

# A Practical And Integrated Approach for Power Switching Supply Teaching: Example of a Boost Converter Topology

Ph. DONDON- J.M MICOULEAU-M.MARTHIENS DAGORETTE  
ENSEIRB Av Dr A. Schweitzer 33405 Talence, France.  
Philippe.Dondon@enseirb.fr

**Abstract:** Teaching the “electronic switching power supplies” design - like other fields of electronic- is not always easy: There is classically theoretical courses and practical lessons. The link between the two is often the most important difficulties that appear for the students. Despite a abundant literature on switching power supplies, a global and simple analysis is rarely found. In order to improve the efficiency of our teaching, we present here a practical and pedagogical approach based on Hermann modelling (including magnetic, practical considerations, design method and flowchart) for understanding and designing classical switching power supplies. It looks like a progressive linear guide from the most simple to the most difficult. A boost converter topology is used to illustrate our approach.

**Key words:** Engineer school, Student’s behaviour, Hermann modelling, Practical approach, Power electronic system.

## 1. Introduction

### 1.1 ENSEIRB short presentation

The “Ecole Nationale Supérieure d’Electronique, Informatique et Radiocommunications de Bordeaux” is one of the graduate national engineering schools, known as '[Grandes Ecoles](#)', in France. It is also one of the oldest, as it was founded in 1920.

### 1.2 Classical general teaching strategy

From previous papers about Herman modelling interest [1] [2], we just can remember that the brain behaviour of a human can be described as two hemispheres left and right and four quadrants modelling:

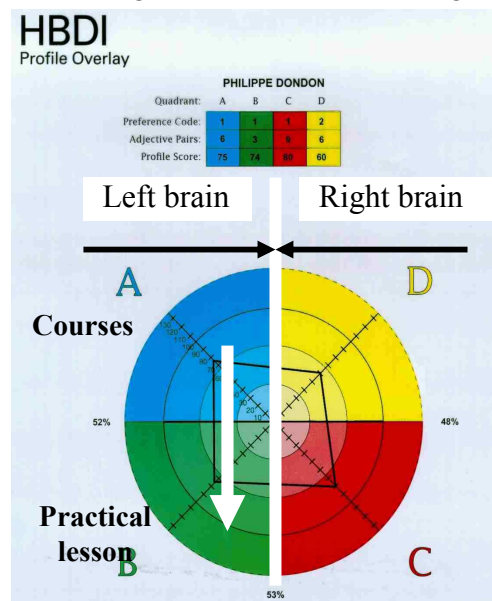
Quadrant A (blue) shows the preference of the individual for logic, modelling, (typical profile: mathematician, data processing specialist ...). B (green) its aptitude for the practice and planning (real time production scheduler, administrative profile...).

The quadrant D (yellow) shows the preference for the risk and projection in the future (typical profile: "start-up" manager, risk manager, artist...). And C (red) for the relational one, emotion (social and commercial workers...).

In scientific curriculum, a classical pedagogical approach consists in theoretical courses (A quadrant solicitation) followed by practical application exercises (B quadrant solicitation). One realises that this process of training requests only the left brain and that is it a mental restrictive “top down” approach [1] (cf figure 1). Unfortunately, from Herman institute

statistics [8], we know that this approach is appropriate only for around 1/4 of the students due to the high variety of existing profiles.

Figure 1 : Hermann modelling



### 1.3 Case of the previous power electronic course

Our teaching approach for power electronic courses was a typical illustration of what we told before: a top down approach with only a left brain solicitation (cf Figure 1). So we decided to improve the teaching process by a more global and didactical approach.

### 1.4 Modified approach

The main idea of our new approach is to sweep [1] as well as possible the 4 quadrants of the Hermann

modelling in order to match to the extremely natural and various Hermann modelling profiles of our students [8].

Thus, as a complement of our classical “power electronic” full class room teaching (12 hours in second year study), our practical lesson (4 hours duration) illustrating switching power supply courses, follows now the mile stones described in next paragraphs 2, 3, 4 and 5: Left and right brain are alternately solicited with several “top down” and “down top” way and returns... which is a first step in teaching effectiveness improvement.

## 2. Components background

Starting the lesson, we first dedicate a short of time for recalling and briefly describing the fundamentals of power components as follow (Quadrant A solicitation):

### 2.1 MOS Transistors and Diodes

The MOS transistors and diodes are, first, considered as perfect switches and we use first a simplified model for a first order Boost behaviour description.

### 2.2 Magnetics materials overview

The characteristics and interest of soft ferrites [6] such as Mn-Zn or Ni-Zn and available shapes (E, EC, ETD, U) used in power electronic to make coils, are shortly described. The impact of an air gap is recalled: indeed, by decreasing the effective permeability of the material, it is then possible to increase the maximum available current through the coils.

### 2.3 Components for energy storage short description

#### 2.3.1 Simple inductances

As the students are generally not familiar with inductances, it is necessary to “demystify” this component and to explain how and where the stored energy is. The aim of magnetic circuits is obviously to minimize the size of the component and to keep the magnetic flux in a small space region and thus to reduce the electromagnetic parasitic fields (EMI).

#### 2.3.2 Magnetic saturation effect understanding

As the effect of the saturation is not always well understood from a theoretical point of view, we

include a practical and graphical explanation as follow: submitting the coil to a periodic squared voltage (Figure 3), can produce a magnetic saturation. Instead of theoretical triangular current waveform, the current becomes a deformed triangle with “spikes”.

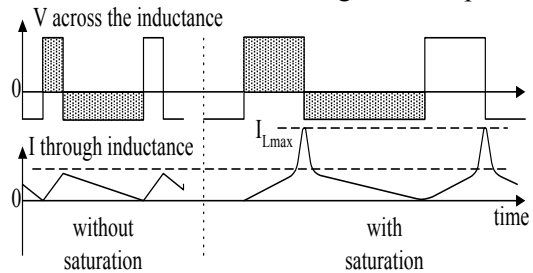


Figure 3 : effect of magnetic saturation

The current can then drastically increase. This dangerous rising can cause energy losses, damages and destruction of one or more components in the circuit.

## 3. Boost converter

After the necessary components recall, we give to the students a simplified, intuitive and graphical description (Right brain solicitation) of a boost converter topology as indicated in section 2.1 and 2.2.

### 3.1 Simplified theory

A simplified approach is done, considering the MOS transistor and the diode as perfect switches. [5]

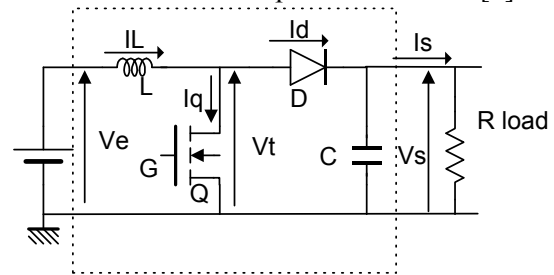


Figure 4 : boost topology

### 3.2 Operating mode

There are two operating modes: continuous and discontinuous [3], [4].

The operating mode is called discontinuous when the flux  $\Phi$  through the inductance  $L$  returns to zero during each cycle (cf figure 5). At the opposite, in continuous mode the current never reach zero. (Figure 6)

In the two modes, the output voltage is greater than the input voltage  $V_e$ . That is why the circuit is called elevator or boost.

$$V_s = V_e / (1 - \alpha)$$

with  $\alpha$  = “MOS on time” / T period ratio.

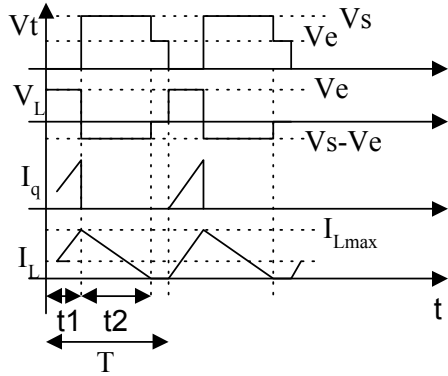


Figure 5 : Discontinuous mode chronogram

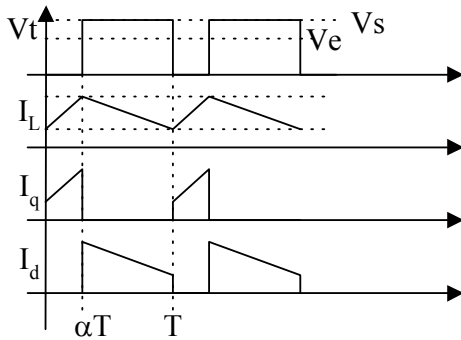


Figure 6 : Continuous mode chronogram

## 4. Practical design and understanding approach

The most important for the students is to link the theoretical basic formulas given during the traditional full class room courses [4] to a practical design as simply as possible: a linear step by step design strategy is thus given below as a kind of student “cooking guide”. (Quadrant A and B sollicitation)

### 4.1 Basic Boost structure design flowchart [7]

- Choose a MOS transistor and look at the breakdown voltage  $V_{(BR)DSS}$  of the transistor.
- Assume that  $V_{dsmax} = 2/3.V_{(BR)DSS}$  (safety margin for voltage spikes)
- Knowing  $E$  and  $V_s$  from specifications, calculate the nominal value of  $\alpha$  from equation (5)
- Choose the switching frequency  $1/T$  (around 100kHz for design facilities).
- Knowing  $V_e$ ,  $V_s$  and  $I_s$  (from design specifications), once compute the maximal current into inductance:

$I_{Lmax} = \frac{V_s}{V_e} \cdot 2 \cdot I_s$  At the critical point (between continuous and discontinuous modes)

- Guess the inductance value  $L$  by :

$$L = \frac{V_e}{I_{Lmax}} \cdot \alpha \cdot T \quad \text{and} \quad \alpha = \frac{V_s - V_e}{V_s}$$

The inductance is then sized using manufacturer data's and curves being careful to not reach magnetic saturation, or by software modelling.

- Check that the chosen transistor is well sized for the maximum current  $I_{Lmax}$  : if not, go back to step a).

- Choose the diode as follow :

- Schottky diode (minimization of conduction losses), sized for :

-a reverse breakdown voltage  $V_r$  greater than  $V_s$

-an average current  $I_{av} = (1-\alpha) I_{Laverage}$

-a peak current  $I_p = I_s / (1-\alpha) + \alpha \cdot T \cdot V_e / 2 \cdot L$

## 4.2 Ending the basic design

### 4.2.1 Output ripple evaluation

The last component of the basic boost structure as shown in figure 4, is the output filtering capacitor.

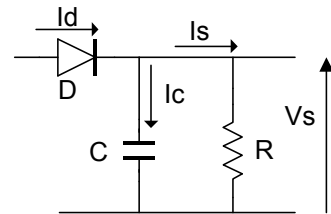


Figure 7: output C capacitor

Using the waveform continuous mode timing shown in figure 8, and assuming that the current through the load is constant, the students can guess the voltage output ripple  $\Delta V_s$  and then the capacitor value  $C$  by the two formulas given below :

$$\Delta V_s = \frac{\alpha \cdot V_e}{(1-\alpha) \cdot R \cdot C \cdot F} \quad \text{and} \quad C = \frac{\alpha \cdot T \cdot I_s}{\Delta V_s}$$

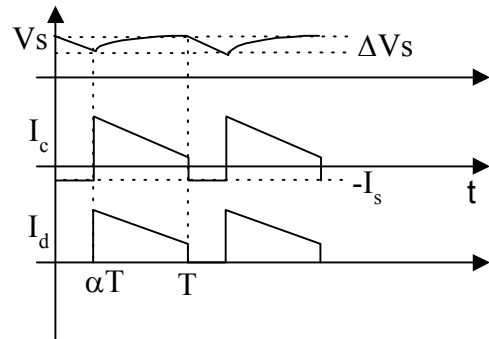


Figure 8 : Output ripple in continuous mode

## 4.3 Voltage regulation feed back loop investigation

At this point of the lesson, the necessity of a feed back loop to control the output voltage is shown to the students through a practical observation of output unwanted voltage variations vs. load current.

**4.3.1 Feed back simple analysis**

Indeed, the boost basic structure can not work “alone”, a feed back loop is required to set  $V_s$  at the nominal output voltage value and to control it. Thus, a voltage reference and a PWM (pulse width modulation) feed back loop which control the duty cycle for MOS conduction (cf. figure 9) are used.

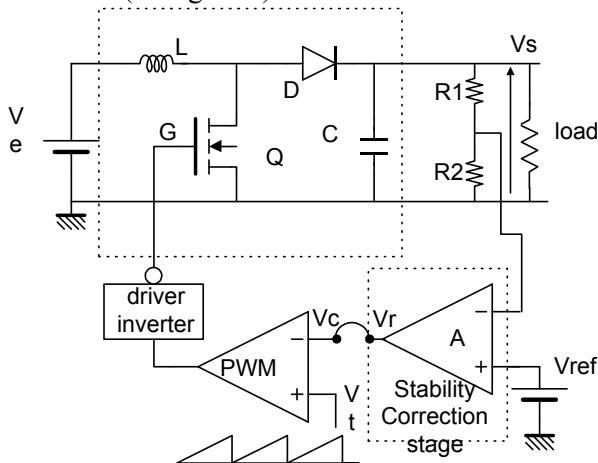


Figure 9 : Feed back loop structure

When the loop is correctly locked, the output voltage is given by:

$$V_s = \frac{R1 + R2}{R2} V_{ref}$$

And  $V_s$  is then theoretically independent of the load and internal boost components.

Referring to the VORPERIAN loop analysis method, the boost transfer function  $V_s/V_c$  is computed by the students in order to make a simplified linear approach of stability study.

**4.3.2 Stability simplified study**

At this step of the pedagogical process,, we know, from our previous teaching experience, that a pure mathematical approach (Quadrant A) is often too much difficult for our students and is not well accepted: So, we prefer to use a more intuitive strategy (Quadrant C solicitation):

Combining graphically the boost response  $V_s/V_c$  and the Op amp/Comparator function, we suggest to the students a very simple (but of course not optimized) integral correction (cf figure 10 and 11).

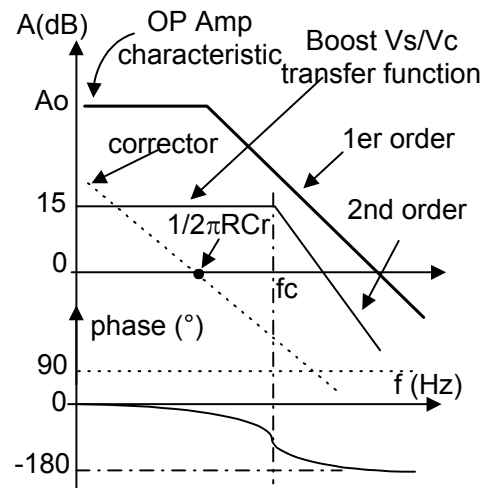


Figure 10 : Open loop modelling

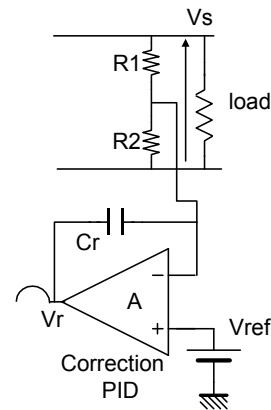


Figure 11 : Proportional/integral correction

In fact, as the correction parameters depend on the load and the biasing point, the detailed computation can become quickly very complex. We just mention these difficulties to the students without other any details.

**5. Complete electronic schematic**

Our electronic board has been designed with classical discrete components for easy maintenance and cost reasons. (Cf figure 13). The nominal input voltage  $V_e$  is set to 5V and the output voltage  $V_s$  is adjustable (by P2 potentiometer) from 7 V to 15 V. The maximum output current is around 500mA. And the switching frequency is variable from 50 to 120 kHz.

For pedagogical reasons, only the most important components calculated and sized by the students can be plugged on the board (ie Inductance, diode, snubber). The other components are hard wired.

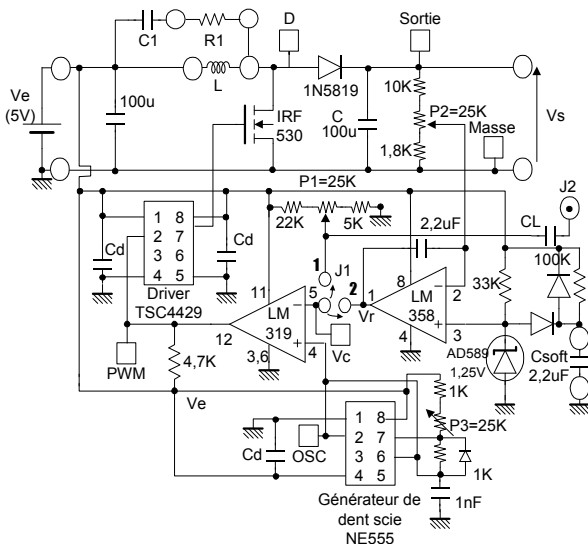


Figure 13: discrete boost practical design

By plugging an optional R1, C1 snubber (figure 13), the students observe that the waveform timing (cf figure 14b) is now closer to theory (figure 5)

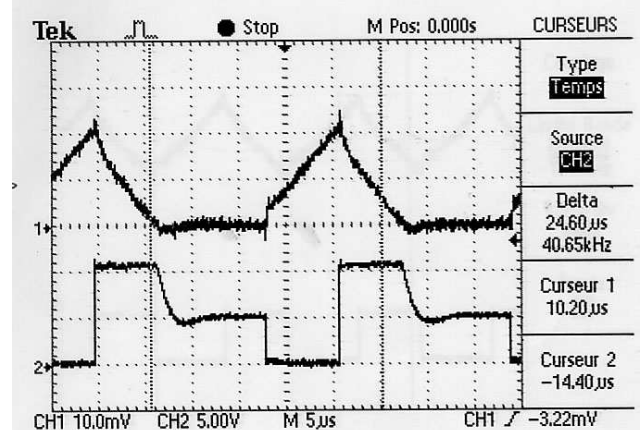


Figure 14b : with snubber

Figure 14 b : Lower trace : drain source MOS voltage with snubber, 10V/div; Upper trace inductance current 0,1A/div; time scale 5us/div.

As the students look “surprised” by this circuit behaviour, this practical observation is an opportunity to go back to a more detailed theory (Quadrant A solicitation) for a while:

At this step of our pedagogical process, we introduce the MOS and diodes components imperfections and equivalent modelling in switching mode and the students determine the snubber values using the following simplified intellectual approach:

At time T2 (cf figure 5), the MOS transistor is still turned off and the current  $I_L$  becomes null. So that the diode turns “off”. The instantaneous equivalent schematic, looks like in figure 12 :

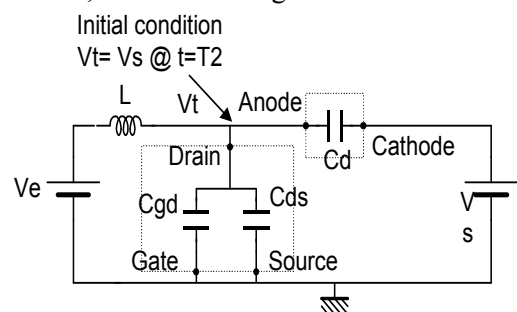


Figure 12: equivalent modelling for parasitic oscillation evaluation

Where  $C_{gd}$ ,  $C_{gs}$ , are the stray capacitances of the MOS and  $C_d$ , the equivalent reverse capacitance of the shottky diode.

Thus, we can guess the frequency of oscillation  $F_o$  by :

$$F_o = \frac{1}{2\pi\sqrt{L \cdot C_T}}$$

## 6. Experimental and back to theory

After the mixed intuitive and theoretical study of a boost structure, the students start the experimental part of the work. For this practical work, the boost converter (input voltage: 5V, nominal output voltage: 10V) is loaded by a programmable electronic load HP4060A. Most of the characteristics presented below were measured by the students.

Students, first, test the basic boost structure in open loop mode, closed loop mode, loaded and unloaded. For example, the figure 14a (without “snubber”) shows that the practical voltage waveform in discontinuous mode looks not like the theory (oscillations potentially dangerous for the MOS transistor when turned “off”)

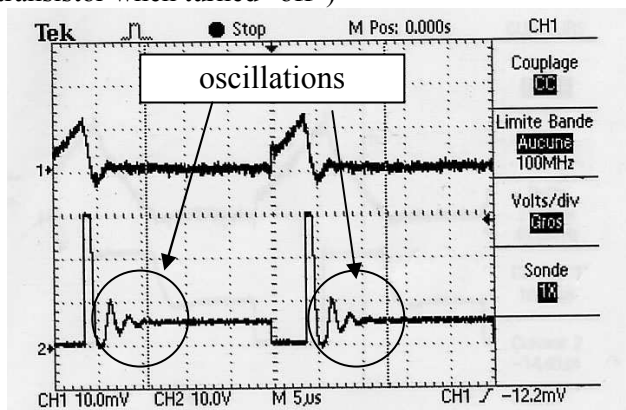


Figure 14a : waveform without snubber

Figure 14 a : Lower trace :  $V_{ds}$  MOS voltage without snubber, 10V/div; Upper trace: inductance current 0,2A/div; time scale 5us/div (measured with a Tek TDS220 oscilloscope and AM503 current probe).

Where  $C_T$  is the total capacitance  $C_{gd}+C_{gs}+C_d$  estimated from MOS and Diode “Data book” tables and curves. Adding the snubber  $R_1, C$  in parallel with  $L$  and assuming that  $1/C_1.2\pi F_0 \ll R_1$  (1), the total equivalent impedance  $Z_e$  of the  $R, LC$  network at the  $F_0$  frequency becomes :

$$Z_e = \frac{\frac{2z}{\omega\omega} \cdot p}{1 + \frac{2z}{\omega\omega} p + \frac{p^2}{\omega\omega^2}} \quad \text{with } z = \frac{1}{2R_1} \sqrt{\frac{L}{C_T}}$$

$$\text{and } \omega\omega = \frac{1}{\sqrt{L \cdot C_T}}$$

$R_1$  is guessed at the 2<sup>nd</sup> order critical response with a damping factor  $z=1$ . Then, we choose  $C_1$  according to the condition (1)

After this “way and return” to theory, the experimentation goes on: the figure 15 illustrates the magnetic saturation: the current waveform is no more triangular as shown on upper trace (0,5 A/div, DC coupling).

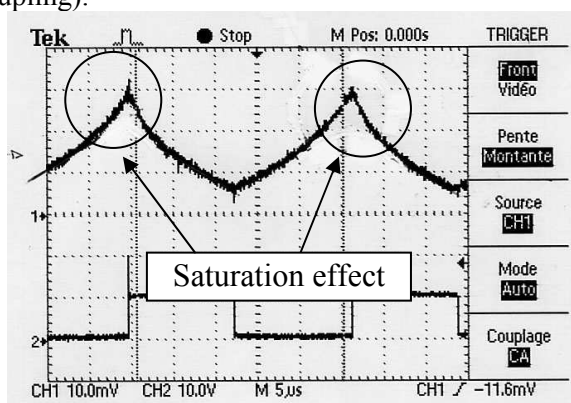


Figure 15 : effect of magnetic saturation

Many other curves can be drawn during the lesson, such as start up waveforms, dynamic response of the loop in case of step output current solicitation...

## 7. Pedagogical strategy summary

During a lesson, we first give a general presentation of power switching devices “world” (Quadrant D solicitation). Then, our students first compute the main components using the mixed mathematical and intuitive design strategy (Quadrant A and C solicitation). Going quickly to experimental (Quadrant B), they are not fed up with the heavy theory. They start the measurements with a simple boost topology and observe the differences between the theory and the practical measurements. Then, they try to identify the technical reasons of the differences. Finally, they understand how to reduce it, by plugging additive

components such as “snubber” components on the basic experimental structure.

Thus, by several “zapping” between mathematical theory, intuitive understanding and practice, all the quadrants in Hermann modelling are swept.

## 8. Results

In order to get some feed back about this strategy, we asked to our electronic department to make an annual opinion poll and report among the students since 2003: around 60% of the students answered to this questioner and the result shows a global satisfaction rate rising from 50% up to 65% for this field of teaching. In particular, they point out a better connection in their mind between the abstract theory and the concrete aspects and also a reduction of the necessary understanding time.

## 9. Conclusion

This paper is a “digest” of our integrated pedagogical approach. We showed how to improve the efficiency of the lesson by an harmonious solicitation of the left and right parts of the Hermann brain modelling and how to improve the link between theory and practice. After two years of experimentation, this approach is now extended in our engineer school, to all the power electronic fields of teaching.

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