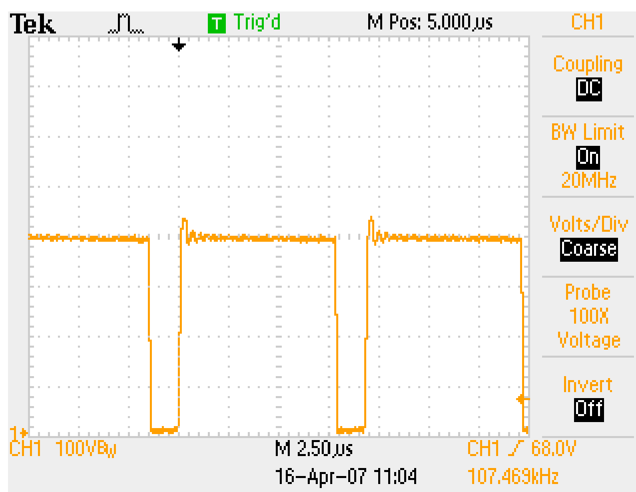


Figure 9.

Figure 10 is the MOSFET drain waveform under no load conditions at 120 Vac input demonstrating skip−mode operation for low input power consumption.

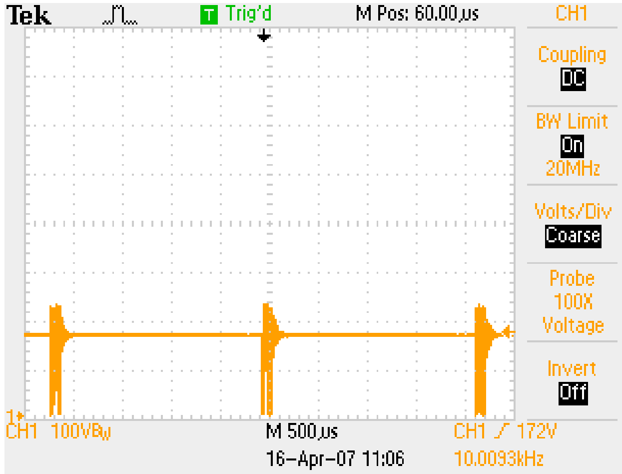
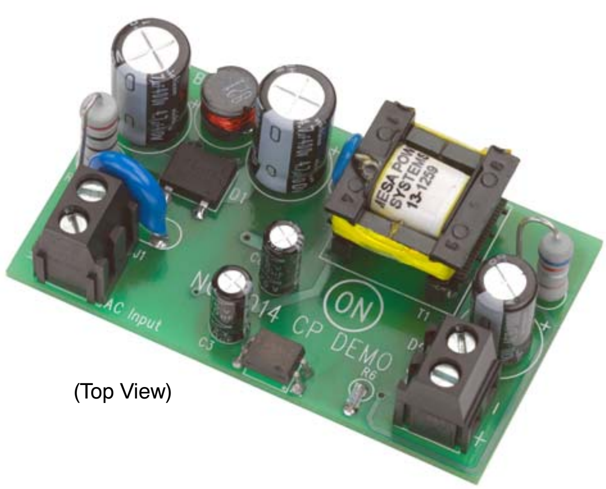


Figure 10. MOSFET Drain Waveform

8 Bill of Materials

Part	Part Type	Quantity	ID	Description
DF04S Bridge Diode	DFS (4 pin)	1	D1	1 A, 600 V Bridge Diode (Vishay)
MURS160T3	SMB	1	D3	1 A, 600 V UFR Diode
MBRS360T3G	SMC	1	D2	3 A, 60 V Schottky
MMSZ5229BT1	SOD−123	1	D5	4.3 V, 500 mW Zener (for 5 V output)
MMSD4148T1	SOD−123	1	D4	100 mA Signal Diode
MMBT2907AWT1G	SOT−23	1	Q1	PNP Signal xstr
Optocoupler	4−pin	1	U2	Vishay SFH−615A−4 or Similar
NCP1014ST (100 kHz)	SOT−223	1	U1	ON Semiconductor Controller
4.7 nF “X” Cap	Thru Hole, Disc	1	C1	4.7 nF “X” Capacitor, 250 Vac
1 nF “Y” Cap	Thru Hole, Disc	1	C9	1 nF “Y” Capacitor, 270 Vac
Ceramic Cap	Disc Cap	1	C5	1 nF, 1 kV Capacitor (snubber)
Ceramic Cap	SMD−0805	1	C6	1 nF, 100 V Ceramic Cap
Ceramic Cap	SMD−0805	1	C7	100 nF, 50 V Ceramic Cap
Electrolytic Cap	Radial Lead	2	C2A, C2B	4.7 or 6.8 μF, 400 Vdc
Electrolytic Cap	Radial Lead	1	C4	820 μF or 1000 μF, 6.3 V (low ESR)
Electrolytic Cap	Radial Lead	2	C3, C8	10 or 22 μF, 25 V
Resistor, 2 W	Axial Lead	1	R1	18 Ω, 2 W Metal Film or Wire Wound
Resistor, 1/4 W	SMD−1210	1	R2	150 k, 1/4 W
Resistor, 1/8 W	SMD−0805	1	R5	68 Ω
Resistor, 1/8 W	SMD−0805	1	R3	200 Ω
Resistor, 1/8 W	SMD−0805	1	R7	10 Ω
Resistor, 1/8 W	SMD−0805	1	R8	2 k
Resistor, 1/4 W	Axial Lead	1	R6	TBD (jumper for 5 V output)
Resistor, 1/2 W	Axial Lead	1	R4	0.62 Ω, 1 W Metal Film (for 1 A output)
EMI Inductor, 820 μH 300 mA	Radial Lead	1	L1	Coilcraft RFB0807−821L
Transformer (see Figure 2)	8−pin Thru Hole	1	T1	Mesa Power Systems # 13−1296 (custom)
AC Connector	Thru Hole	1	J1	DigiKey # 281−1435−ND (LS = 0.2″)
Output Connector	Thru Hole	1	J2	DigiKey # 281−1435−ND



(Top View)

Figure 11. Board Picture

9 Appendix

References:

- Draft Commission Communication on Policy Instruments to Reduce Stand−by Losses of Consumer Electronic Equipment (19 February 1999) − http://energyefficiency.jrc.cec.eu.int/pdf/consumer_electronics_communication.pdf
- European Information & Communications Technology Industry Association − http://www.eicta.org/
- http://standby.lbl.gov/ACEEE/StandbyPaper.pdf

CSC (ex−CECP China):

- http://www.cecp.org.cn/englishhtml/index.asp

Energy Saving (Korea):

- http://weng.kemco.or.kr/efficiency/english/main.html#

Top Runner (Japan):

- http://www.eccj.or.jp/top_runner/index.html

EU Eco−label (Europe):

- http://europa.eu.int/comm/environment/ecolabel/index_en.htm
- http://europa.eu.int/comm/environment/ecolabel/product/pg_television_en.htm

EU Code of Conduct (Europe):

- http://energyefficiency.jrc.cec.eu.int/html/standby_initiative.htm

GEEA (Europe):

- http://www.efficient−appliances.org/
- http://www.efficient−appliances.org/Criteria.htm

ENERGY STAR:

- http://www.energystar.gov/
- http://www.energystar.gov/index.cfm?c=ext_power_supplies.power_supplies_consumers

1 Watt Executive Order:

- http://oahu.lbl.gov/
- http://oahu.lbl.gov/level_summary.html

Additional Collateral from ON Semiconductor:

- Design note DN06009/D: 5 W, CCCV Cell Phone Battery Charger
- Design note DN06017/D: Efficient, Low Cost, low Standby Power (<100 mW), 2.5 W Cell Phone Charger
- Design note DN06003/D: NCP1014: 8 W, 3−Output Off−Line Switcher
- Design note DN06005/D: NCP1014: 10 W, 3−Output Off−line Power Supply
- Design note DN06020/D: NCP1014: 10 W, Dual Output Power Supply
- Data sheet NCP1014/D: Self−Supply Monolithic Switcher for Low Standby−Power Offline SMPS
- Data sheet MBRS360/D: 3 A, 60 V Schottky Rectifier
- Data sheet MMSD4148/D: 100 V Switching Diode
- Data sheet MURS160/D: 1 A, 600 V Ultrafast Rectifier
- Data sheet MMSZ5229B/D: 500 mW Zener Diode
- Data Sheet MMBT2907AWT1/D: PNP Transistor

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