Final Degree Project

Boost Converter DC-DC

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Appendix A

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A. CALCULATIONS

A.1 Previous calculations

Previous information:

Input voltage	Vin = V_i = V_E = 12V
Output voltage	Vout = V_O = 15V
Output current	Iout = 5A
Frequency	F = 40Khz

Considering the two points already previously explained when we want to fix the frequency, to work with 40KHz, a good value for our converter, 50 could be too. Lower than 10KHz will have noisy problems and higher some dissipations problems.

With all this information could be obtained other important values for the boost design.

Using some equations announced before and some other news could be obtained the parameters to start the boost design.

$$P_i = P_o \Rightarrow V_i \cdot I_i = V_o \cdot I_o \qquad \text{(Eq.1)}$$

With the first equation we will obtain the power value with the output information, like the power is a constant value between the input and the output.

$$P_o = V_o \cdot I_o \Rightarrow 15 \cdot 5 = 75W \qquad \text{(Eq.2)}$$

With this new value and as it is known the input voltage the input values could be calculated.

$$P_o = P_i = V_i \cdot I_i \qquad \text{(Eq.3)}$$

$$75W = 12 \cdot I_i \Rightarrow I_i = \frac{75W}{12} = 6{,}25A$$

Another important value is the duty cycle D or δ, time in the period that the switch is closed.

$$D = \frac{T_{ON}}{T} \rightarrow 0 < D < 1 \quad \text{(Eq.4)}$$

Don't confuse this D with the D of the diode.

Using a relation between the input and the output voltage it could be observed that the average value in the inductance has to be 0.

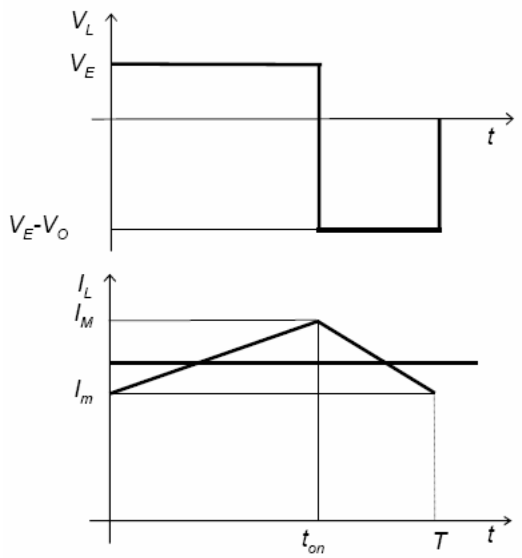

Fig.1: Inductance voltage and current graphics. Source: Udg power electronics lectures.

So have to be verified with the following equation.

$$V_E \cdot t_{ON} + (V_E - V_O) \cdot (T - t_{ON}) = 0 \quad \text{(Eq.5)}$$

Operating with this equation we will obtain:

$$\frac{V_O}{V_E} = \frac{1}{1-D} \quad \text{(Eq.6)}$$

A relation between input and output voltage.

And from this equation (6) obtain the duty cycle.

$$D = 1 - \frac{V_E}{V_O} \quad \text{(Eq.7)}$$

$$D = 1 - \frac{12}{15} = 0{,}2$$

Another useful equality is found when no losses are supposed, so could be considered the input voltage equal than the output voltage.

Using equation (1) another time and (7).

$$V_i \cdot I_i = V_o \cdot I_o \Rightarrow \frac{V_o}{V_i} = \frac{I_i}{I_o} \Rightarrow \frac{V_o}{V_i} = \frac{1}{1-D} \quad \text{(Eq.8)}$$

From this last equation the next equality is obtained, that could help us when we want to find the relation with the current and the duty cycle.

$$\frac{I_o}{I_i} = 1 - D \quad \text{(Eq.9)}$$

A.2 Commutation block

For the election of the transistor I take in consideration the voltage and the current that will have to resist.

There is a useful view in the following graphs.

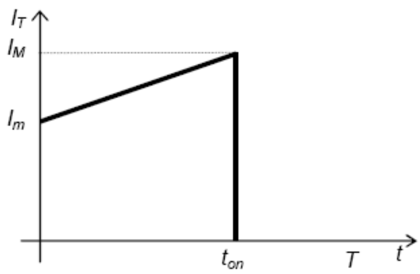

Fig.2: Transistor current. Source: Udg power electronics lectures.

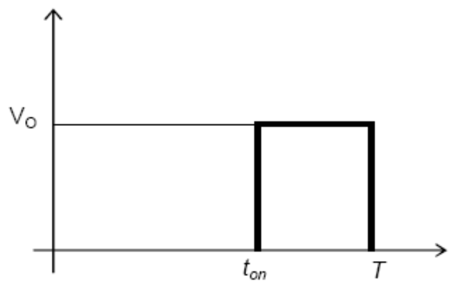

Fig.3: Transistor voltage. Source: Udg power electronics lectures.

In this converter, the graphs give a view at first sight of the values to take in consideration for the election of the transistor. In the case of the current it is I_M and for the voltage it is V_O.

The maximum current value that will cross the transistor is in the on time, $0 < t < t_{ON}$ interval, when the T it is switch on.

I have the following equation.

$$I_{LAv} = \frac{I_M + I_m}{2} \quad \text{(Eq.10)}$$

It is known for the type of converter that the average voltage in the inductance it is equal than the input voltage E, in average. Will work in the continuous mode but the calculations made it for the boundary of this mode, so I can affirm that the minimum current I_m has to be zero.

With equation (10), I_m=0 and I_{LAv}= $I_{EAv.}$

$$I_{LAv} = I_{EAv} = \frac{I_M + I_m}{2} \Rightarrow I_M = 2 \cdot I_{EAv} = 2 \cdot 6{,}25 = 12{,}5A$$

Calculating the current increase.

$$\Delta I_L = I_M - I_m \quad \text{(Eq.11)}$$

Taking in consideration as it was announced before I_m=0.

$$\Delta I_L = I_M - I_m \Rightarrow \Delta I_L = 12{,}5 - 0 = 12{,}5A$$

When we talk about the voltage the value to consider is the maximum voltage that the transistor has to resist, that situation will happen at the moment the transistor will be OFF, switch to the open position, in the interval $t_{on} < t < T$.

In this case this value is exactly the output voltage, so without any equation I affirm that $V_{max}=V_O= 15V$.

With the values of the I_M and V_{max} and looking on the datasheets of the different transistors suppliers and chose, it is interesting to chose something higher, that was calculated, for security and because we can make some modifications afterwards.

A.3 Low filter

With the calculations of the elements that compound the low filter as inductance, diode and output capacitors.

A.3.1 Inductance

Developing this equation and with the information known I can obtain the result of the inductance as we saw before.

$$V_L = L \cdot \frac{\Delta I}{\Delta t} \qquad \text{(Eq.12)}$$

The result of our inductance was $L = 4{,}8\mu H$. I obtained some graphs from a professor Schmidt-Walter program simulation, now I will use again this tool to obtain some other graphs, where we could see how affects modify the inductance value above or down the calculation.

To begin I will increase the value of our inductance, a little bit far from calculated, the Simulation will run with an inductance $L = 7\mu H$, the next one with a lower value $L = 4\mu H$ and the last one $L = 5{,}3\mu H$, with it we obtain the limit current result of the continuous mode.

Enter the rest of the values as before, because these values are fixed for the characteristics of our converter and necessities.

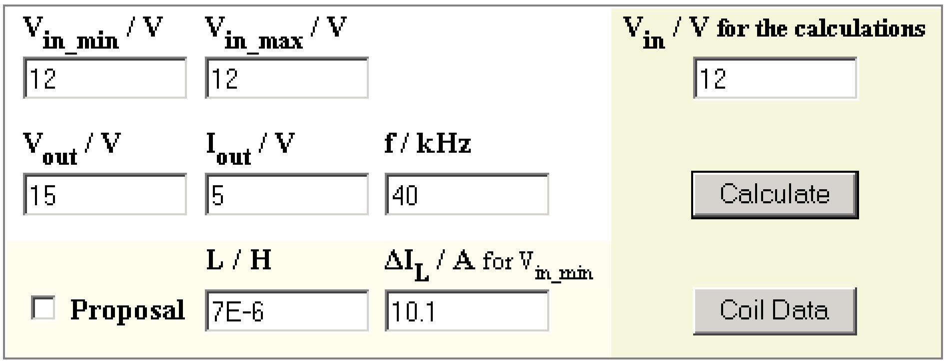

Fig.4: Simulation program, input values. Source: Dr. Schmidt-Walter website.

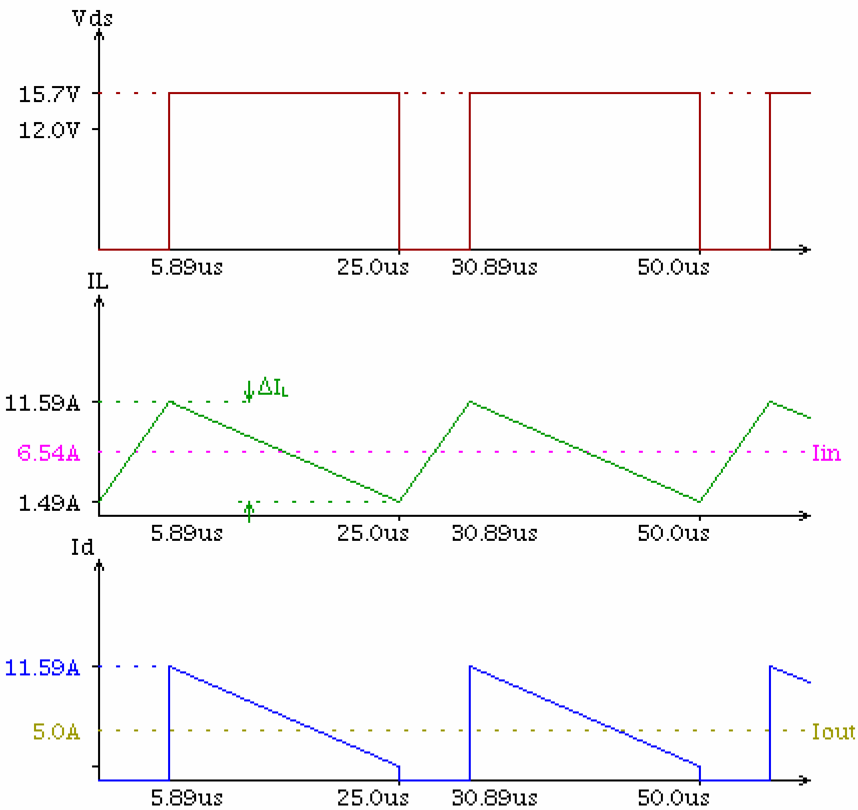

Fig.5: Simulation program, wave's results. Source: Dr. Schmidt-Walter website.

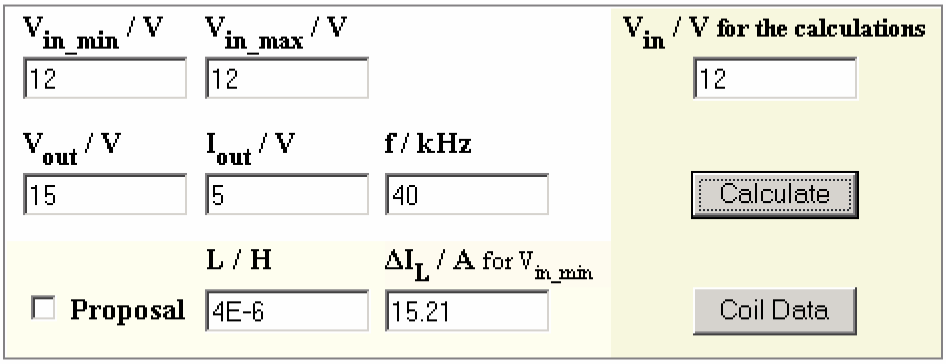

Fig.6: Simulation program, input values. Source: Dr. Schmidt-Walter website.

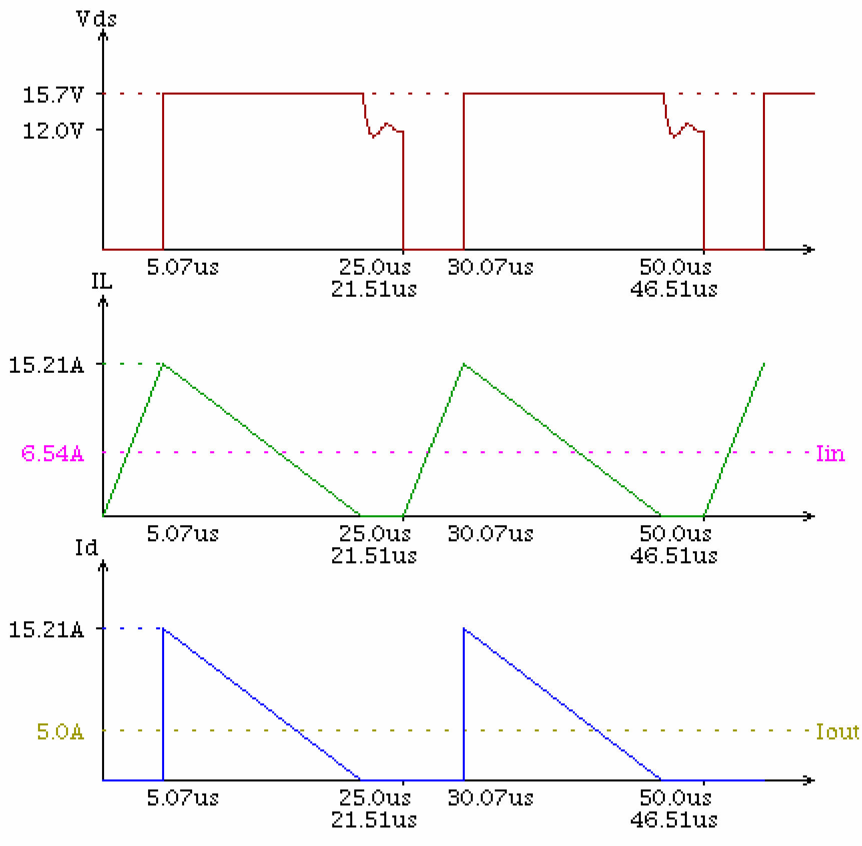

Fig.7: Simulation program, wave's results. Source: Dr. Schmidt-Walter website.

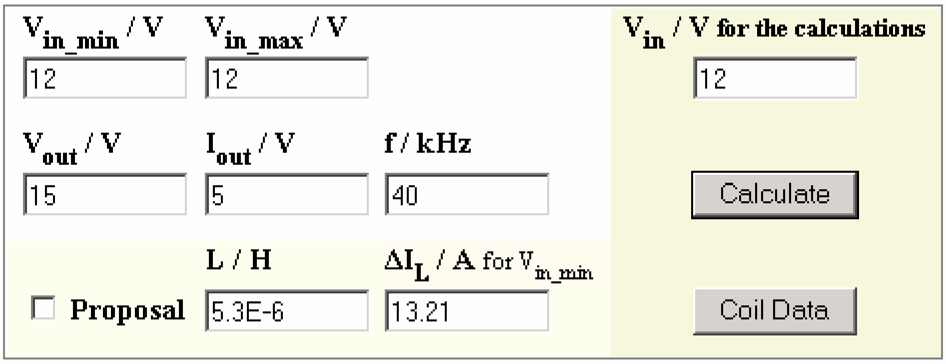

Fig.8: Simulation program, input values. Source: Dr. Schmidt-Walter website.

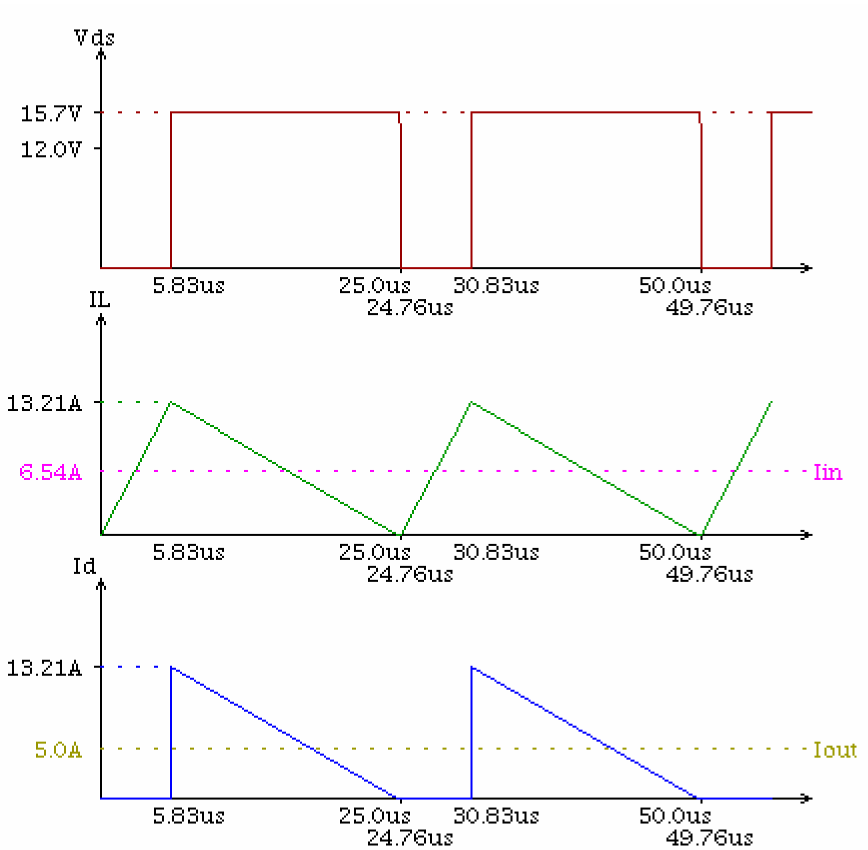

Fig.9: Simulation program, wave results. Source: Dr. Schmidt-Walter website.

Seeing figure (5) that corresponds to $L = 7\mu H$ It could be observed that we are far form the discontinuous mode, the lowest value of our current it is 1,49A, far from zero. The next simulation figure (7) and $L = 4\mu H$, the interval that the current it is equal to zero it is longer around 4µs, but looking the last one, figure (9) we are on the boundary of the continuous mode, what we are searching and that happens for a calculate value of $L = 5{,}3\mu H$.

As I said the inductance main function is to limit the current slew rate through the power switch and store energy.

It is possible to express the stored energy of an inductor with the *W*.

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

In our case it is:

$$W = \frac{1}{2} \cdot 4{,}88\mu H \cdot 12{,}5^2 = 375\mu VAs$$

The size of an inductor is approximately proportional to the stored energy. The field energy in the inductor is given for the following equation.

$$W = \frac{1}{2} \cdot \int \vec{H} \cdot \vec{B} dV \approx \frac{1}{2} \cdot \overrightarrow{H_{Fe}} \cdot \overrightarrow{B_{Fe}} \cdot V_{Fe} + \frac{1}{2} \overrightarrow{H_{\delta}} \cdot \overrightarrow{B_{\delta}} \cdot V_{\delta} \qquad \text{(Eq.13)}$$

The previous equation it could be divided in two parts, the energy in the ferrite and the energy in the air gap.

$$W_{Fe} \approx \frac{1}{2} \cdot \overrightarrow{H_{Fe}} \cdot \overrightarrow{B_{Fe}} \cdot V_{Fe} \qquad \text{(Eq.14)}$$

$$W_{\delta} \approx \frac{1}{2} \overrightarrow{H_{\delta}} \cdot \overrightarrow{B_{\delta}} \cdot V_{\delta} \qquad \text{(Eq.15)}$$

The magnetic field density $\vec{B}$ is continuous and within the air gap and the ferrite is approximately equal so I can say that $\vec{B} \approx \overrightarrow{B_{FE}} \approx \overrightarrow{B_\delta}$. The magnetic field strength $\vec{H}$ is not continuous, within the air gap it is increased by a factor μ_r compared to that than within the ferrite. If this is substituted in equation (13) and considering the next equations:

$$\vec{B} = \mu_o \mu_r \cdot \vec{H} \quad \text{(Eq.16)}$$

$$V_{Fe} = I_{Fe} \cdot A \quad \text{(Eq.17)}$$

$$V_\delta = \delta \cdot A \quad \text{(Eq.18)}$$

A new equality is obtained to express the field energy in the inductor.

$$W \approx \frac{1}{2} \cdot \frac{B^2}{\mu_o} \cdot \left(\frac{I_{Fe}}{\mu_r} + \delta \right) \cdot A \quad \text{(Eq.19)}$$

μ_r of the ferrite amounts to 1000…4000. The magnetic length of the ferrite is reduced by μ_r like we can see in the equation (19). Therefore we can see that the energy is mainly stored within the air gap.

So Ican announce another equation.

$$W \approx \frac{1}{2} \cdot \frac{B^2 \cdot A \cdot \delta}{\mu_o} \quad \text{(Eq.20)}$$

So as was demonstrate the air gap it is a basic element of the inductance. To calculate the air gap we need to take into consideration the following steps.

We know as we announced before that the energy is given by equation (12).

The core material has a limit for the maximum magnetic flux density B, this limit is about $B_{\max} = 0{,}3T$ for usual ferrite materials. This leads to a minimum required volume V_δ of the air gap.

$$V_\delta = A \cdot \delta \geq \frac{L \cdot \hat{I}^2 \cdot \mu_o}{B^2{}_{\max}} \quad \text{(Eq.21)}$$

A core can be selected from a data sheet of ferrite cores when we know the required volume of the air gap.

The number of the turns N can be calculated with the help of the magnetic conductance A_L. We find the value A_L in the datasheet of ferrite cores.

$$N = \sqrt{\frac{L}{A_L}} \quad \text{(Eq.22)}$$

The maximum flux density should not be higher than 0,3T. The maximum flux density within the ferrite can be calculated using the data of the core datasheet.

$$B = \frac{L \cdot \hat{I}}{N \cdot A_{\min}} = \frac{N \cdot A_L \cdot \hat{I}}{A_{\min}} \leq 0{,}3T \quad \text{(Eq.23)}$$

We can obtain the value of $A_{\min}$, minimum cross-cut of the core, of the information in the datasheet. An interesting observation is that the flux density has its maximum at $A_{\min}$.

To calculate the wire:

The current density S of the wire can be chosen between 2 and 5 A/mm^2, depending on the size and the isolation, which determines the heat transport of the inductor, that will drive to the diameter of the wire d.

$$d = \sqrt{\frac{4 \cdot I_{RMS}}{\pi \cdot S}} \quad \text{(Eq.24)}$$

$$S = 2 \ldots 3 \ldots 5 \frac{A}{mm^2}$$

That election of S depended of the magnitude of our current.

After the calculations, when all the equations are valid, we have to expect that the result will obtain will be what we are looking for, but unfortunately some times it is not the case.

We have the following values:

$$L = 4{,}8\mu H$$
$$N = \sqrt{\frac{4{,}8\mu H}{201nH}} = 4{,}88$$
$$B = \frac{5 \cdot 201\mu H \cdot 12{,}5A}{71mm^2} = 0{,}177$$

Obtained from equations (12), (22), (23), we chose previously an air gap $\delta = 0{,}5mm$.

When I proved the board the current grew to fast activating the current limitation circuit, so It could not arrive until the maximum value of current, 10A, that would give the output current equal to 5A, what we needed. The output current was lower than 5A, around 4,5A enough to force us to make some changes to obtain a better result.

The first element to analyze is the inductance, we must review the calculations.

We have to follow a new strategy, different of what we used the first time, when we started with the inductance calculations, using the dates fixed for the circuit.

Like the problem is a high ripple of the increase current, find the maximum number of turns that will give a bigger inductance too, to control the current. Change the air gap too $\delta = 1mm$.

The rest of the values needed like before, in the datasheet of the core.

$$A_{\min} = 71mm^2$$
$$A_L = 124nH$$

To obtain $N_{\max}$ I will use equation (23).

$$N_{\max} = \frac{B \cdot A_{\min}}{A_L \cdot \hat{I}} = \frac{0{,}3 \cdot 71mm^2}{124nH \cdot 12{,}5A} = 13{,}74$$

$N_{\max} = 14$ turns.

Using the same equation (23) again we will know what is the biggest current magnitude that we can resist.

$$I_{\max} = \frac{0{,}3 \cdot 71}{0{,}124 \cdot 14} = 12{,}26A$$

The same equation will be used to determinate the maximum flux density.

$$B = \frac{14 \cdot 124\mu H \cdot 12{,}5A}{71mm^2} = 0{,}30$$

$B = 0{,}29 < 0{,}3T$ So all the equations are verified and like before try to see if the results is what we want. The final value of inductance $L = 24{,}30\mu H$

Effectively after the prove board, we could realise that with this change the result improved until our first objectives.