TALLINNA TEHNIKAÜLIKOOL

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Hübriidne toiteallikas

DIPLOMITÖÖ

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2014

Hübriidne toiteallikas

Andrey Knyazev

Tallinn, 2014

Töö koosneb 44 leheküljest, mille hulgas on 44 jooniseid ja 1 tabel.

Töö on kirjutatud inglise keeles.

Töö on kirjutatud isiklikult Andrey Knyazev'i poolt, ehk on unikaalne ja ei koosne varem kirjutatud lõputööde lõikudest.

Diplomitöö eesmärgiks on välja töötada, koostada ja simuleerida alalispinge regulaatori, mis võimaldab alandada pulsatsioone alla 1mV-ni täiskoormusel.

Töö on simuleeritud Multisim 12 programmis, mis annab kuju pingeregulaatori karakteristikutest.

Hybrid power supply

Andrey Knyazev

Tallinn University of Technology, 2014

The diploma work consists of 44 pages, including 44 diagrams and 1 table.

The work is written in English.

The work is written personally by Andrey Knyazev and is unique, as well as does not consist of previously written diploma works.

The main idea of this work is to develop, compile and simulate DC voltage regulator that allows maintaining low voltage ripple at below 1mV.

The work is also simulated in Multisim 12 program, that describes overall characteristics of the regulator.

Гибридный блок питания

Андрей Князев

Таллиннский Технический университет, 2014

Дипломная работа состоит из 44 страниц, в числе которых 44 рисунка и 1 таблица.

Работа написана на английском языке.

Работа написана лично Андреем Князевым и является уникальной, а также не состоит из отрывков ранее написанных работ.

Основная цель дипломной работы – разработать, собрать и просимулировать стабилизатор напряжения постоянного тока, пульсации на выходе которого не превышали бы 1мВ.

Работа просимулирована в программе Multisim 12, что описывает основные характеристики спроектированной схемы.

Table of contents

Introduction

There are many different situations known where efficient power supplies or voltage converters are needed nowadays. The use of them helps to reduce power dissipation during the convertion of a non-stable input to exact voltages that are needed for core supply, audio power amplifier units, or for laboratory use where efficient power supply modules may be found the more often during the past decades, since the first transistor oscillation and rectifying converter power supply system was filed and patented in 1959.

In order to minimize wasted energy losses there are **Switching Mode Power Supplies** (or **SMPS**) used often nowadays. The actual efficiency of working power converters usually lays between 70% and 95%, when there are even more efficient power supplies known where this parameter may exceed 98% in certain conditions. If we are talking about home use power supplies (for example, the ones that supply modems, DVD players, computers, cheap home cinema systems and other low power equipment), there is a huge advantage of SMPS mode power supplies over traditional heavy steel core transformers in the efficiency as well as in overall dimensions and final product weight. In some cases (quite often) the SMPS power supplies are even cheaper to produce than traditional metal core power supplies.

However, it is still quite hard to find switching power source in expensive brand home theatre audio receivers (power amplifiers), small signal audio/video converters or in those power supplies that are commonly specified for laboratory use. The reason of these exclusions is in comparatively high output pulsations which are usually not in compromise with the load requirements and are really hard to minimize using standard methods such as LC and RC (for low and high voltages respectively) filters.

Therefore the prototyping of high-efficient SMPS mode power supply with extremely low output pulsations (or output voltage ripple) is actual due to rised power requirements of modern electronics as well as due to rised importance of reducing power losses as much as possible. And thanks to up-to-date components and tested working topologies it is possible to nearly eliminate most of output ripple using so called Hybrid power supply that will be based on both SMPS and linear mode voltage converters at once.

1. Short overview of modern power converting topologies

1.1. Theory of operation. SMPS mode voltage converter

The traditional SMPS mode power supply consists of the next parts [1]:

1. Input rectifier
2. Inverter controller
3. Inverter („Chopper“)
4. Output transformer
5. Output rectifier and filter

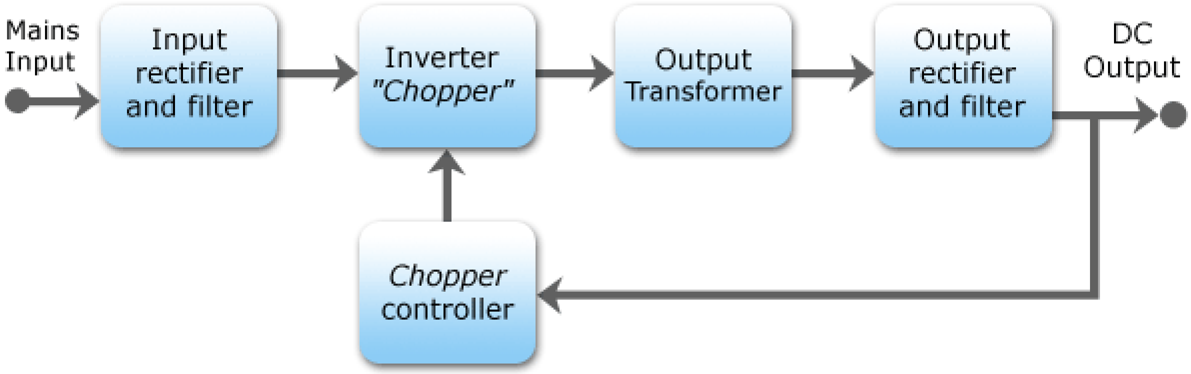

Figure 1.1. Traditional SMPS mode power supply stages

During the above mentioned stages the AC input voltage is being converted into DC regulated output with affordable efficiency in most cases.

1.1.1. Input rectifier and filter

The simplest part of the SMPS mode power supply called input rectifier usually consists of up to 4 diodes, a smoothing capacitor (or capacitors) and in most cases a kind of EMI filtration in order to minimize high frequency noise coming from the power supply to mains outlet. However, in many low power (o several watts) power supplies the stage of input filter is missing regarded to overall cost minimizing and simplifying the diagram.

The most usual to see input filter and rectifier is shown on Figure 1.2. [2]

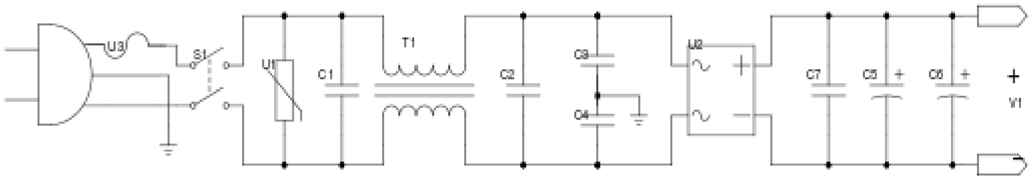

Figure 1.2. Traditional input rectifier and filter of SMPS power supply

1.1.2. Inverter controller

The Inverter controller (PWM controller) adjusts duty cycle to determine when the output mosfets are open in order to get proper readings at the output of power supply (Figure 1.3).

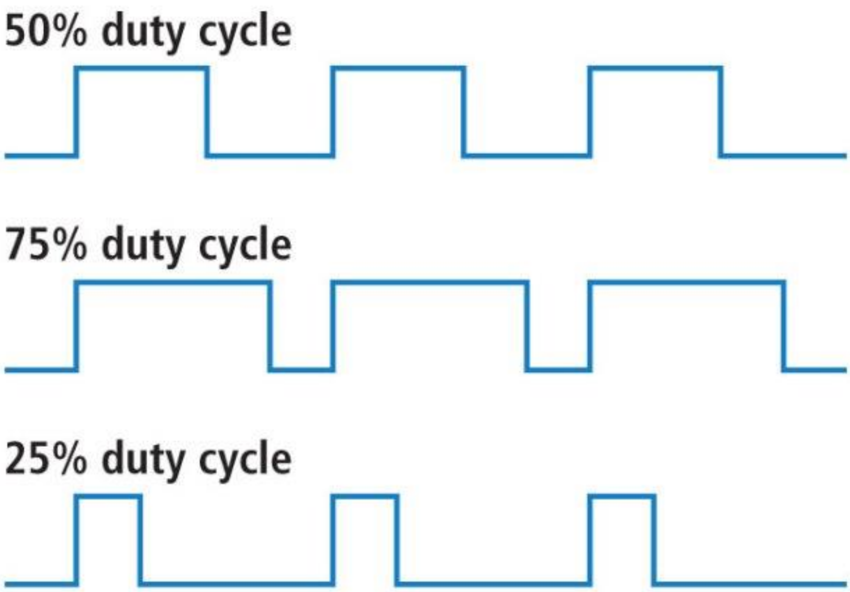

Figure 1.3. PWM duty cycle adjustments in 50%, 75% and 25% cases

The feedback as fed back whether by using a voltage divider or an optocoupler (most commonly) that adjusts actual duty cycle by terminating gerenation of output signals at certain period of time. The example of using an optocoupler is shown on Figure 1.4. [3]

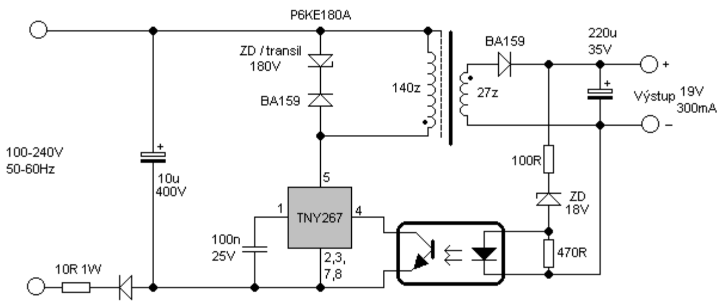

Figure 1.4. Simple example of feedback loop using an optocouple

The switching stage is usually controlled by IC mosfet drivers, small transformers or simply by pairs of complementary transistors or even optocuplers driven by main controller unit shown on Figures 1.5. to 1.8. [4]

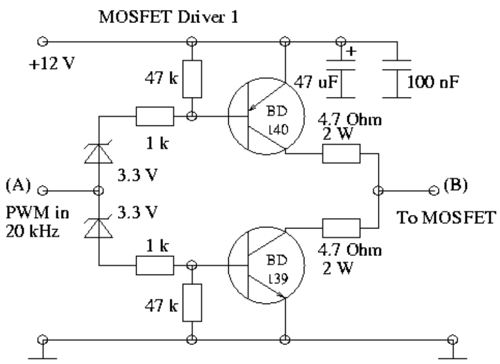

Figure 1.5. Transistor driver for output Mosfet

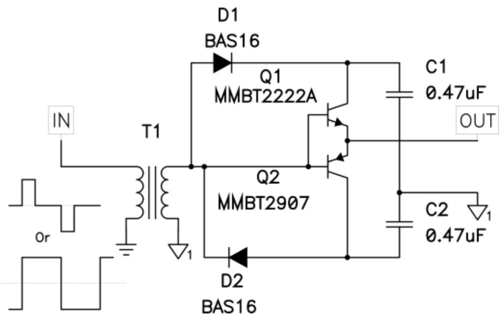

Figure 1.6. Transformer-transistor driver for output Mosfet

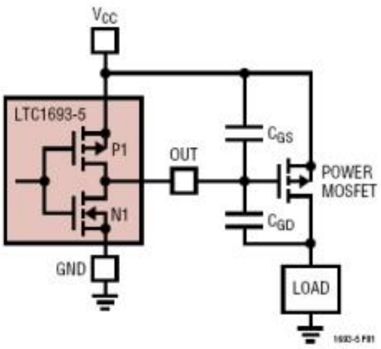

Figure 1.7. IC mosfet driver for output Mosfet

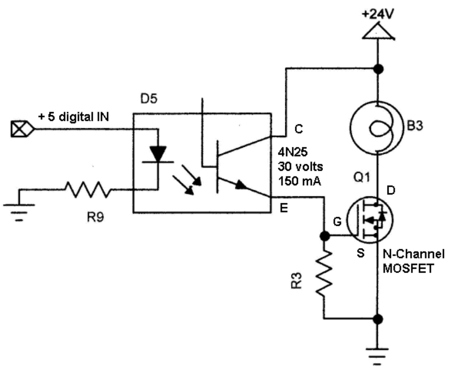

Figure 1.8. Optocoupler as a driver for output Mosfet

However, there are many examples of using mosfet drivers internally of the PWM controller, such as a family of UC384x controllers which actually need the only one resistor going from it to the Mosfet. This typical schematic diagram is shown on Figure 1.9. [5]

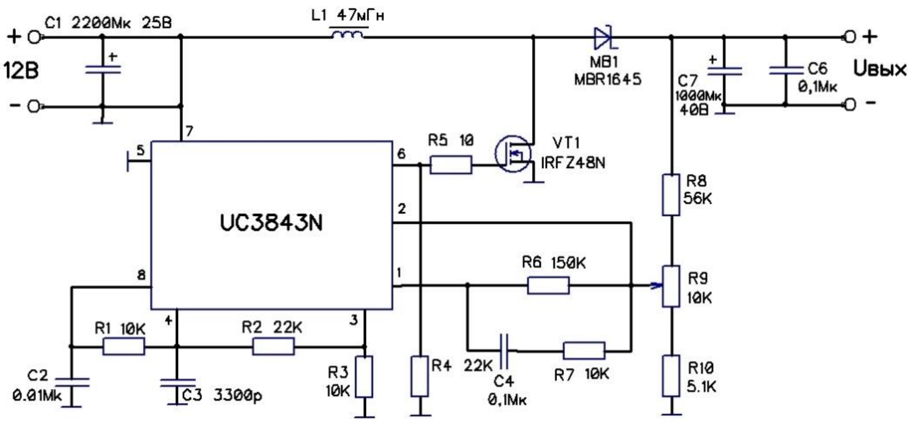

Figure 1.9. PWM controller as driver for output Mosfet

1.1.3. Inverter (the switching stage)

The Inverter stage consists of DC to AC converter switching parts like Mosfet or bipolar transistors of thyristors (rarer). They are used to transform DC power into alternative current with a frequency barely inaudible for human ear (above 20kHz). However, many designs allow converting voltages at lover (5-20kHz) frequencies that can be heard by human, as well as much higher ones (up to 200kHz and higher), especially used in extremely efficient power supplies.

Here are just few of inverter desings usually used in mains power supplies (Figure 1.10) [6]:

1. Flyback (up to 250W)
2. Forward, half-forward (up to 200-250W)
3. Push-pull (up to 1kW)
4. Half-bridge (up to 2kW)
5. Full-bridge (up to 5kW and over) figure 13

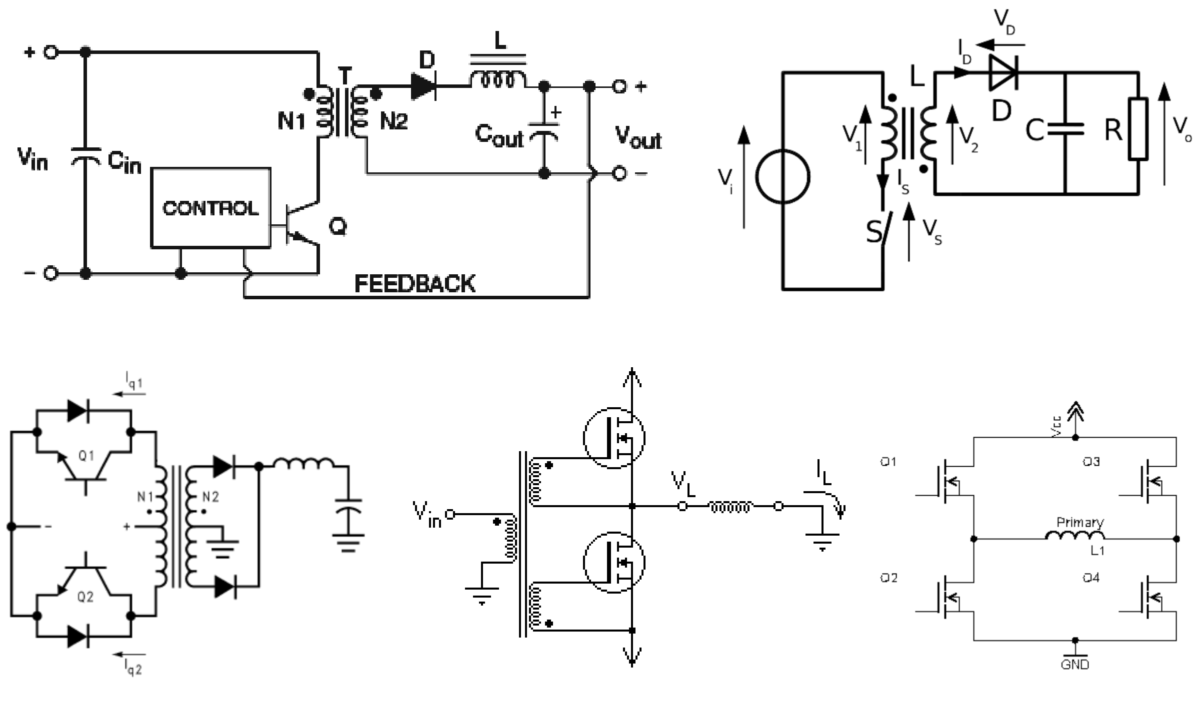

Figure 1.10. The most commonly used designs of the switching stage

1.1.4. Output transformer

The Output transformer of mains switching power supply commonly consists of 2 or more windings. The use of output transformer is in galvanic isolation of load from the mains power. The use of high frequencies allows to minimize dimensions of the transformer and to use low power loss ferrite cores that are widely available nowadays.

There are also many different ways to build the output transformers and one of the most common is captured on Figure 1.11. [7]

Figure 1.11. Different types of ferrite core based switching transformers

The other type of transformers begin to spread along mostly efficient power converters as all the windings are actually printed on the PCB (mostly multi-layer). The result is the highest available efficiency, better power dissipation, higher power density and lower skin effect that is becoming a big problem at higher frequencies. The transformer itself shown on Figure 1.12.

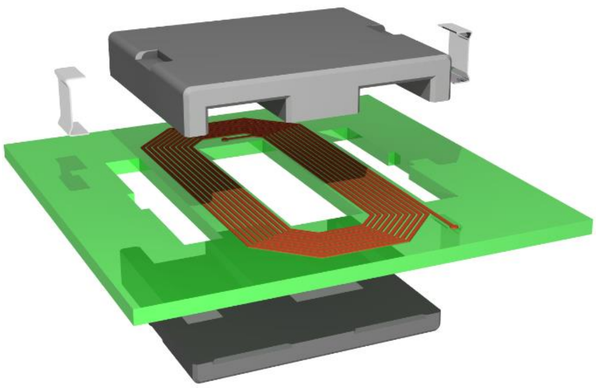

Figure 1.12. PCB based slim ferrite core transformer

1.1.5. Output rectifier and filter

The voltage coming from the output transformer's secondary winding should be rectified and filtered in order to get stable DC output at various load currents.

There are many ways to rectify the output voltage. The cheapest and most widely spread way is to use high frequency diodes. It is possible to switch between several rectifying schematics as winding of switching transformers consist of several turns, so that it is not as hard to make double windings as in case of traditional 50/60Hz transformer. Some different ways of rectification are shown on Figure 1.13.-1.14. [8]

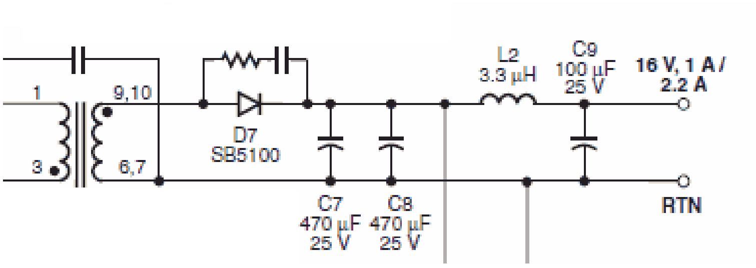

Figure 1.13. An example of half-brigdge rectifier

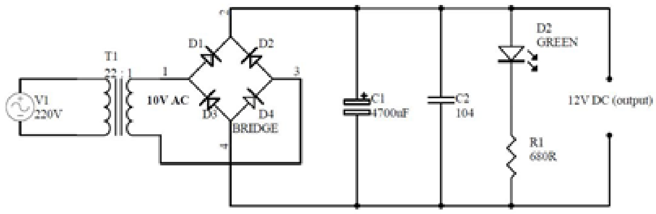

Figure 1.14. Another example of full-brigdge rectifier

The other more efficient way to rectify the output voltage is to use so called „Synchronous rectifier". This method is expensive and needs much more expirience in building switching power supplies as in this case all the current is being rectified by additional mosfets working synchronously with the ones on the primary side. The simple example is on Figure 1.15. [9]

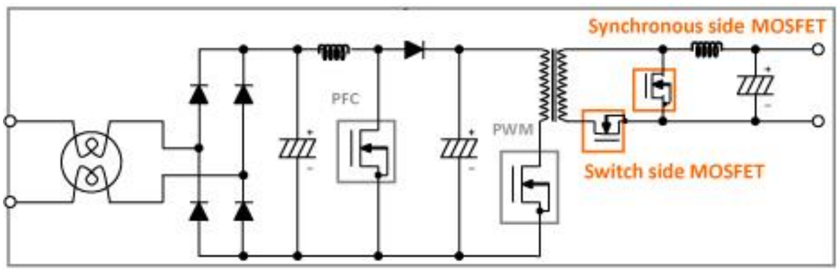

Figure 1.15. An example of synchronous mosfet rectifier

The output filter (whether LC or RC) should be used in order to minimize output pulsations caused by high frequency switching as well as to risen the overal efficiency of the power supply at higher power consumptions. Generally, in case of loads that do not exceed 1-2A or about up to 20W there are many designs where the output filters are not used beacause of simplifying and depreciation of low power power sources. Such a decision may be applied in case where low output voltage ripple readings are not needed (for example, in low voltage lighting transformers). Nevertheless, it is usually important to use an output filter and some of them are shown on figures 1.16. to 1.18. [10]

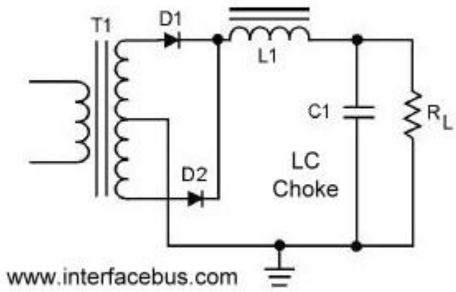

Figure 1.16. An example of LC filter used in low voltage systems

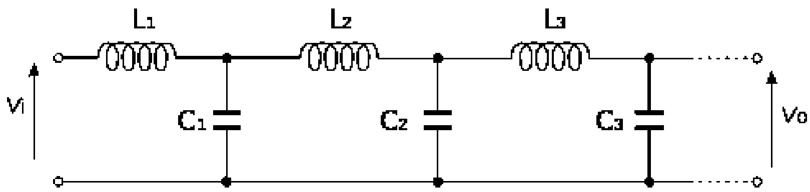

Figure 1.17. An example of multistage LC filter used in low voltage systems

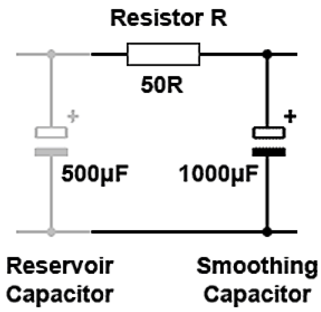

Figure 1.18. Simplificated RC filter used in high voltage systems

1.2. Theory of operation. Linear voltage regulator

Linear voltage regulators are usually used in conditions where stable output voltage is needed in various current consumptions. Especially they are easy to find in such electronic devices like low power amplifiers, high precision voltage sources, laboratory power supplies and many other devices that are strict to the quality of the supply voltage.

This type of regulators was used most widely in mid-end 20th century when there were no other possibilities to convert the input voltage to desired one, or in the very beginning of SMPS mode power supply era. Nevertheless, when the efficiency of such type regulators drops much lower than in case of switching power supplies, linear regulators are still used till nowadays thanks to their ability to quite easily minimize output pulsations. This is a compromise between cost, regulated voltage quality and overall efficiency.

The common view of linear regulator is shown on Figure 1.19, where a kind of regulating element (transistor, zener diode, thyristor, etc.) is marked as a variable resistor. [11]

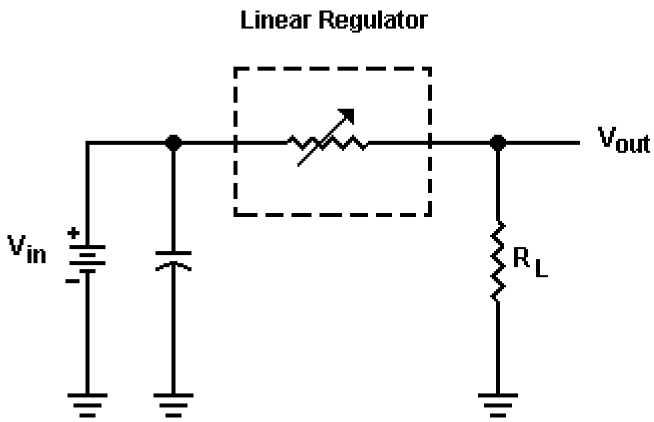

Figure 1.19. Simplificated linear voltage regulator

There are different types of linear regulators known, such as simple zener regulator, series regulator based on regulating transistor, linear regulator ICs or even Mosfet type transistor connected as a linear regulator. The variouty of them is nearly limitless, but the most common are shown below.

1.2.1. Simple zener regulator

This type of regulators is the most cost-efficient, as well is not as stable as it is needed in some cases. The output has a very low power and varies with the input voltage and the load applied to it. However, in order to get averagely regulated voltage as a reference source, this type of regulators is very widely spread and can be found in nearly any electronic devices. The basic diagram of it is shown on Figure 1.20.

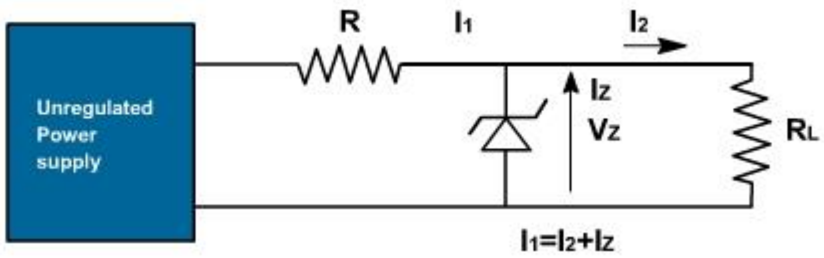

Figure 1.20. Simple zener regulator circuit

In order to get more precision voltage at the output, the so called shunt regulator can be used. These regulators are electronic and are adjustable in many cases. One of the most famous shunt regulators is shown on figure 1.21. The TL431 is the IC that can maintain voltage between anode and cathode pins at wide range of 2.5 to about 35 Volts. The only external components needed are 2 resistors, that are used as a divider with the output voltage of 2.5V connected to the load in parallel. This regulator can handle up to 100mA of sink current and maintain steady output voltage within wide input voltage range as well as different loads applied to it. [11]

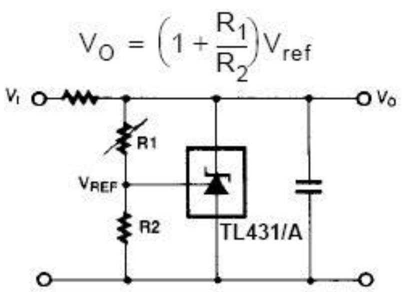

Figure 1.21. TL431 as a shunt regulator

1.2.2. Series regulator

In case when higher power outputs are needed, a zener regulator can be connected with a power transistor, let it be a bipolar, IGBT or Mosfet in order to minimize power losses while maximizing maximum output power. Simplified diagrams of series regulator circuits are shown on Figures 1.22 and 1.23 (using bipolar and mosfet transistors respectively).

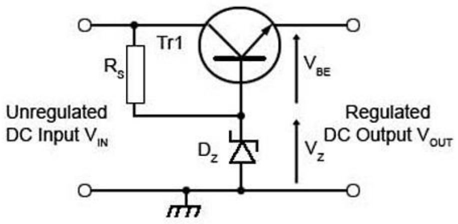

Figure 1.22. Simplified series regulator based on n-p-n transistor

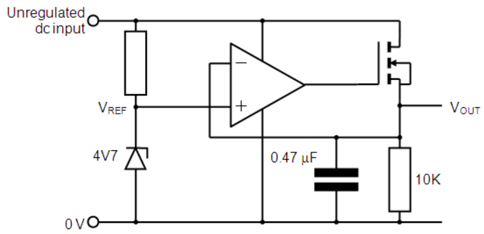

Figure 1.23. Operational amplifier controlled Mosfet based series regulator

1.2.3. IC voltage regulator

When an averagely good stabilisation and medium power (up to 5 Amps, up to 50 Watts) are needed both, there are also IC regulators that basically include all the components of traditional series regulator and allow to maintain steady output as well as the output short circuit protection (Figure 1.24) [13]

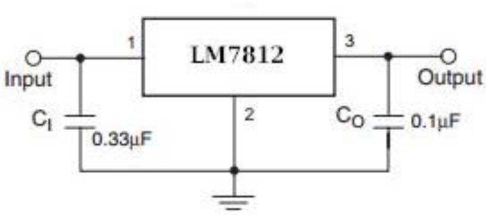

Figure 1.24. Integrated circuit 12V linear regulator example

1.3. From the theory to practice. The idea of Hybrid power supply

To summarize all the written above, there are many power supply topologies that are widely spread in modern schematics, but all of them have their own plusses and minuses. Let it be the efficiency, overall dimensions, weight, output ripple elimination or product final cost.

Nevertheless, a desire to approach an ideal power converter that would not have any power losses neither supply noises makes it possible to create the newer designs that somehow help to maximize the efficiency of using up-to-date components in order to get even closer to the aim.

Practically, this actual work will demonstrate on of the ways of power converting with lowest possible losses that is used rarely nowadays, but still starts to develop and can already be found in some commercial products.

The talking is about Hybrid power supply that combines both:

- High power conversion efficiency
- Highly stable power output
- Lowest possible output ripple
- Good quality to cost ratio

In this particular work, it will be developed and simulated low power hybrid converter with the next main parameters:

- Output voltage exactly +12VDC
- Output current up to 1A
- Output voltage ripple below 1mV at full load
- No need of active cooling either secondary parts heat sinking

The hybrid power supply will be made of both SMPS mode converter and an ULDO linear regulator based on low impedance Mosfet transistor as a ripple eliminator. The actual design is unique and was made personally by author of this work.

Finally, a practically working prototype of another mains hybrid power supply will be shown. That unit was also developed by an author and seems to be in absolutely working condition and maintain desired characteristics for at least past 2 years of everyday use.

2. Structure diagram of Hybrid power supply

The main idea of the work is to develop one of the most efficient output ripple suppression unit that will be made of widely spread components that are available for affordable prices.

As there will be several ripple-suppressing methods shown, the block of output ripple suppressor will be realized in several schematic decisions, as well as will be simulated too to conclude the benefits and negative aspects as well.

The final version of Hybrid power supply itself will consist of the next blocks:

- Input rectifier
- Inverter
- Output rectifier
- Output feedback loop
- Output ripple suppressor

The structure diagram of hybrid power supply is shown on Figure 2.1.

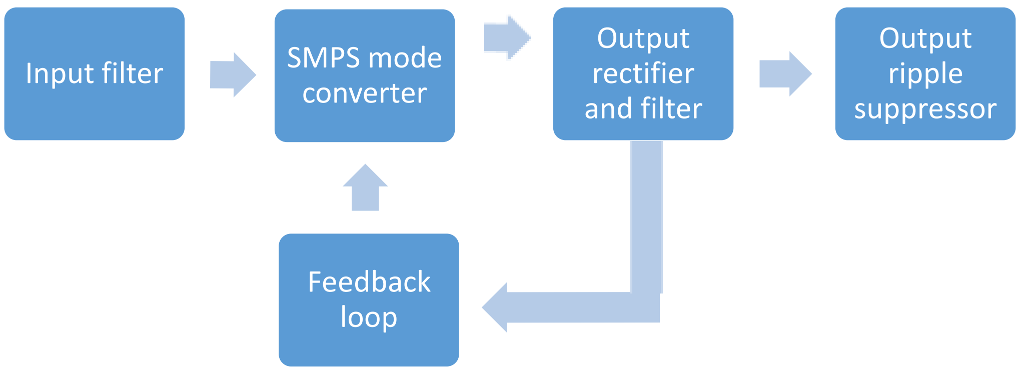

Figure 2.1. Structure diagram of hybrid power supply.

3. Schematic design development

The hybrid power supply consists of 2 schematic diagrams split together:

- SMPS mode power supply and
- Output ripple suppressor

Firstly, it will be developed, described and simulated primary part of the Hybrid power supply. Then there would be shown different methods of output ripple suppression and the final variant of schematic diagram will be simulated as well.

3.1. SMPS mode power supply

3.1.1. The brain of SMPS unit

The switching power supply is based on UC3842 PWM controller as a widely used component that actually can be found in most low power mains converters. It has its own current protection circuit so that can be used as a brain of a CC-CV power source as well if needed. The internal block diagram of it is shown on Figure 3.1. [14]

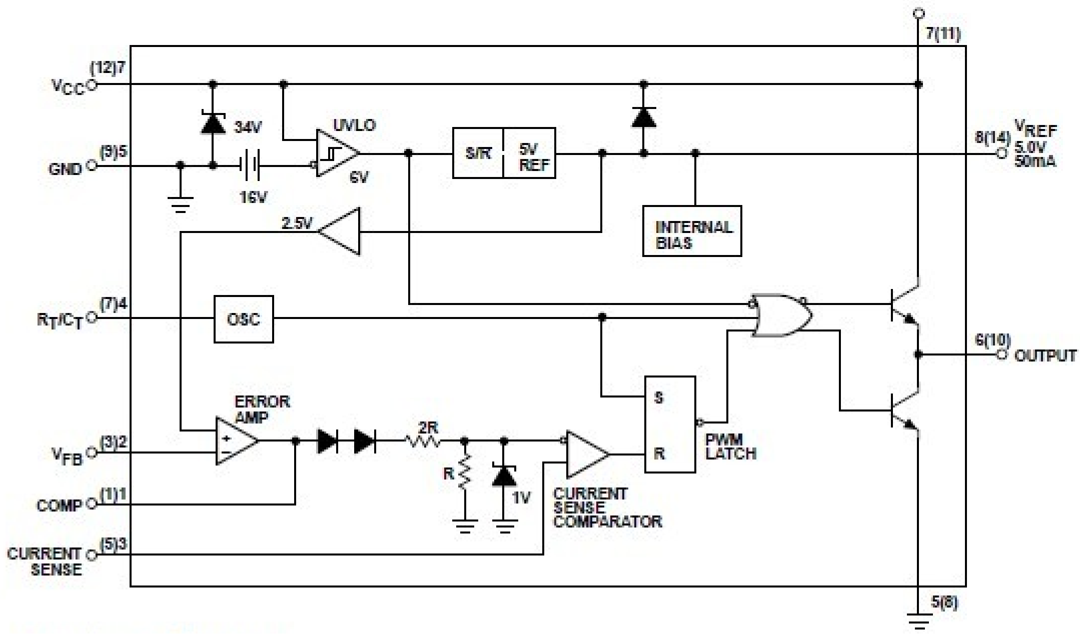

Figure 3.1. Typical block diagram of UC3842 controller

The integrated circuit has only 8 pins and therefore can be hooked up very simply nearly to any type of power supply. The particular PWM controller is mainly used in Flyback power supplies, which power does not usually exceed 100 Watts.

The controller consists of the next blocks:

- Internal power management block
- Internal BIAS supply
- Reference voltage regulator
- Oscillator
- Error amplifier
- Current sense comparator
- PWM controller itself

Actually, there is more than enough that is needed for low power converter. The IC has internal output driver as well, so that any nearly Mosfet can be connected to the output of the controller.

The function of the pins is listed below:

- Pin 1: Comparator, the output of internal error amplifier. The output pulse-width modulation can be decreased by applying a potential of lower than +1V to this pin.
- Pin 2: Feedback, can also be used for decreasing PWM whenever the potential at this pin exceeds +2.5V
- Pin 3: Current sense, used to sense peak currents going throw the power Mosfet by using an external source resistor. The oscillation blocks if the potential at this pin >+1V.
- Pin 4: Rt/Ct timing circuit. Two timing components should be connected to this pin as nearly to the IC as possible.
- Pin 5: Ground pin that is common for all the internal circuitry.
- Pin 6: Output, should be connected directly to Mosfet through a gate resistor
- Pin 7: Vcc, the supply of the controller and all its internal circuits
- Pin 8: Vref, the reference voltage of +5V that can be loaded up to 50mA.

3.1.2. Typical Flyback schematic diagram of UC3842

The UC3842 controller is used in most low power converters and their schematic diagrams does not differ a lot from each other. The most common example of Flyback power supply used for such electronic devices like WiFi routers, modems, switches, mobile charges is shown on Figure 3.2. [15]

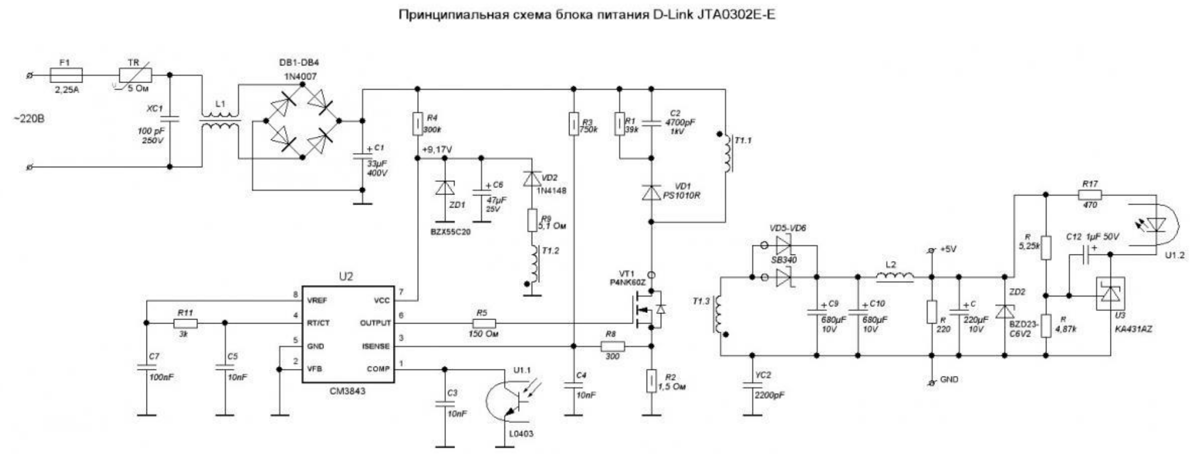

Figure 3.2. Typical schematic diagram of Flyback power supply based on UC3842

This actual schematic is drawn down from working modem power adapter D-Link JTA0302E. This is a good example of using this IC as a controller for Flyback power supply. The output of this adapter is rated at 5V 2.5A, so that this is a 12.5 Watt power supply.

This schematic will be taken as a reference for all the next modifications of the Hybrid power supply.

The output power will be maintained at the same level, when the output voltage will be rised.

This power supply can be considered as a stand-alone unit that only converts 230VAC input to regulated output with quite big output ripple.

The schematic diagram of this power supply will be drawn using Multisim 12 program in the next chapters.

3.1.3. Actual schematic diagram of SMPS unit

The actual schematic diagram of the SMPS unit is shown on Figure 3.3.

The output voltage of this power supply is adjusted to 12V. The feedback loop consists of elements: R5, R6, U4, R10 and U3. Resistors R5 and R6 form a resistive voltage divider with a potential in middle point of 2.5V. This is needed to operate TL431 shunt regulator which controls an optocoupler U3. In order to get 2.5 Volts in middle point of voltage divider at 12V output, here is a formula taken out of UC3842 datasheet [15]:

$$Vout = \left(1 + \frac{R1}{R2} \right) \bullet Vref \qquad (3.1)$$

where Vout is output voltage, Vref is reference voltage and R1 and R2 are R5 and R6 respectively in this schematic. In other words we have:

$$12V = \left(1 + \frac{R5}{R6} \right) \bullet 2.5V \qquad (3.2)$$

Let R6 be 1kΩ, then R5 should be:

$$R5 = \left(\frac{12V}{2.5V} - 1k\Omega \right) \bullet R6 = 3.8k\Omega \qquad (3.3)$$

The nearest available resistor nominal is 3.9kΩ, so the actual output voltage will be:

$$Vout = \left(1 + \frac{3.9k\Omega}{1k\Omega} \right) \bullet 2.5V = 12.25V \qquad (3.4)$$

The voltage seen on the output in the schematic is a bit lower (12.17V) due to output ripple. By this time simulated circuit seems to be working right.

The R7 resistor is used as an ohmic load of 12 Ohms, so that it would load 12V power supply right at 1A, or 12 Watts of power. This nominal will not be changed during all the next tests.

Resistors R3 and R4 imitate internal resistance of transformer T1 secondary coil and capacitor C3 internal ESR resistance. A low ESR capacitor of 1000µF is desired in all the next diagrams.

The R10 resistor limit current flow through an optocoupler U3 at (12.25-1.25)/220 = 50mA.

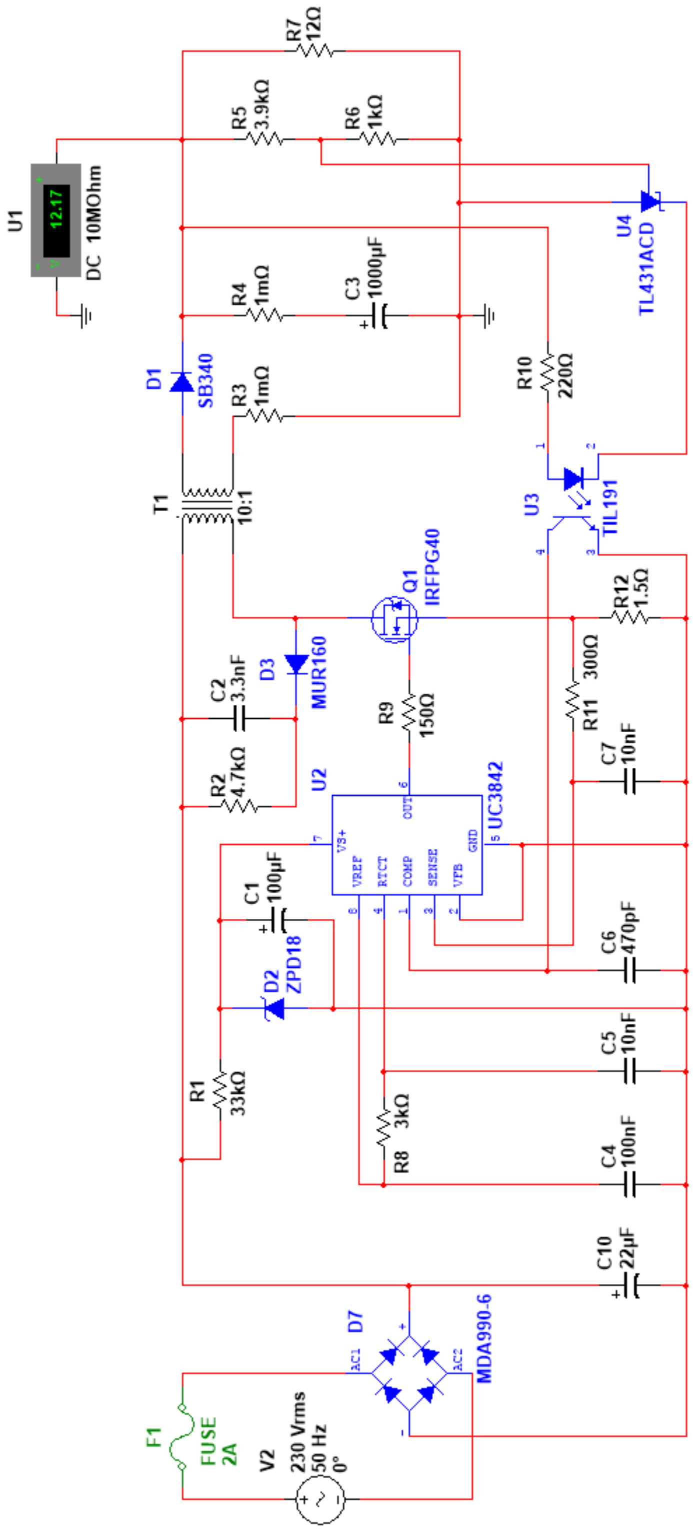

Figure 3.3. Actual Flyback SMPS unit

A chain of D3, R2 and C2 forms a snubber, that lower high frequency pulsations during operation of switching Mosfet Q1. Using no snubber may blow up the switch with thousands of volts. No nominals were changed in comparison with an original schematic.

The switching transistor Q1 is chosen IRFPG40 because of its working Drain-Sourse voltage of 1000V. The Flyback topology desires a minimum working working switch voltage of doubled the supply voltage. This parameter can be found using the next formula:

$$Vq1 = 2 \bullet 230V \bullet \sqrt{2} = 650.5V \qquad (3.5)$$

where 230V is mains outlet voltage of 230VAC.

In most applications there are 600V Mosfets used, as they can still handle a bit higher voltages for a short period of time. But it is still adviced to use at least 700V ones in such conditions.

A chain of R1, D2 and C1 is used to supply the controller U2 with a voltage of 18VDC. The maximum supply current is limited at about 10mA by a 33kΩ resistor R1.

C5 and R8 both form a RtCt timing circuit with a nominal frequency of [16]:

$$F = \frac{1.8}{Ct \bullet Rt} = \frac{1.8}{10 \bullet 10^{-9} \bullet 3 \bullet 10^{3}} = 60kHz \qquad (3.6)$$

C4 and C6 are used for switch transient suppression.

A chain of R12, R11 and C7 form a current sense input that is roughly limited by R12 at:

$$Imax = \frac{1}{R12} = \frac{1}{1.5} = 0.67A \qquad (3.7)$$

This does not mean, that the maximum power output is limited by a current flow of 0.67Amps, but this means that any switching current of more than that level will result in shutting the oscillator down till the next pulse of PWM controller.

Finally, the C10 capacitor filters input 100Hz pulsations and is calculated by the formula [19]:

$$C = \frac{Pout}{\eta \bullet F \bullet (Vdc\_min^2 - Vin\_min^2)} \bullet \left(1 + \frac{\arccos\left(\frac{Vin\_min}{Vdc\_min}\right)}{\pi}\right) =$$

$$\frac{12}{0.8 \bullet 50 \bullet (260^2 - 200^2)} \bullet \left(1 + \frac{\arccos\left(\frac{200}{260}\right)}{\pi}\right) = 13.3\mu F \qquad (3.8)$$

The nearest nominal of capacitor is 15µF, but it is adviced to use a bit higher capacitance due to degradation of filtering capacitors during operation. Then a 22µF 400V capacitor is advised.

Any of bridge rectifiers can be used with a nominal voltage and current of 400V and 1A respectively.

3.1.4. Output characteristics of SMPS unit

The described above power supply was simulated in Multisim 12 programm.

A Transient analysis was applied for first 400µS of working time in every next simulation.

Note: The simulation does not describe start-up processes, but only describes correctly working power supply after startup.

Here is actual output oscillogram shown on Figure 3.4.

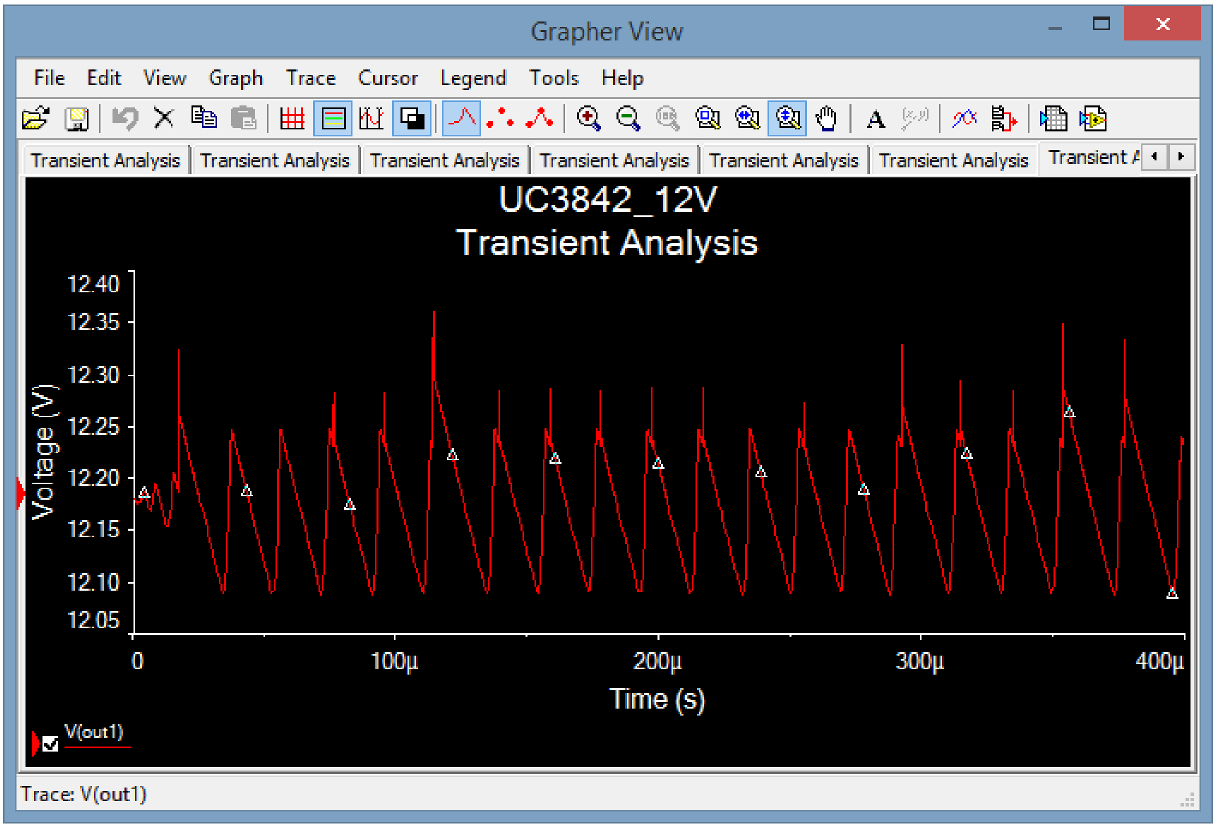

Figure 3.4. Output signal form of traditional UC3842 power supply

As predicted, output ripple seems to be too high for power supply quality sensitive loads. An average of 12.17V output voltage actually drifts within **12.08V** to **12.36V** resulting in **280mV** pulsations. This result might be affordable for lighting setups (but probably not for LEDs), while not for any kind of microphone amplifiers or somethink of that series.

3.1.5. Schematic diagram of Hybrid SMPS + LM7812CT unit

There are some ways to beat those pulsations and one of them is to go with traditional linear regulators. In order not to complicate the diagram a lot, there was a 12-Volt LM7812CT linear regulator added at the output. The schematic diagram is shown on Figure 3.5.

As 78xx series regulators need a minimum dropout voltage of 3 Volts, then it was needed to rise the output voltage of the SMPS unit up to about 15 Volts. The actual LM7812CT Multisim model has an output voltage of nearly 11.7 Volts, so 14.9 Volts resulted after R5 calibration were just suitable for these conditions.

The R5 resistor was chosen to be a 5kΩ as of the result of the formula [15]:

$$R5 = \left(\frac{14.7V}{2.5V} - 1k\Omega\right) \bullet 1k\Omega = 4.88k\Omega \qquad (3.9)$$

Other components have the same nominals as before.

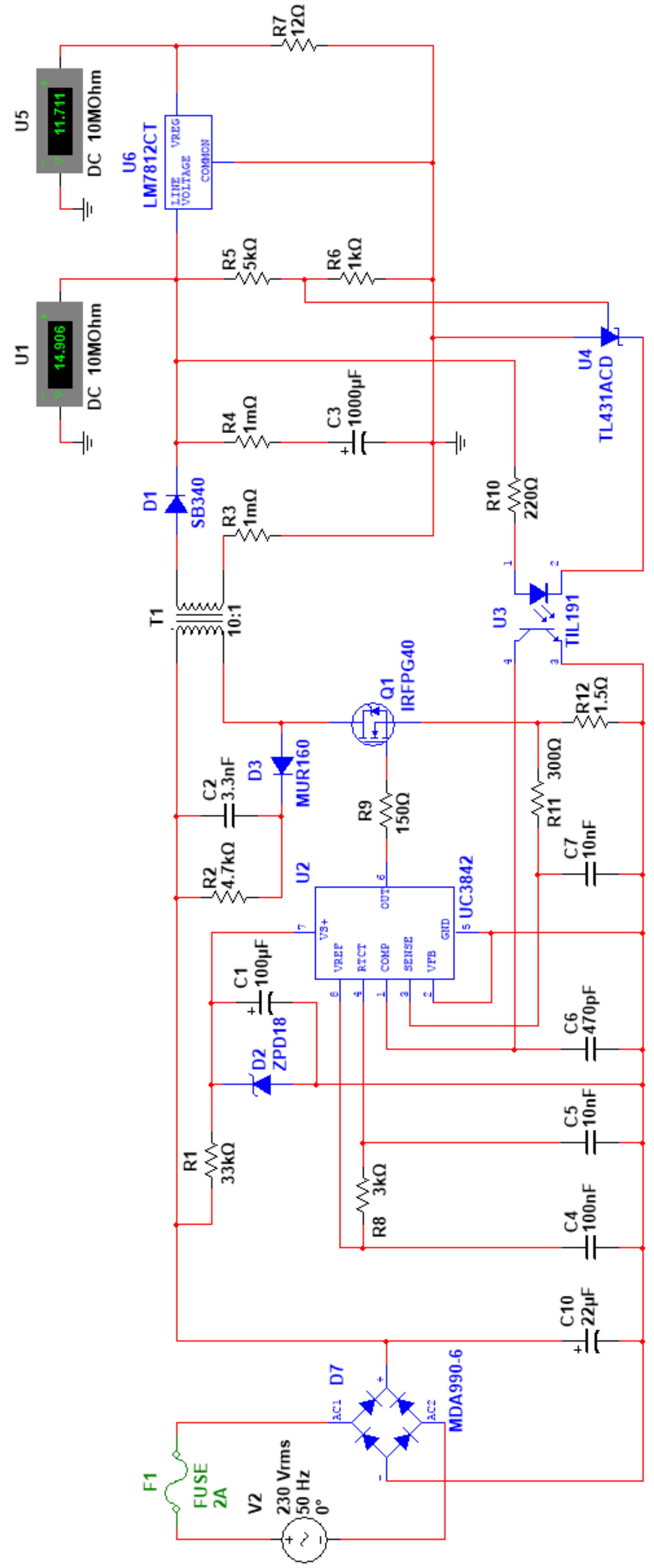

Figure 3.5. Schematic diagram of Hybrid SMPS + LM7812CT power supply

3.1.6. Output characteristics of Hybrid SMPS + L7812 unit

As a positive result of adding the LM7812CT regulator is the output ripple, that is significantly lower, that in previous setup, when the SMPS was used alone. This can be seen on Figure 3.6.

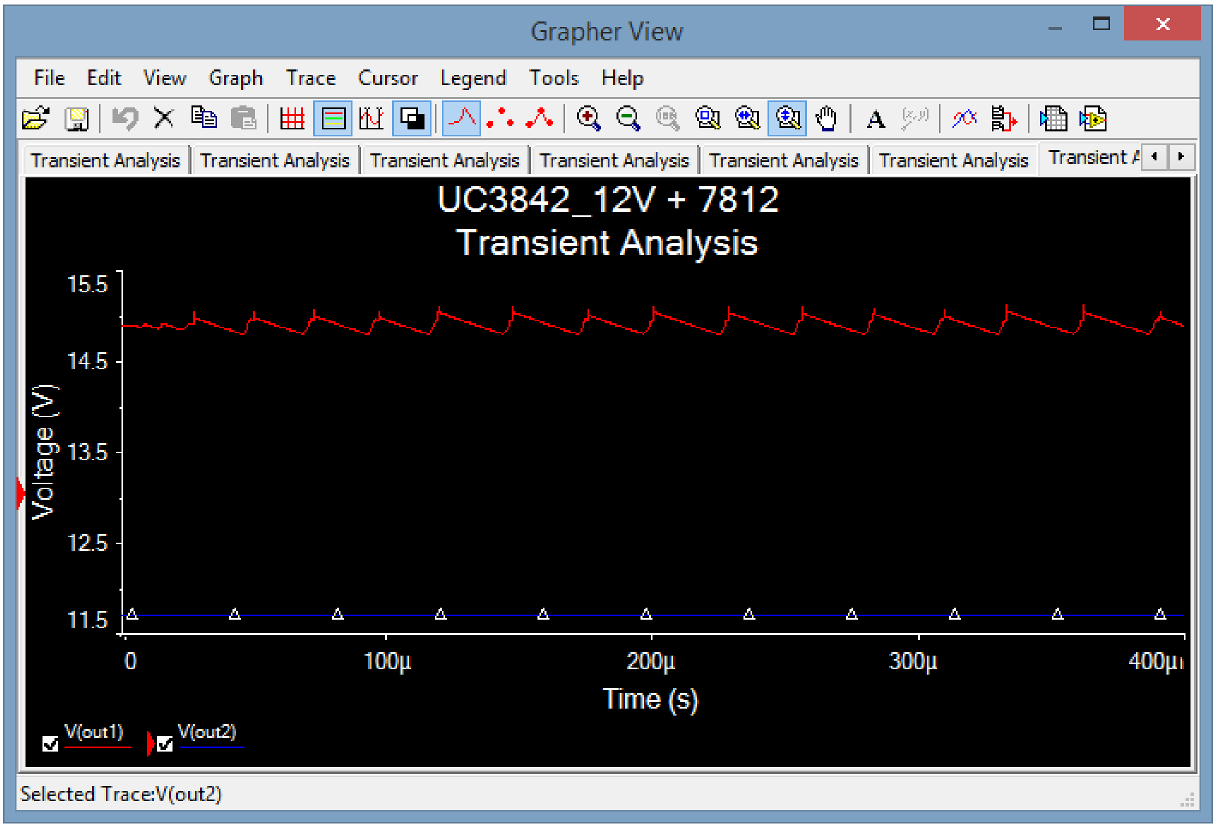

Figure 3.6. Output signal form of hybrid UC3842 + LM7812CT power supply

The red line shows the output pulsations at the SMPS unit, that are still at high level of about 300mV peak-to-peak. The blue one shows the filtered output voltage going from a LM7812CT. Thanks to magnification possibility it can be seen, that output pulsations still occur, but are significantly lower. The resulting image is shown on Figure 30.

The actual ripple is slightly over than 1mV, that is nearly 200 times less, then captured previously (Figure 3.7.).

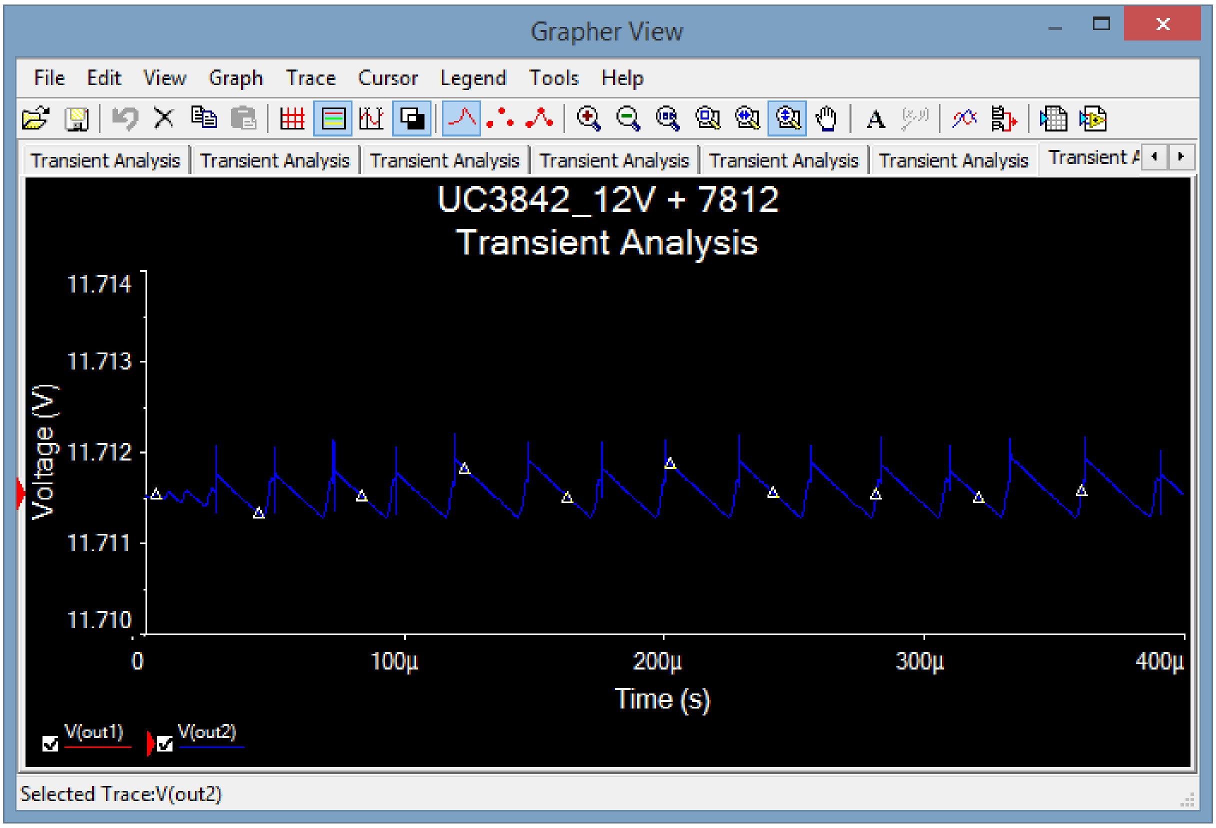

Figure 3.7. Magnificated output signal form of hybrid UC3842 + LM7812CT power supply

The negative aspects are the next:

- Current schematic decision has lots of power losses due to a minimum of 3 Volt dropout voltage on the LM7812CT circuit
- The output voltage is lower than 12V (only 11.71V) that is caused by internal circuitry of 78xx series regulators that trend to have a slightly lower output voltages than they have to. Noteworthy, that a Multisim model also describes this situation virtually.
- The circuit needs to have cooling due to 3 Watts of power being dissipated by the LM7812CT regulator.
- Having massive heatsink means having significantly heavier, bigger and more expensive final product, that is not welcome nowadays.
- Dispite of quite good fitration of the output voltage, there is a slightly bigger ripple, than 1mV. That is not critical, but still not enough for the task.

3.1.7. Schematic diagram of Hybrid SMPS + TL431 + Mosfet unit

The use of Mosfets allows to save lots of space, as well as energy. This is caused by extremely low dropout voltages on Drain-Source junction. In this particular case there is a IRL3803S low Rds-on resistance of 6mΩ transistor used. That results in practically no power losses when the Mosfet conducts current through it.

On Figure 3.8 there is shown a schematic diagram that ensures lowest possible ripple voltage at the output and the highest efficiency at the same time.

The voltage divider of R15, R16 and R6 adjusts exactly 12.0V output using a TL431 shunt regulator. The TL431 therefore controls the power Mosfet by closing it whenever the output voltage is just over 12.0V.

While transistor's gate should have at least several volts higher potential than the output voltage, then a voltage booster was added to the schematic. A chain of C8, D4, and D5 doubles the supply voltage that is suppressed by a R14 resistor.

The D6 zener diode is desired in order to keep Source-Gate junction voltage below 18 Volts in order not to damage the Mosfet.

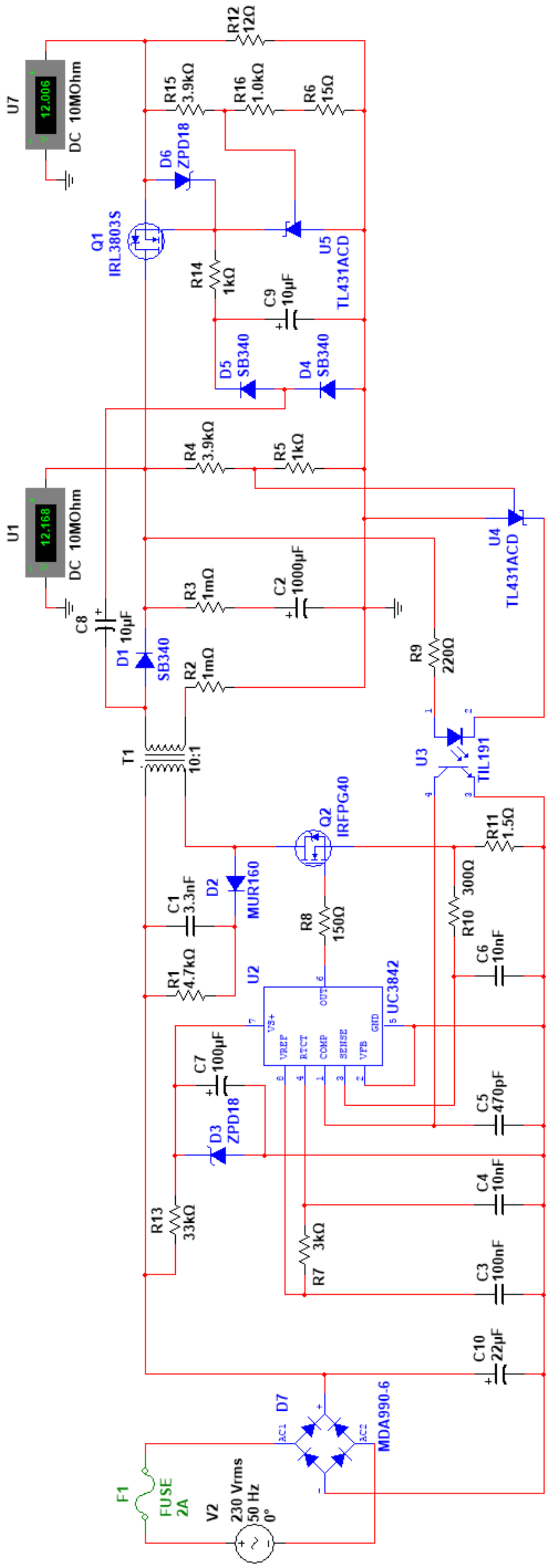

Figure 3.8. Schematic diagram of Hybrid SMPS + TL431 + Mosfet power supply

3.1.8. Output characteristics of Hybrid SMPS + TL431 + Mosfet unit

This schematic decision may also be called as ULDO (Ultra Low Dropout Voltage) regulator.

This results in lowering output pulsations when not having excess power losses.

The resultative output ripple is shown of Figure 3.9.

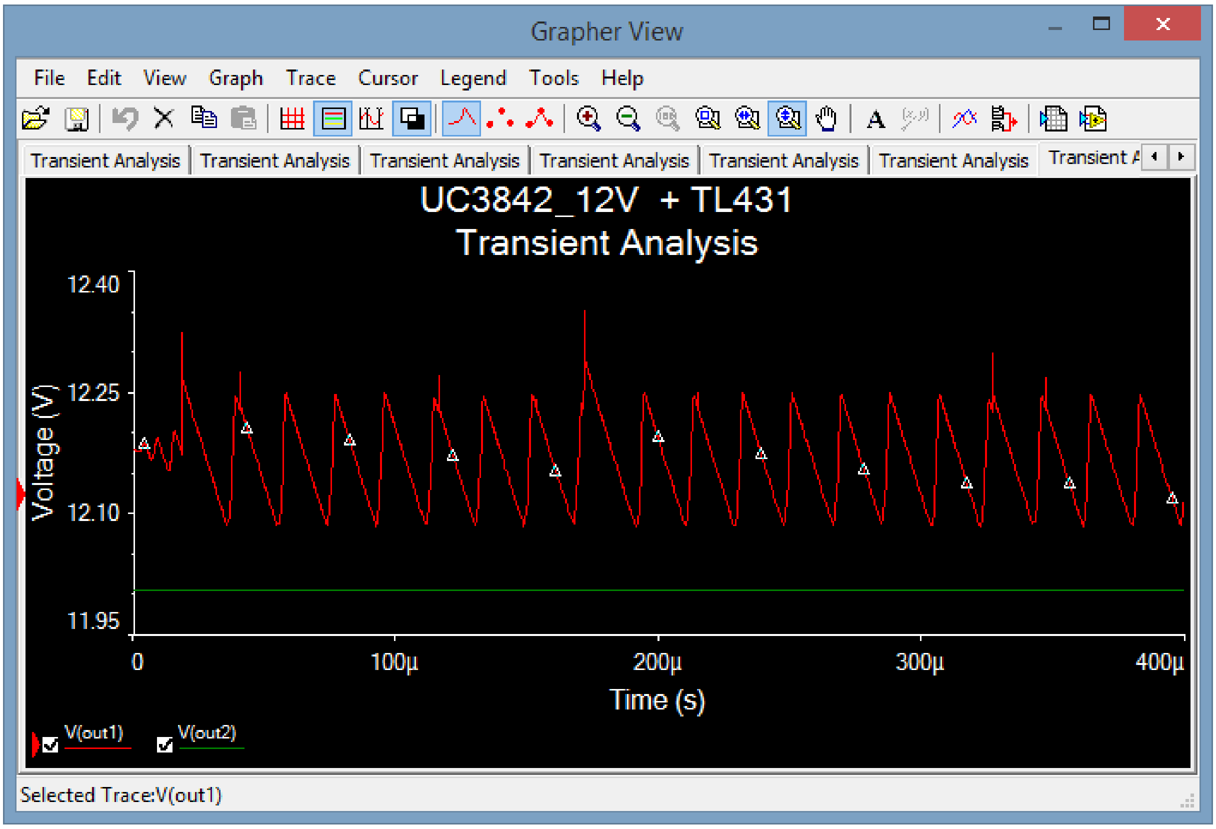

Figure 3.9. Output signal form of hybrid SMPS + TL431 + Mosfet power supply

On this capture it is clearly seen that the output (green) and input (red) voltage potentials of ULDO regulator do not differ much.

Actually, there is only 70mV of dropout voltage at the lowest and about 250mV at the highest point that results in about 160mV of an average dropout.

In fact, it is possible to archieve even better results, but even in this case the dissipated power of just 160mW does to need any heatsinking for power Mosfet.

So that the first aim of the highest possible efficiency was just archieved.

The other points can be discussed by staring at magnified oscillogram of the output on Figure 3.10.

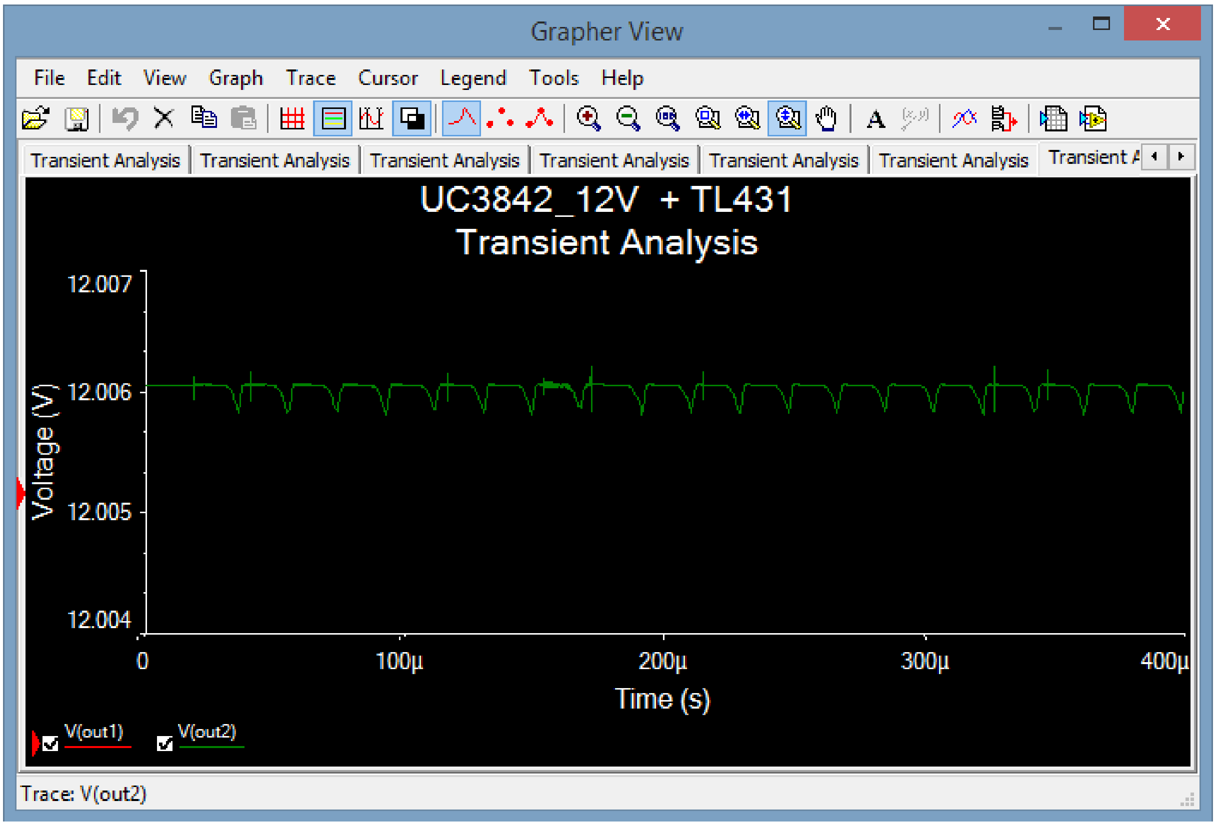

Figure 3.10. Magnificated output signal form of hybrid SMPS + TL431 + Mosfet power supply

Here it is quite easily seen that the output ripple is even lower than in a case of hybrid version based on LM7812CT regulator.

Overall output pulsations do not exceed 250µV that is over 1000 times better result than in case of the first versioon of SMPS and is significantly lower than it was planned (1mV).

The biggest advantage of this type regulator is its high efficiency.

All the measurements were taken at full load of 1A in same conditions.

4. The Printed Circuit Board

The PCB in actual size of the final version of ULDO Hybrid power supply is shown on Figure 4.1.

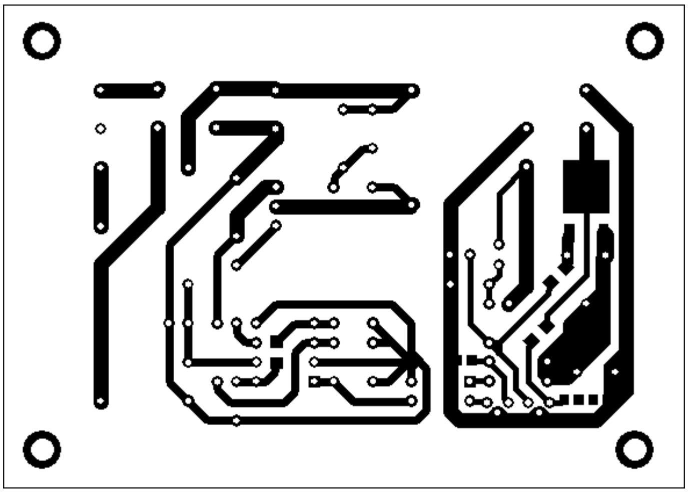

Figure 4.2. PCB of hybrid SMPS + TL431 + Mosfet power supply

The PCB is single-layer and has a layout at the bottom side. Thru-Hole as like as SMD components are used. The actual size of the PCB is 89mm by 63mm. The printed circuit board was made in Sprint Layout 6 program as one of the most usable freewares.

On Figure 4.2. there are all the components placement shown as well.

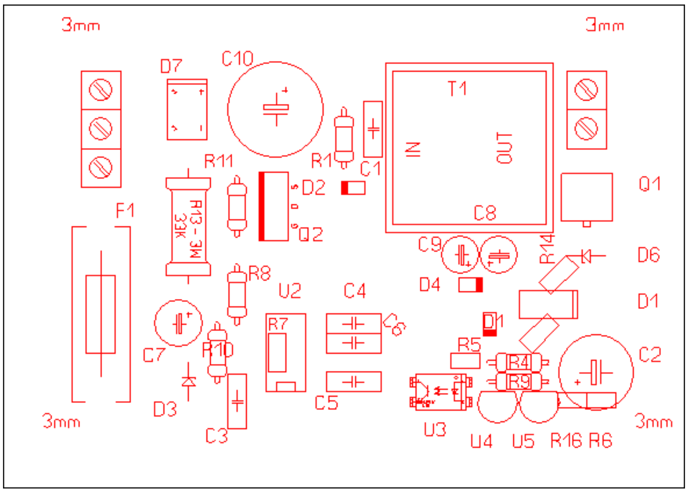

Figure 4.2. Components placement PCB of hybrid SMPS + TL431 + Mosfet power supply

The Figure 4.3 demonstrates actual drill hole sizes of the PCB.

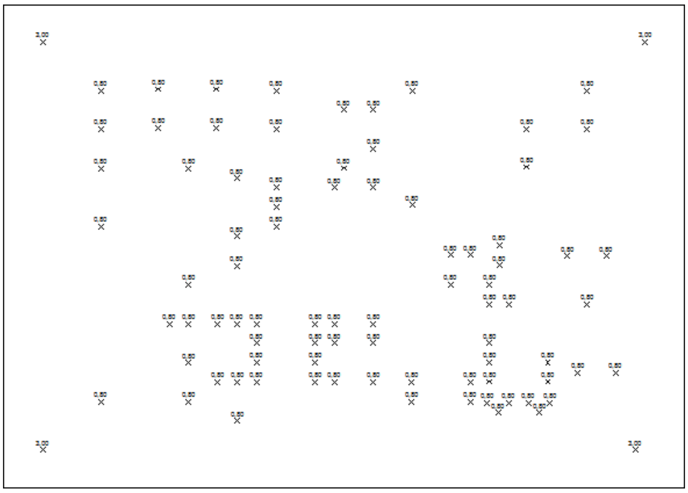

Figure 4.3. Drill holes diameters of PCB of hybrid SMPS + TL431 + Mosfet power supply

5. Production costs

Below is a table of listed components including actual market prices.

As the work was not oriented on mass production, there might exist an excessive production cost, that may be eliminated if needed.

Component number	Nominal / Description	Cost (in EUR as of Sept 2014)
C1	3.3nF 250V	0.50
C2	1000µF 16V electrolythic low ESR	0.10
C3	100nF 50V	0.10
C4	10nF 50V	0.10
C5	470pF 50V	0.10
C6	10n 50V	0.10
C7	100µF 25V electrolythic	0.10
C8	10µF 25V electrolythic	0.10
C9	10µF 25V electrolythic	0.10
C10	22µF 400V electrolythic	0.30
R1	4.7K 0.25W	0.05
R4	3.9K 0.25W	0.05

R5	1K 0.125W	0.05
R6	15R 0.125W	0.05
R7	3K 0.25W	0.05
R8	150R 0.25W	0.05
R9	220R 0.25W	0.05
R10	300R 0.25W	0.05
R11	1.5R 0.25W	0.05
R13	33K 0.25W	0.05
R14	1K 0.125W	0.05
R15	3.9K 0.125W	0.05
R16	1K 0.125W	0.05
D1	SB340	0.30
D2	MUR160	0.15
D3	ZPD18 18V zener	0.10
D4	SB340	0.30
D5	SB340	0.30
D6	ZPD18 18V zener	0.10
D7	MDA990-6 bridge rectifier	1.00
U2	UC3842	0.40
U3	TIL191 optocoupler	0.30
U4	TL431ACD	0.15
U5	TL431ACD	0.15
Q1	IRL3803S	1.00
Q2	IRFPG40	3.00
T1	10:1 ratio switching transformer	2
F1	2A 5*20mm Fuse	0.3

Table 1. Production costs

The total components cost of first board production would be **11.65 EUR.**

Those costs do not include PCB manufacturing costs and production (soldering, cutting, etc.) costs. However, all the listed components are available in wholesales, so that actual component costs would be 3 to 5 times lower in small series production.

6. Summary

To summarize all the written above it should be said that there are different ways of minimizing output pulsations of switching mode power supplies. Some of them are the cheapest, another ones bring better efficiency. And it is always a question of a choice between cost-effective production process or high grade power supplies built for laboratory use and some electronic devides that need to be supplied with the lowest ripple only possible.

In this particular work there were described few methods of using different schematic decisions in order to archieve the aim of supplying loads with the lowest output noise level.

The Multisim program allows to discover and describe processes that barely can not be seen really. The preliminary simulation of complicated schematic diagrams allows to prevent big costs in case of human mistake.

The idea behind the Hybrid power supply lies in the fact of possibilities that might be taken to maximize power converting efficiency as well as to minimize output pulsations.

From different sides of view the main idea was archieved during this work.

Materials used

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7. Addition

In order not to leave all the said above unsubstantiated, here is a picture of real prototype.

Figure 7.1. Hybrid mains power supply prototype

This hybrid power supply is based on mains lighting transformer (the bottom side of the unit) with the output parameters of 2 by 11.5V and 200W in total.

The schematic diagram of it is shown on Figure 7.2.

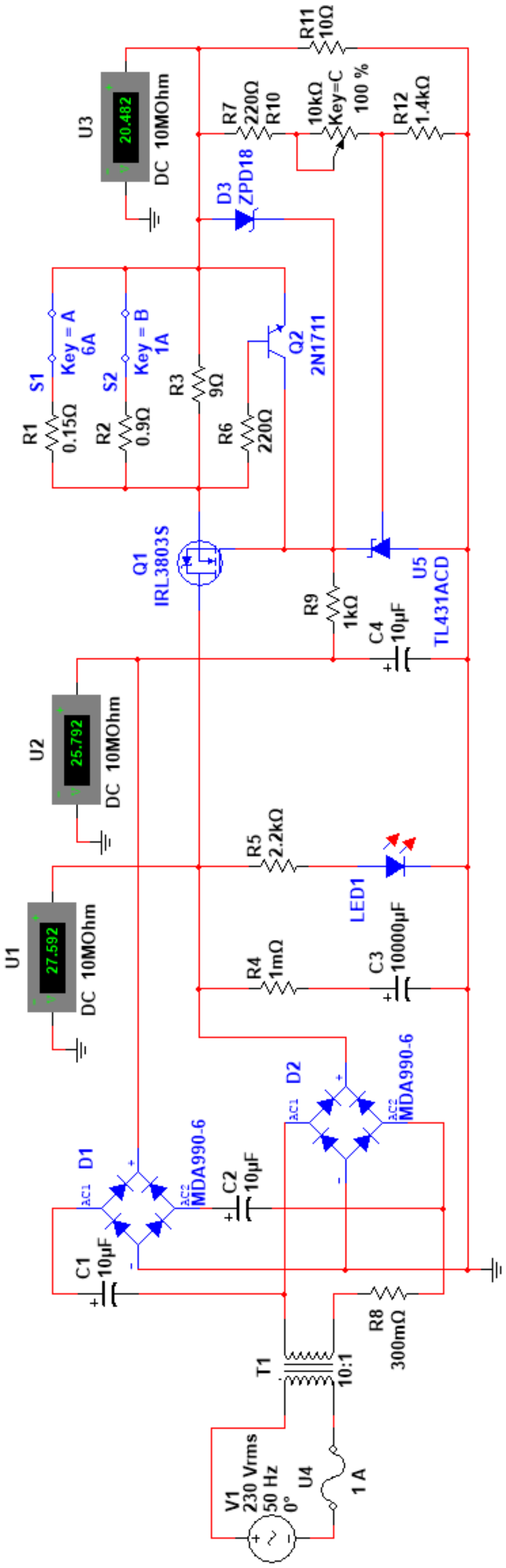

Figure 7.2. Schematic diagram of Hybrid mains power supply prototype

The power supply is built up using the same principle described before.

Key characteristics are:

- Output voltage: +3...20VDC
- Output current: up to 6A
- Output power: up to 120W
- Output overcurrent protection: adjustable in 3 steps – 0.1A, 1A, 6A
- Output short circuit protection: continuous
- Output ripple (real conditions, at full load): no more than 2mVp-p
- Overtempetarute protection: continuously adjustable fan speed

The mains transformer has internal secondary winding resistance of about 0.3Ω, that is also shown on schematic diagram as R8 resistor.

The input DC voltage is filtered by a bank of low ESR capacitors C3 with a ESR of 1mΩ (R4).

A voltage doubler is built by a chain of C1, C2, D1 and C4 and is suppressed by R9.

The power Mosfet Q1 has as low as 40mV dropout voltage at full load in real conditions.

The output short circuit protection as well as current protection is made by R1, R2, R3, R6 and Q2 components. This chain immediately closes the power Mosfet Q1 in case of overcurrent.

The output voltage is adjustable by a 10kΩ virtual potentiometer marked on diagram as Key=C.

On Figure 7.3 is an oscillorgam of the output voltage at 20V 5A (100W) load.

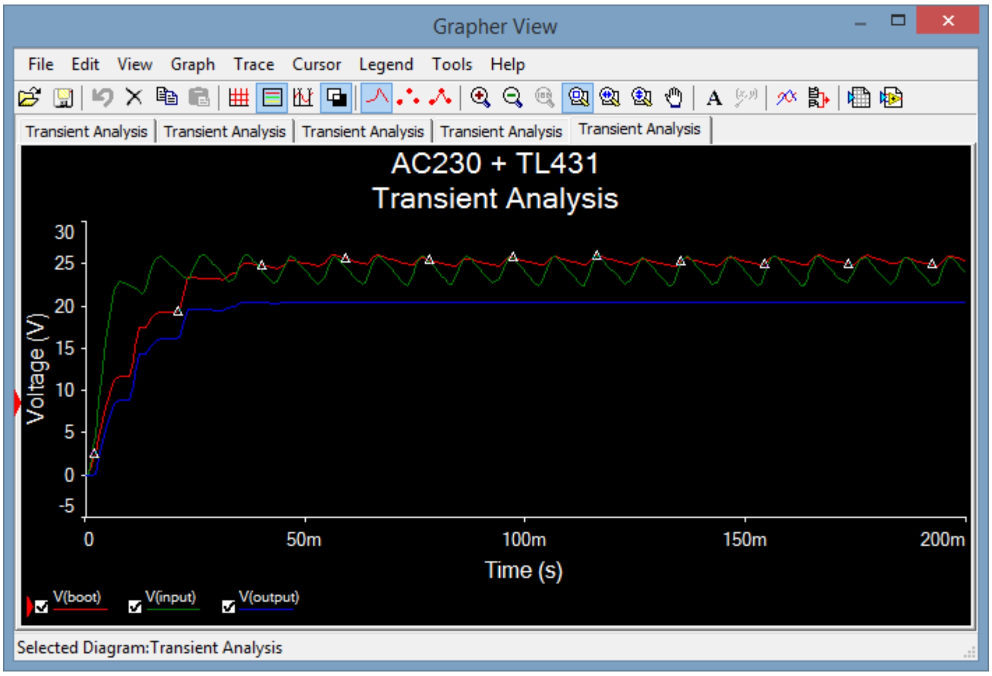

Figure 7.3. Output signal form of hybrid 120W power supply

The green line describes the rectified voltage with a ripple of about 4V. The red one is the boot voltage that is slightly higher, but more stable. The blue one is the actual output voltage.

On Figure 7.4 the output voltage oscillorgam is magnified is order to see a ripple of just 200µV.

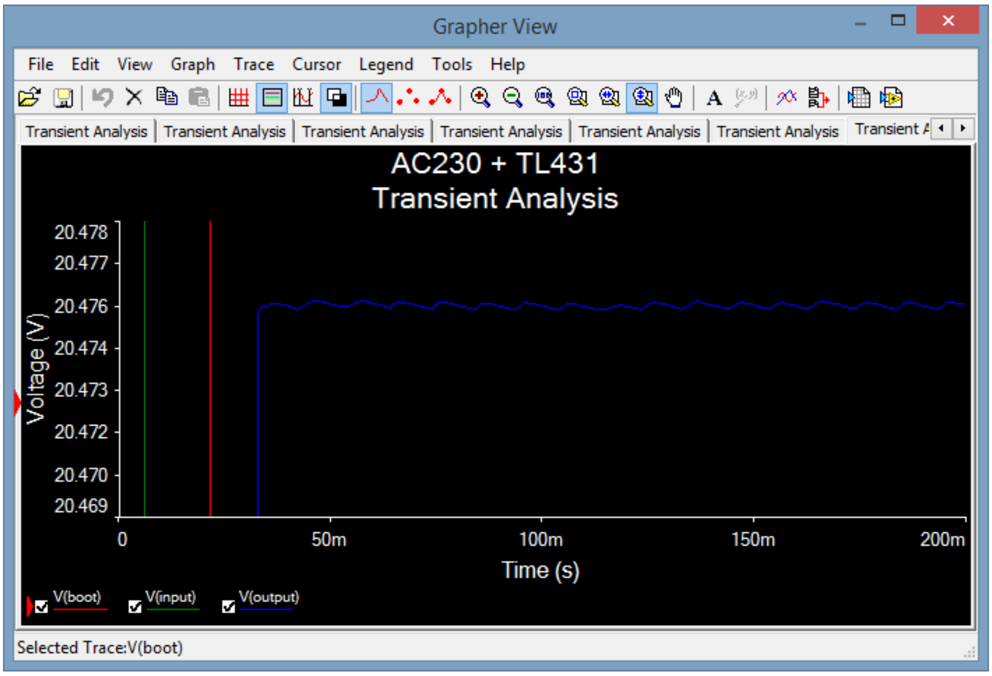

Figure 7.4. Magnified utput signal form of hybrid 120W power supply

In short circuit conditions, the ripple is slightly higher and ends up with about 20mVp-p, but the output is still well regulated and is 640-660mV in case of 0.1Ω load in 6A current mode. The output characteristics in short circuit case can be seen on Figures 7.5 and 7.6.

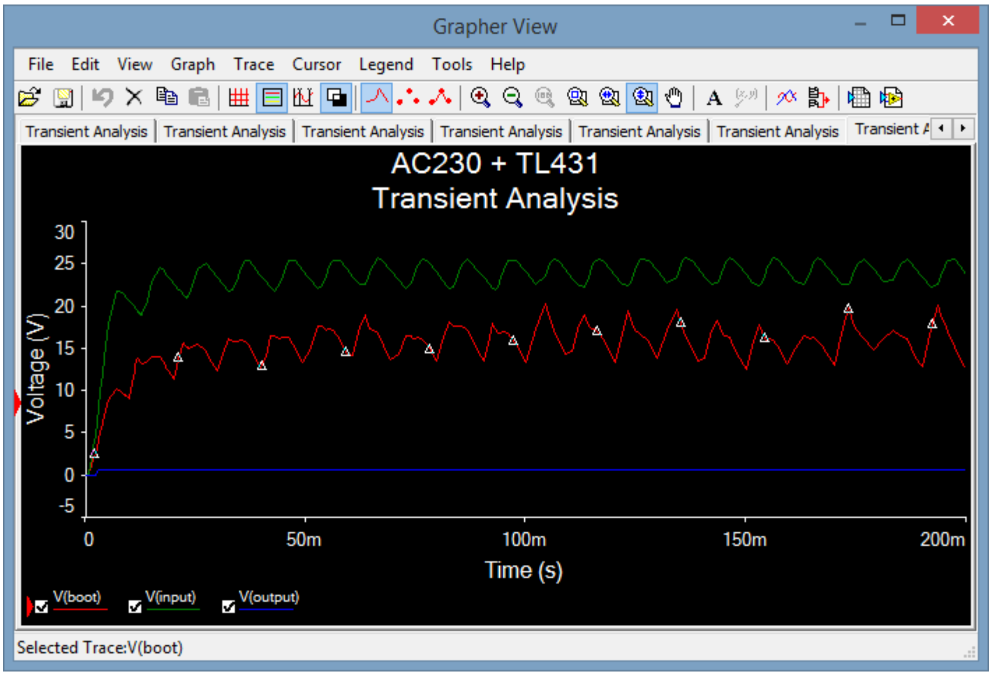

Figure 7.3. Output signal form of hybrid 120W power supply

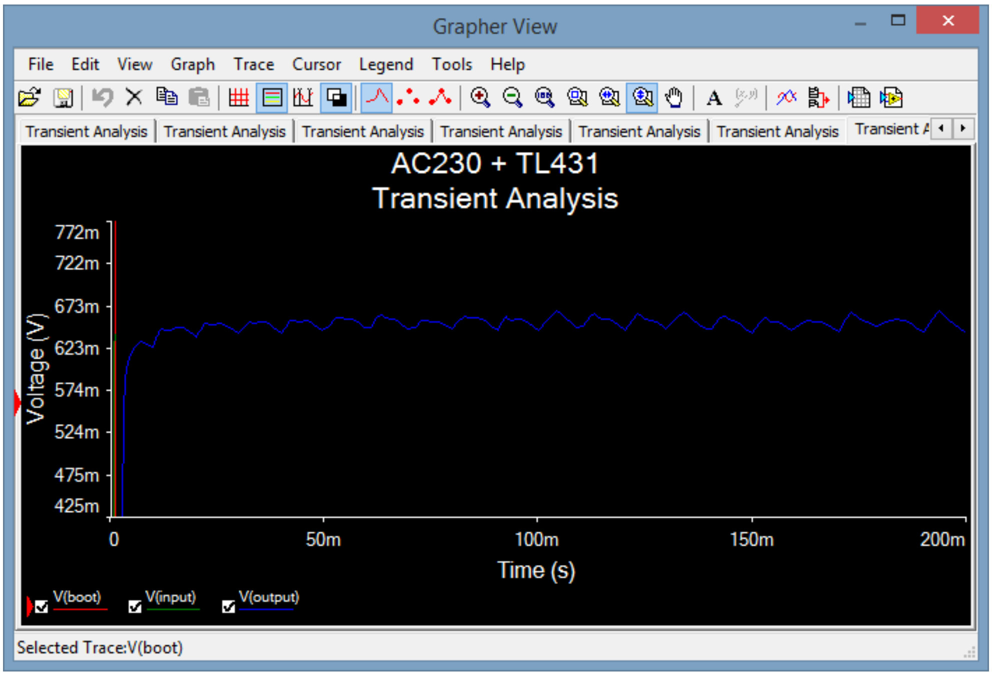

Figure 7.3. Output signal form of hybrid 120W power supply

This also proves the efficiency of using Mosfet transistors in linear regulator circuits.