
Comparison of switching mode power supplies

Booklet of laboratory practical
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Abstract

Aim of this report is to get an overview about efficiency, distortion and heat dissipation of laptop power supplies. This study would lead to a bachelor thesis, that focuses the construction of a [180W laptop powersupply, which can be inserted into the ODD-/media bay of notebook](#). This report answers questions like: Are compact power supplies less efficient?, Will the output voltage break down on high currents?, Can power supplies be connected in parallel?, Will an internal power supply influence the mainboard?, ...

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Introduction

Off-shelf power supplies does not specify their full characteristics. For example input and output distortions are seldom mentioned. If user wants to use such power supplies in a different working environment, he needs to find the full behaviours of these power supplies by himself. In this report, an idea to build a 180 Watt in-system power supply by using two off-shelf 90 Watt power supplied in parallel is discussed. This new system should also be able to fit inside Optical Drive Bay (ODD-bay, also called media bay / ultrabay). To use the power supplies in parallel, their output voltage characteristics should be identical. It can be achieved by a negative gradient of function $V_{out}(I_{out})$. It is also important to determine the thermal resistivity of the ODD bay and to find out, how much heat can be dissipated without overheating the mainboard, GPU, CPU or whatever.

Presentation and all measurement data can be found at:
mitjastachowiak.de/projects/netzteil/practical/presentation.html

The measurements where done for the following power supplies:

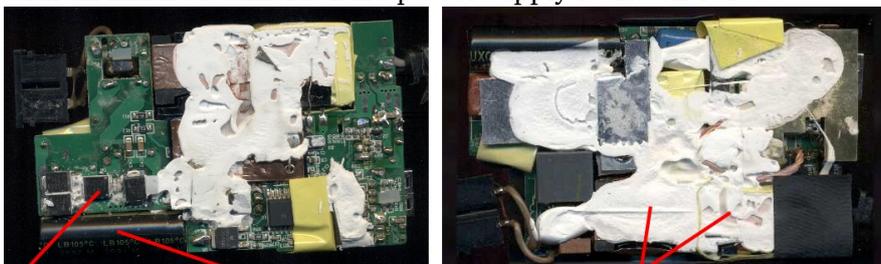
name	power / W	power density / W*cm ⁻³	condition
Hama Ultra Slim Power Supply, 00054190	90	1.14	open
Cooler Master, RP-120-USNA-J1	120	0.75	normal
P150HM, FSP180-ABAN1	180	0.31	normal
TDK CME150-24	150	N. A.	open

In addition, the following measurement devices have been used:

type	name / description	in circuit	values
powermeter	Hameg HM8115-2	P_{in} , P_{out}	
programmable load	Metrawatt SPL 250-30	R_L	
digital oscilloscope	Tektronix tds2024b	Ch 1, CH 2	
transformator	galvanic separation	N:N	$U_{out} = 250V$ eff.
power resistor	constantan wire in DVD-drive case	R_H	$R = 23$
measurement resistor	short constantan wire for current meas.	R_M	$R = 0.624$

In addition to this electrical measurement devices, an infrared camera was used, to visualize heat dissipation and to see, wich parts of the power supply generate most power losses.

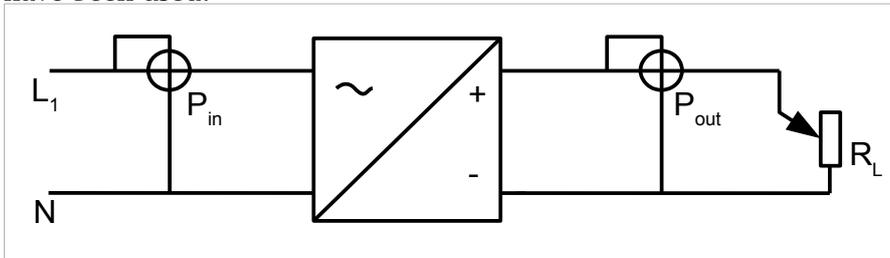
Plastic case, thermal paste, and the metal shielding of Hama power supply was removed to excess the internal components. This arrangement also allows to monitor the temperature of internal components with an infrared camera. Bare power supply is shown below:



Transistors Capacitor (250V) Transformers

1 Voltage stability, Efficiency

First experiment should show the efficiency and other electrical values, like voltage, current or power on the primary and secondary side as a function of load resistance. For measurement, the following circuit have been used:



Programmable load is also capable of measuring it's input current and voltage. This feature allows us to validate the data taken from the second power meter. To make the outgoing power linear, the resistance is changed hyperbolically. At each measurement (set resistance), the following values are stored: load resistance, input voltage, input current, input power, output voltage, output current, output power, load voltage, load current. The result of the measurements are text-based tables.

1.1 Program

It was task for this experiment, to automate this measurements. The devices got a serial port, that can be connected to USB, using FTDI interface. There is a standard called SCPI, that defines text-based commands to control the devices. For capturing the data and controlling the load, a small program was written, using Lazarus/Free Pascal. There is a unit, called SynaSer (part of the Synapse project), that provides sending of such ASCII-commands to the COM ports. But there are a lot of restrictions, the commands must fit, such as flow control bytes, delays or different line delimiters. The HAMEG devices are out-dated and don't use standard SCPI. In the end, it was a real challenge, to get a sufficiently stable program, that can do the measurements.

One problem, the program has to solve, is that the HAMEG devices are very slow sampling and even the call for new data needs several hundreds of milliseconds. During this time, the program execution stops, so there is a significant delay between the measurement of primary and secondary side values. To keep this delay as minimal as possible, multithreading is used. But this requires a complex communication between main- and secondary threads, because for some commands, the main thread has to wait for response, some commands don't have any response and some comands got continuous, asynchronous responses. The HAMEG devices send some flow control, after each command is processed. The program must not send new commands, until flow control arrives. The Metrawatt device got a kind of command queue and there is a special command, that causes signaling response, when it is processed. But after some commands, a delay to the next command has to be observed.

A certain unit (*scpihread.pas*), that tries to abstract from all this rules and exceptions was the consequence. There are special units for each device type now, that take use of this unit and implement the device's functionality in a graphical and programmable way. The manufacturers only hold such units for lab view, so this program might be helpfull for other projects and was published here: mitjastachowiak.de/components/pascal/scpi/.

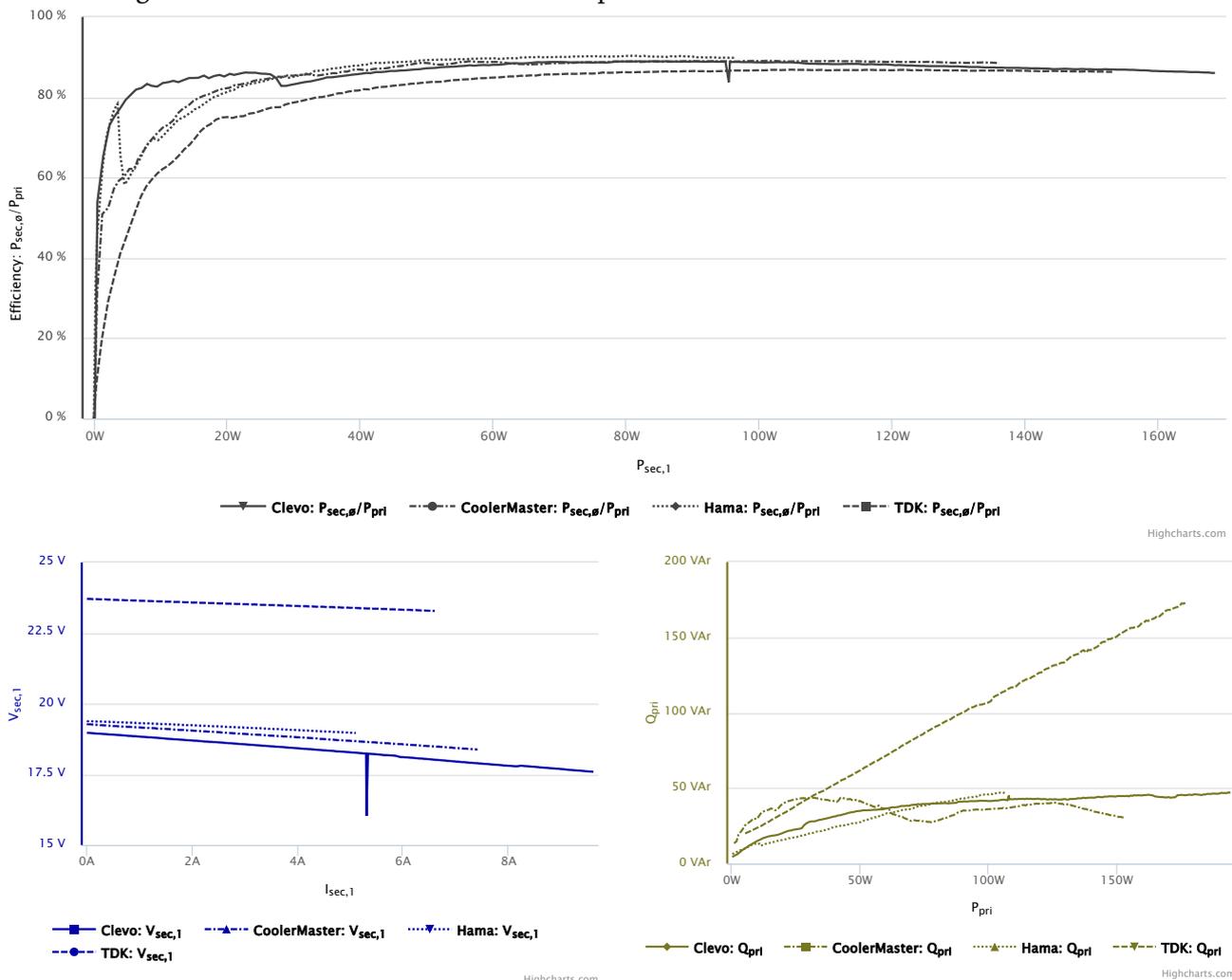
1.2 Measurement

The Hameg and TDK power supplies were equipped with suitable laboratory connectors, for the Clevo and Cooler Maser power supply, a special circuit board having a 19.5V DC socket, was brazed. But this 19.5V socket has not really been designed to carry more than 4A. So with the 120W and 180W power supplies, this connector became hot, what means, some millivolts are lost along the wiring. This applies to the connection between second power meter and load, too. This is the reason, why the voltage on the load is a bit smaller, than on the power meter. Nevertheless, on some measurement points, the programmable load registers higher power consumption, than the powermeter, so the measurement accuracy is in the range of the wiring losses.

Data, measured at the second powermeter, is suffixed with 1, the load data is suffixed with 2. The suffix \emptyset indicates, that an average between powermeter and load values is computed. For most currents greater than 0.5 A, the relative difference between P_1 and P_2 is lower than two percent. This gives an assumption about the total measurement accuracy.

1.3 Result

The following charts visualize the results of this experiment:



1.4 Interpretation

It can be seen, that the output voltage decreases by 0.1 Volts per Ampere on the Hama power supply and up to 0.49 Volts per Ampere for the Clevo one. This means for the Hama power supply an inner resistance of 0.1 Ohm, which corresponds to about 6 meters of 1mm² cooper wire. The wire length from the Hama power supply to the output power meter P_{out} was about $2 \cdot 0.5m = 1m$ bidirectional, but it is difficult to say of which alloying the wire is made and what is the resistance of the power meter or the connectors. So a significantly large part of this voltage drop may be caused by the wiring losses. The 0.1 Ohm of inner resistance seems to be too small for connecting two Hama power supplies parallely. They would shortcut eachother or the power would not balace equable.

The reactive power has to be considered carefully, because there is a lot of distortion on the current (See [last experiment](#)).

Interesting is the efficiency trend of Hama and Clevo: There is a significant break down in the first quater. Maybe there are two voltage converters in the power supply, one for low power and low open loop consumption and a second one for high power but with even high open loop consumption, that is turned-off for low powers. This phenomenon should be subject of continuing studies.

For TDK it can be said, that this power supply is described with 82% efficiency by the manufacturer.¹

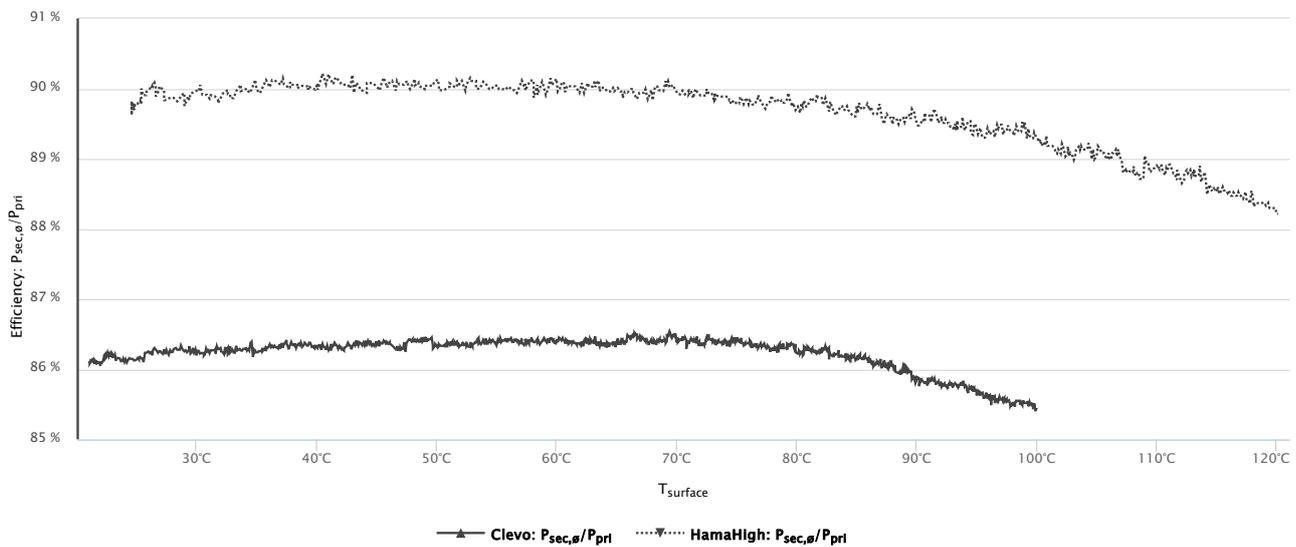
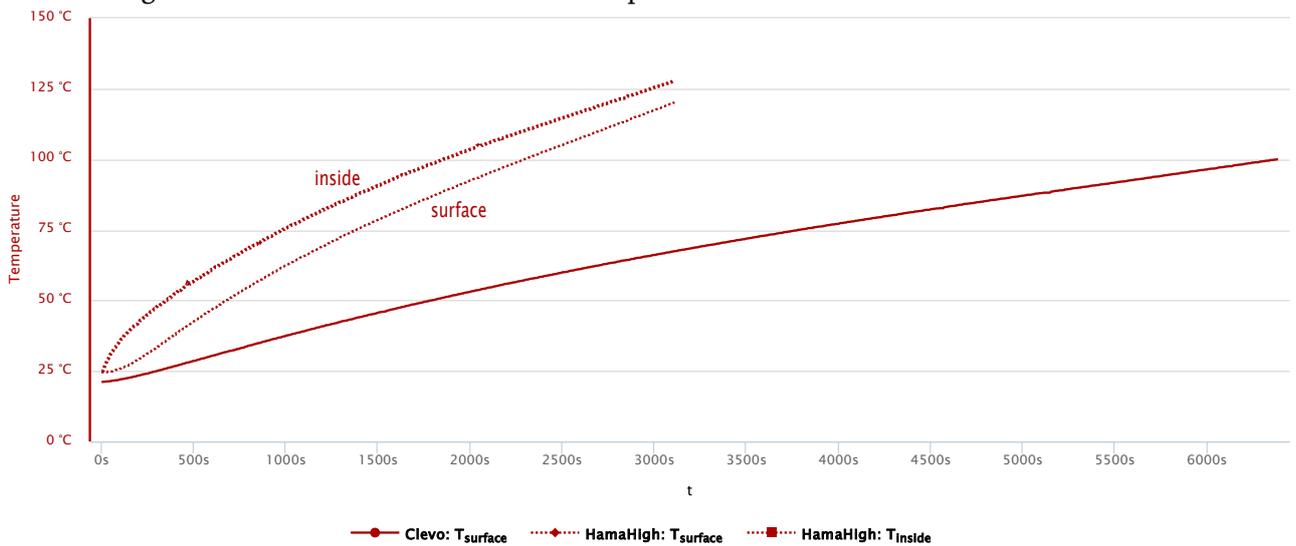
2 Thermal Characteristics

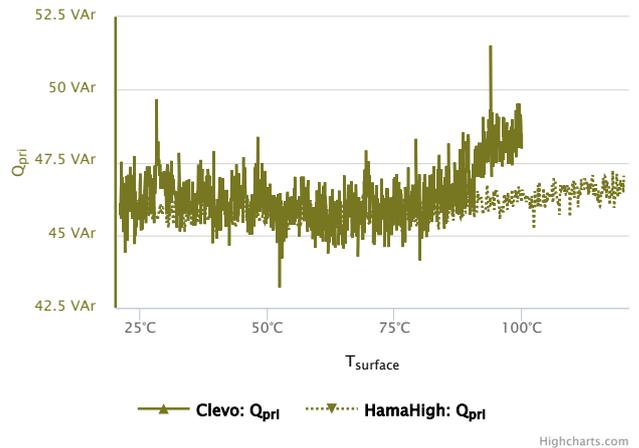
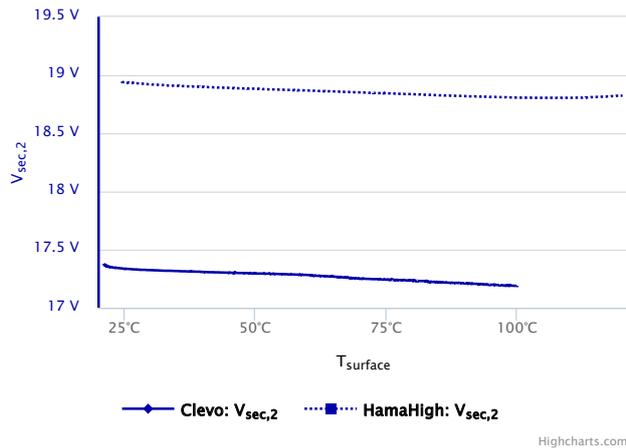
2.1 Measurement

This experiment is a repetition of the first one, but with constant load resistance (1.7 Ohm for Clevo and 4 Ohm for Hama). The power supplies were wrapped in fleece and in addition, the surface temperature (And on the Hama power supply even the inner temperature between the big capacitor and the transistors) is measured.

2.2 Results

The following charts visualize the results of this experiment:





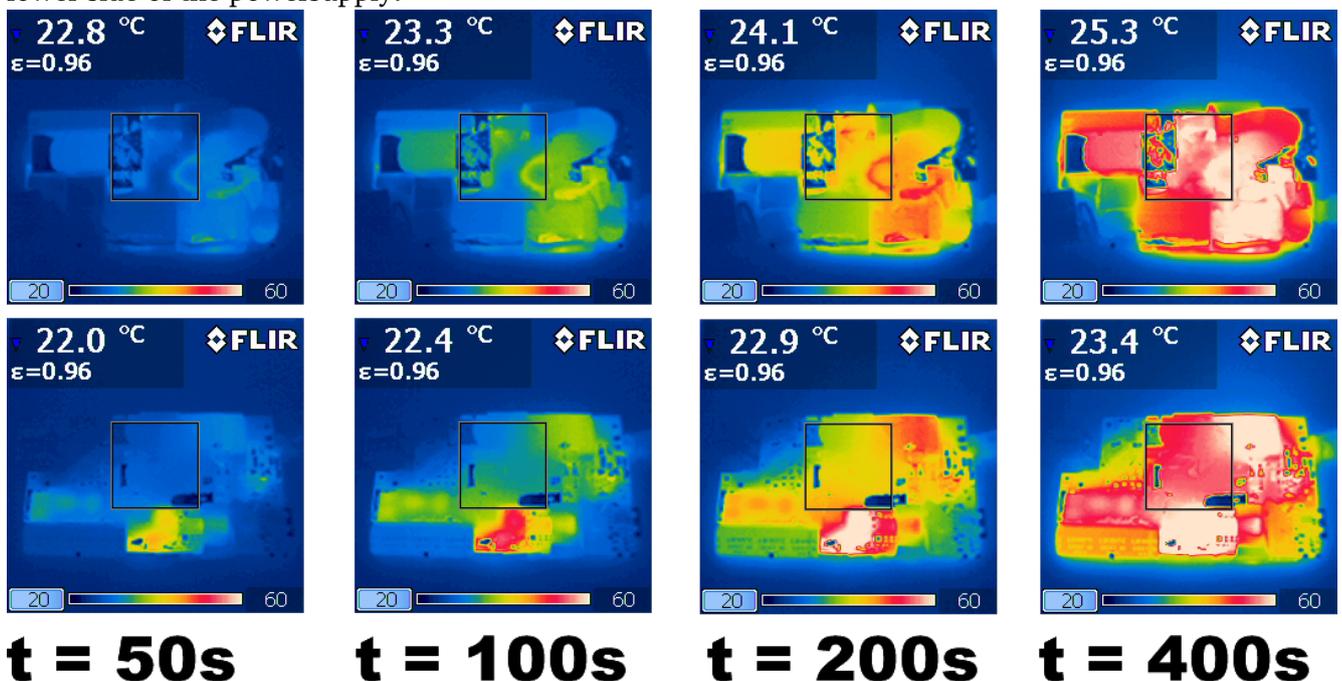
2.3 Interpretation

It can be seen, that voltage and reactive power are not significantly influenced by temperature. The efficiency increases with low temperatures and decreases with high temperatures. Striking on the temperatures is, that none of the regarded power supplies seems to have an overheating protection, even if Hama sais, there is one.² Both power supplies survived this experiment, but the Clevo one is loudly humming at low currents, now.

3 Effects of Heat on laptop performance

3.1 Open Hama power supply in infrared

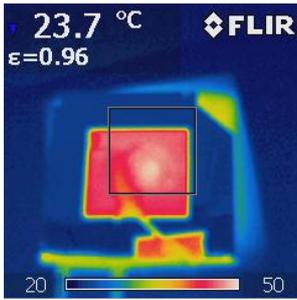
In this experiment, the Hama power supply was taken out of its case, bounded with 4 Ohms and temperature was recorded by using an infrared camera. This experiment was repeated for upper and lower side of the powersupply:



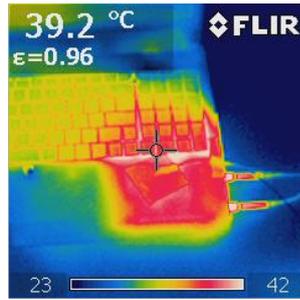
In comparison to the board layout (See [first picture](#)), this pictures show, that most waste heat is produced in the transistors and transformers. Orientation: The cool edge is the one with the 230V socket.

3.2 Defined waste-heat into a DVD-drive's case

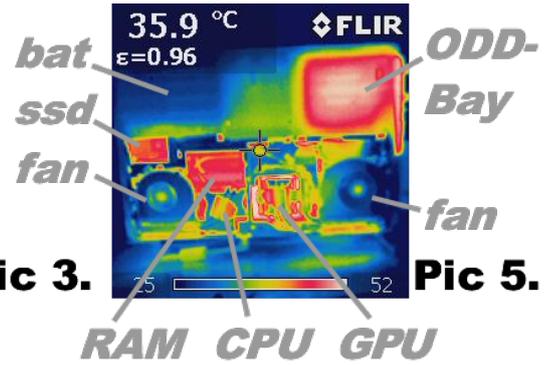
For next experiments, "Constantan" wire was twisted on paperboards and put into the metal case of an unused laptop DVD-drive. This is the *power resistor* R_H . Using a laboratory power supply, it is possible, to send a defined ammount of power into this case. This way, a working powersupply in the case can be simulated, regarding the waste-heat.



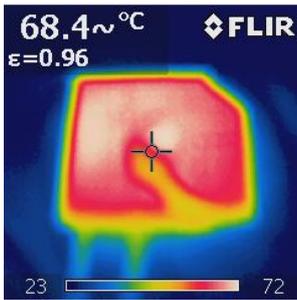
Pic 1.



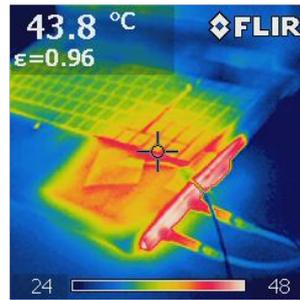
Pic 3.



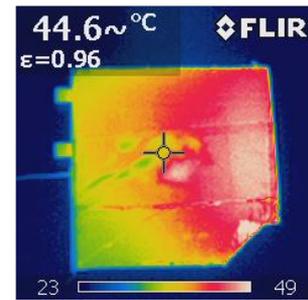
Pic 5.



Pic 2.



Pic 4.



Pic 6.

First, this self-made resistor was provided with $22V * 0.96A = 21.12W$, which corresponds to an efficiency factor of 89.4%; room temperature 23.2 C. The resistor was placed on two thin paperboards, to be surrounded with air. This set-up was placed on a fleece, this was, to prevent long term heatup of the tableboard, that influences the ongoing experiment. Two thermometers were used, to measure the surface (T_s) and the inner (T_i) temperature of the resistor. After a while, the temperatures stabilized at $T_s = 82$ C, $T_i = 123$ C (Picture 1). It can be seen, that the metal case does not emit infrared light; the red square in the middle is the emission of a plastic sticker.

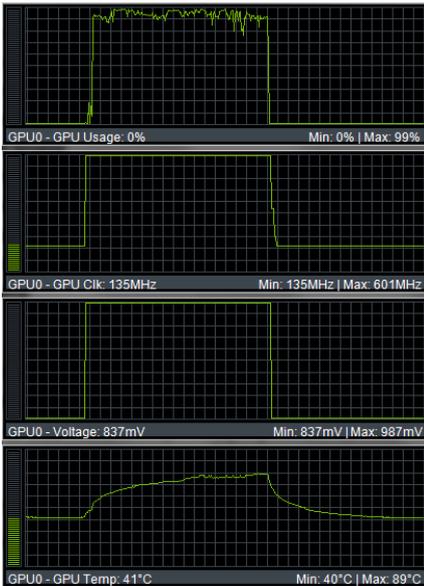
So the complete resistor was pasted with plastic tape (Picture 2). The temperatures now faded to $T_s = 68.5$ C, $T_i = 111.6$ C. This is one more reason, why metal is not suited for surface material.

Next, the resistor was moved into the laptop's media bay. The laptop ran in idle. Pictures 3 and 4 show the heat dissipation in the laptop. Normally, on idle, the GPU-fan is mostly off, it only works on lowest level for some seconds every minute. With the resistor, this proportion inverts. The laptop was a Clevo P150EM with Nvidia Quadro K5000M GPU, the CPU and other parts are not influenced by the waste-heat. The surface thermometer was now placed on the laptop's surface (T_s^*). The temperatures stabilized at $T_i = 118.2$ C, $T_s^* = 47.6$ C. This experiment shows, that the laptop environment is no problem for the power supply, but maybe for the graphics card.

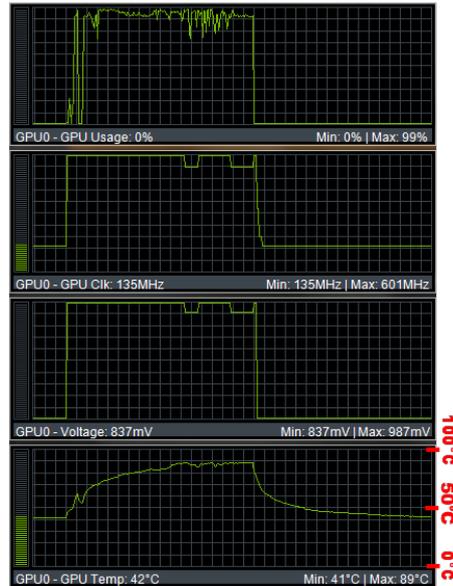
3.3 Influence of waste-heat on the GPU

The data above show, that a total power loss of 21 W is too much for an internal powersupply without active cooling. So for next experiment, the delivered power was reduced to $15.7 V * 0.67 A = 10.519 W$, what means an efficiency factor $> 94.4 \%$. Picture 5 shows the lower side of the laptop with open service cover and the reduced 10.519 W in the ODD-bay. Under this conditions, a GPU benchmark (Metro Last Light) was ran, in comparison to a benchmark without resistor:

normal

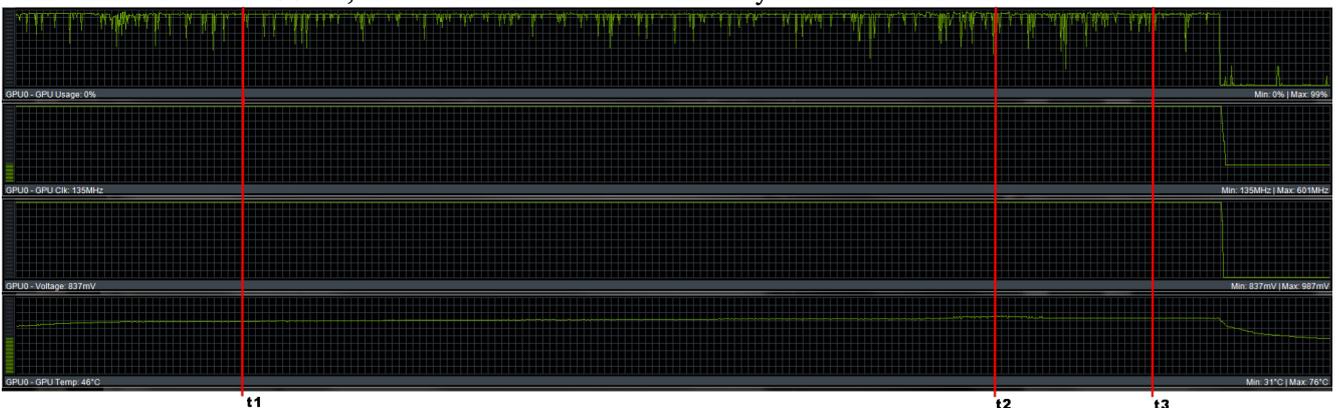


with resistor



It can be seen, that the 10.5 W can be handled, but the temperature is 10 K higher, than in normal condition and the GPU throttles a bit. If we look at the GPU's total power consumption of 100 W, even the total 10.5 W of the resistor doesn't seem to be a big problem, so this result is partly surprising. Maybe, because the working resistor had dissipated the full 10.5 W long time before the benchmark started, there was a bigger amount of pent-up heat, that the cooling system has to carry out during the benchmark.

To analyze this, the experiment was repeated, but with a long time benchmark, that startet before the resistor was moved into the ODD-bay. In the meantime, the laptop was switched into a HP 8770w, but with same GPU. On 8770W, the GPU is next to the ODD-bay like in the P150EM.



For benchmarking, Metro 2033 was used. After some time, the temperature seemed to stabilize at 69 C. Then, the resistor was moved into the ODD-bay (t1) and very, very slowly, the temperature climbed to 74 C. Finally, the player in the game was moved to a more complex viewpoint (t2), which means higher GPU usage. The temperature again increased about two K, but after returning to previous viewpoint, it fades back to 74 C. In this scenario, the resistor was no problem for the GPU.

4 Distortion

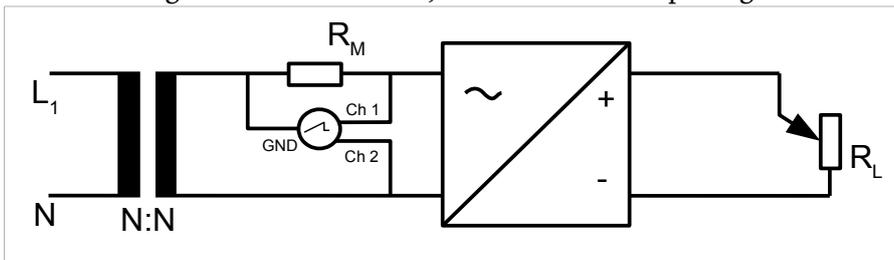
Last experiment should determine the exact signal form and the distortion of the primary and secondary side currents.

4.1 Input signal

To measure the input signal means capturing the waveform of input voltage and current. Devices heaving more than 75 W have to be conform with norms (EN61000-3-2), restricting the distortion factor of the current³. The distortion factor is the relation between fundamental wave and it's harmonics. This factor cannot be measured directly, it can be computed using fourier analysis of the signal. This is not done for this practical, yet.

4.1.1 Measurement

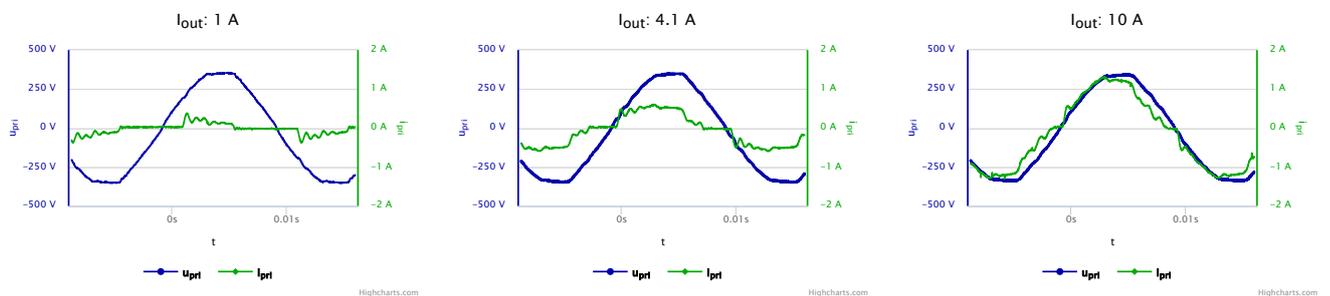
The following circuit can be used, to measure the input signal:



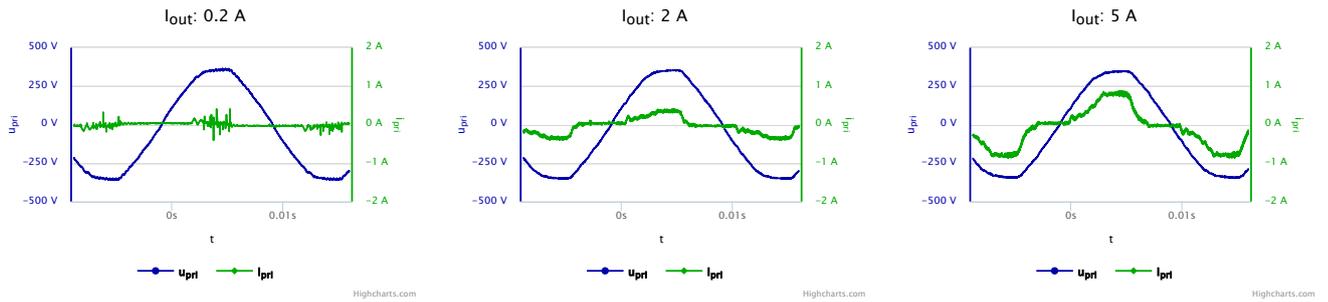
For this experiment, the transformator for galvanic separation ist absolutely nescessary, because the oscilloscope's input socket is grounded and missing galvanic separation resulted in shortcut.

4.1.2 Results

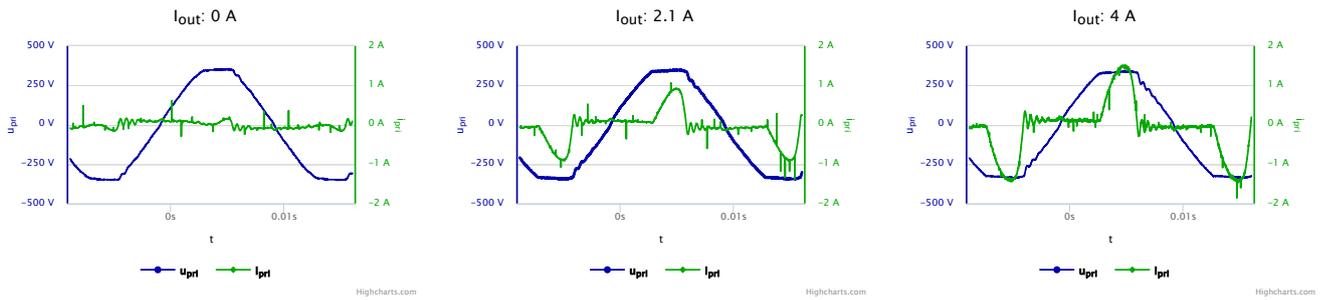
Clevo power supply:



Hama power supply:



TDK power supply:



4.1.3 Interpretation

The waveform of the input current gives a first impression, about how complex the power supply is. The TDK model got the simplest layout of all regarded power supplies. The Hama power supply spends a lot of effort for its power factor correction (PFC), there is a big capacitor on the 250V level (See [first picture](#)). There are different kinds of PFC, being used in power supplies and the Clevo's and Hama's input current looks like a simple, active PFC.

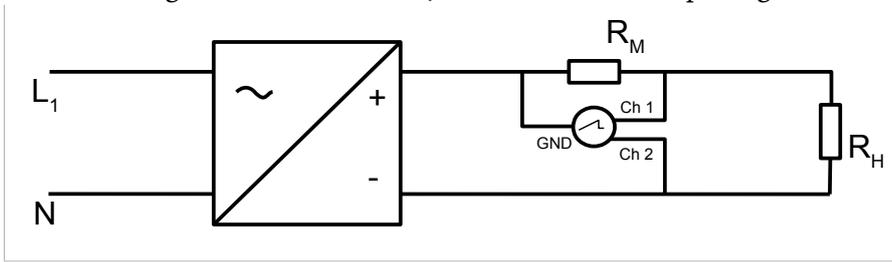
Advanced, active PFCs are multi quadrant choppers, that control the input current to be sinusoidal. So complex switched-mode power supplies consists of two stages: One, that sends a sinusoidal current into a big capacitor and one, that takes a discrete current from this capacitor to the output. Galvanic isolation and voltage transformation can principally be done in either of this stages, to obtain good efficiency, a reasonable trade-off has to be found. With the known data, it is difficult to say, what exact layout Hama and Clevo use for this power supplies.

4.2 Output signal

Output voltage and current are not perfectly discrete, there is still a more or less significant AC percentage (jitter) on this signals. This experiment tries to measure the natural power supplies' jitter and the laptop caused one's.

4.2.1 Measurement

The following circuit can be used, to measure the output signal:

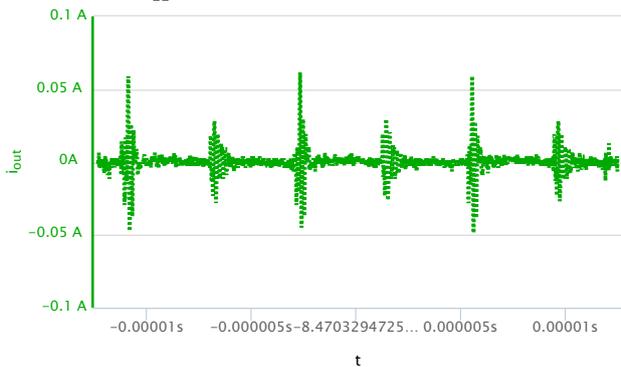


The programmable load was not suitable for this experiment, because it creates a lot of distortion itself. So the constantan resistor was used instead. Therefore the output signal is measured just for one resistance. The oscilloscope was set to ac-mode.

4.2.2 Results

For the test resistor of 23 Ohm, the power supplies shew the following AC signal part:

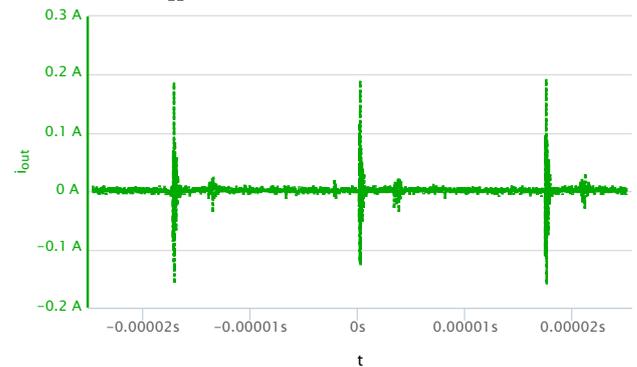
Hama with R_H



..... HamaR: i_{out}

Highcharts.com

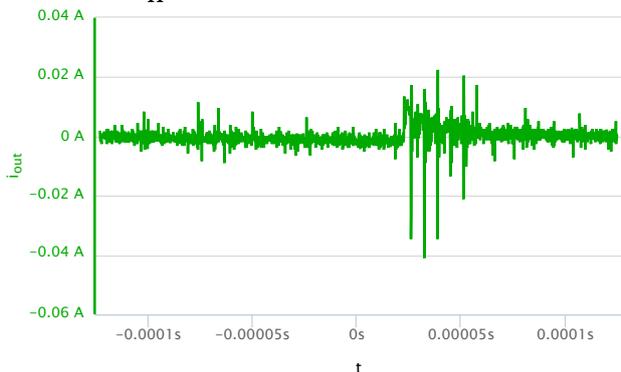
TDK with R_H



..... TDKR1: i_{out}

Highcharts.com

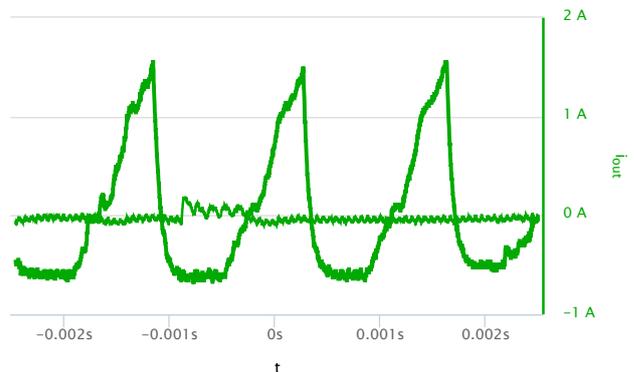
Clevo with R_H



..... ClevoR: i_{out}

Highcharts.com

Clevo with P150HM



..... ClevoP150Akku: i_{out}

..... ClevoP150idle1: i_{out}

Highcharts.com

With R_H the DC part of the current was about 0.82 A for Clevo and Hama and about 1 A for TDK. On the last chart, the Clevo power supply was connected to a P150HM laptop. The highly oscillating graph was captured on idle operation, but with loading battery, the smoother graph was idle operation without battery.

It was not possible, to measure the current during graphics benchmark, because the measurement resistor R_M was not able, to handle this high current. Furthermore, an unhealthy humming from the mainboard was hearable, due to the voltage drop.

4.2.3 Interpretation

This experiment shows, that switched-mode power supplies create small, but significant jitter on their output current in tight time intervals. But this jitter is comparatively negligible with regard on the jitter, that the mainboard's power transformers create.

An other interesting fact is, that the output voltage must not break down on high currents. The laptop's power transformers don't operate well at voltages less than maybe 18V. This is an interesting view on the often discussed CPU whining problem of some motherboards. Maybe an other power supply can fix this problem...

Conclusion

This practical rendered interesting facts on power supplies. Due to the measurement results, it can be said, that:

- Power supplies control their output voltage precisely and relatively independently from current and temperature.
- Compact power supplies are not necessarily less efficient, than large ones; compact design and little surface force the power supplies to be efficient due to overheating problems.
- Common laptop power supplies does not have an overheating protection.
- Most power losses are caused by the transistors and the transformers.
- Metal is unsuitable for surface material, due to low infrared emission coefficient.
- ODD bay power supply without active cooling needed efficiency factor higher than 94%.
- Power factor correction is a major issue when designing switched-mode power supplies.
- Laptop circuit produces a big current jitter at the output of power supply.

For ongoing studies, more power supplies should be measured and more precise devices and assumptions on wiring losses are required. With the measured data, more analytics, such as fourier transformation and distortion factor calculation can be done.

References

Notes

¹http://www.tdk-lambda.com/products/sps/ps_pcb/cme150_24/indexe.html, 2016.02.14

²<https://www.hama.com/00054190/hama-notebook-netzteil-19-v-90-w-ultra-slim>, 2016.01.31

³<http://kompendium.infotip.de/pfc-power-factor-correction.html>, 2016.02.06