smart ctrl

control design for power electronics

PSIM – SmartCtrl link

Tutorial –April 201-

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Table of contents

1. Introduction

SmartCtrl1[1] is a general-purpose controller design software specifically for power electronics applications. This tutorial is intended to guide you, step by step, to design the control loops of a boost converter in single loops with the SmartCtrl Software.

The example used in this tutorial is the boost converter circuit that comes with the PSIM example set (the PSIM file is "Boost VMC MCC.psimsch" under the folder "examples"). The PSIM schematic is shown below:

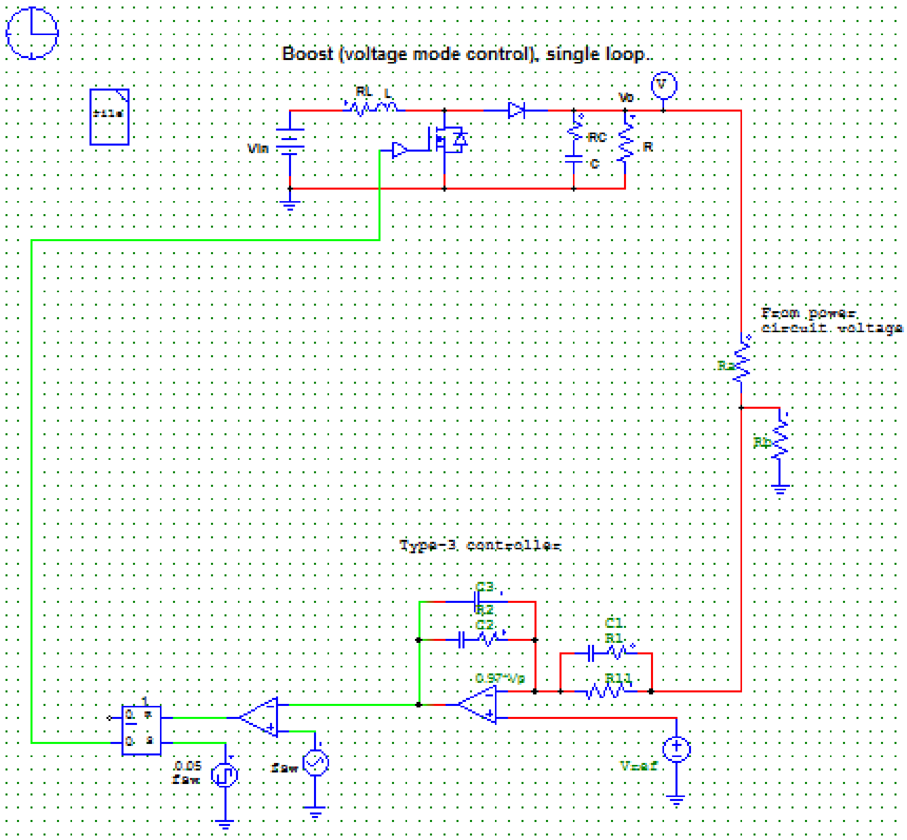


Figure 1

SmartCtrl allows design boost converter in three different control modes: Voltage Mode Control and Average Current Mode Control when the inductor current is sensed (L Current Sensed) and when the diode current is sensed (Diode Current

[1] SmartCtrl is copyright © 2009-2012 by Carlos III University of Madrid, GSEP Power Electronics Systems Group, Spain

Sensed). Voltage Mode Control has been selected as the example shown in this tutorial.

2. Boost converter design using PSIM and SmartCtrl

To start the design process, in SmartCtrl, click on the icon , or select from the Design menu: Predefined topologies -> DC/DC converters -> Single loop -> Boost -> Voltage mode controlled.

The boost converter is controlled by a single loop control scheme. Note that the boost converter design must be carried out sequentially. The SmartCtrl program will guide you through this process.

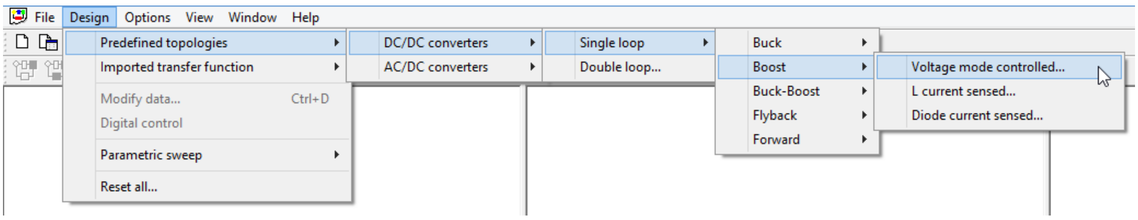


Figure 2

2.1. Define the converter power-stage

This dialog will appear as follows.

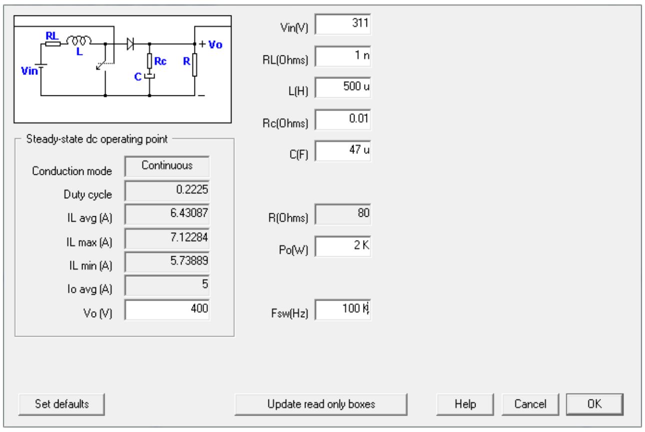


Figure 3

Complete the parameters in the corresponding input data window. Note that steady state operating points are automatically calculated. If you introduce any change in the input values, press “Update read only boxes” to upgrade the steady state values. When finished, click OK to continue.

2.2. Select the voltage sensor

Select the voltage sensor among the available types. In this example, select Voltage divider. When using a voltage divider, one must enter the reference voltage, and the program will automatically calculate the sensor gain. In this example, the reference voltage is 2.5V. The sensor input data window is shown in Fig. 4.

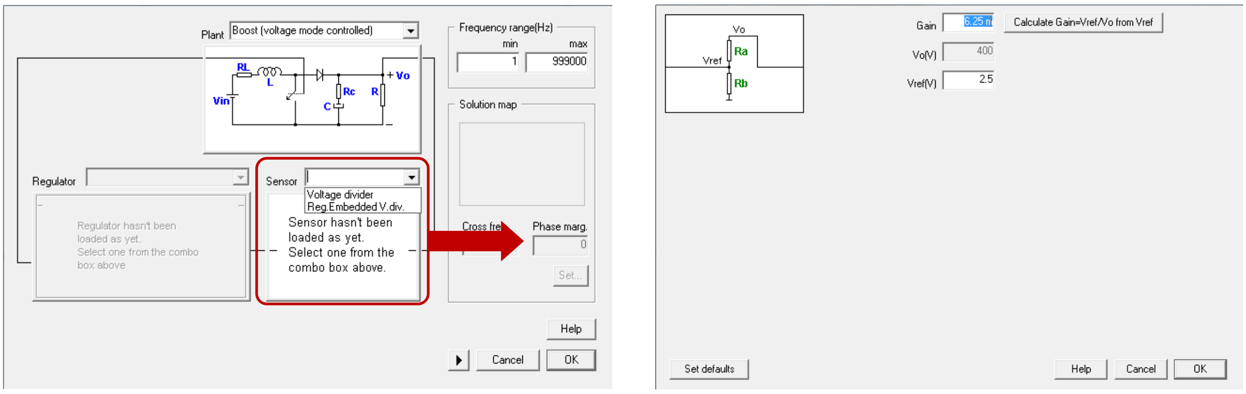


Figure 4

2.3. Select the voltage regulator

Select the voltage regulator among the available types drop-down menu, select Type3 as the voltage regulator type.

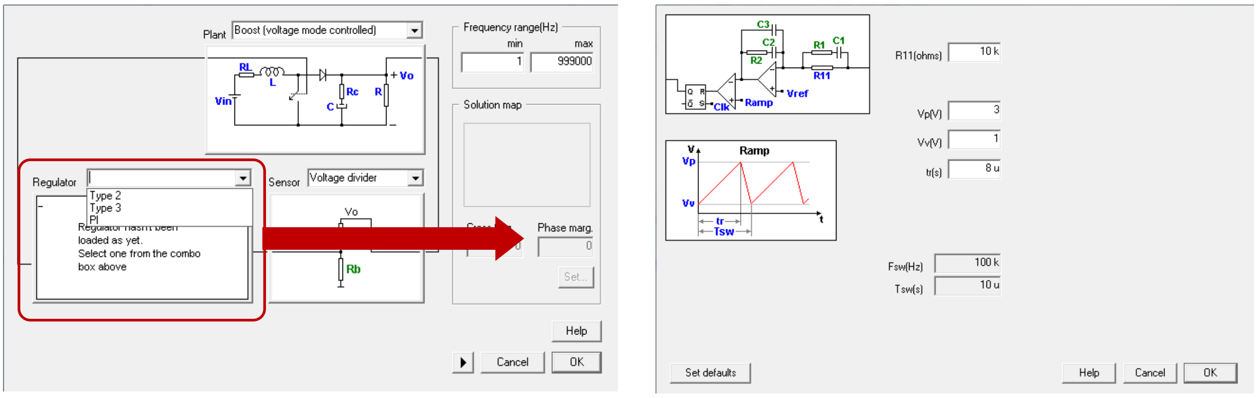


Figure 5

2.4. Select the crossover frequency and the phase margin

SmartCtrl provides a guideline and an easy way of selecting the crossover frequency and the phase margin through the Solutions Map. Click on the Set button, and the Solution Map will be shown as in Fig. 7.

In the Solution Map, each point within the white area corresponds to a combination of the crossover frequency and the phase margin that leads to a stable solution. In addition, when a point is selected, the attenuation given by the sensor and the regulator at the switching frequency is provided. If this attenuation is not high enough, the ripple at the output of the compensator could be very high leading to high frequency instability (high ripple than the than ramp amplitude).

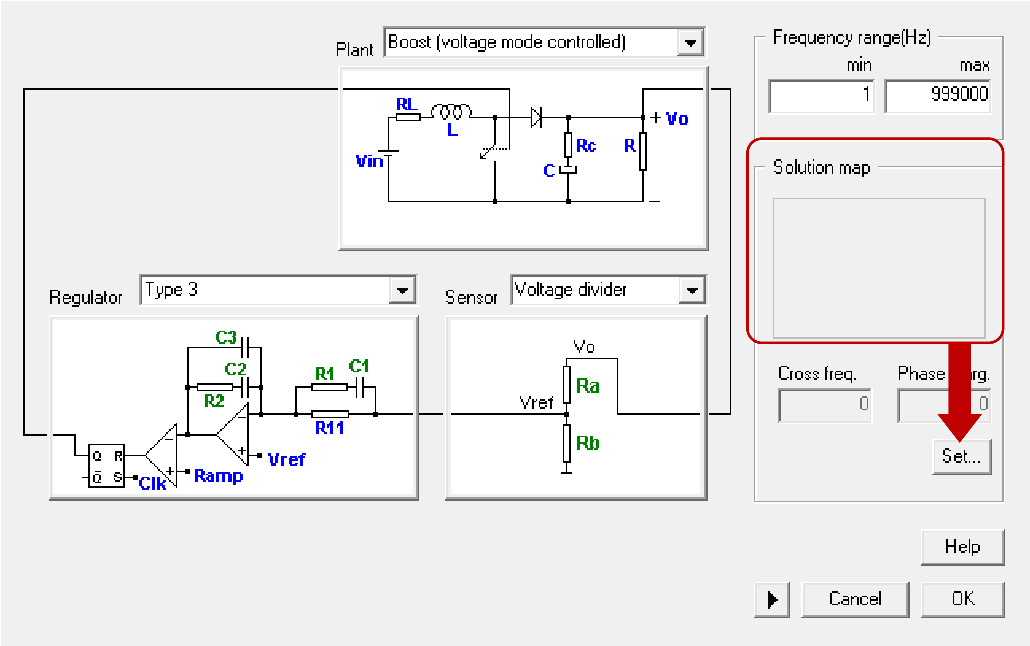


Figure 6

To carry out the selection, left click a point within the white area, or enter the crossover frequency and the phase margin manually.

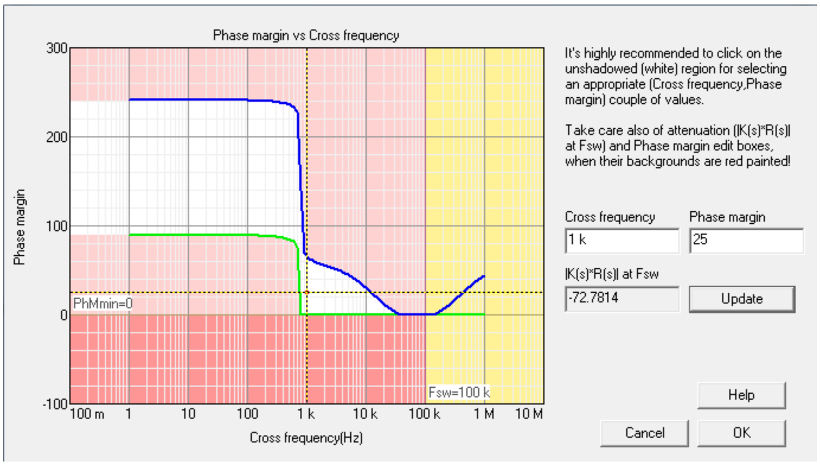


Figure 7

Once the crossover frequency and the phase margin are selected, the Solution Map will be shown on the right side of the converter input window. If, at any time, one needs to change the crossover frequency or the phase margin, click on the white area of the Solution Map, as shown in the figure below.

Click on Ok button to confirm the design, the program will automatically show the system performance in terms of the Bode and Nyquist Plots and transient response, (Fig. 9)

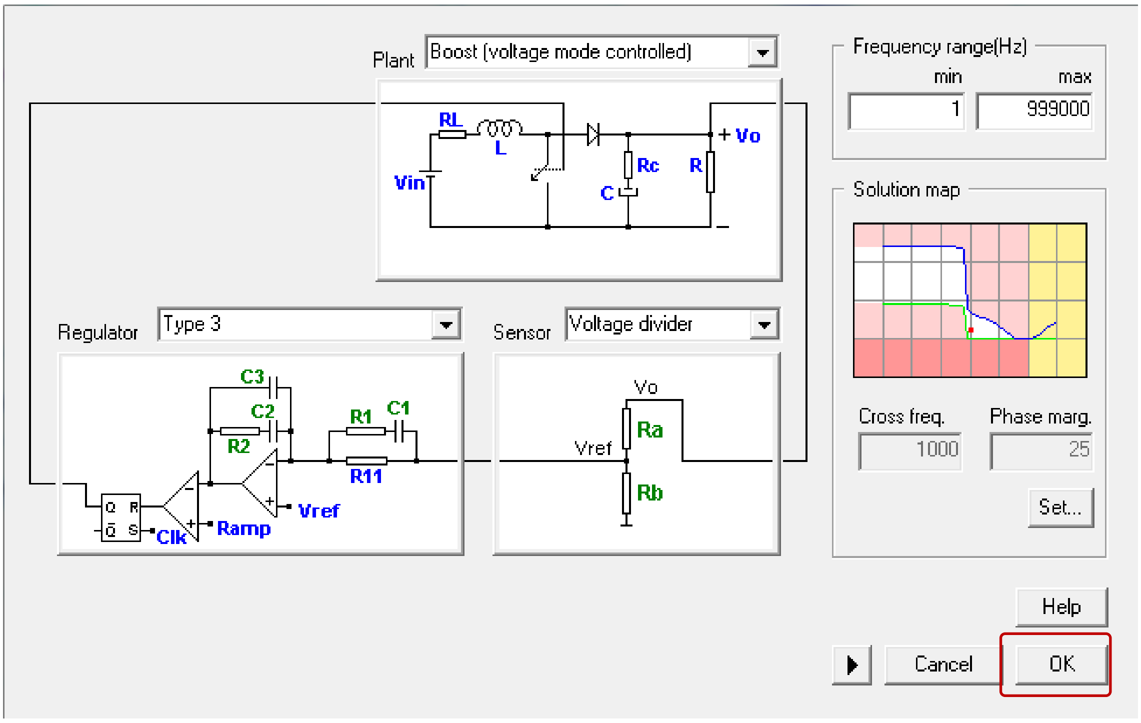
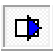


Figure 8

SmartCtrl provides the regulator component values needed to implement the regulators, as well as the voltage divider resistors. These values are given through the “Output Data” text panel  or directly can be used to perform a PSIM simulation.

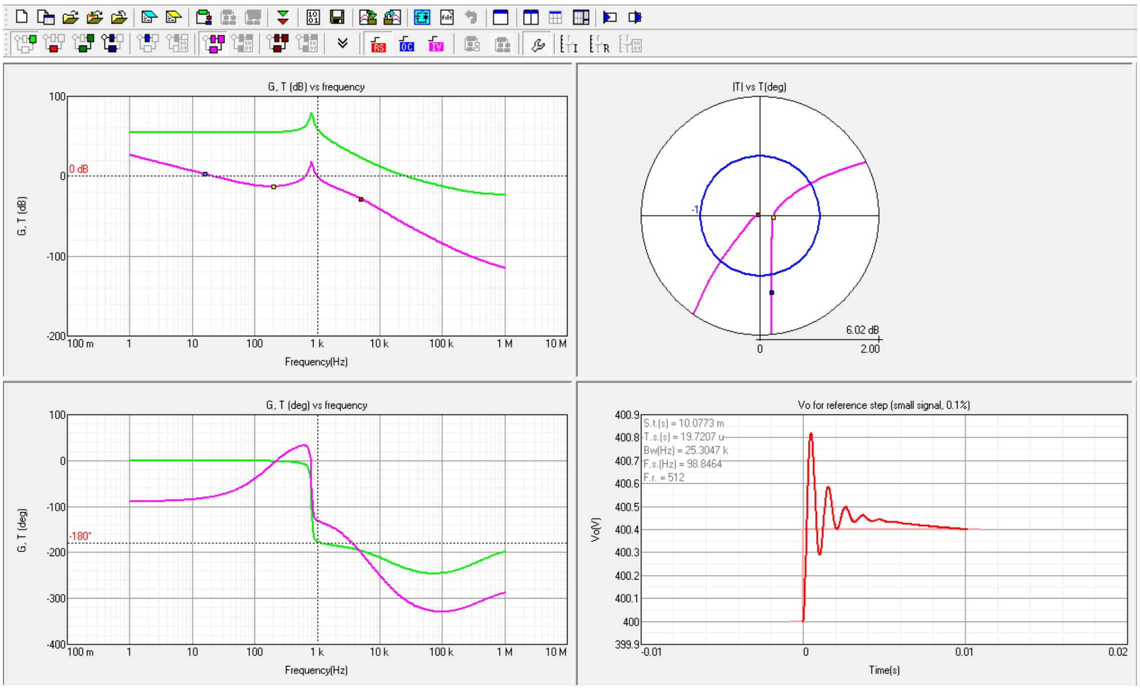


Figure 9

A good practice could be saving the design created, SmartCtrl will generate a file: *.tro

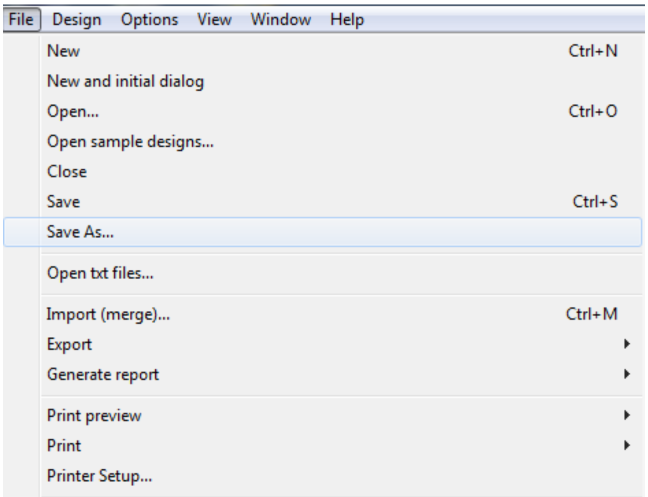


Figure 10

2.5. Export to PSIM

The designer will be able to export to PSIM everything He needs to perform a PSIM simulation in closed loop.

There are two ways to export data to PSIM. Regulator exporter to PSIM, schematic and parametric files, ; or only parametric files . The first option should be used the first time because the complete circuit is placed in the schematic, and the second option must be used the second and further times to update the parameters values after the design has been debugged.

In the first step the user will be asked to select the path and the name of the PSIM file in which the schematic will be inserted. If the file has not already been created, a new PSIM file will be created with the name provided by the user.

The first time that data is exported to PSIM, must be done with , then choose the **Regulator exporting way** (see Fig. 13):

- "Components (R1, C1, ... are given)": the schematic and parameters of the compensator will be exported with an analog implementation (Operational amplifier and passive components).

- "s-domain coefficients": the schematic and parameters of the compensator will be exported in the form of PSIM control blocks.

- "z-domain coefficients": the schematic and parameters of the compensator will be exported in the form of a z-domain transfer function. Therefore it is necessary to configure the "Digital Settings" before selecting the z-domain format for exportation to PSIM. Besides the z-domain transfer function that represents the digital compensator, additional blocks are added. This option is only available in SmartCtrl 2.0 Pro.

In addition to the exporting options, user must select the elements to be exported to PSIM:

- Uncheck the options "Power stage and sensor" and "Initial conditions" to export only the compensator.
- Check "Power stage and sensor" to export the power stage and the sensors of the converter.

- Check "Initial Conditions" to export to PSIM the initial value of the power-stage´s inductor current and capacitor voltage. This will reduce significantly the start-up transient[2].

In the tutorial´s example, the complete circuit and initial conditions will be exported to PSIM.

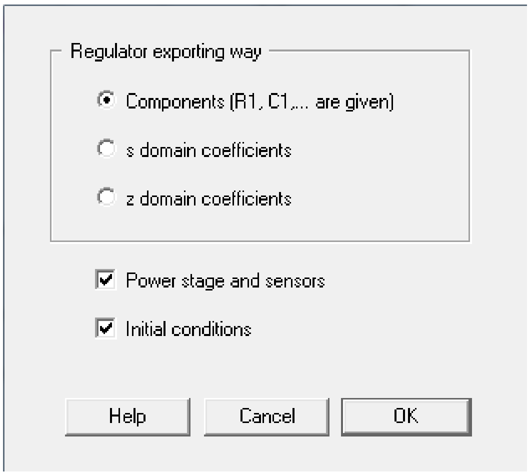


Figure 11

Once this last selection process has been finished, press OK button to automatically run the PSIM simulation[3].

In Fig. 13 the complete schematic is shown together with the content of the parameters file that SmartCtrl send to PSIM. It can be seen how the following groups of parameters are listed:

- Regulator parameters
- Sensor parameters
- Power stage parameter
- Modulator parameters
- Other parameters

[2] The steady state of a power converter depends on all the state-variable values. The state variables are not only those of the power stage (inductor current and capacitor voltage) but also the voltages of the compensator capacitors. If additional reduction of the start-up transient is desired, SmartCtrl provides the steady-state voltages of all the compensator capacitors for both singl and double loops. This voltages are shown in the "Input data" text panel.

[3] PSIM will automatically start simulation of the complete circuit in closed loop. For that aim the simulation parameters have been set to some safe but slow in some cases.

```
//SmartCtrl parameters


//Outer Regulator parameters
R1 = 367.925 Ohm
C1 = 23.5014n F
C3 = 346.708p F
R2 = 25.8572k Ohm
C2 = 9.42334n F
Vref = 2.5 V
Vp = 3 V
R11 = 10k Ohm


//Outer Sensor parameters
Ra = 2.86854k Ohm
Rb = 18.0411 Ohm


//Power Stage parameters
R = 80 Ohms
RC = 10m Ohms
C = 47u F
IC_C =
RL = 1n Ohms
L = 500u H
IC_L =
Vin = 311 V


//Modulator parameters
Vpp = 2 V
fsw = 100k Hz
Dramp = 800m
Vv = 1 V


//Other parameters
fdc = 3.46737k Hz
fp1 = 18.4063k Hz
fp2 = 18.4063k Hz
fz1 = 653.182 Hz
fz2 = 653.182 Hz
```

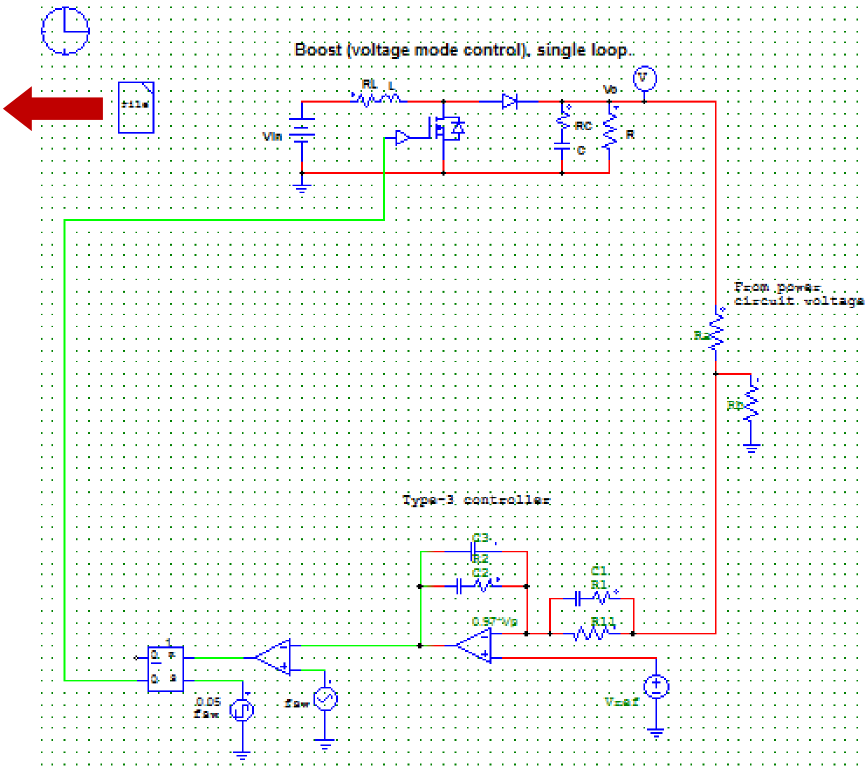


Figure 12

In Fig. 14 the simulation results are shown (output voltage, Vo, and inductor current, I(RL1).

Since the crossover-frequency (fc) is just 1 kHz and the phase margin (MF) has been set to 25º, slow response (large settling time) as well as underdamped response is obtained at the startup transient, even considering the initial conditions in of the power stage elements.

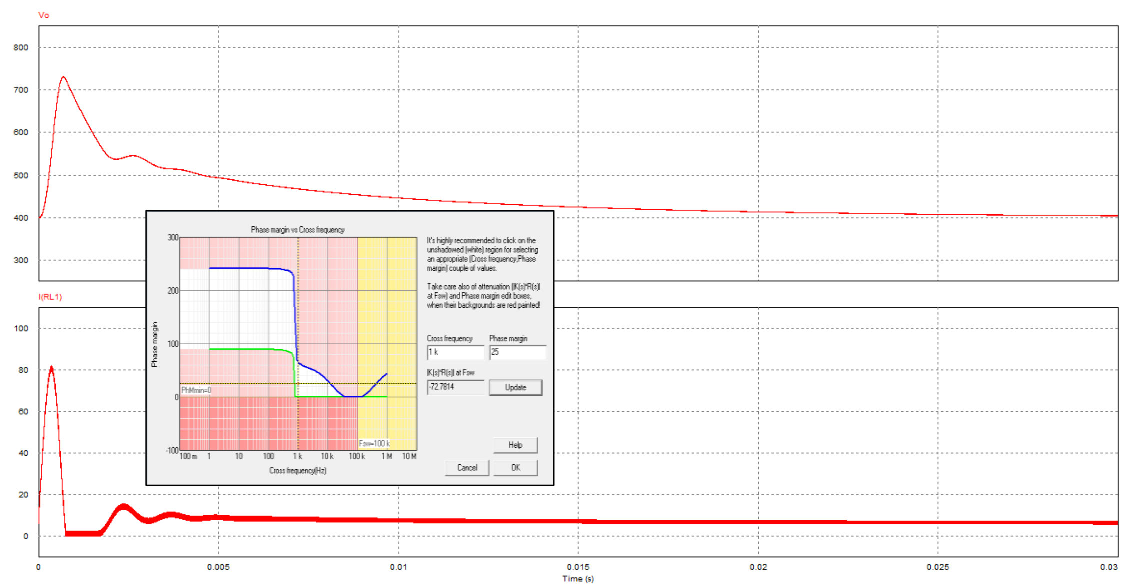


Figure 13

The complete set of results for the selected design (fc = 1kHz, MF =25º), provided by SmartCtrl is shown in Fig. 15. It can be seen how there are several crossing points of the open loop gain with the 0 dB axes. Therefore lo bandwidth and reduced MF is obtained. Definitely this is not a good design.

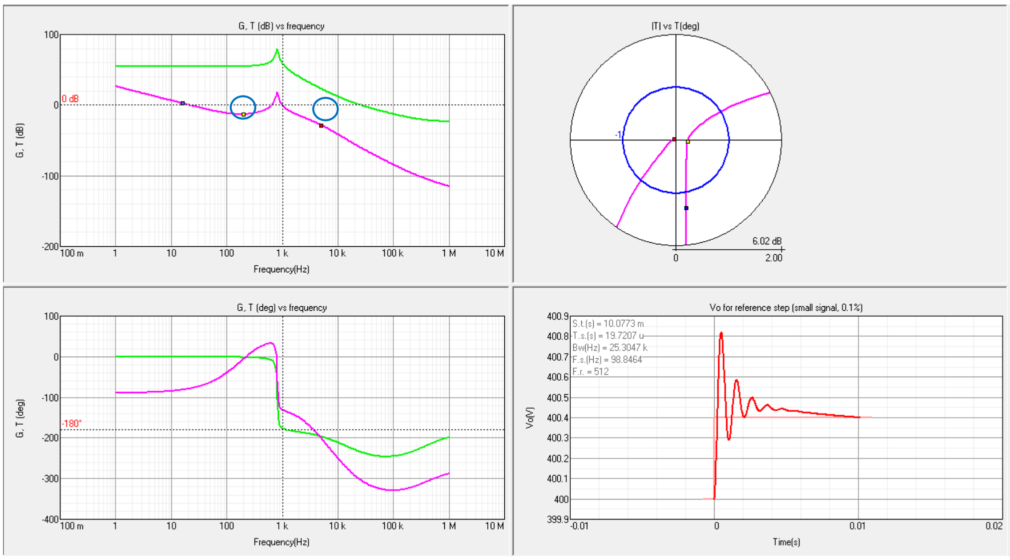


Figure 14

A redesign of the compensator could be necessary in this case. For that aim, user can go back to SmartCtrl and change accordingly the design and change the design since SmartCtrl.

2.6. Back to SmartCtrl

A new design can be selected by simply clicking the mouse on a different point on the Solutions Map. In this case a higher crossover frequency (fc=4 kHz) and a slightly higher phase margin (MF = 30º) have been set.

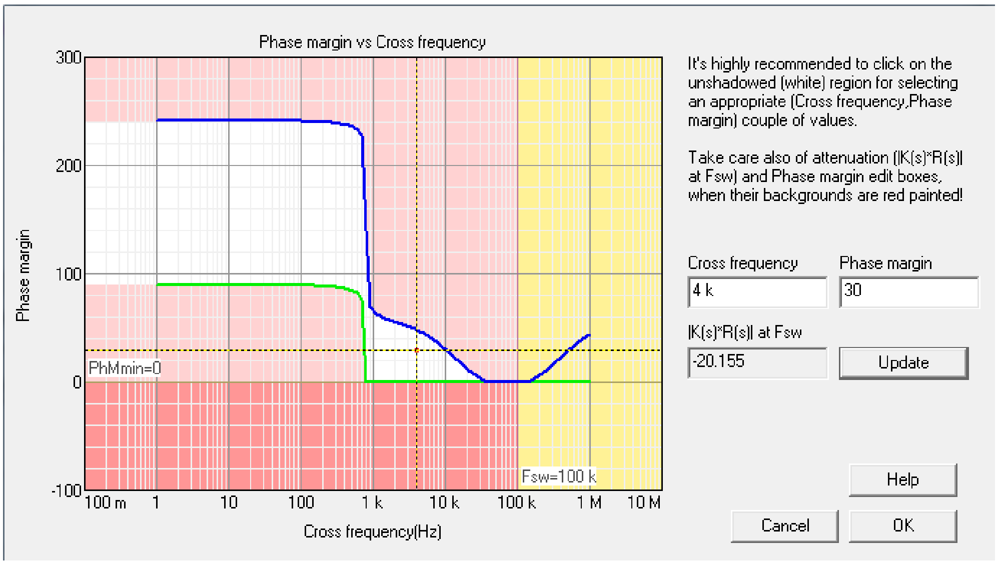


Figure 15

After changing the design point on the Solutions Map (Fig. 17), a unique crossing point is obtained at 4 kHz with higher gains at any frequency below fc. This will deal which faster small signal response as it can be seen in Fig. 18. Note that the SmartCtrl transient plot also shown the effect of the Right-Half Plane Zero (RHPZ) typical of Boost converter in continuous conduction mode operation.

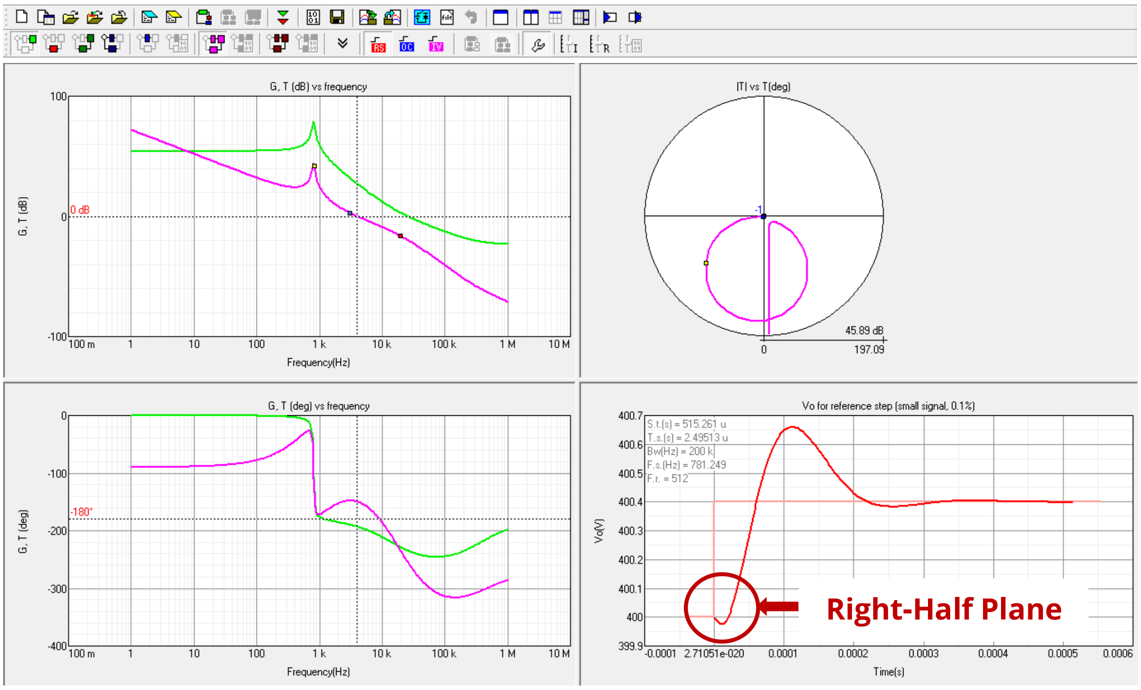


Figure 16

Once you have redefined the design, the new parameters of the compensator, etc. must be exported again to PSIM through the option "update parameter file", just by clicking on [icon] icon. Automatically PSIM runs a new simulation according to the new compensator parameters.

In Fig. 18 the simulation results, corresponding to the designs listed in Table 1, are compared.

Table 1

Design #1	**Design #2**
Cross frequency = 1kHz Phase Margin = 25º	Cross frequency = 4kHz Phase Margin = 30º

The start-up transient is a large signal transient because it implies a non-linear behavior of the converter (duty cycle will be saturated, etc.). However, there is a strong relationship between the small signal characteristics of the open loop (fc and MF) and the time that the converter spent to reach the steady state.

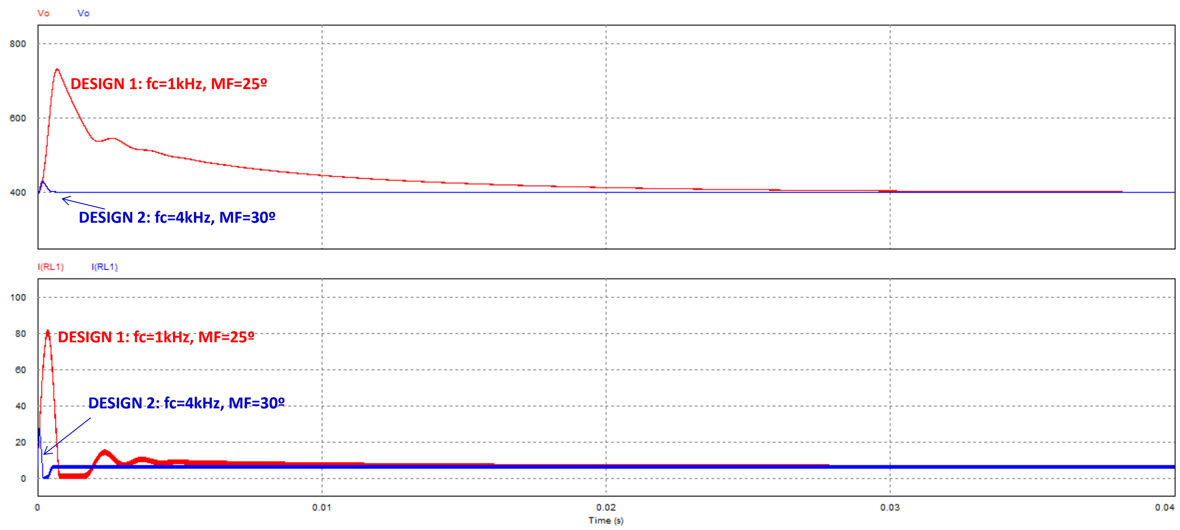


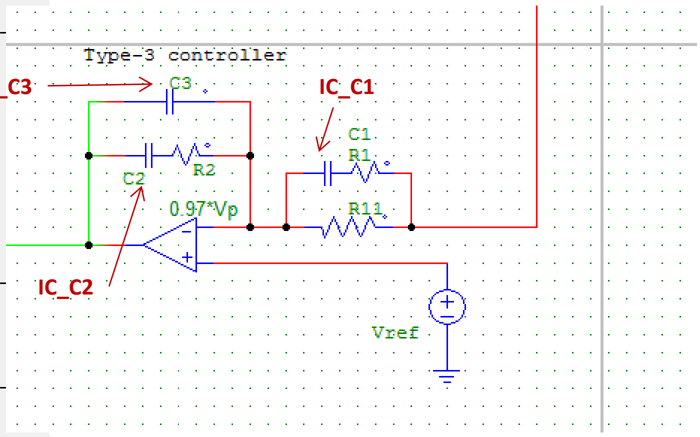
Figure 17

TRICK: Reducing start-up transient

Even in case a fast compensator would be selected, the start-up transient can be reduced if the compensator capacitors are initialized by setting their initial conditions in the same way of the initial conditions of the power stage components (inductor and output capacitor).

The value of the initial conditions of these capacitors is provided in the INPUT DATA text window (see Fig. 20).

```
INPUT DATA
Single loop

    ---------------------------------------
    Frequency range (Hz) : (1, 999 k)
    Cross frequency (Hz) = 3.46737 k
    Phase margin      (°) = 36

    Plant
    ---------------------------------------
        Boost (voltage mode controlled)
        R (Ohms)   = 80
        L     (H)  = 500 u
        RL(Ohms)   = 1 n
        C     (F)  = 47 u
        RC(Ohms)   = 10 m
        Vin   (V)  = 311
        Vo    (V)  = 400
        Fsw  (Hz)  = 100 k

        Steady-state dc operating point
        -----------------------------------
        Mode       = Continuous
        Duty cycle= 0.2225
        Vcomp(V)   = 1.83438
        IL     (A) = 6.43087
        ILmax(A)   = 7.12284
        ILmin(A)   = 5.73889
        Io     (A) = 5
        Vo     (V) = 400

    Sensor
    ---------------------------------------
        Voltage divider
        Vref/Vo   = 0.00625

    Regulator
    ---------------------------------------
        Type 3
        Gmod       = 0.4
        R11(Ohms)  = 10000
        Vp(V)      = 3
        Vv(V)      = 1
        tr(sec)    = 8e-006
        Vref(V)    = 2.5

        Steady-state dc operating point
        -----------------------------------
        IC_C3(V)   = 665.625m
        IC_C2(V)   = 665.625m
        IC_C1(V)   = 0
```



Initial conditions for compensator capacitors

Figure 18

In Fig. 20 the simulation results (for the Design #2: fc = 4kHz, MF = 30º), with and without taking into account the initial conditions IC_C1, IC_C2 and IC_C3 are shown. It can be observed how the transient is drastically reduced using the initial conditions.

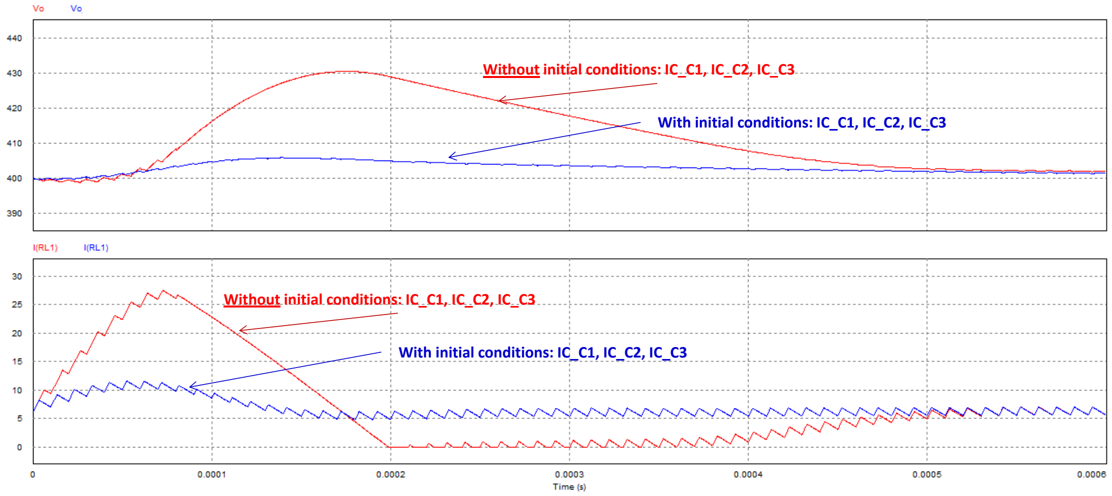

Vo
Vo
Without initial conditions: IC_C1, IC_C2, IC_C3
With initial conditions: IC_C1, IC_C2, IC_C3
I(RL1)
I(RL1)
Without initial conditions: IC_C1, IC_C2, IC_C3
With initial conditions: IC_C1, IC_C2, IC_C3
Time (s)

Figure 19