CONTENTS

1   INTRODUCTION

1.1   Antecedents

Electronic devices are very important today, in the present time. They help us to regulate and control a great part of our daily tasks, making our lives easier. Everyday Electronic becomes more important such as mobile phones, GPS… and of course the notebooks.

The notebooks are an essential element in our lives, motivated to eliminate one of the restrictions in the use, we are slaves of the battery duration or connections. We want to give the option to the users, to work and charge their notebooks in the car, taking advantage of 12V connectors that we can find in the car.

1.2   Purpose

In this project, we want to implement a theoretical typology of a converter, the Boost converter, which is also named "Step-up converter". We also want to bring it to the practical area, where we could work and obtain a useful service, particularly our objective is to obtain a power supply for a notebook. We will give the possibility to work, charge etc. our device in the car and obtain another work station.

1.3   Specifications and reach

The reach is obtaining a design that will give us the possibility to use the car 12V connector for using or charging the notebook. When we enter 12V in the input we obtain 15V in the output, so will obtain our objective.

The converter specifications are:

Input voltage V_{in} = 12V

Output voltage V_{out} = 15V

Output current I_{out} = 5A

Frequency   f = 40 KHz

2   CIRCUIT DESCRIPTION

If we need to work constantly and our computer is an essential element of our job and we do not have time to loose, with this circuit we will obtain the possibility to work or charge the battery of our notebook in the car, depending of our necessities.

The Step-up circuit is compounded of one electrolytic capacitor C_{in} in the input. Ideally, there are continuous voltage and current at the Boost input, so many times it does not appear in the diagrams. In practice, there is a rectifier connected before the boost. As the current I_{in} fluctuates, the input voltage V_{in} has a residual fluctuation too. Because we need a continuous voltage at the converters input, it is here where the electrolytic capacitor will eliminate all the rests of fluctuations making our input signal optimal.

The inductance L, the next component, stores the electrical energy as a magnetic field, when the I increase, and returns the energy in the form of an electrical voltage when the intensity of the current decreases.

 The diode D closes the circuit.

The output capacitors C_{out} are to eliminate the ripple output voltage. Because there are variations of current in the inductance, the output voltage varies. With the use of the capacitors which consume the voltage ripples we can be sure that we have a continuous voltage signal again.

These three elements, (the inductance, the diode, and the capacitors), are part of a passive filter.

The transistor T, is a power Mosfet, works as a control switch that switches at a high frequency with a calculated duty cycle. The duty cycle will decide the output voltage.

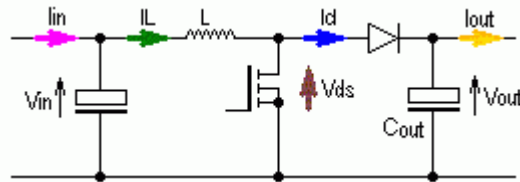These are the basics elements to obtain a Boost converter.

Fig.1: Shows the principle composition of a Boost converter. Source: Dr. Schmidt-Walter lectures

The DC-DC voltage converters work like energy transfer bridges between sources and loads, both may have got continuous currents, but they often are not compatible, for example: one load needs to be fed with a specified voltage V but the available source could only provide a Potential V_1, which could be greater or less. In our case, where we are talking about the Step-up, the output voltage magnitude is greater than the input voltage magnitude.

That creates the problem, of transferring the energy from the source, with the amplitudeV_1, to the load that needs a voltage V with loosing a minimal power in the transfer. Here is when the DC-DC converters are useful.

The way it works is simple: connect the input of the circuit to a switch that provides 12V, and then in the output obtains 15V and 5A, where you can connect a notebook.

2.1   Step-up or Boost theory

2.1.1   Introduction

The DC-DC converters are power electronics configurations, which are able to convert voltages from a DC constant source control to a continuous output voltage in the converter output. DC-DC converters become very important because of the increasing use of portable devices which are supplied by power from batteries, such as mobile phones, notebooks, etc.

There are three different typologies:

Step-Down or Buck

Step-Up or Boost

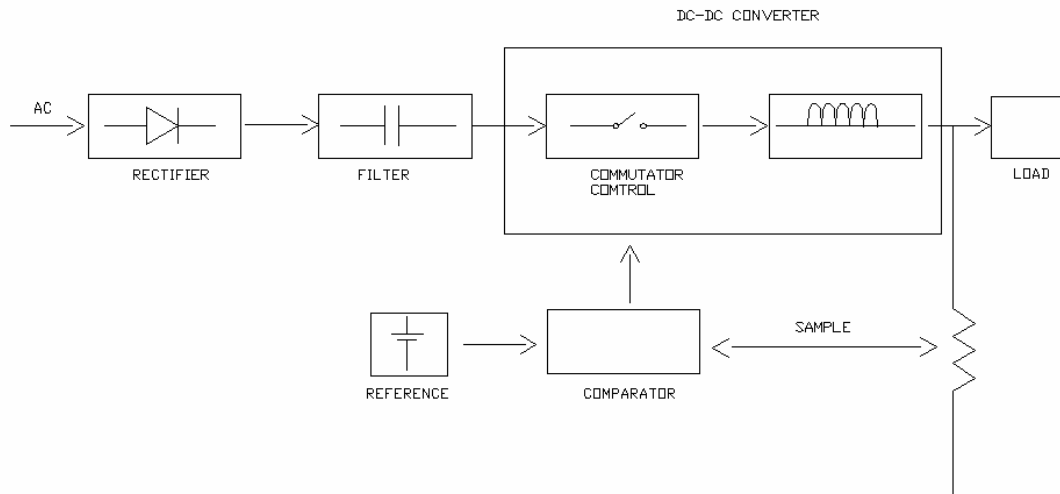Buck-Boost

A DC-DC converter has the following structure:

Fig.2: DC-DC converter structure

The converters functions are taking intervals of (conduction-block) from the continuous input signal. When the pulse character is eliminated, it returns a regulated and continuous signal to the output.

We can divide in two different blocks:

    Commutation block

    Low filter

The commutation block is basically formed of one transistor, which adapts the input filter signal, depending of the signal that is given in the control element.

The low filter functions returns the continuous character to the pulse signal in the entrance. It is formed by one inductance L, one Capacitor C and one diode D.

2.1.2   Boost converter topology

Conduction time, T_{ON}: Time when the switch, in our case the Mosfet, is closed and the load is isolated.

Non conduction time, T_{OFF}: Time when the switch is opened and the load is been connected with the energy primary source.

Period, T: Period in which the switch is opened and closed.

$$T = T_{ON} + T_{OFF}$$ (Eq.1)

Duty cycle, D or δ: Time in the period that the switch is closed:

$$D = \frac{T_{ON}}{T} \rightarrow 0 < D < 1$$ (Eq.2)

2.1.3 Step-up or Boost converter schemes

In this converter the voltage in the output is greater than the voltage in the input.
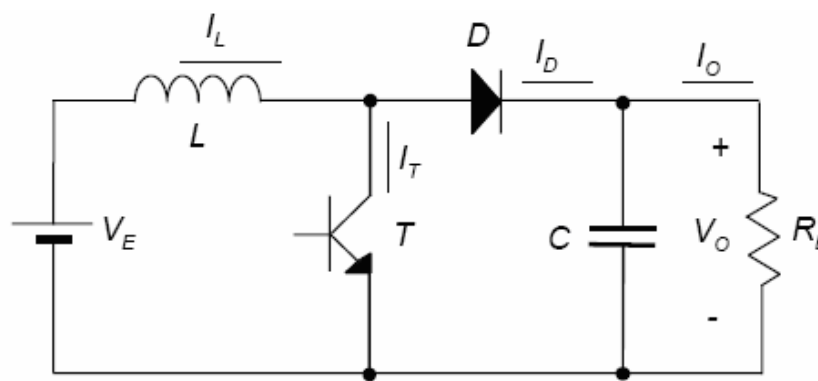

Fig.3: Boost converter scheme. Source: Udg power electronics lectures

We consider that for the inductance current always circulates. That means continuous conduction; the current will fluctuate between two values but will never be zero. When the current arrives to the value of zero for certainly instants it is called discontinuous mode.
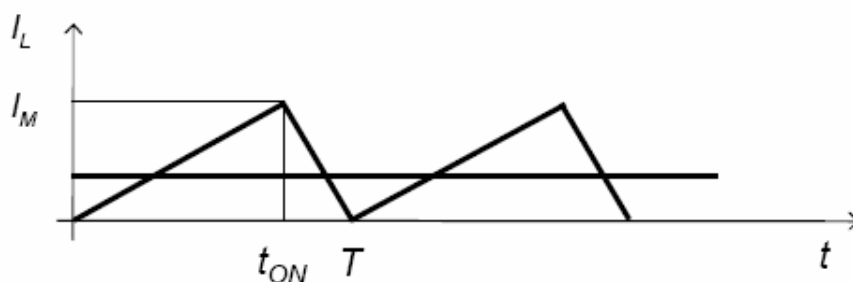

Fig.4: Boundary of continuous mode. Source: Udg power electronics lectures.

We define two intervals times and for each one we define one equivalent circuit:

$0 < t < t_{on}$

$t_{on} < t < T$

In this first interval, $0 < t < t_{on}$, the transistor T it is ON, providing the inductance L and the diode D OFF.
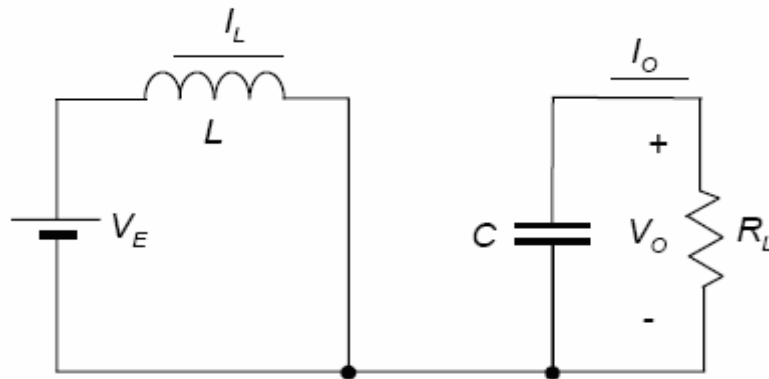

Fig.5: $0 < t < t_{on}$ scheme. Source: Udg power electronics lectures

In the second interval of time, $t_{on} < t < T$, the transistor T switches OFF. The addition of the E and the back electromotive force from the inductance is loading the capacitor through the diode D. This is the way to obtain the higher voltage in the output.
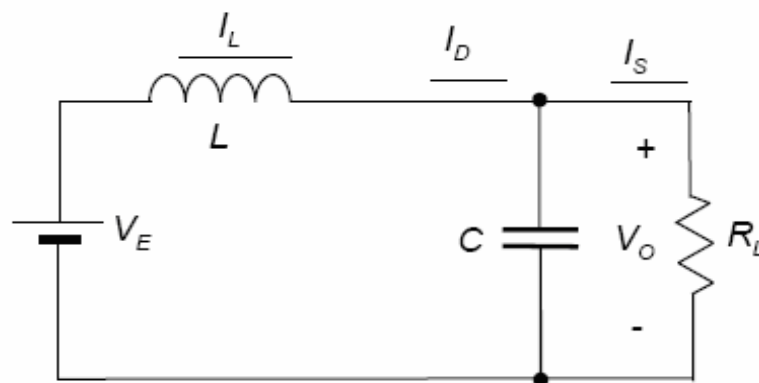

Fig.6: $t_{on} < t < T$ scheme. Source: Udg power electronics lectures

2.1.4 Voltage and current in the inductance

In the interval where t is between 0 and t_{on}, $0 < t < t_{on}$, the inductance voltage is V_E, or called V_{in}, the input voltage. We can observe seeing the equivalent scheme figure 5; in

this time the current flows through the inductance, increasing from I_m until I_M. If we assume that the switch has been opened for a time, the voltage across the capacitor is equal to the input voltage. At the time that the switch closes, the input voltage, $+V_E$, is impressed through the inductor and the diode will be, not correctly polarized, off. This prevents the capacitor from discharging $+V_O$ to ground. The current through the inductor rises linearly, because the input voltage is constant, with time at a rate proportional to the input voltage divided by inductance:

$$\Delta \frac{di}{dt} = \frac{V_L}{L} \qquad \text{(Eq.3)}$$

In the following interval where t is between t_{on} and T, $t_{on} < t < T$, there is the opposite situation, the current decreases from I_M until I_m. The transistor is blocked as it is described in the previous point, the circuit scheme correspond to figure 6. It could be observed that in one side of the inductance we have the input voltage V_E and in the other one we have V_O. The output capacitor gives back the voltage V that is stored during the previous time, so inside the inductance, there is the difference, $V_E - V_O$.

When the switch opens again, the current inductor continues to flow into the diode to charge the output. The output voltage rises until equilibrium is reached for:

$$V_L = L \cdot \frac{di}{dt} \qquad \text{(Eq.4)}$$

We can see that the current average in the inductance, I_{LAv}, is the input current average, I_{Eav}. An analysis of the two equivalent circuits corresponding with the both work periods shows that the inductance is always connected to the input, so the only current that flows is the input current.
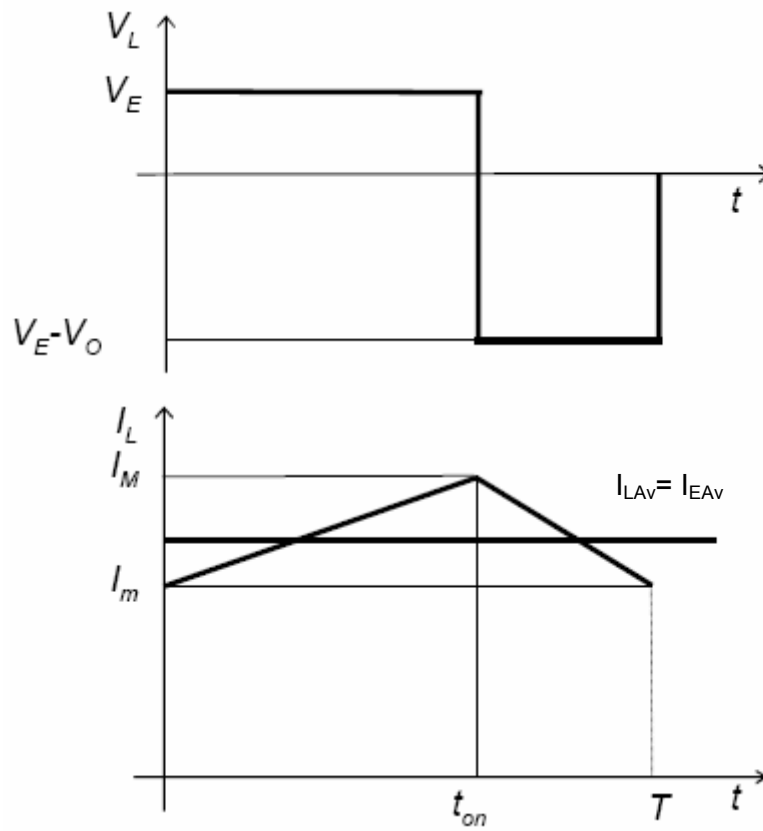
Fig.7: Inductance voltage and current graphics. Source: Udg power electronics lectures

3   DESIGNED BOOST CIRCUIT

The circuit diagram will be designed as described in the point number 2 composed by one capacitor in the input, one inductance, one diode and one output capacitor. I will use more output capacitors to obtain a better result. I will also use a control pwm that will give the V_{Cont} as we can see in the next figure.
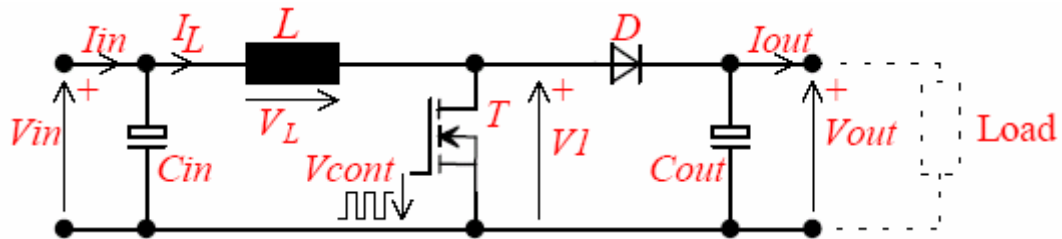

Fig.8: Circuit diagram. Source: Dr. Schmidt-Walter lectures.

But more components will be necessary to work and obtain an optimal signal. In the schematics diagram could be observed all the elements except the cooler.
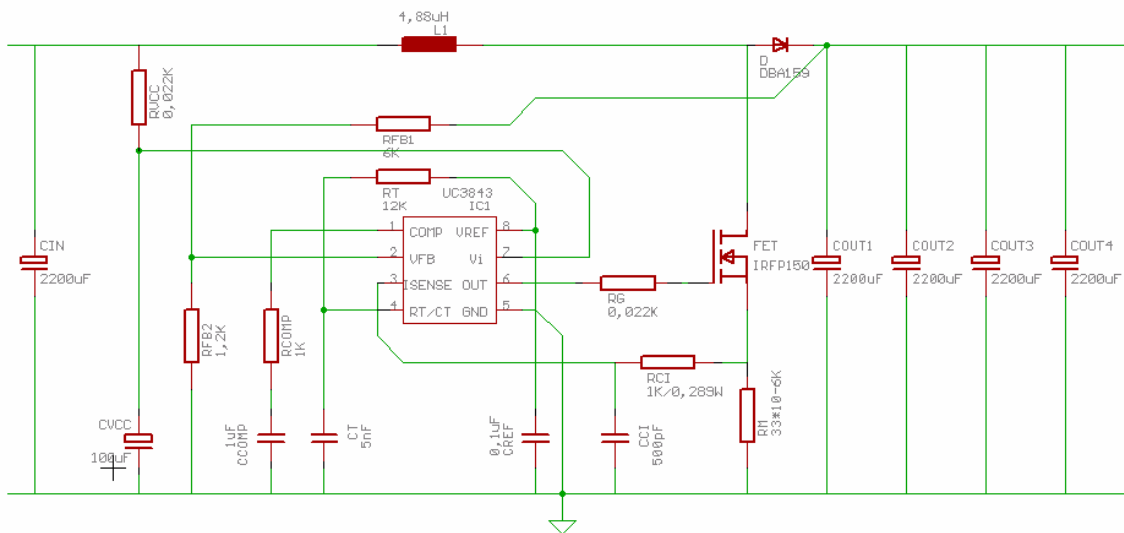

Fig.9: Schematics diagram

3.1   Previous calculations

The device is used as power supply, able to work with a car 12V connector for a notebook, so there are some previous specifications fixed. First the output voltage 12V obtained from the car, so that voltage has to be the input voltage of the converter. The notebook characteristics input voltage is 15V and current 5A, which will fix the output voltage and current of the device in 15V and 5A.

Another value previously fixed is the frequency f. We have that the inductance size could be smaller when we have a high switching frequency. It is important to obtain a just size that will make the device smaller and cheap. But therefore there will be higher commutation losses in the transistor, so this is another point that we have to take into consideration.

The equation (4) adapted to $di \rightarrow \Delta I$ and $dt \rightarrow \Delta t$, will give the equation needed here because we are working in high frequency:

$$V_L = L \cdot \frac{\Delta I}{\Delta t} \Rightarrow L = V_L \cdot \frac{\Delta t}{\Delta I} \qquad \text{(Eq.5)}$$

We know that the frequency is the inverse of the period.

$$f = \frac{1}{T} \Rightarrow T = \frac{1}{f} \qquad \text{(Eq.6)}$$

Considering before that the increase time to consider for the inductance is the $t_{ON.}$

$$\Delta t = T \cdot D \qquad \text{(Eq.7)}$$

The equations (5), (6) and (7) give another equation where you could see the influence of the f in the size of L. This equation later will be used to calculate the inductance.

$$L = V_L \frac{D \cdot 1}{\Delta I \cdot f} \qquad \text{(Eq.8)}$$

Working with higher values of power it is better to use a medium-lower frequency, when there are lower values of power it is possible to use higher frequency values.

So, as I said before, there are several conditions previously fixed to design the converter.

With this value, the previous equations and some other ones, it is possible to find all the values in order to design the converter correctly.

It is known that the input power is equal at the output power.

$$P_i = P_o \Rightarrow V_i \cdot I_i = V_o \cdot I_o \qquad\qquad\qquad\qquad \text{(Eq.9)}$$

With this equation it is possible to calculate the value of the input power and the input current.

The duty cycle is obtained with this equation.

$$D = 1 - \frac{V_E}{V_O} \qquad\qquad\qquad\qquad \text{(Eq.10)}$$

3.2 Commutation block

This block is basically formed by the transistor; I chose a Mosfet transistor in this case.

A Mosfet is a specific type of metal oxide semiconductor field-effect transistor, designed to handle large powers. The main advantage, if we compare with other power semiconductor devices as IGBT, Thyristor…, it is the high commutation speed and good efficiency at low voltages. It also has an isolated gate that makes it easy to drive.

The power Mosfet is the most used in power supplies, DC-DC converters and motor controllers like a switch.

Some other characteristics that explain why a Mosfet has been we have been chosen are:

  They are devices controlled for a voltage with high input impedance.

  Mosfet generate a lower noise level than BJT.

  Mosfet are more stable than BJT.

Mosfet could dissipate a higher power and switch high currents.

The chosen Mosfet is the IRFP 150N, with a TO-247 package.

$$V_{DSS} = 100V$$
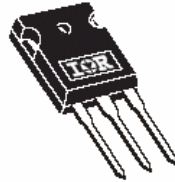$$R_{DS(on)} = 0.036\Omega$$
$$I_D = 42A$$

Fig.10: Mosfet TO-247 package. Source: IR Datasheet.
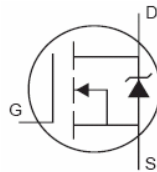
Fig.11: Internal structure Mosfet channel N. Source: IR Datasheet.

3.3   Low filter

The following block is formed by the inductance, diode and output capacitors.

With this block, the energy is stored during the on time that will be returned in the off time of the transistor. This block also returns the continuous character to the pulse signal in the entrance.

3.3.1   The inductance

The inductance main function is to limit the current slew rate through the power switch and to store energy. This limits the otherwise high-peak current, Î. The key advantage for using an inductor in switching regulators it is when the inductor is used to drop voltage, its stores energy. This energy could be expressed in Joules as a function of the current.

$$E = \frac{1}{2} \cdot L \cdot I^2 \qquad \text{(Eq.11)}$$

Fig.12: Inductance.

The inductance value can be obtained using the equations previously announced as (5), (6) and (10) and additionally by the information and values that are fixed.

The following results are calculated with (6) and (10).

$$T = 0{,}25\,\mu s$$
$$D = 0{,}2$$

The value of the inductance could be obtained with (5).

$$L = V_L \cdot \frac{\Delta t}{\Delta I} = 12 \cdot \frac{0{,}2 \cdot 25\,\mu s}{12{,}5V} = 4{,}8\,\mu H$$

This is the minimum value of the inductance to guarantee the continuous mode.

I used a very interesting tool, a Dr. Heinz Schmidt-Walter program, found in the net. I used this tool to simulate and verify if calculations are in the right way.

Fig.13: Simulation program, input values. Source: Dr. Schmidt-Walter website.

I got some graphs resulted of the simulation.

I filled the squares with the information and the value of the inductance previously calculated.

When all the values are entered I was able to start and obtain the waves pressing the button "calculate".

The result of the simulation is shown in figure (14).

Boost Converter

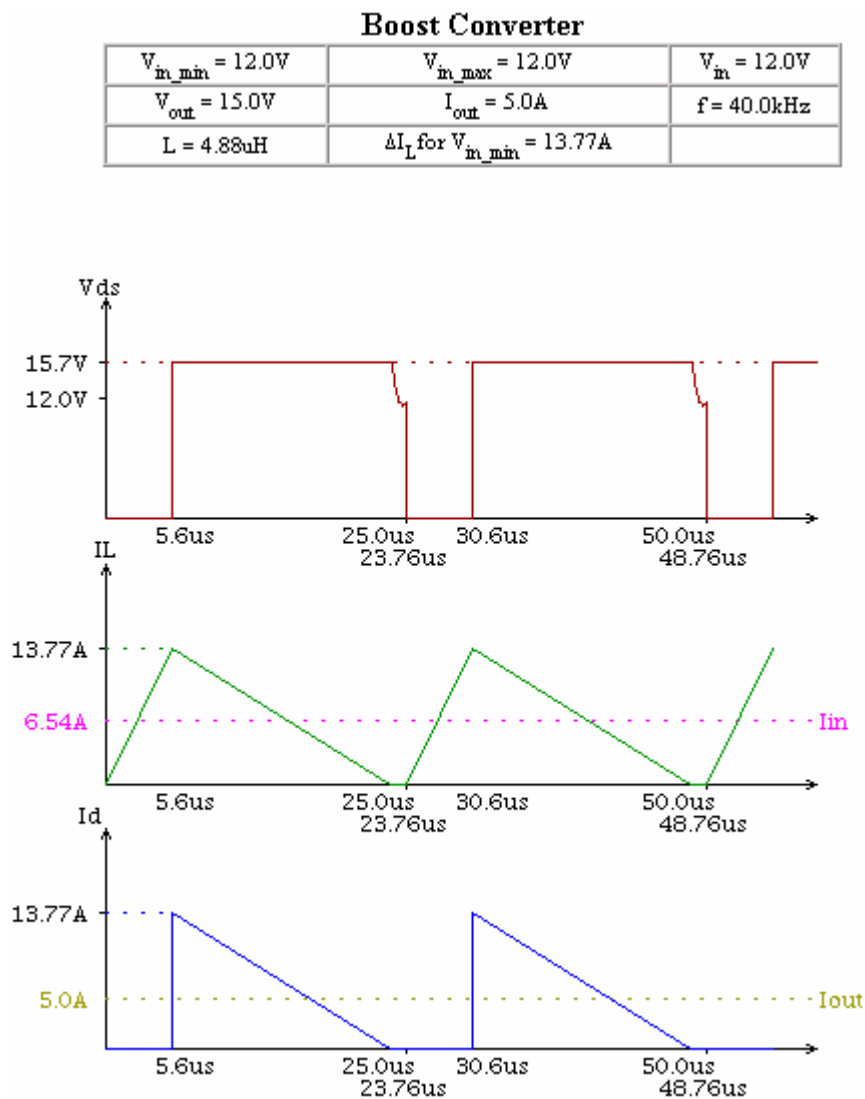| $V_{in\_min} = 12.0V$	$V_{in\_max} = 12.0V$	$V_{in} = 12.0V$
$V_{out} = 15.0V$	$I_{out} = 5.0A$	$f = 40.0kHz$
$L = 4.88uH$	ΔI_L for $V_{in\_min} = 13.77A$	

Fig.14: Simulation program, wave results. Source: Dr. Schmidt-Walter website.

Observing the result of the simulation shows that the values obtained are a little bit different of what is expected. Taking attention to the current wave, it could be observed that we are not in the continuous mode because, just for a very short time the current arrives to be equal to zero, but as said this is a help tool and it is an acceptable value to start.

The objective is that the converter should work, so all the values are subjected to this important rule and everything could be modified if this goal is not reached.

When we obtain an acceptable inductance value we have to verify It with some other restrictions fixed for the following equations and rules.

Inductors store magnetic energy generated by current variations. Inductors need an air gap for storing energy. The material cores are normally ferrite.

The stored energy of an inductor could be calculated with the following equation.

$$W = \frac{1}{2} \cdot L \cdot \hat{I}^2$$ (Eq.12)

It is determined with a certain inductance L and certain peak current $\hat{I}$. This energy is stored as magnetic field energy, within the ferrite core and within the air gap.
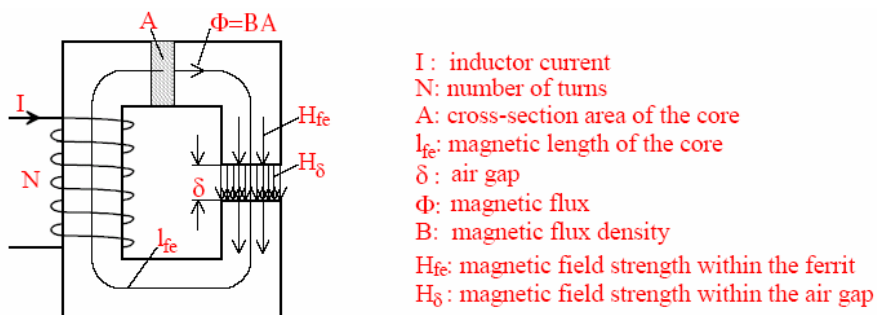

Fig.15: Inductor with its magnetic and mechanical sizes. Source: Dr. Schmidt-Walter lectures.

The size of an inductor is approximately proportional to the stored energy. The energy is stored in the air gap, so the inductor requires an air gap to store energy, with a certain volume to store a certain amount of energy.

This condition must be fulfilled, that it is very important.

The energy is given by equation (12). The core material has a limit for the maximum magnetic flux density *B*, this limit is about:

$$B_{max} = 0,3 \cdot T$$
(Eq.13)

Usual ferrite materials. This leads to a minimum required volume V_δ of the air gap.

Knowing the required volume of the air gap, a core can be selected from a datasheet of ferrite cores. I chose an ETD 29 core, the smallest size that could be found for the job. If not I will chose another one, because one of the objectives is to obtain the best result with the cheapest and smallest design. The air gap selected to start will be 0,5 mm.

In this case, as before, the Dr. Heinz Schmidt-Walter program could be a very interesting aid.

No.	Core	Ident.	Manufacturer	A_L/nH	A_{in}/mm^2	l_{in}/mm	A_{min}/mm^2	W_{max}/µWs	B_{max}/mT	N1
16	ETD54	2.0	Siemens	229	280	127	280	15406	52	5
17	ETD59	1.0	Siemens	508	368	139	368	11996	59	4
18	ETD59	1.5	Siemens	381	368	139	368	15995	51	4
19	ETD59	2.0	Siemens	311	368	139	368	19595	46	4
20	E13/7/4	0.04	Siemens	250	12	30	12	27	1246	5
21	E16/8/5	0.1	Siemens	212	20	38	19	80	722	5
22	E16/8/5	0.5	Siemens	69	20	38	19	245	412	9
23	E20/10/6	0.25	Siemens	162	32	46	32	283	384	6
24	E20/10/6	0.5	Siemens	100	32	46	32	458	301	7
25	E25/13/7	0.25	Siemens	250	52	58	52	477	295	5
26	E25/13/7	0.5	Siemens	151	52	58	52	790	229	6
27	E25/13/7	1.0	Siemens	91	52	58	52	1312	178	8
28	E30/15/7	0.18	Siemens	300	60	67	49	360	340	4
29	E30/15/7	0.34	Siemens	195	60	67	49	554	274	5
30	E32/16/9	0.5	Siemens	244	83	74	81	1222	185	5
31	E32/16/9	1.0	Siemens	145	83	74	81	2056	142	6
32	E36/18/11	0.5	Siemens	312	120	81	112	1809	152	4
33	E36/18/11	1.0	Siemens	183	120	81	112	3085	116	6
34	E42/21/15	0.5	Siemens	454	178	97	175	3036	117	4
35	E42/21/15	0.64	Siemens	378	178	97	175	3646	107	4
36	E42/21/15	1.0	Siemens	272	178	97	175	5067	91	5
37	E42/21/15	1.5	Siemens	201	178	97	175	6856	78	5
38	E42/21/20	0.5	Siemens	603	234	97	229	3914	103	3
39	E42/21/20	1.0	Siemens	354	234	97	229	6666	79	4

L=4.8µH

The core is...
very good
good
suitable
too small

Help

Print

Wire dimensions:

d ≥ 1.67 mm
A ≥ 2.18 mm^2

Fig.16: Simulation program, core recommended list. Source: Dr. Schmidt-Walter website.

To obtain a list of the different cores as the calculate inductance, I have to press the button "calculate" in the figure (13), then I will obtain a list of some recommended cores.

The simulation program gives a recommendation of the different values that affects the inductance as the core, air gap, the number of turns…and appears in green that means that it is a suitable value.

This is a helpful program but the result must be verified and calculated if it is a solution for our objective.

The next equation is given to obtain the number of turns N, the magnetic conductance A_L, given for the constructors in the datasheet.

$$N = \sqrt{\frac{L}{A_L}}$$ (Eq.14)

For example the chosen ETD-29 core and the air gap of 0,5 mm. give back the value of the A_L, seeing in the gapped information of the datasheet.

$$N = \sqrt{\frac{4,8\mu H}{201 nH}} = 4,88$$

This is the number of turns that must be given for creating the inductance, with the wire; we will give 5 turns to begin.

Corroborate that all the results are valid with the equation (13), the maximum flux density should not be higher than 0.3 Tesla. The maximum flux density within the ferrite can be calculated using the data of the core datasheet.

$$B = \frac{L \cdot \hat{I}}{N \cdot A_{min}} = \frac{N \cdot A_L \cdot \hat{I}}{A_{min}} \le 0,3T$$ (Eq.15)

We have all the values included the A_{min}, minimum cross-cut of the core. The flux density has its maximum at A_{min}, we will obtain this value from the datasheet.

$$B = \frac{5 \cdot 201 \mu H \cdot 12{,}5A}{71 mm^2} = 0{,}177$$

Like we obtain a value small than 0,3T we can affirm that our values are right for our purpose, because we fulfil the last condition and the other ones too.

The last step is to prove, if in the practice works or not, if it does not work we have to make some changes in our calculus depending of the problem, because in the practice many things could affect our calculation values.

In our case, the result was acceptable, very close of our expectative, but not as well as we wanted to obtain.

After proving the board we obtained a high ripple of the increase current, current grew to fast activating the current limitation circuit, we will see later, so It could not arrive until the maximum value of current, 10A, that would give the output current equal to 5A, what is needed. The output current was a little bit lower than 5A, around 4,5A enough to force us to make some changes to obtain a better result.

The first element that we analyzed was the inductance, expecting improves our results only changing the inductance. After the change of the inductance our practical result improved until our expectations.

The final inductance characteristics:

Air gap=1mm^2

N= 14 turns

L= 24,30µH

B= 0,29T

3.3.2   Diode

The diode has two basic functions; one of them is preventing the capacitor to discharge from $+V_O$ to ground, when the switch closes, because the diode is not correctly polarized. The other one is minimizing the switching losses by reducing the transient times, on to off and off to on, of the power Mosfet switch.

From the circuit scheme, figure (6), could be seen how the maximum current in the diode is equal than the maximum inductance current. With analogous exposition could

be seen that the current average in the diode is the output current, figure (6) when the transistor is OFF.
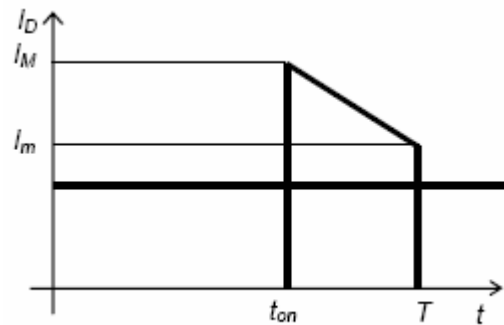

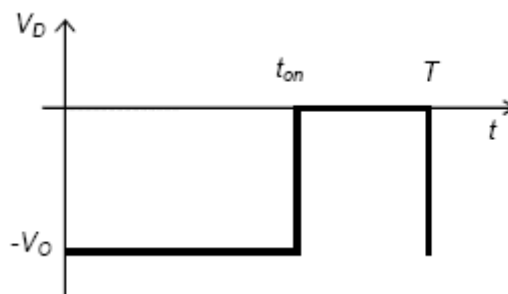Fig.17: Current in the diode. Source: Udg power electronics lectures.

Fig.18: Voltage in the diode. Source: Udg power electronics lectures.

The values that we need to choose correctly our diode are:

$$I_{d_{max}} = I_M = 12{,}5A$$
$$V_d = -15V$$

With these dates, a datasheet of the different typologies can be consulted, that is the most important decision, which kind of diode we will choose.

I chose a Schottky diode, an unipolar device. The benefit of unipolarity is the absence of stored carriers and, therefore, theoretically instantaneous switching transients that are limited only by small parasitic capacitances. This allows the minimization of switching losses by reducing the interval, on-to-off and off-to-on, transition times of the power Mosfet switches, reducing those times in which high instantaneous currents and

voltages occur simultaneously.

3.3.3   Output capacitor

The output capacitor C_{out} is to eliminate the ripple output voltage. The capacitor is charged by pulses. The ripple ΔV_{out} of the output voltage results from the pulsating charge current I_D and is mainly determined by the impedance Z_{max} at the switching frequency of capacitor C_{out}. We will obtain the value of Z_{max} in the datasheet.

Their total impedance Z, which depends on frequency, can be represented by an equivalent circuit consisting of a series resistance, inductance and capacitance.

Due to ripple and leakage current, the voltage drop on the equivalent series resistance primarily causes the power losses in the capacitor. The current depends on capacitor type, temperature and operating voltage and is not influenced by switching frequency.

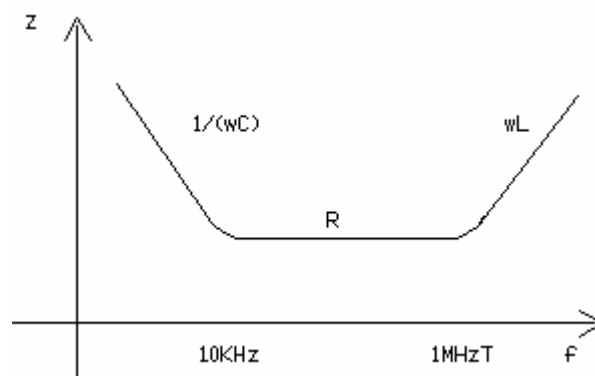The equivalent series resistance depends of the frequency.

Fig.19: Capacitor impedance in function of frequency.

We can see in the previous figure how varies the inductance in function of the frequency. Between 10KHz and 1MHz is where the inductance response as a resistance, what we want. We can not calculate, that is a characteristic that depends of the constructor. We will choose the capacitor due the voltage that have to resist and the smallest inductance to obtain the minimum potential fall.

$$\Delta V_{out} = I_D \cdot Z_{max} \qquad\qquad\qquad\qquad\qquad\qquad (\text{Eq.16})$$

We can calculate the output voltage ripple with the previous equation.

We will choose the same capacitance for the input and output capacitor, it is not obligatory, we can adjust our calculations to the real necessities. To be sure that we will not have problems we will take a value a little bit higher, so when we know the voltage that will work, we can choose the capacitors looking in the datasheet, it is very important the value of Z , as we said it is a fixed value, that we have to accept but we need that will be smallest as could be.

We choose a capacitor of rated voltage of 25V, for the Z , we look for a small one in equilibrium with the capacitance, that affects the size of the capacitor and our design.

We find a good value of impedance, $Z = 0,020\Omega$ for a capacitor $C\ =\ 2200\ \ \mu F$.

We can calculate the potential fall in the inductance if we choose this capacitor, $V_Z = 0,020\Omega \cdot 30A = 1,5V$, this value could help us to take the final decision, looking this result if we think that is an acceptable result for our purpose, we can take this device if not we have to choose another one with a lower inductance. In our case we think that is a good value of impedance.

To obtain a better result in the output signal we will place four capacitors. In the laboratory there are some capacitors that will be the first option, previous verification that is an optimal value for the purpose. I will use four of 470 µF.

3.4   Control PWM

As we said before depends of the duty cycle we will have an output voltage or another. So the duty cycle controls the output voltage with respect the input voltage.
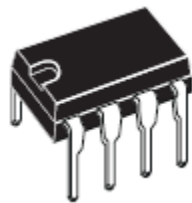

Fig.20: PWM, minidip package. Source: ST Datasheet.

The pulse width modulation, PWM, is the most common control method. It takes a sample of the output voltage and subtracts this from a reference voltage to establish

a small error signal V_2. This error signal compared to an oscillator ramp signal. The comparator outputs a digital output PWM that operates the power switch. When the circuit output voltage changes, V_2 also changes causing the comparator threshold to change. The output pulse width also changes. This duty cycle change then moves the output voltage to reduce the error signal to zero, completing the control loop.
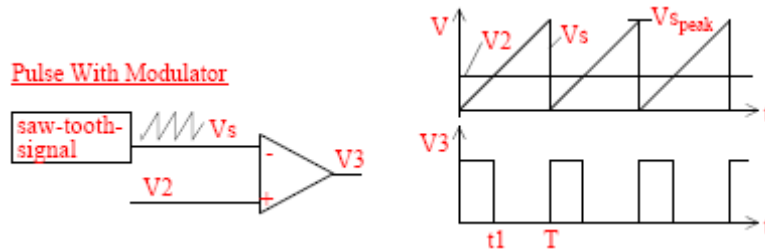

Fig.21: Pulse width modulator. Source: Dr. Schmidt-Walter lectures.

The output voltage of a switch mode power supply is kept constant with the help of closed loop control. The value of the output voltages is compared with a reference voltage. The difference between these two voltages controls the duty cycle of the transistor. The function of the control loop is to regulate the variation of the mains and the changes of the output current. It is called line and load regulation.

There are two methods of regulation, the voltage and current mode control.

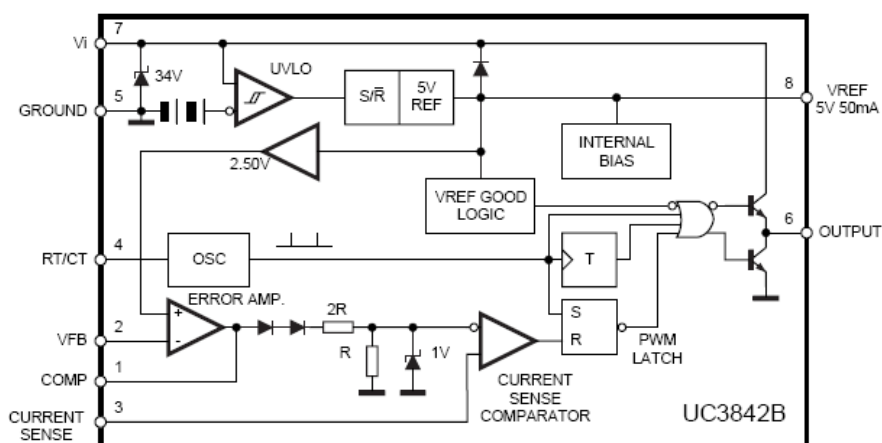Both control methods are included in the control device.

Fig.22: Block diagram. Source: ST Datasheet.

If we want to implement these control methods we need to connect the pin connection number 1 and 2 with the respective values of the elements to obtain a good control.
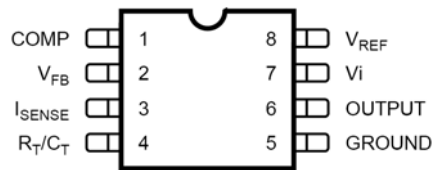

Fig.22: Pin connection. Source: ST Datasheet.

3.4.1   Voltage mode control

The voltage method control is associated with the pin number (1) and (2), V_{FB} and Comp respectively, we can see in the figure (22). We need to calculate the value of the resistances of the voltage divider to obtain a value of 2,5V because that will be the value that the pwm uses internally to compare with the sample that comes to the output through the divider, and connects the divider in the pin (2) the inverting input of the error amplifier.

In our design the divider is formed by two resistances $R_{FB1} = 6K\Omega$ and $R_{FB2} = 1,2K\Omega$, that we can see in the figure (23).

R_{FB1} It is formed for two resistances of $12K\Omega$ in parallel.

These values are obtained taking in consideration the output value15V, we know that internally the value of the comparator 2,5V, and so using a divider equation (17) we can find a relation between the resistances.

$$15V \cdot \frac{R_{FB2}}{R_{FB2} + R_{FB1}} = 2,5V \tag{Eq.17}$$

This relation must be the most exactly possible cause our output voltage control depends of the fidelity of these values.

The pin (1) Comp, is the error amplifier output and I made for the loop compensation. We have to calculate and choose the value of the capacitor and resistance that formed part of the PI regulator, that in our scheme are called $C_{comp} = 1\mu F$ and $R_{comp} = 1K\Omega$.

These two values were recommended for Dr. Heinz Schmidt-Walter experience.

The rest is implemented in our integrated circuit.

With this control, the voltage control, we regulate de duty cycle $\dfrac{t_{ON}}{T}$, which means that the voltage across the L is controlled. This voltage operates on a second order system, formed by L, C_{out} and R_L.

3.4.2   Elements associated to the pwm

To obtain the result that we want of the pwm, we have to add some elements more as resistances and capacitances, some of these elements are recommended for the constructor and the values too.
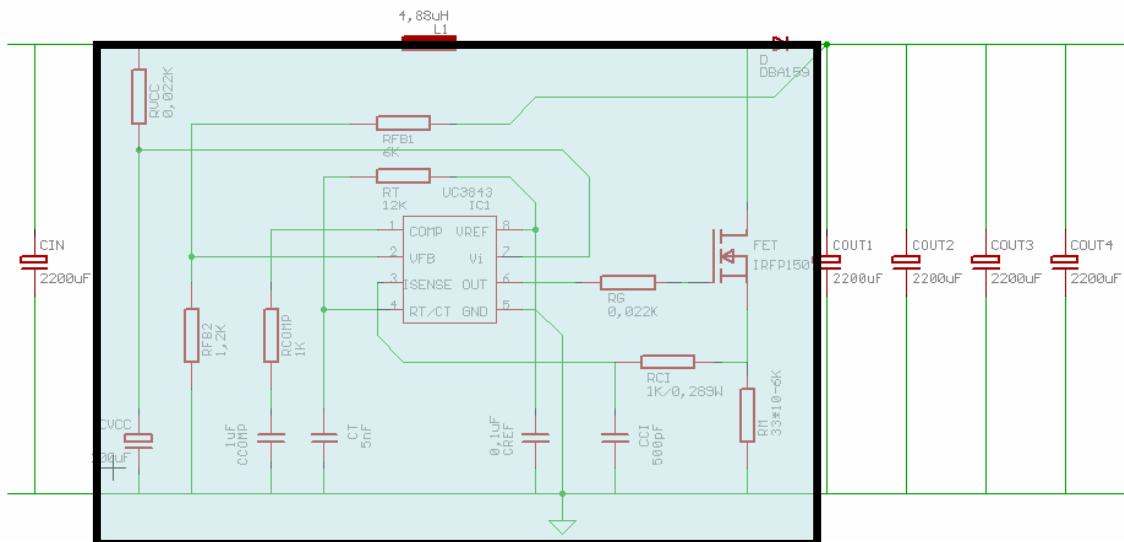

Fig.23: Associated elements to the pwm.

Most of these elements are for protect the integrated circuit as R_{Vcc}, C_{Vcc}, RM, R_{CI}, C_{CI} and R_G. The other two elements R_T and C_T, connected to pin (4), are for program the oscillator frequency and maximum output duty cycle. We can see in the previous figure, inside the black rectangle, all the elements that we need for a correct function of pwm.

To choose the values of R_T and C_T we must look in the pwm datasheet. We have a graph where different values of resistances appear, capacitances and oscillator
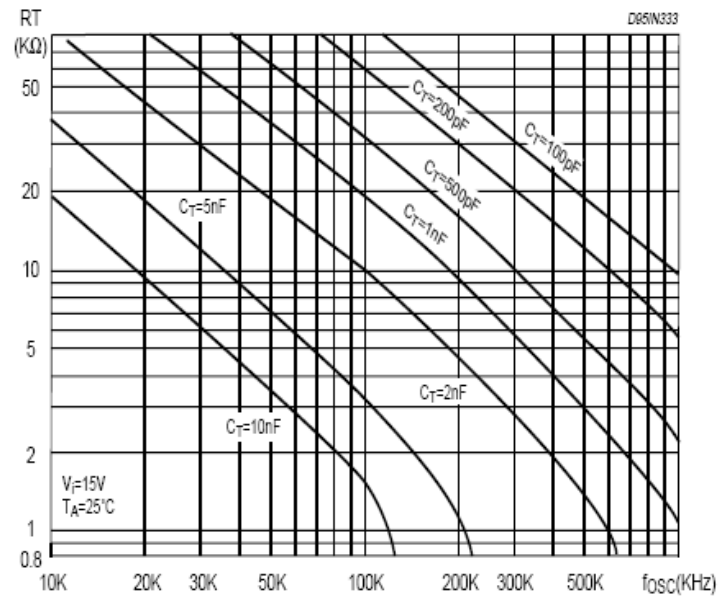
frequency.

Fig.24: Timing resistor vs. oscillator frequency. Source: ST Datasheet.

When we have the oscillator frequency fixed we look for this value in the previous graph and depend of the capacitor we will choose, between all the possibilities, the value of the resistance will be fix.

We have a value of f=40KHz, we decided to look the value of R_T in the curve $C_T = 5nF$, so the value of the resistance is fixed for these two coordinates and the result is $R_T = 9K$.

The RC filter formed for, R_{CI} C_{CI} is required to suppress the switch transients.

$$I_{S\,\max} \approx \frac{1V}{RM}$$
(Eq.18)

We find this equation in the datasheet; we can calculate the value of RM.

$$RM = \frac{1V}{12,5A} = 0,08\Omega$$

$$P = I^2 \cdot R \Rightarrow 5A \cdot 0,08\Omega = 2W$$

The value of the intensity in this branch we can find consulting the datasheet.

$$R_{CI} = \frac{15V}{17mA} = 882,3\Omega$$

$$P = 17mA^2 \cdot 882,3\Omega = 0,255W$$

To calculate the capacitor associated to pin (3), we know that our $\tau = 500ns$.

$$\tau = R \cdot C \qquad\qquad\qquad\qquad\qquad\qquad\qquad \text{(Eq.19)}$$

With equation (19) we can find the value of the capacitor C_{CI}.

$$\tau = R \cdot C = 500ns \Rightarrow C_{CI} = \frac{\tau}{R} = \frac{500ns}{882,3} = 566.7\,pF$$

The resistance R_G could be a small value as 22Ω or 47Ω.

The purpose of R_{Vcc}, C_{Vcc} is to protect the integrated circuit of the input peaks. For this reason the resistance does not have to be an important values, it is enough a value as for example R_G. For the capacitor C_{Vcc} we chose an electrolytic capacitor of $100\,\mu F$.

All of these values could be modified depending of our stock, because one of the main purposes is the cheapest design, or possibilities to find the commercial values.

For the values of the capacitors is not very important the magnitude that we finally choose, these values gave an idea, but the truth is as near of these values we work, more success options.

The election of the pwm is made for the under-voltage lockout thresholds, UVLO, and maximum duty cycle range.

Our election was the UC3845B, of ST, the corresponding thresholds are 8,5V (on) and 7,9V (off), we have to remember that our input was 12V, so we need an integrated that could be fed with our input voltage. The duty cycle range goes from $0 < D < 50\%$, that is a right one, because we need jus a $D = 0,2$.

3.5 Cooler

We need a cool system for the diode and the transistor, to refresh the two components. To choose a cooler first of all we need to determinate the R_{th}.

Fig.25: Cooler. Source: Fischer elektronic.

$$R_{th} = \frac{\Delta \vartheta}{P_V}$$ (Eq.20)

With this equation we can calculate the value of the thermal resistance, that we need to determinate the proportion of the cooler.

We know:

$$P_{out} = 75W$$

We want a $\eta = 90\%$.

We could obtain P_V.

$$P_V = P_{out} \cdot (1 - \eta)$$ (Eq.21)

$$P_V = 75W \cdot 0,1 = 7,5W$$

$$. \Delta \vartheta \approx 40K$$

We replaced these values in equation (20) and we can obtain R_{th}

$$R_{th} = \frac{\Delta \vartheta}{P_V} = \frac{40K}{7,5W} = 5,3 \frac{K}{W}$$

With this value we can look for a cooler in the datasheet of the different manufacturers, the size will be recommended.

We chose a cooler with length 50mm. and $R_{th} = 2,5\dfrac{K}{W}$ because it was the minimum length that we found and much better that we really need for our magnitudes.

3.6 Input capacitor

As it announced before in many boost diagrams don not appear an input capacitor. Ideally in the input of the converter the voltage and the current are continuous, but in practice no, because I_{in} fluctuates and makes that V_{in} has a residual fluctuation too where we need a continuous voltage, in the converter input, it is here where the electrolytic capacitor will eliminate all the rests of fluctuations making our input signal optimal.

This capacitor it is choose as the output capacitors, chapter 3.3.3 , find an acceptable value of Z and the capacitance.

It was chose in this design the same capacitor that in the output.

4   CONCLUSIONS

The main purpose that was obtained, was a cheap device, with small dimensions and that response to our necessities.

For one of these objectives it was necessary to adapt the results of the calculations to the values of components that we have in stock, commercial and available components values.

For this reason it is presented a table with the finally values of the components used.

COMPONENT	VALUE/MODEL	OBSERVATIONS
R_Comp	1,2kΩ	no observations
C_Comp	100nF	no observations
R_T	12KΩ	no observations
C_T	4,7nF	no observations
R_FB1A	12KΩ	no observations
R_FB1	12kΩ	no observations
R_FB2	1,2KΩ	no observations
C_Ref	100nF	no observations
R_Vcc	12Ω	no observations
C_Vcc	100µF	electrolytic
C_CI	470pF	no observations
R_CI	1,2KΩ	no observations
R_G	47Ω	no observations
R_M	1Ω	no observations
C_IN	470uF	manufacturer Siemens
C_OUT1	470uF	manufacturer Siemens
C_OUT2	470uF	manufacturer Siemens
C_OUT3	470uF	manufacturer Siemens
C_OUT4	470uF	manufacturer Siemens
Diode	BYT 30P-1000	fast recovery rectifier diode; manufacturer ST
Transistor	IRFP150N	manufacturer IR
PWM	UC3845B	manufacturer ST
Inductance	24,30µH	N=14;,Air gap= 1mm; manufacturer Fischer EleKtronic
Cooler	50mm	Rth=2,5K/W; manufacturer Siemens

Fig.26: Table with final used components.

The boost converter obtained with this design and the final values proposed response to the initial specifications as was expect.
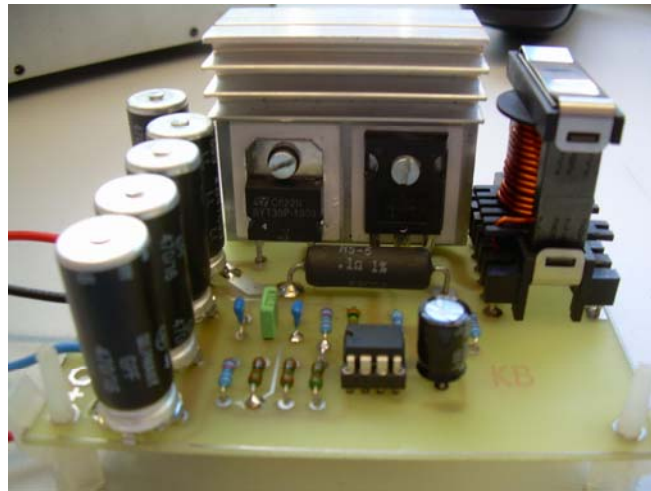

Fig.27: Front view of final result. Implemented boost converter.

It was obtained from input characteristics:

$$V_{in} = 12V$$

An output:

$$V_{out} = 15V$$
$$I_o = 5A$$

An output with the notebook input characteristics, necessary for use the converter with it purpose, as power supply for the computer.

Even when this converter is designed with these particularities to be used with specific purpose, it could be used for another device with the same input characteristics, as GPS, mobile…

If the intentions it is to be used for another device with different characteristics it is not sure that will work without modifications, so surely we will need to adapt the output signal of the converter to the input characteristics of the new device.
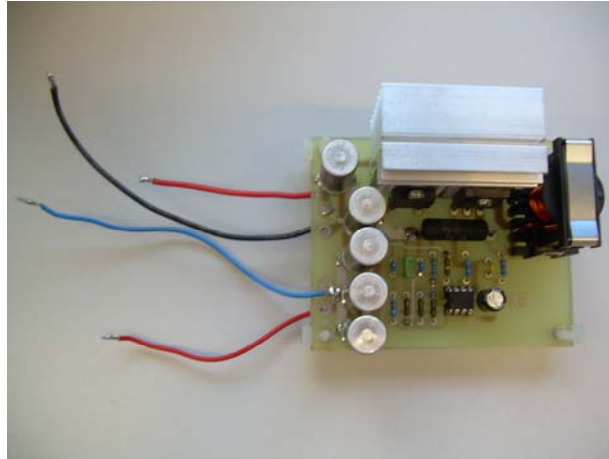
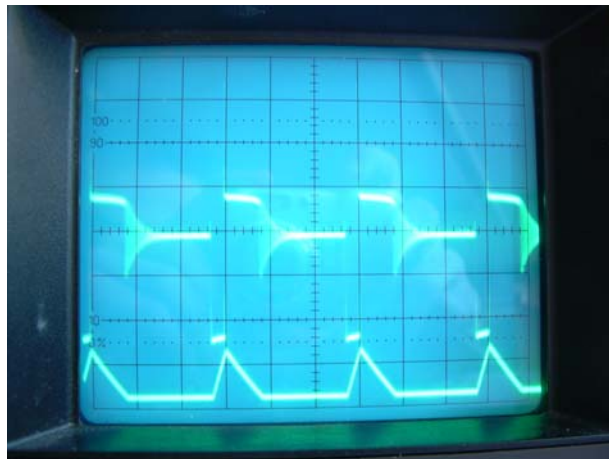Fig.27: Top view of final result. Implemented boost converter.

Fig.28: Oscilloscope image, transistor voltage and output current.

In the previous image it could be seen the response of the converter, the wave on the top corresponds to voltage in the transistor and the other to the inductance current, where we could appreciate the increase and the decrease of the current.

5   DOCUMENT RELATION

The following project is formed of two documents, the first is the Memory that contains: Appendix A, with calculations and Appendix B, with improves and observations and Appendix C the lasts modifications of the final design. The second document is the design schemes.

6   REFERENCES

SCMIDT-WALTER, HEINZ. (http://schmidt-walter.fbe.fh-darmstadt.de) 20th October of 2006.

WIKIPEDIA. (http://www.wikipedia.org) February 2007

ZVEREV ILIA / Sic Schottky diodes improve boost converter performance. (http://powerelectronics.com) February 2007.

SCHURICHT.Datasheets components.
(http://www.distrelec.com/ishopWebFront//home.do/para/language/is/en/and/shop/is/Y Y.html). February 2007.

KORIES, RALF; SCHMIDT-WALTER, HEINZ / Electrical engineering: A pocket reference / Springer 2003.

RAMON POCH, JOAN ANTONI / DC-DC converters / Power electronics lectures / University of Girona 2003.

ANTONIO, R; ABUD, D; JIMENEZ, G, ARAU,J / Evaluation of boost / CIEP / Puebla, Mexico 21-25th August 1994.

MALO, SHANE; GRIÑÓ, ROBERT / Análisis y diseño de controladores lineales para el convertidor elevador bidirecional en corriente / Universitat Politècnica de Catalunya july 2005.

CAMPOS DELGADO, DANIEL / Experimentos en Teoria de Control: Convertidores CD-CD / Facultad de ciencias (UASLP) 2003.

HART, D.M / Electrónica de potencia / Prentice Hall 2000.