Double Loop Control Design

Tutorial –December 2025-

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Power Smart Control SL

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1. Introduction

SmartCtrl is a general-purpose compensator design software which is specifically conceived for power electronics applications.

This tutorial is intended to guide you, step by step, to design the controller (or regulator) of a dc/dc converter with double control loop with the help of SmartCtrl software.

The converter in this example is a buck converter with inner current loop and outer voltage loop, as shown in**Error! Reference source not found.**.

The objective is to design the current and voltage regulators, as highlighted in the red boxes.

Specifications:

1. Input voltage: 30 V
2. Output voltage: 15 V
3. Reference voltage: 2.5 V
4. Output inductance: 100 uH
5. Output capacitance: 470 uF
6. Switching frequency: 100 kHz

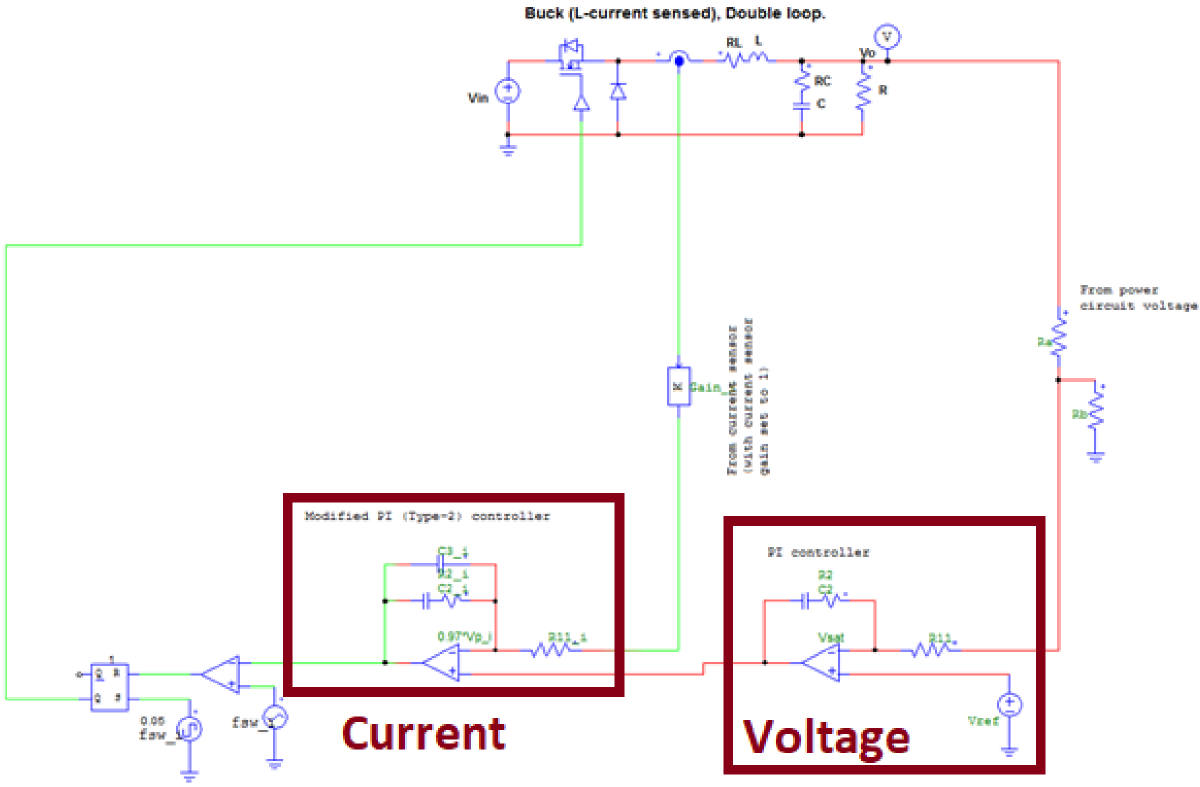
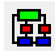


Figure 1: Required system

1. Define the converter and control loop structure

   To begin the design process in this example, in SmartCtrl, click on the icon . Or from the **Design** menu, choose **Predefined topologies** -> **DC/DC converters** -> **Average Current Control**. See Figure 2.

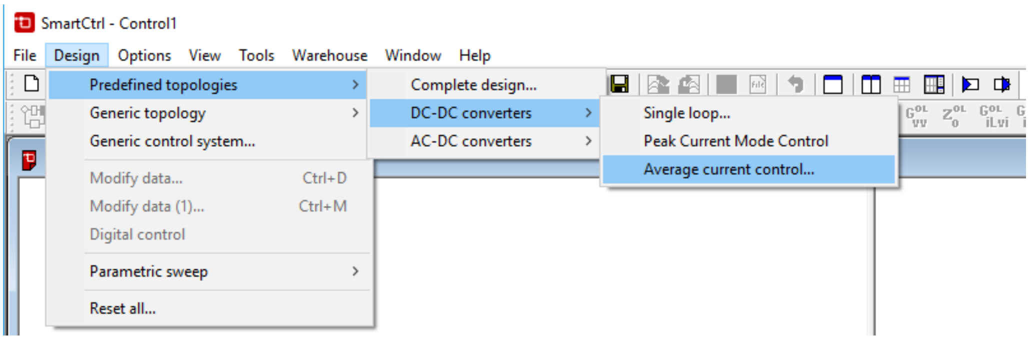


Figure 2: Access the wizard of a double loop design

From the dialog window, select the **Plant** drop-down menu and choose **Buck (LCS-VMC)**, as shown in Figure 3.

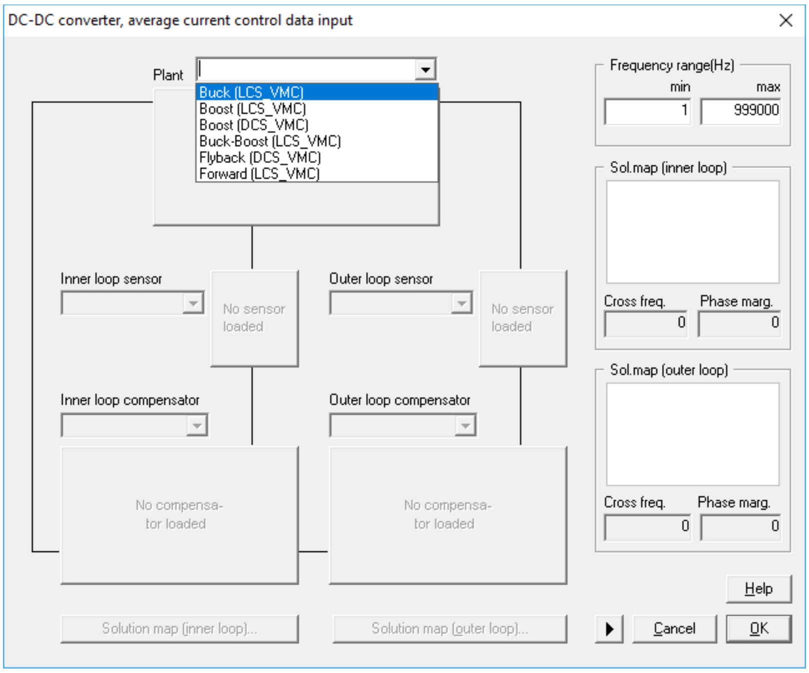


Figure 3: Selecting the plant topology

Similar to the single loop design, the double loop design must be done sequentially, and SmartCtrl will guide you through the process.

Note that in all the available plants, the outer loop is voltage mode control (VMC), while the inner loop is current control (LCS). Depending on the selected plant, the controlled current can be from either the output inductor (LCS) or from the diode (DCS). In this example, the current from the output inductor is selected.

2. Inner Loop Design

1. Define the converter

   Complete the parameters of the plant, and click OK to continue. See figure Figure 4.

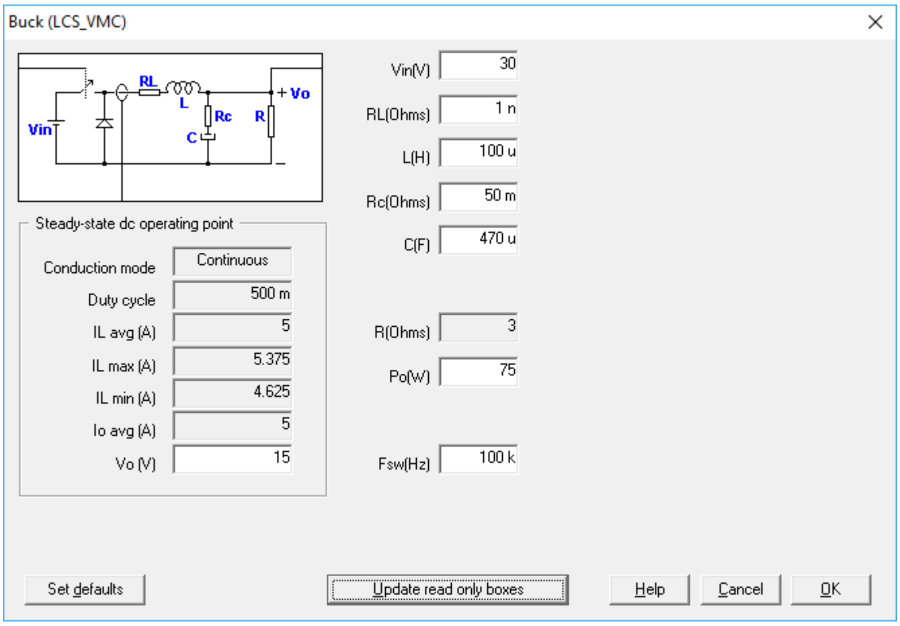


Figure 4: Parameters of the plant

2. Select the current sensor

   Once the plant is selected, depending on the variable being controlled, SmartCtrl will display the appropriate sensor selection. See Figure 5.

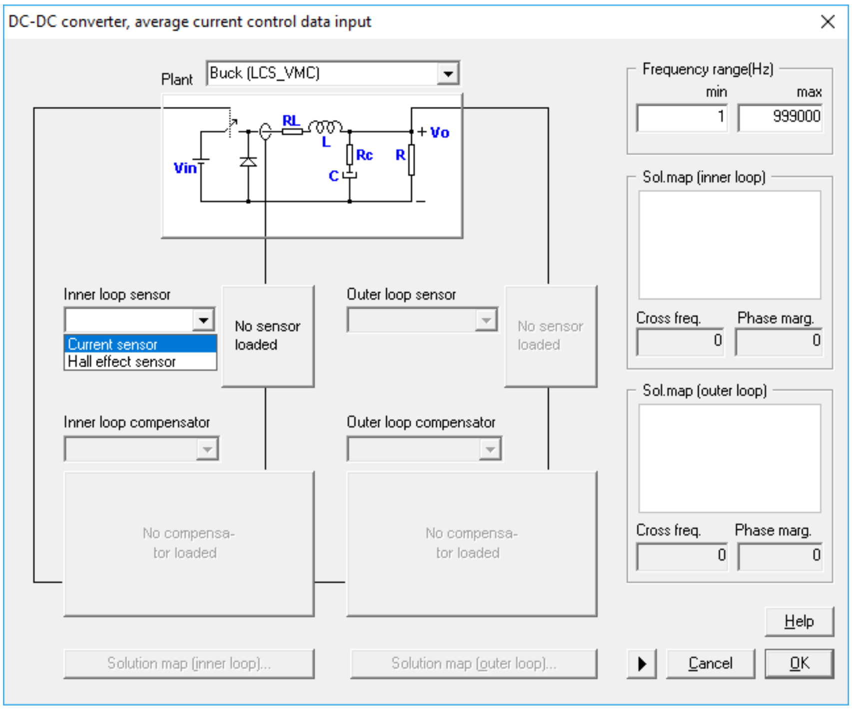


Figure 5: Choose a current sensor

In this example, select **Current Sensor**, and specify the sensor gain, as shown in Figure 6. Click OK to continue.

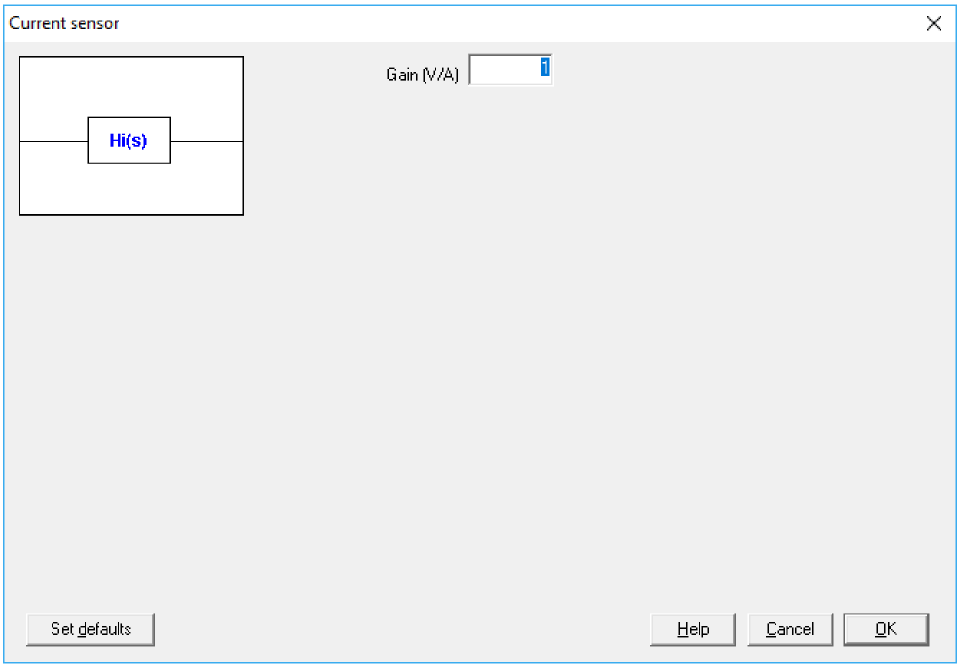


Figure 6: Current sensor definition

3. Select the current regulator

   Select the current regulator type from the inner loop regulator drop-down menu as shown below.

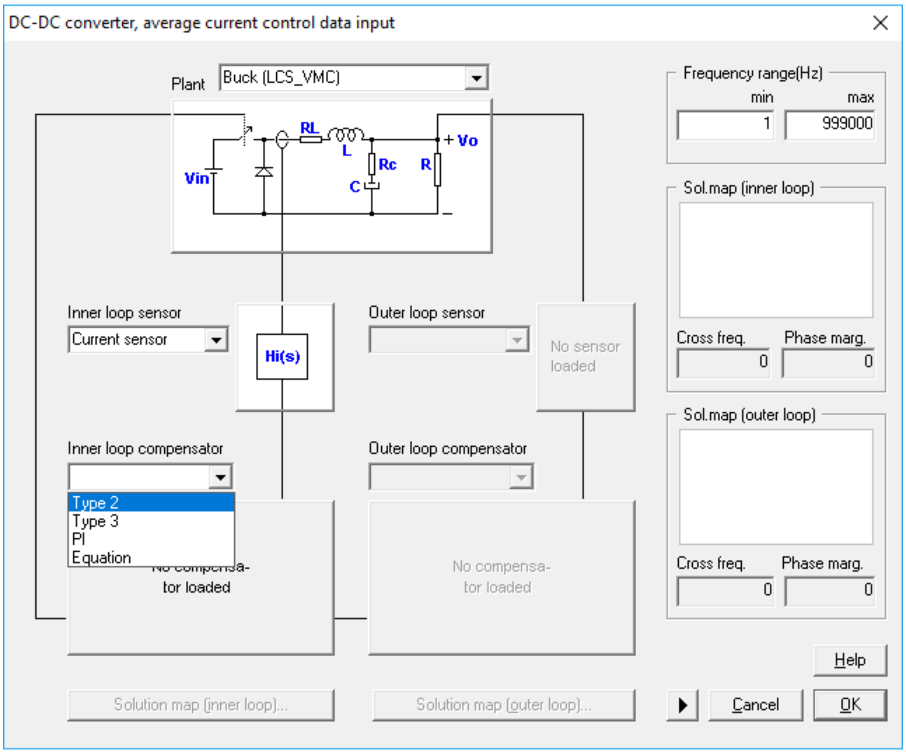


Figure 7: Selecting a Type 2 controller

The type of regulator depends on the plant controlled. In this example, the proper choice is a Type 2 regulator. Select the Type 2 regulator see Figure 7, and enter the parameters as shown in Figure 8.

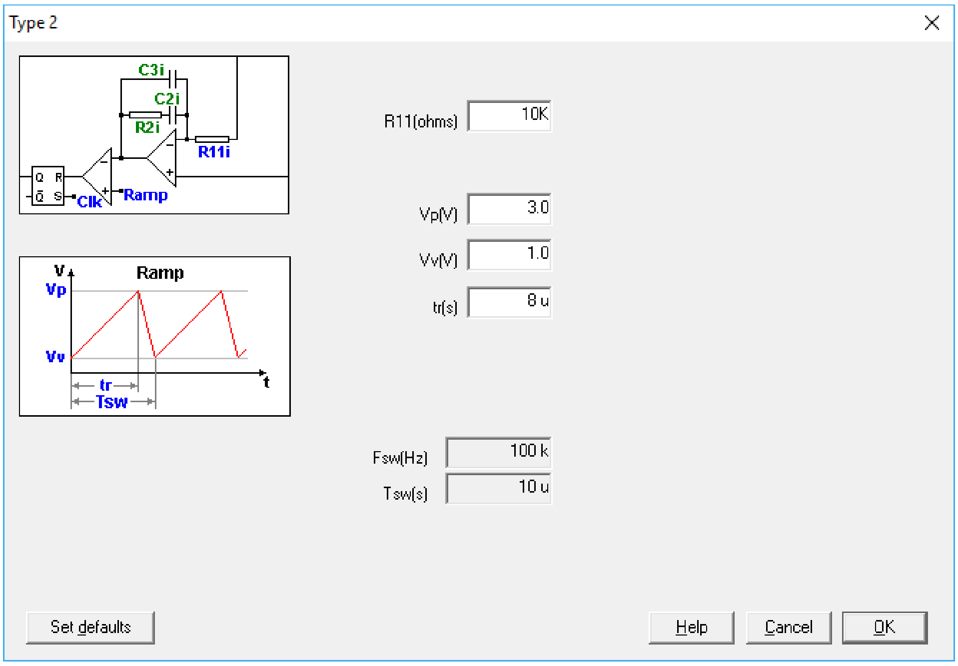


Figure 8: Type 2 inner current loop configuration

4. Select the crossover frequency and the phase margin of the inner loop

SmartCtrl provides a guideline and an easy way of selecting the crossover frequency and the phase margin through the ***Solution Map***. Click on the **Set** button, and the Solution Map will appear as shown in Figure 9.

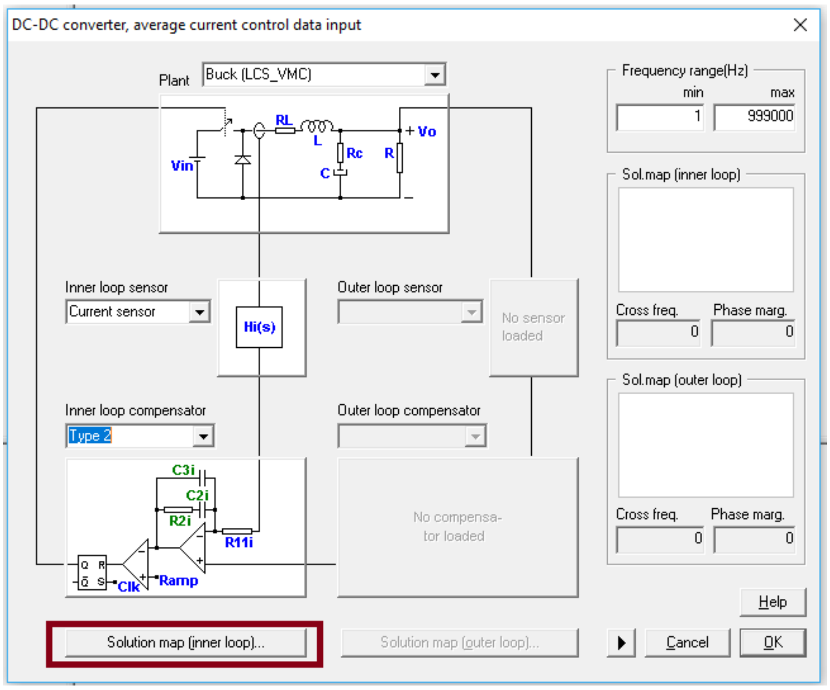


Figure 9: Access to the inner loop solution map

Based on the converter parameters and the type of regulator selected, SmartCtrl will generate a safe design area shown as a white area. Any selection of the crossover frequency and the phase margin that is within this white area will lead to a stable solution.

Note that the x-axis of the Solution Map is the crossover frequency and the y-axis is the phase margin. See Figure 10.

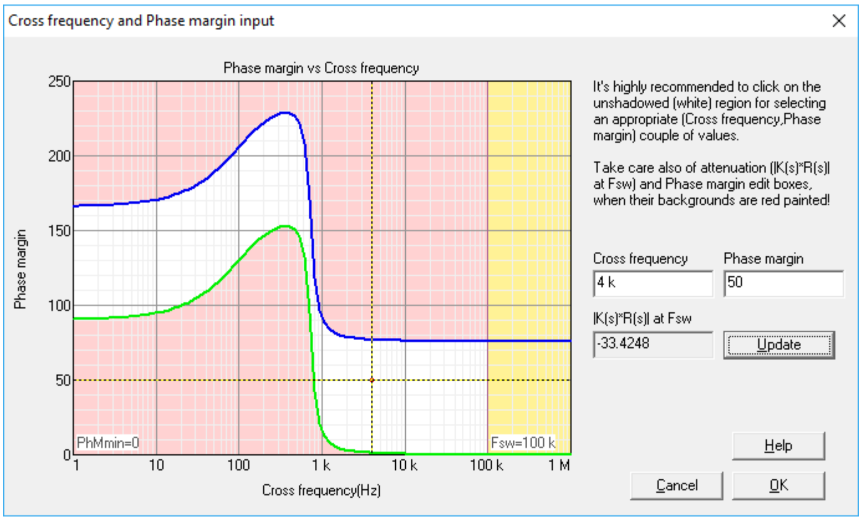


Figure 10: solution map for the inner loop

The desired crossover frequency and phase margin can be selected either by entering the corresponding values in the edit boxes and clicking the **Update** button, or by left-clicking directly on the Solution Map. The selected design is then shown as a red point on the Solution Map.

Given a particular design, the attenuation given by the sensor and the regulator at the switching frequency is calculated and displayed in the edit box **|K(s)*R(s)| at Fsw**.

Note that if there is not enough attenuation at the switching frequency, the system will likely oscillate in the high frequency region.

Also, if a design is not proper, the edit boxes will be change to the red color, warning users to re-select the design.

To select the crossover frequency and the phase margin the following rule of thumb can be followed:

a) Choose a crossover frequency of 1/10 of the switching frequency.
b) Choose a phase margin of 45 to 60 deg.

In this design the crossover frequency has been set at 4 kHz and, the phase margin, at 50 degrees

As it can be seen in Figure 10, the design is intended to work in the white area.

Click OK to continue.

The solutions map will be shown on the right side of the input data window, as shown in Figure 11.

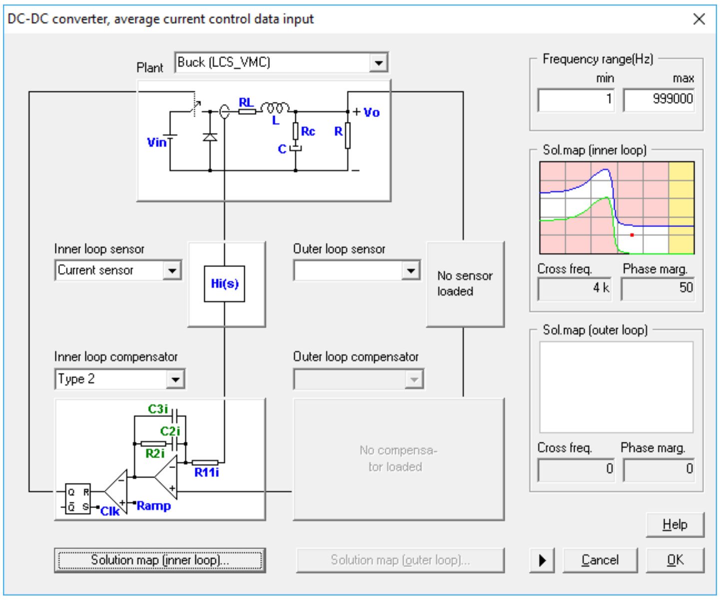


Figure 11: inner current loop fully defined

When selected the point in the solution map, SmartCtrl will automatically made all the inner loop calculations. The result of these calculations can be seen in Figure 12.

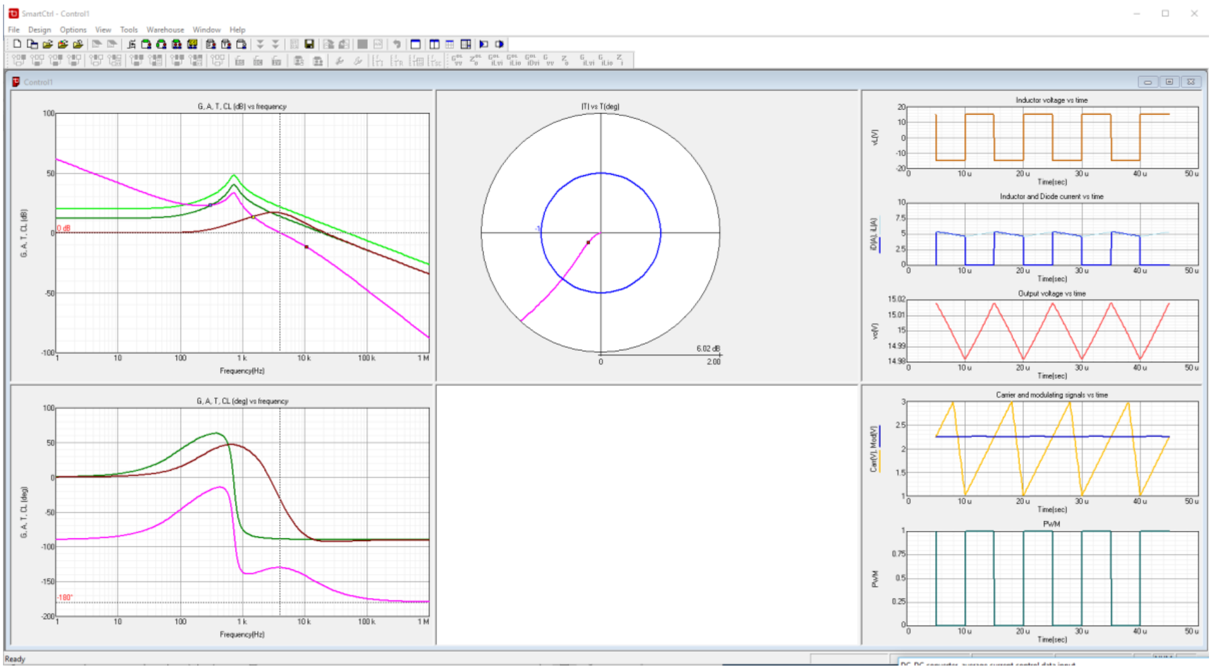


Figure 12: SmartCtrl inner loop information

Click OK to complete the design of the inner current loop. One can move on to the outer voltage loop design.

3. Outer Loop Design

The procedure of designing the outer loop is similar to that of the inner loop, as described below.

1. Select the voltage sensor

Choose the voltage sensor type from the outer loop sensor drop-down menu. In this example, the Voltage divider type is selected, as shown in Figure 13.

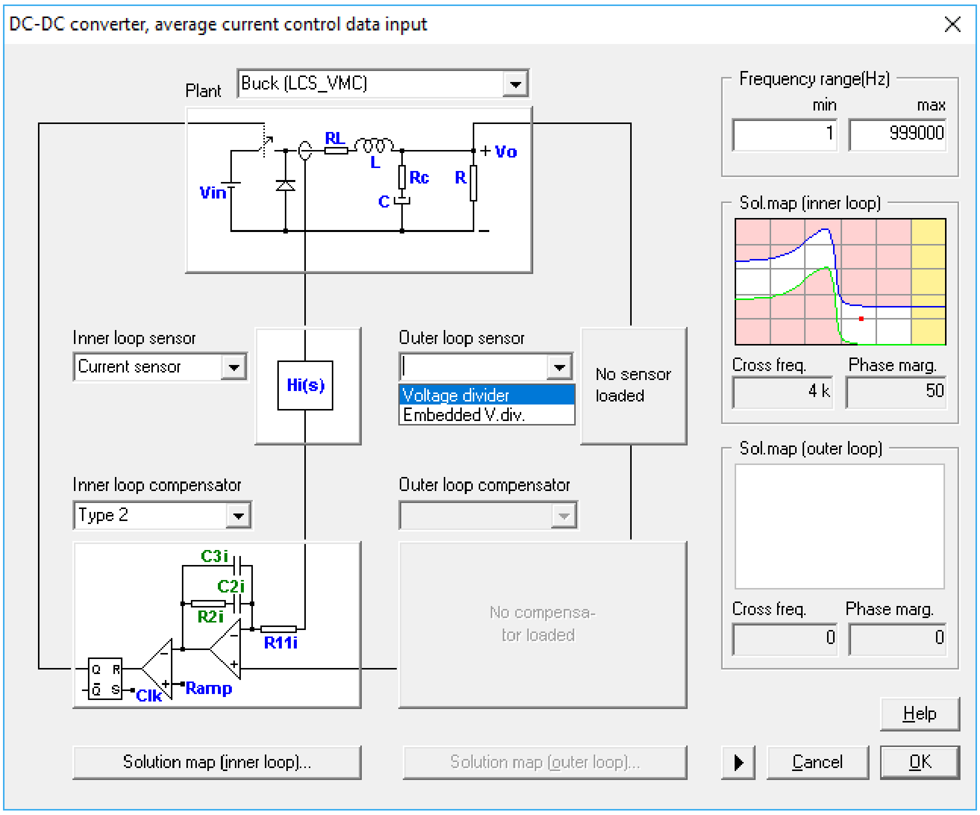


Figure 13: Outer loop sensor list

For a voltage divider, one must enter the reference voltage. SmartCtrl will automatically calculate the sensor gain. In this example, the reference voltage is set at 2.5V. The sensor input data window is shown in Figure 14.

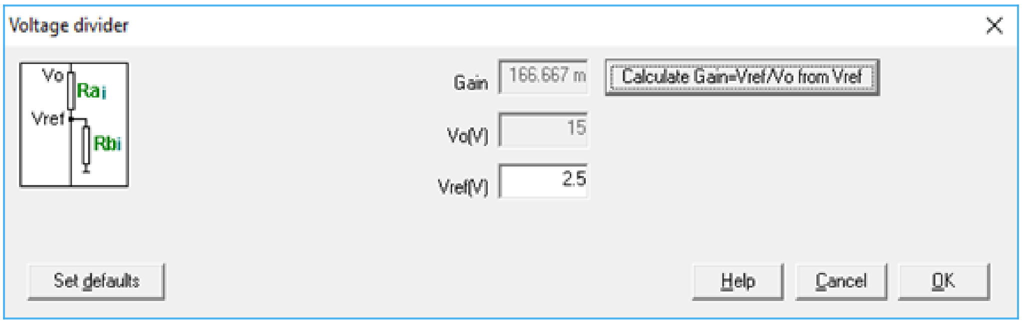


Figure 14: Outer sensor definition

Note that the rest of the design will be using this gain, and the resistor values to implement the voltage divider will be provided by the program together with the regulator component values.

2. Select the outer loop regulator

Select the regulator type from the outer loop regulator drop-down menu as shown in Figure 15. In this example, a PI regulator will be selected and parametrized according to Figure 16.

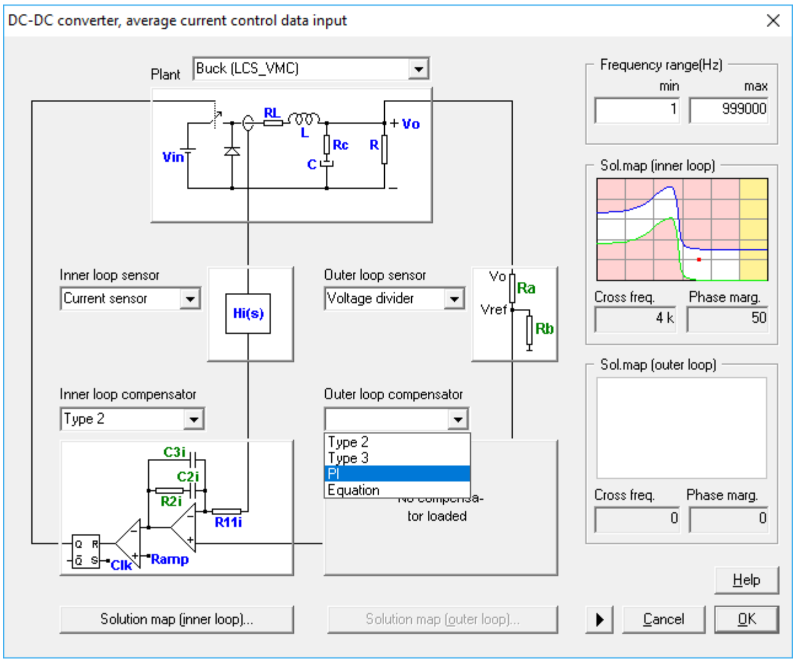


Figure 15: list of available outer loop compensators

Complete the parameters in the dialog window as shown in Figure 16:

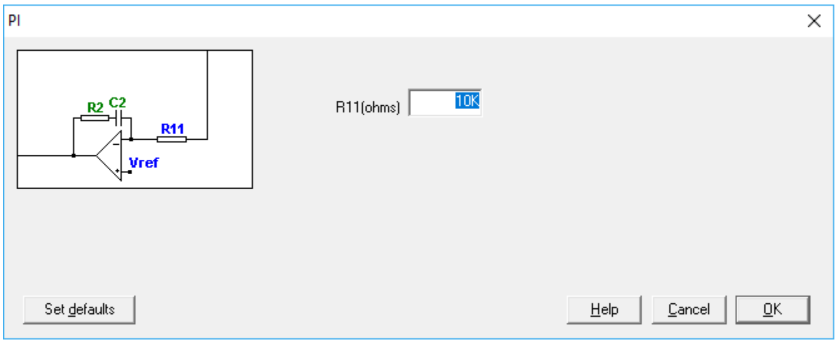


Figure 16: outer compensator parametrization

Notice that, as the outer loop compensator has no modulator associated, parameters like Vp, Vv or tr are not required.

3. Select the crossover frequency and the phase margin of the outer loop. Again, SmartCtrl provides a Solution Map to help users select the crossover frequency and the phase margin for the outer loop.

   To make the selection, just click on the **Solution map (outer loop)** button. See Figure 17. Then select a point within the white area with a left mouse click. Alternatively, one can enter the crossover frequency and phase margin values in the edit boxes.

   In this example, the crossover frequency is selected at 750 Hz and the phase margin is selected at 75 deg. See Figure 18.

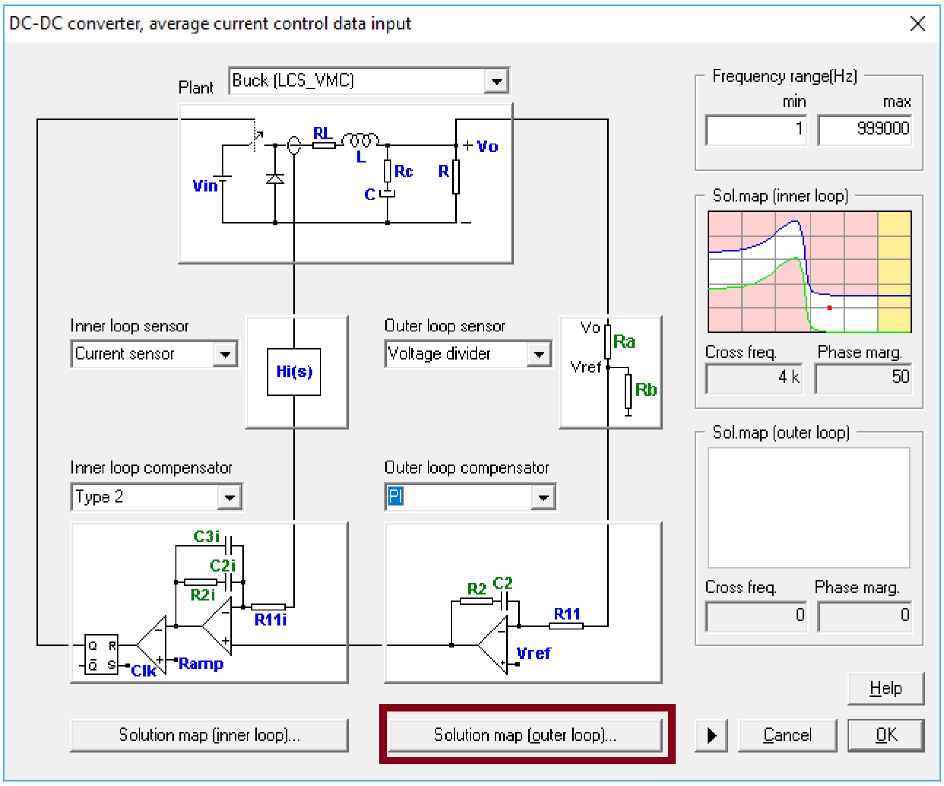


Figure 17: Select the outer loop solution map

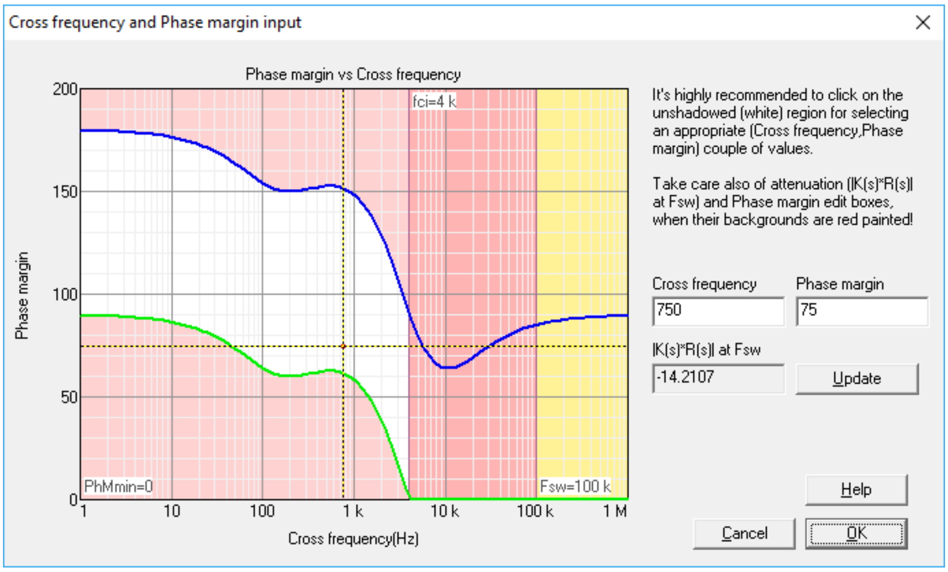


Figure 18: outer loop solution map

4. Click OK to confirm the design and Figure 19 will be shown.

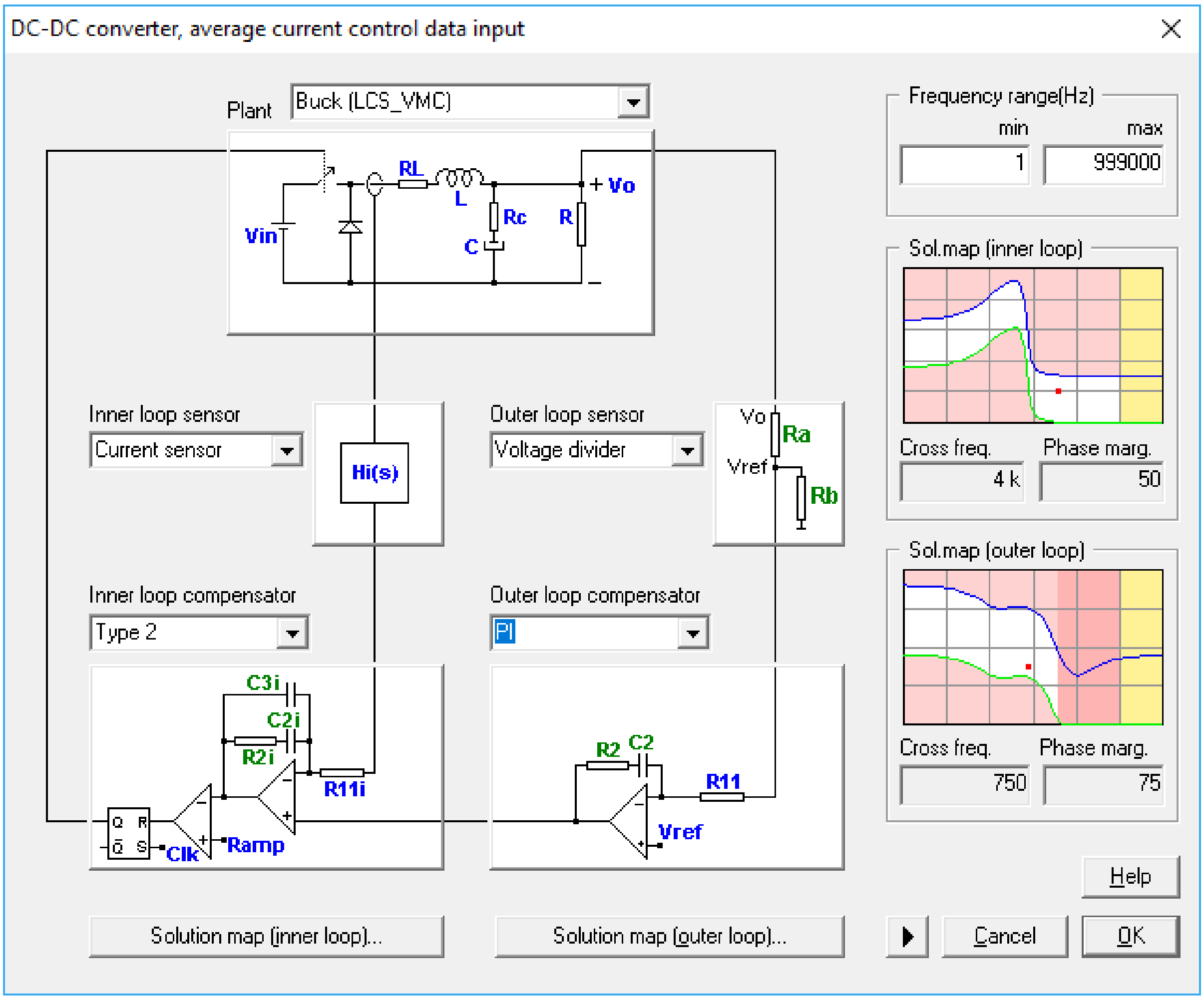


Figure 19:Double loop buck controller fully defined

5. Click OK again and the program will automatically show the performance of the system in terms of the frequency response, polar plot, transient response, etc.

   By default, SmartCtrl will show the outer loop results. To change to inner loop results just click the button inner/outer loop in the top bar. See Figure 20.

   To change the solution map from outer loop to inner loop, just click on the option below it. See Figure 20.

   Additionally, by selecting **Design** -> **Parameter sweep** -> **Input parameters** or **Compensator components** in SmartCtrl, sensitivity analysis can be performed. See Figure 21 and Figure 22.

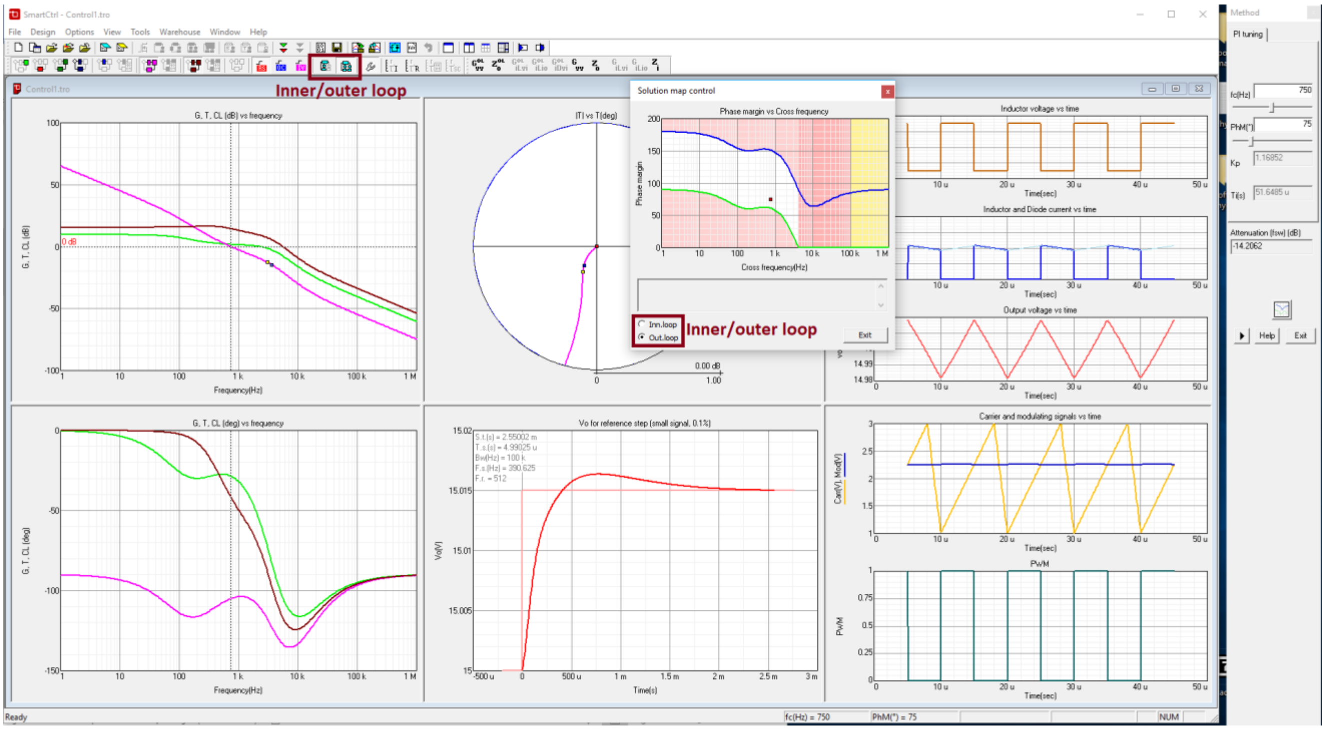


Figure 20: SmartCtrl double loop solution window

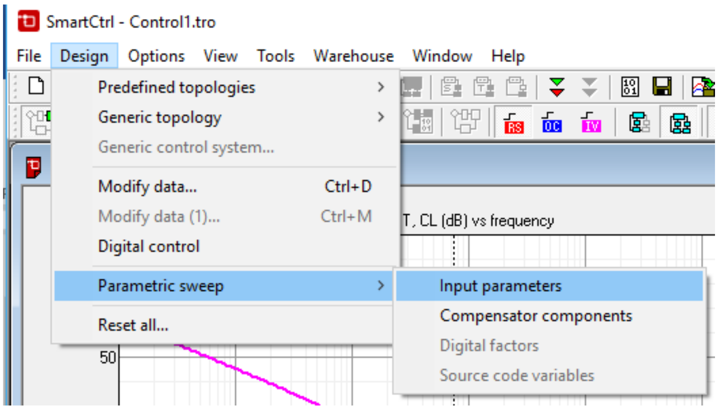


Figure 21: Accessing the parameter sweep capability

Parameter sweep capability is quite interesting as it allows to check how a modification in each parameters affect the loop result. Inner and outer loop parameters can be sweep in a visual easy way. See Figure 22. It needs the definition of the upper and lower boundaries.

SmartCtrl provides the regulator components values needed to implement the regulator, as well as the voltage divider resistors. Since there are two control loops, users must select which one to display.

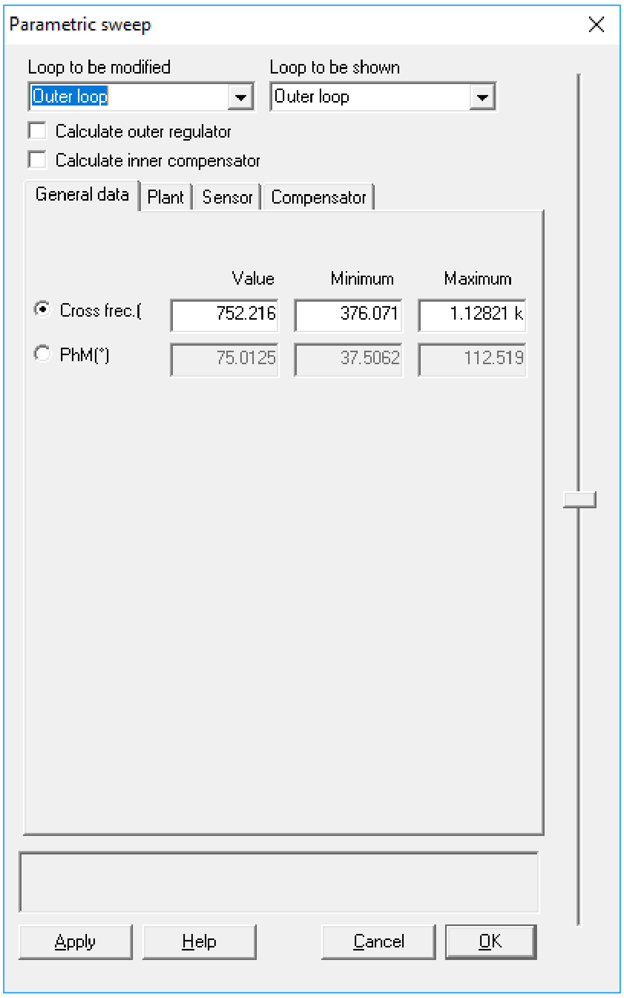


Figure 22: Outer loop general data parameters sweep

4. Validation

1. Validate the regulator design

   After the design is completed, SmartCtrl provides everything required to perform a simulation in PSIM so the design can be validated. To do this, click on the button highlighted in Figure 23.

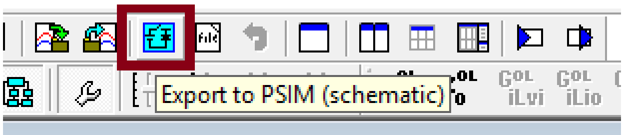


Figure 23: Exporting to Psim SmartCtrl button.

Window of Figure 24 gives further exporting possibilities, in this tutorial, no changes have been done in this window.

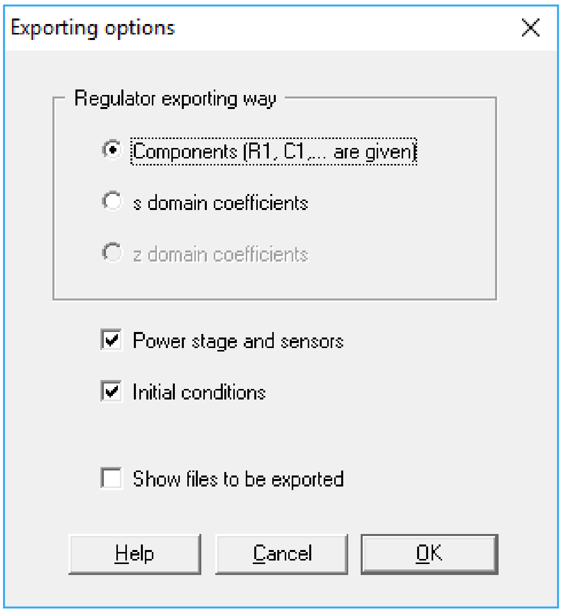


Figure 24: Exporting to Psim options

The system of Figure 25 is the one which is created by SmartCtrl in Psim, if simulation is launched, the results of Figure 26 are obtained.

This results are, by default, the current thought the inductor and the output voltage as those are the controlled magnitudes.

It can be seen how the output voltage is 15V, the very same that was specified in SmartCtrl at the beginning of the tutorial.

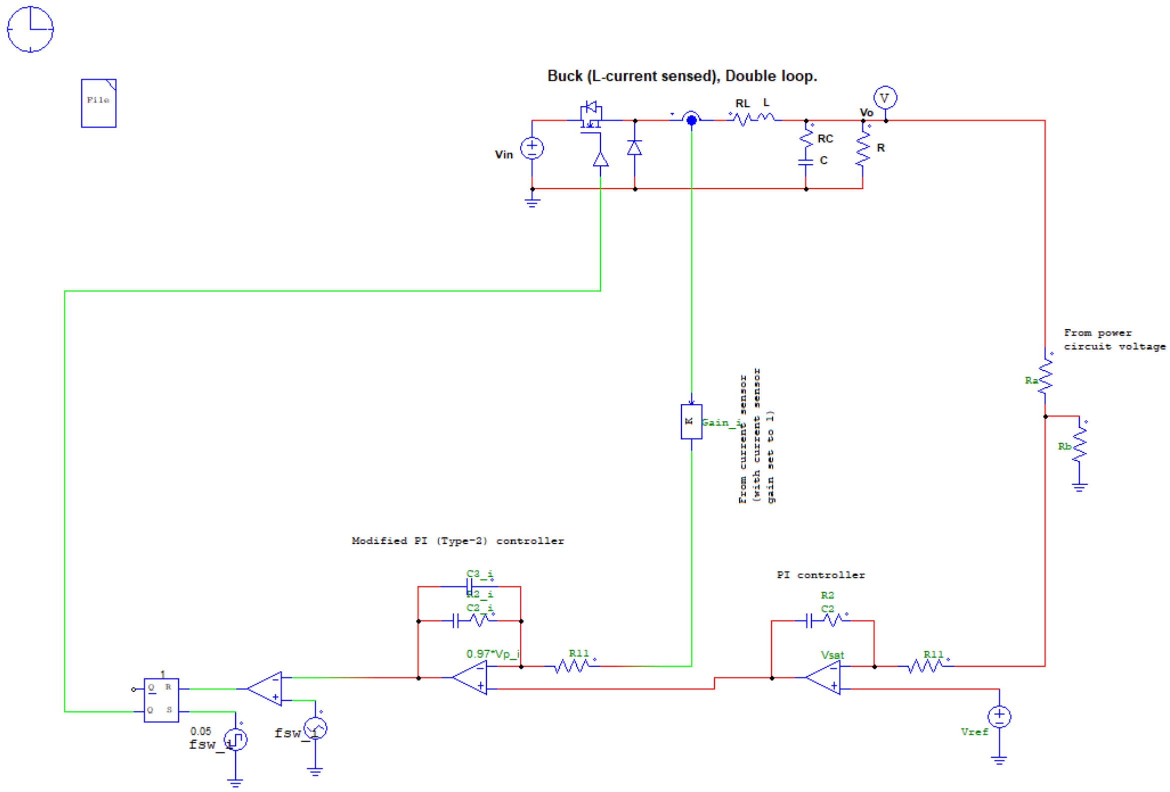


Figure 25: Psim schematic generated by SmartCtrl

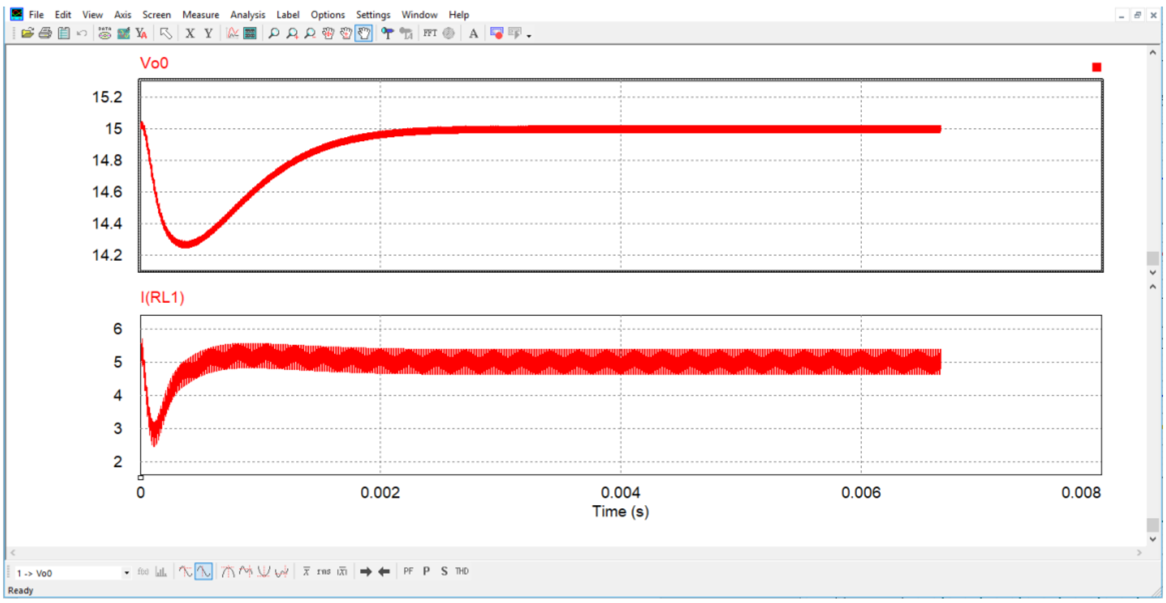


Figure 26: Result of Psim simulation

2. This result present a time domain check, but this check can be done in terms of a frequency analysis. To do that, only minor modifications of the schematics are required. See Figure 26.

In figure 26 the inner current loop has been measured whose result can be seen in Figure 27. **Click file** -> **save as** -> T2_Psim_Double_control_loop_design**.txt**

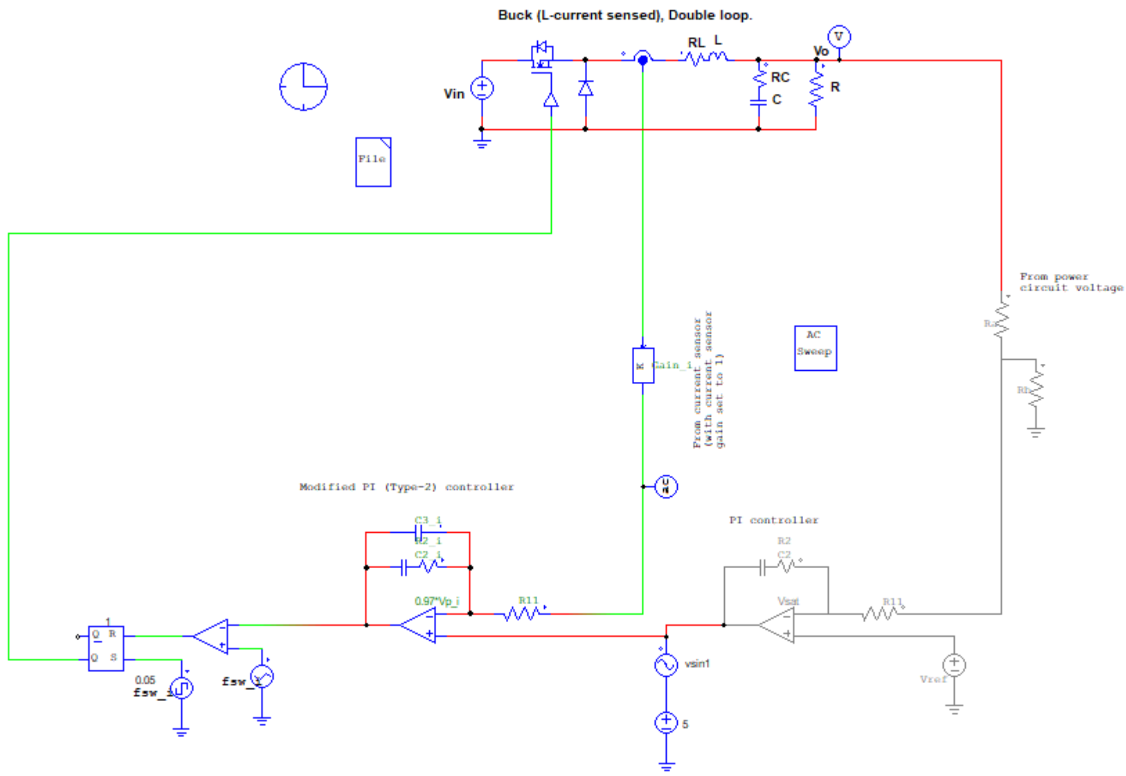


Figure 26: Ac seep analysis schematic

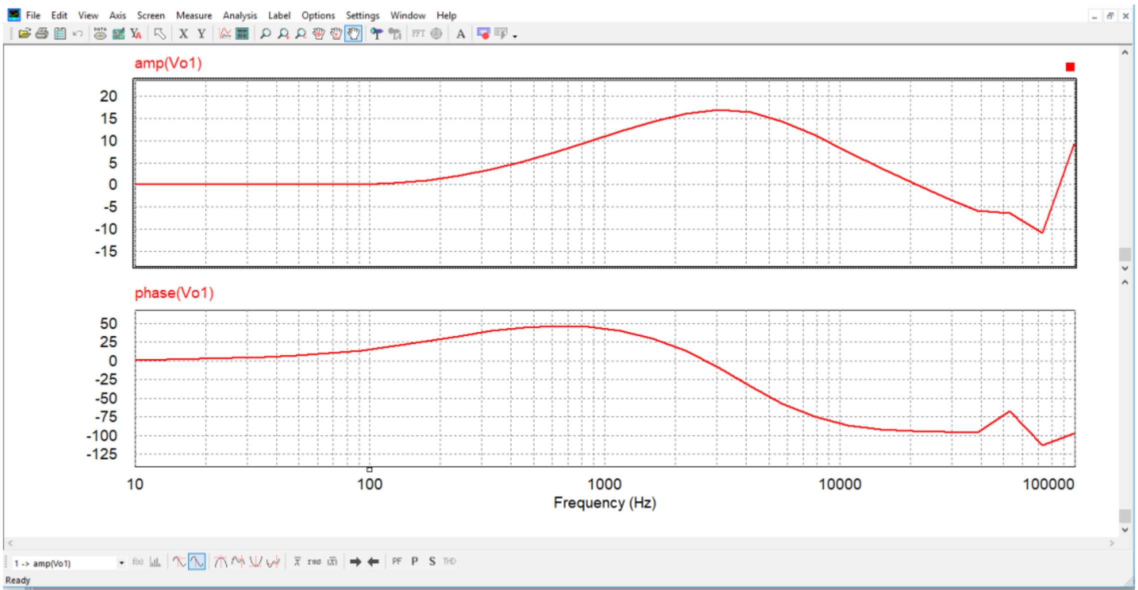


Figure 27: inner current loop measured in Psim (inner current close loop transfer function)

The transfer function seen in Psim is quite similar to the one calculated by SmartCtrl. But can both traces be plotted together? Yes!

3. To do this, configure SmartCtrl as in Figure 28 so the closed loop transfer function of the inner loop is shown.

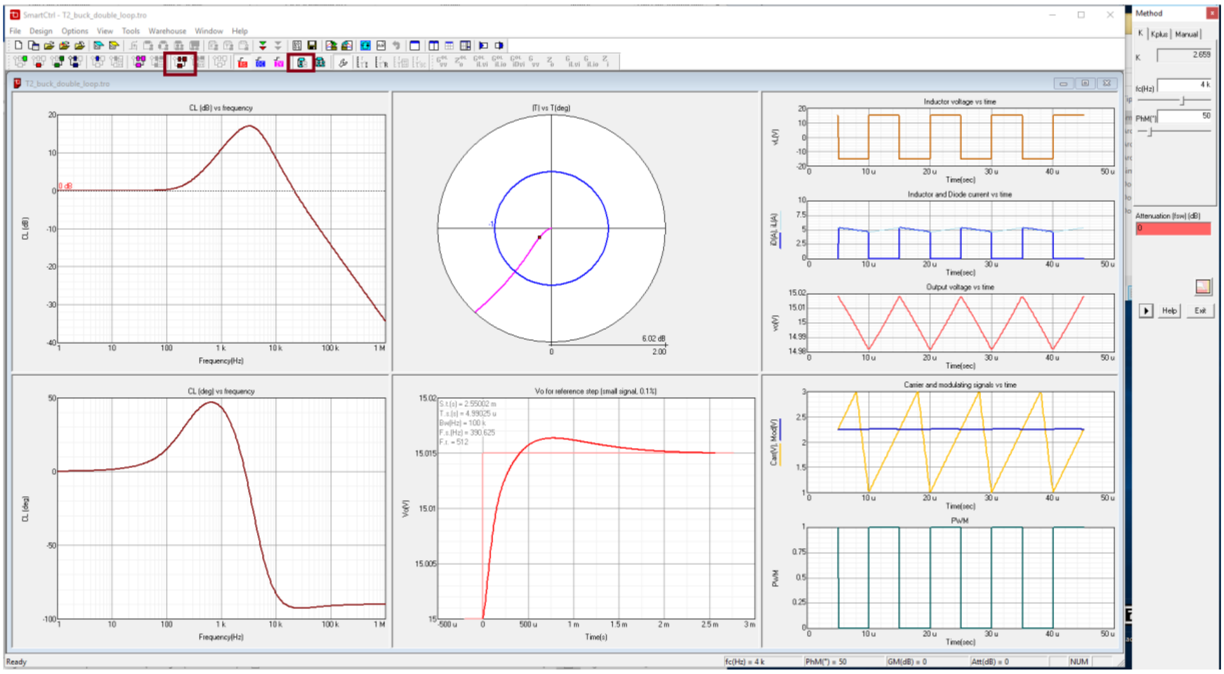


Figure 28: SmartCtrl with inner current close loop transfer function plotted

4. Use the menu **File** -> **Transfer function** -> **inner loop** -> **CL(f) Reference to output**. See Figure 29. And configure the outputs according Figure 30.

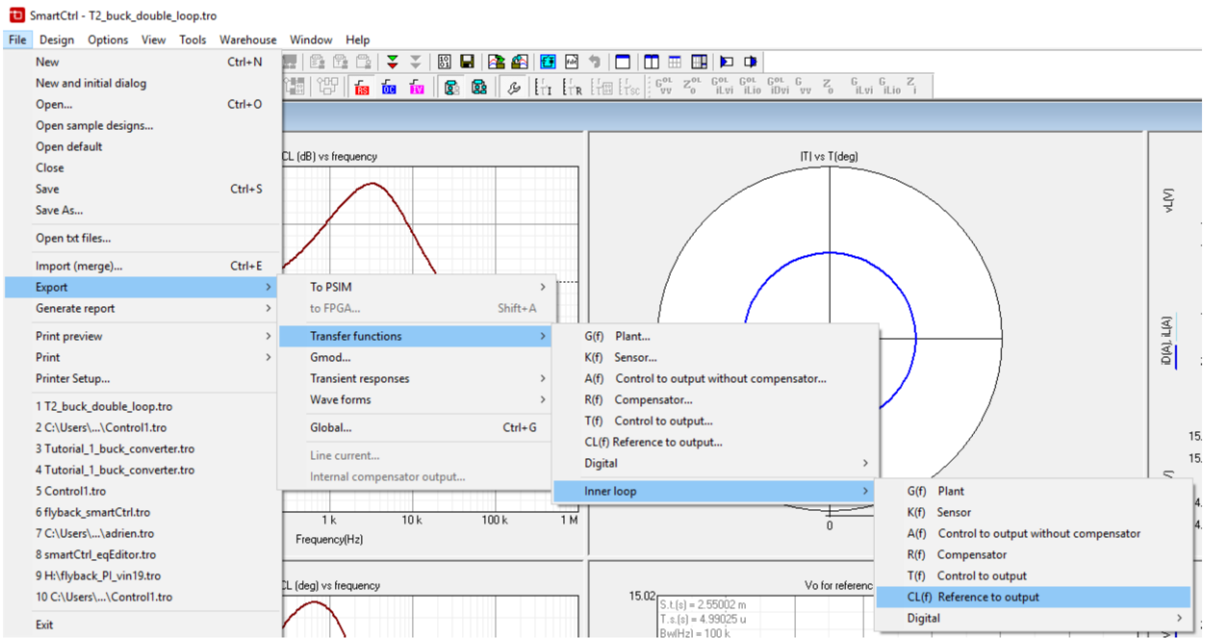


Figure 29: Exporting inner current close loop transfer function plotted

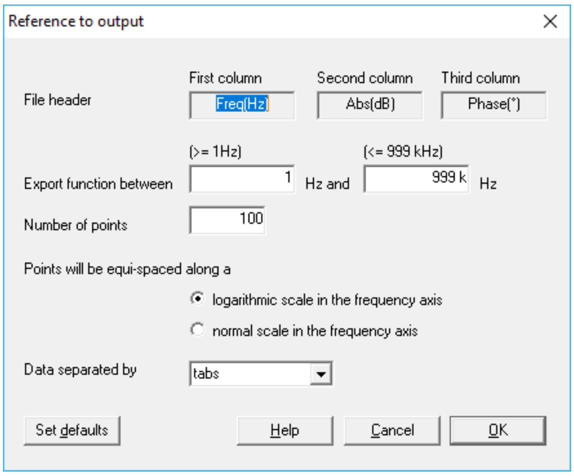


Figure 30: Transfer function exporting options

5. Close SmartCtrl project and open a new SmartCtrl design selecting s-domain model editor option in voltage mode. See Figure 31 and Figure 32.

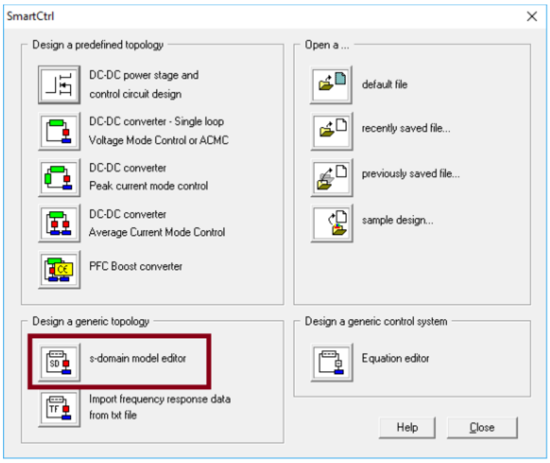


Figure 31: s-domain model editor

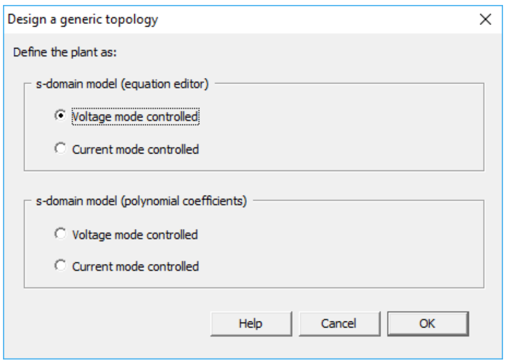


Figure 32: s-domain model editor options

6. The window of Figure 33 will appear. Use the Add external function button to add the Psim frequency response (file T2_Psim_Double_control_loop_design.txt) and the exported SmartCtrl.

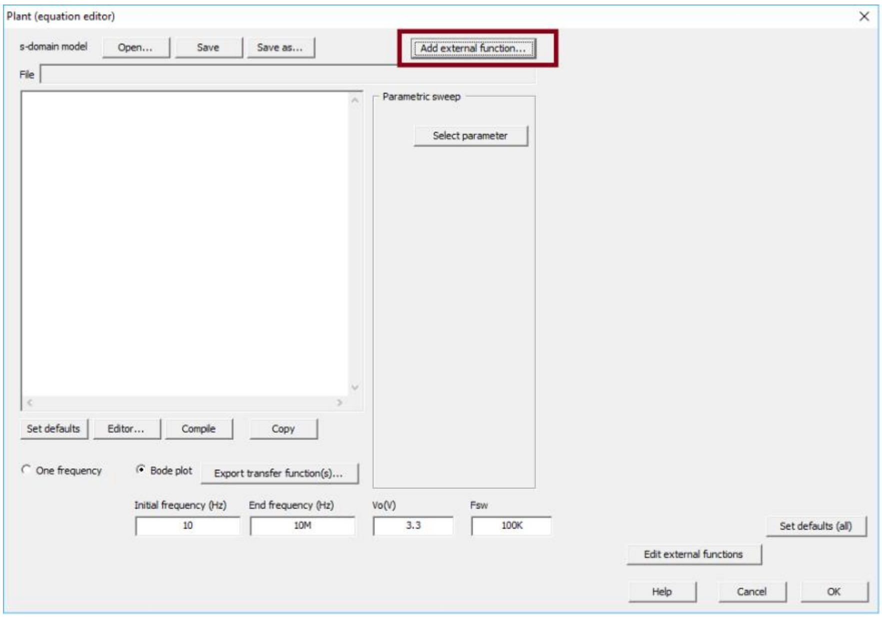


Figure 33: Adding external transfer functions in SmartCtrl

7. When done both transfer functions (the calculated by SmartCtrl [red] and the simulated in Psim [blue]) can be compared. See Figure 34.

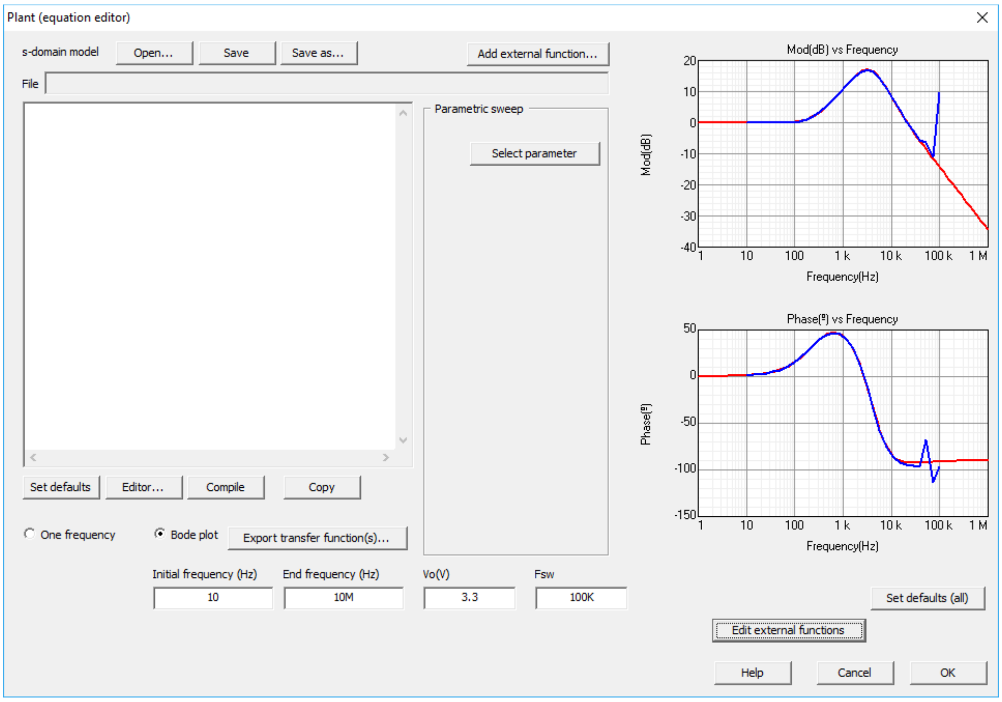


Figure 34: Transfer function comparison

As it can be seen in Figure 34, SmartCtrl solution is completely correct and accurate.