TND317/D
Rev. 4, Jul-06

90 W Notebook AC-DC Adapter

Reference Design Documentation Package

Overview

This reference document describes a built-and-tested, GreenPoint™ solution for a Notebook Ac-Dc adapter.

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

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

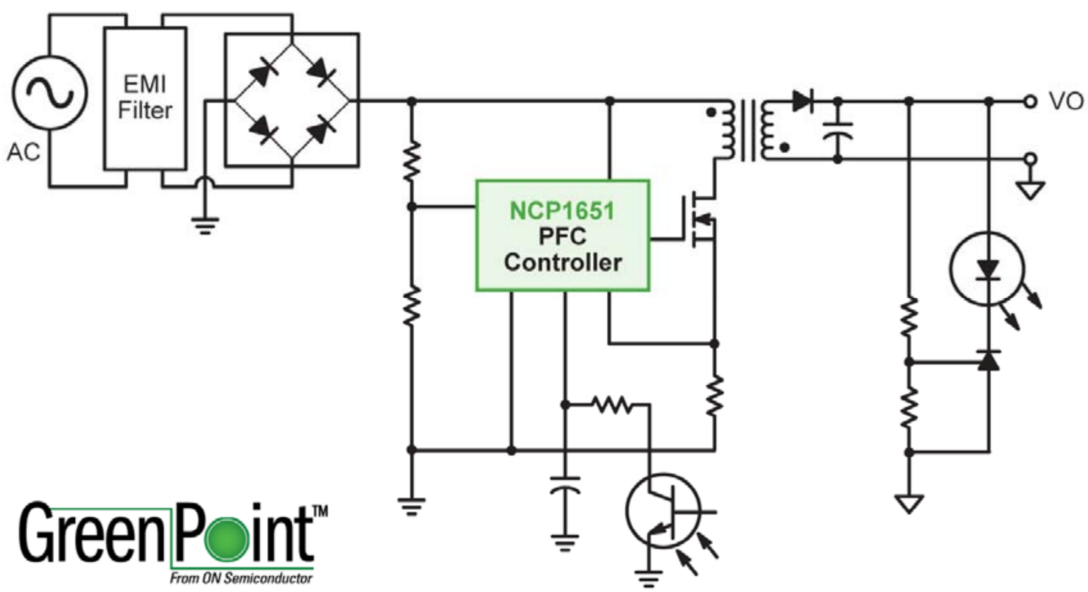


Figure 1

1 Introduction

In a not too distant past, the power requirements of notebooks adapters were in the 50-70 W range but lately they have risen over the 100 W levels. One can see a two-fold growth in power requirements:

- Notebook computers functionality becomes richer, so the power demand scales up.
- Battery capacity (or density) increases, thus the charging requirements also go up.

Crossing the threshold of 75 W input has significant consequences. In effect, 75 W is the power threshold beyond which the regulation (IEC1000-3-2) for the reduction of harmonic currents applies to class D electrical equipments. Notebook adapters are classified under the class D. This regulation stipulates the maximum level of harmonic currents that class D equipment can inject on the mains AC line. The IEC1000-3-2 regulation is currently mandatory in Europe and Japan. In a sense, the mobile/global nature of the notebook adapters make them the first mass market power supply to fall under the IEC1000-3-2 target.

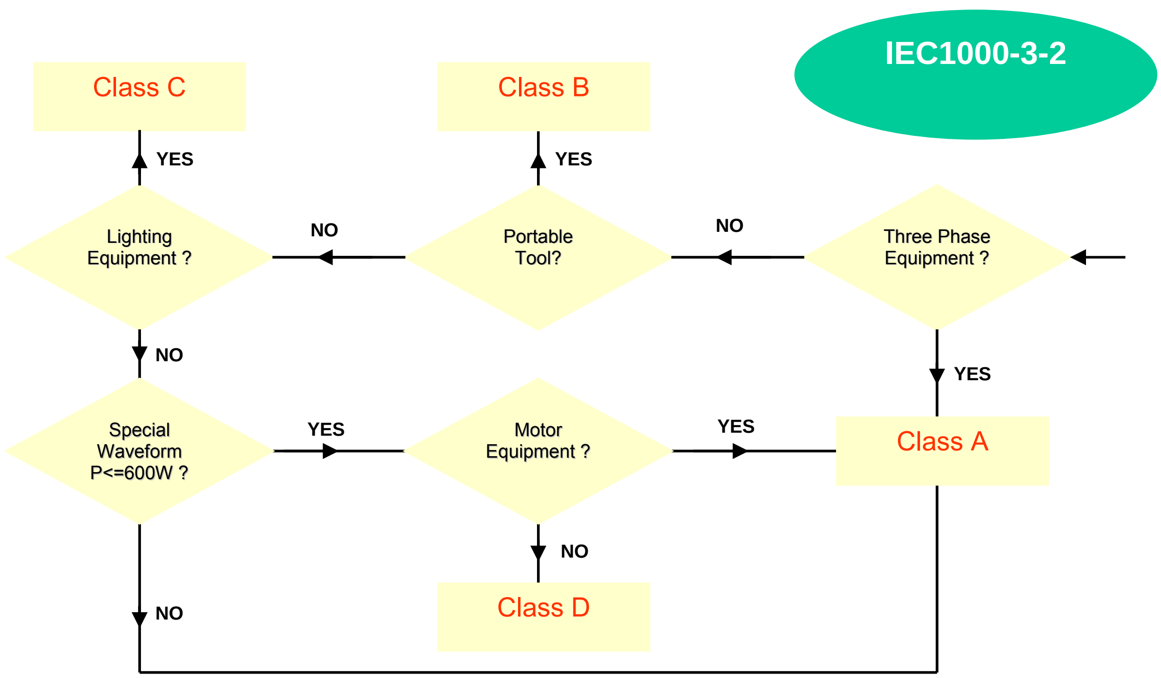


Figure 2

Furthermore, additional regulatory requirements addressing low standby power consumption and efficiency in active mode for external power supply (EPS) add extra constraints in the design of the notebook adapter.

These requirements target two issues:

- Get rid of the losses in a no load situation (e.g.: when the notebook adapter is plugged in even when it is not connected to the computer).
- Achieve a good average 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**

  - ***Energy Efficiency Criteria for active mode***

Nameplate Output Power (P_{no})	***Minimum Average Efficiency in Active Mode (expressed as decimal)***
0 to < 1 Watt	$\geq 0.49 * P_{no}$
>1 and ≤49 Watts	$\geq [0.09 * Ln(P_{no})] + 0.49$
> 49 Watts	≥ 0.84

  - ***Energy Consumption Criteria for No Load***

Nameplate Output Power (P_{no})	***Maximum Energy Consumption in No-Load Mode***
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**

  - ***No-load Power Consumption***

Rated Output Power	*No-load power consumption*	
	Phase 1 1.1.2005	***Phase 2 1.1.2007***
> 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 1.1.2005 to 31.12.2006)***

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 1.1.2007)***

Nameplate Output Power (P_{no})	***Minimum Four Point Average (see Annex) or 100 % Load Efficiency in Active Mode (expressed as a decimal)[2]***
0 < W < 1	$\geq 0.49 * P_{no}$
1 < W < 49	$\geq [0.09 * \mathrm{Ln}(P_{no})] + 0.49$
49 < W < 150	≥ 0.84[3]

Notes:
[2]: "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.
[3]: Power supplies that have a power factor correction (PFC) to comply with EN61000-3-2 (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%).

- **<u>Korea:</u>**
    - External Power Supply -No load: 0.8 W
    - Battery Charger - No load: 0.8 W

This reference design document provides a solution to address the design challenges brought about by these regulations: compliance with IEC1000-3-2, with requirements for standby power reduction and active mode energy efficiency increase at a reasonable cost.

2 Notebook AC-DC adapter requirements

For Notebook OEMs, the AC-DC adapter is a commodity. So, they impose their own stringent specifications and derating 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 notebooks around the world, all of the AC-DC adapters for Notebooks are designed to cope with universal mains voltage: 90 Vac to 265 Vac, 47-63 Hz.

The output power of notebook adapters varies between 50 and 125 W while the output voltage is between 18 and 21 V.

As discussed in section 1, the IEC1000-3-2 regulation specifies the maximum harmonic currents for class D equipments. The harmonics of the input current shall not exceed the values given in Table 2.

Harmonic order N	Maximum permissible harmonic per watt mA/W	Maximum permissible harmonic current A
3	3.4	2.30
5	1.9	1.114
7	1	0.77
9	0.5	0.40
11	0.35	0.33
etc…		

Table 2

3 Limitations of the existing two-stage architecture

For many years, the most effective solution (economically and technically) for notebook adapters has been a flyback topology. If the power level of the adapter is below 75 W, no additional power stage is needed to comply with the IEC1000-3-2 regulation.
For notebook adapters with >75 W power requirements, the notebook manufacturers face the following choice. They can either design the adapters for universal AC line voltage and include a power factor correction (PFC) stage or they can implement separate design for markets that require PFC (Europe and Japan). Addition of the PFC stage adds complexity and cost, thus making the design more challenging.

A classical two-stage approach is represented in Figure 3: the Power Factor Correction stage is followed by the Flyback stage.

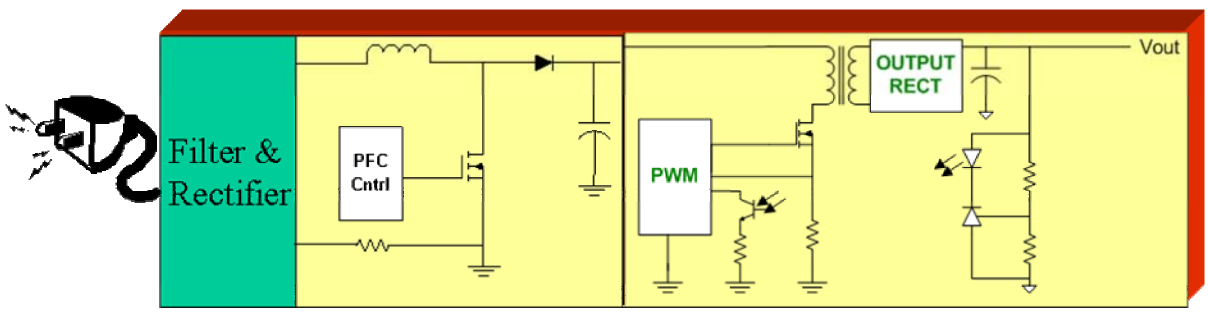


Figure 3

Furthermore, while we all want maximum functionality and more crunching power from our laptops, we also get weary of the weight and the size of the machines. We would like to keep at least the same form factor for the adapter while more power is needed. Size is the limitation of the classical two-stage approach as the main elements have to be used twice: 2 magnetic elements, 2 controllers, 2 FETs.

4 Overcoming limitations with the NCP1651-based single-stage flyback architecture

How to eliminate the burden of two power processing stages? Achieving an efficient and cost effective single stage power conversion has been the quest of the designers for a long time.

While many single stage solutions exist, they all have some limitations. These are:

1. The output voltage ripple contains a low frequency component which can not be inherently eliminated without using additional energy storage capacitance.
2. Many schemes try to use current steering to achieve a better trade-off between low output voltage ripple and low THD (Total Harmonic Distortion). These tradeoffs require extra engineering effort for each design.
3. Certain specifications such as output ripple, transient response and hold-up time are harder to meet than the two-stage architecture.

The current reference design presents a proprietary innovative single-stage architecture that addresses the above mentioned limitations. The enabling device for the reference design is the **NCP1651**, an active power factor correction controller designed for operation over the universal input range (85 Vac- 265 Vac) in 50/60 Hz power systems. It provides a low cost, low component count solution for isolated AC-DC converters with mid-high output voltage requirements and eases the task of meeting the IEC1000-3-2 harmonic requirements. The NCP1651 uses a proprietary multiplier design that gives significantly more accurate operation than conventional analog multipliers

To reduce output ripple and maintain harmonic currents within the class D requirements as specified by IEC1000-3-2, the reference design utilizes a dual loop ripple/power-factor optimization technique developed by Energy Recovery Systems Corporation – a technology and product development company ON Semiconductor worked with on the adapter reference design.

Figure 4 represents the NCP1651-based single stage solution:

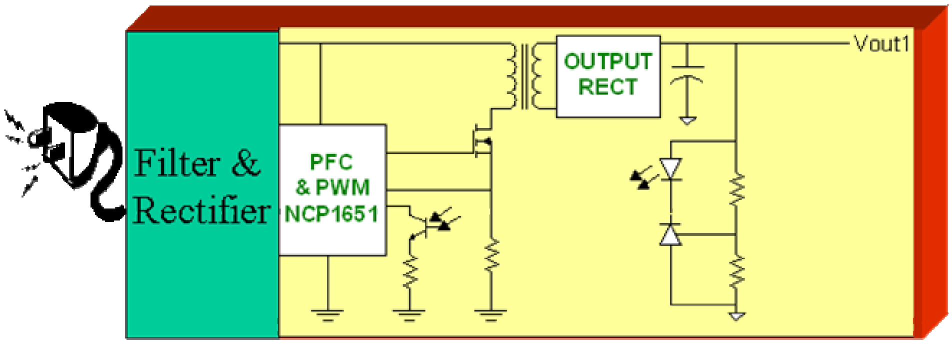


Figure 4

When compared to the traditional two-stage architecture, the key advantage of the NCP1651-based single stage architecture is the substantial cost reduction of over 20% and the drastic component count reduction while still complying with the IEC1000-3-2 regulation.

This architecture also brings an increase of the efficiency of about 3%. It is important to note that the main issue is not the efficiency per se but the whether or not this architecture meet the skin temperature rise requirements for OEMs. These requirements as well as their test methodologies change from OEM to OEM. This reference design complies with all of them. This reference design also meets the leakage current OEM requirements of < 100 micro-amperes (µA).

5 Specifications

Input Voltage: Universal input 90 Vac to 265 Vac, 47-63 Hz

Output: +19.5 V, 4.62 A max (90 W) regulated

Protections:

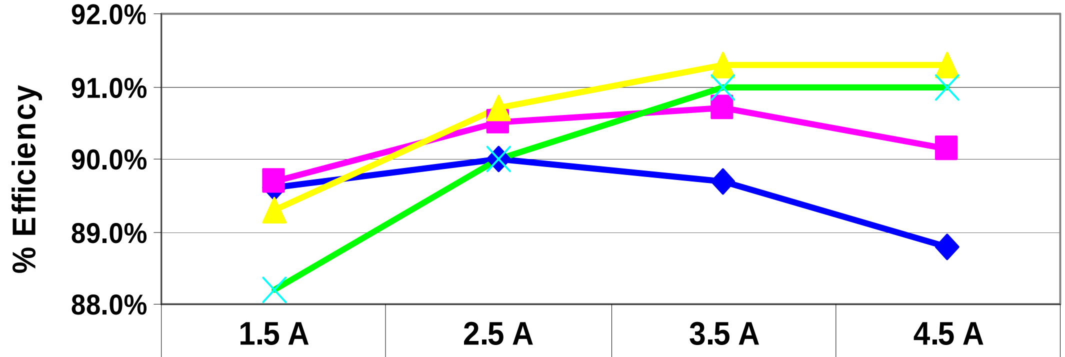
- Short-circuit,
- Latching over-power
- Latching over-voltage

Standby Power: P_{in} = 390 mW @ P_{out} = 0 and V_{in} = 230 Vac

Power Factor Correction / Current Harmonics: Compliant with IEC1000-3-2 for class D

6 Reference design performance summary

6.1 Efficiency



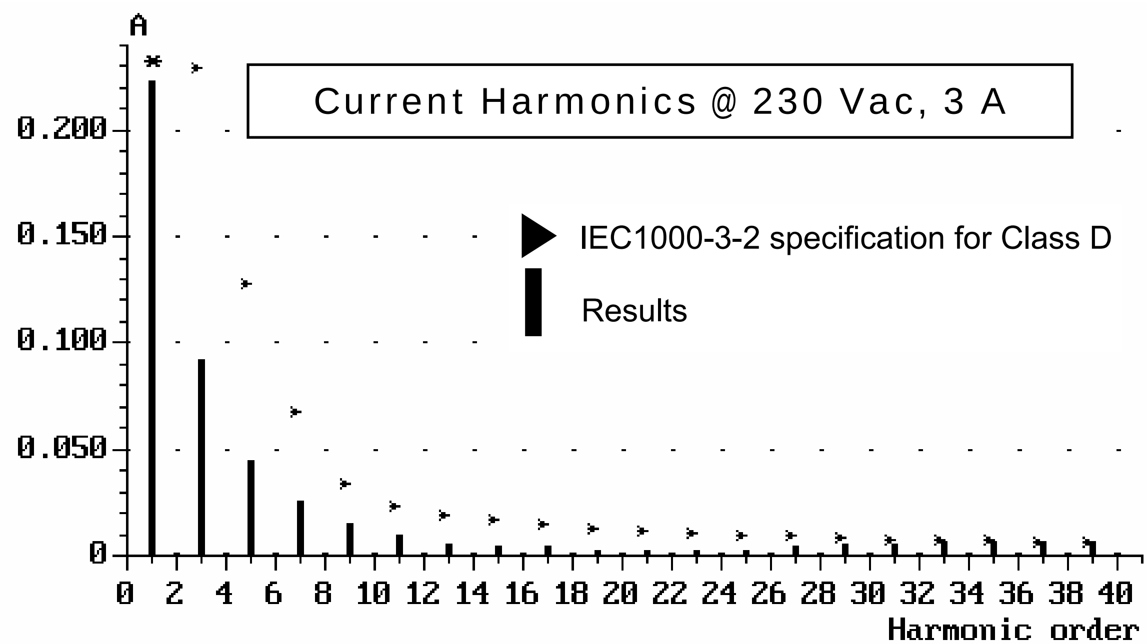
	1.5 A	2.5 A	3.5 A	4.5 A
90 Vac	89.6%	90.0%	89.7%	88.8%
115 Vac	89.7%	90.5%	90.7%	90.2%
230 Vac	89.3%	90.7%	91.3%	91.3%
264 Vac	88.2%	90.0%	91.0%	91.0%

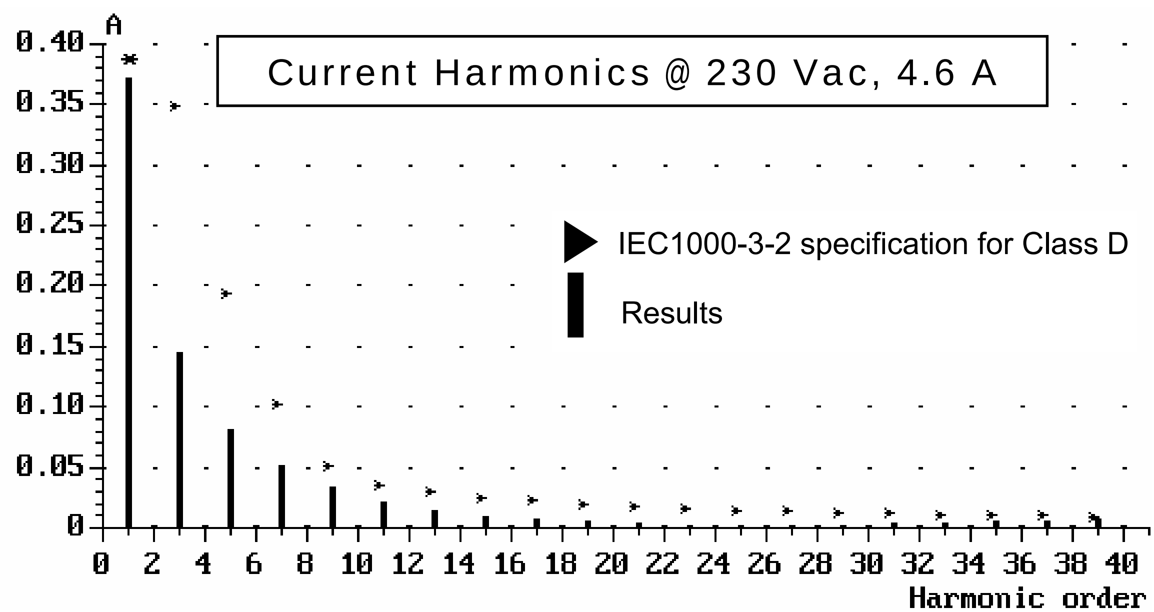
Output Current (A)

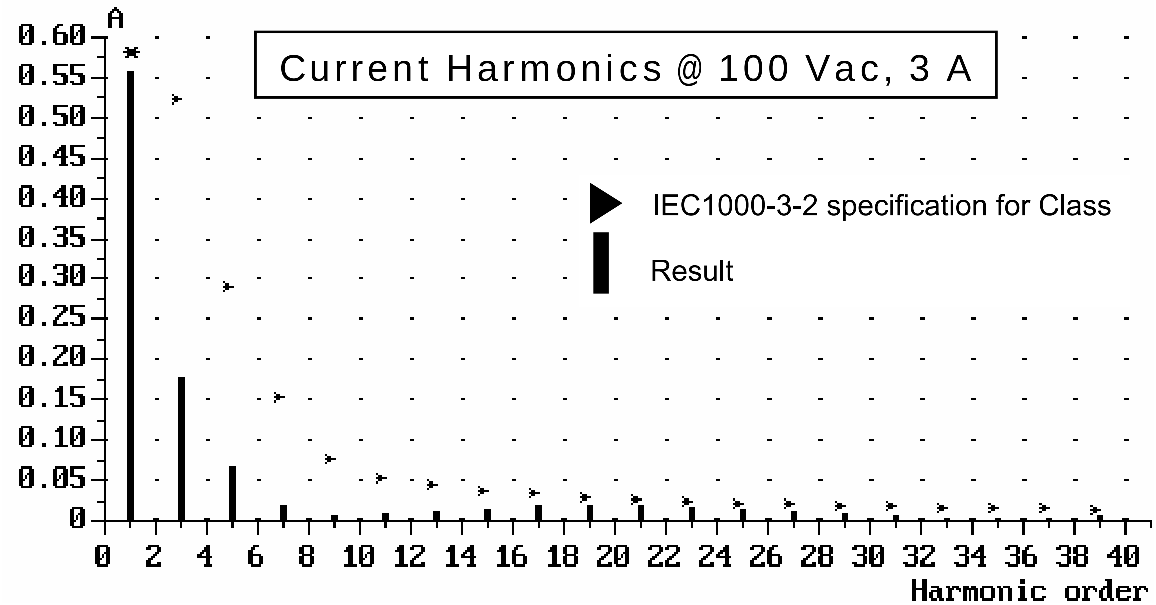
6.2 Standby Power

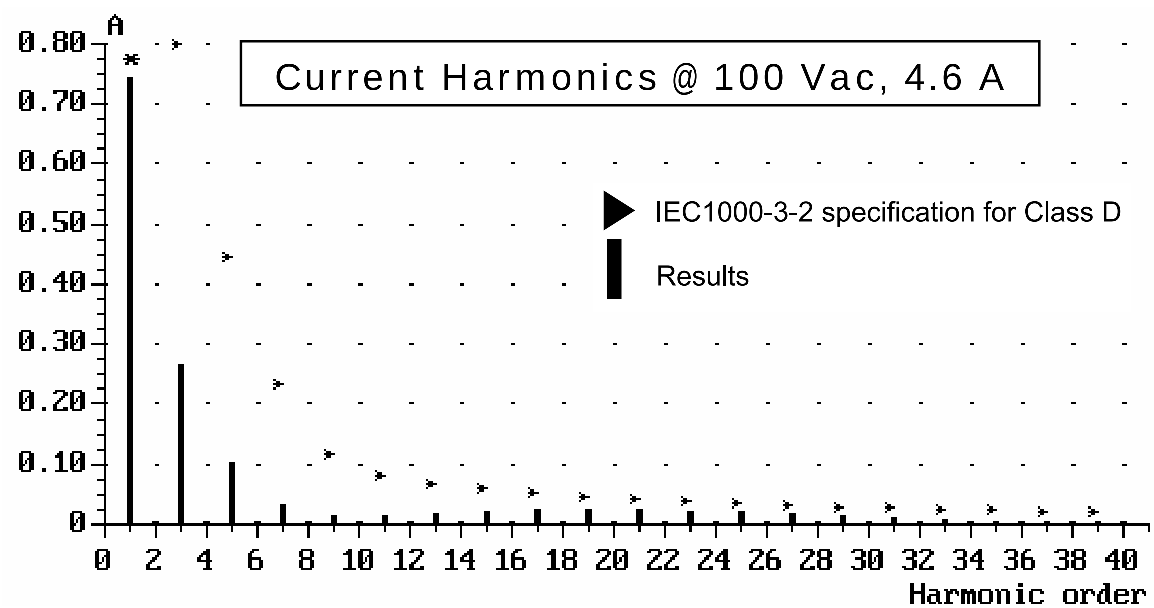
P_{in} = 390 mW @ P_{out} = 0 and V_{in} = 230 Vac

6.3 Power Factor Correction / Current Harmonics

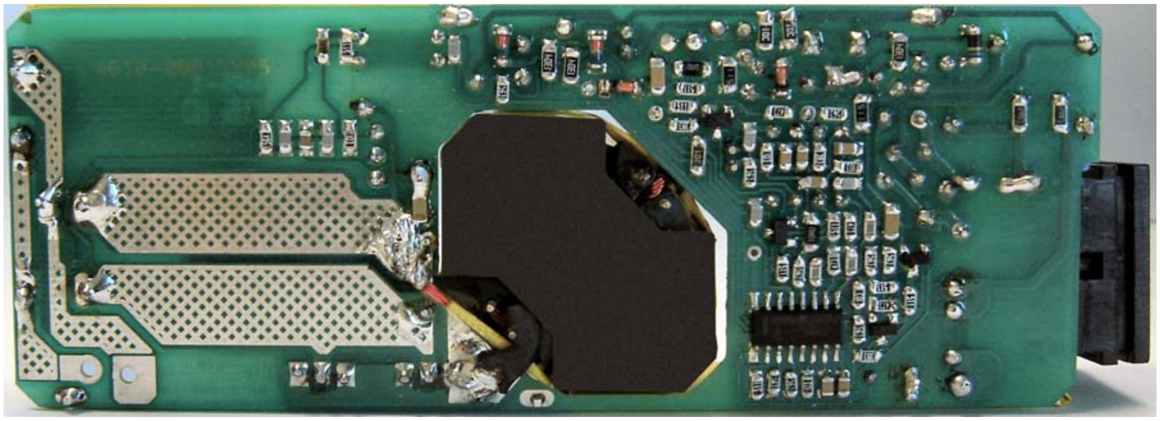




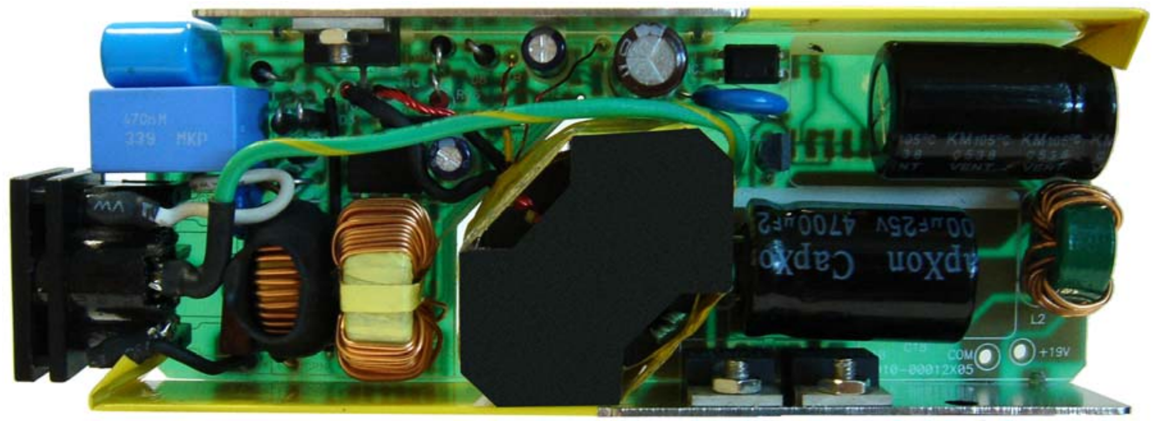

Current Harmonics @ 100 Vac, 3 A
IEC1000-3-2 specification for Class
Result
A
0.60
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40
Harmonic order


Current Harmonics @ 100 Vac, 4.6 A
IEC1000-3-2 specification for Class D
Results
A
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40
Harmonic order

7 Board Picture



Bottom view



Top view

8 Schematic, Board Layout, Bill-of-Materials

Complete Electrical schematics with board layout and bill-of-materials are available from ON Semiconductor and/or from Energy Recovery Systems Corporation.

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

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=product_specs.pt_product_specs

1 Watt Executive Order:

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

Additional collateral from ON Semiconductor:

- AND8209/D: 90 W / 18.5 V_{out}, Single Stage, Notebook Adaptor
- AND8124/D: 90 W / 48 V_{out}, Universal Input, Single Stage, PFC Converter
- AND8147/D: An Innovative Approach to Achieving Single Stage PFC and Step-Down Conversion for Distributive Systems.
- NCP1651: Product page for the NCP1651 on onsemi.com
- TL431
- LM358
- LM393
- MBR20H100

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