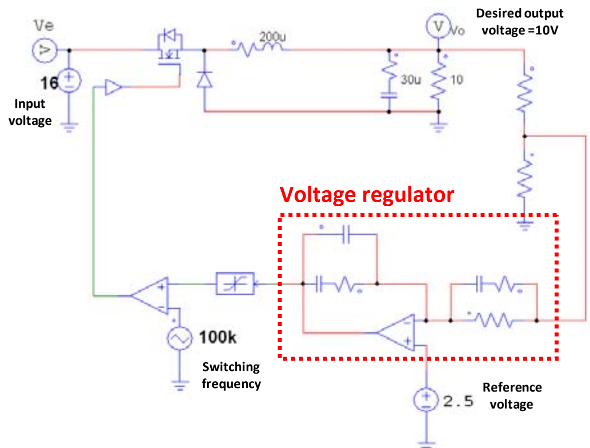
SmartCtrl Tutorial

Single Control Loop Design

SmartCtrl[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 controller (or regulator) of a dc/dc converter with a single control loop using the SmartCtrl software.

The converter selected in this example is a buck converter with voltage model control, as shown in the figure below. The voltage regulator to be designed is highlighted in the red dotted box.



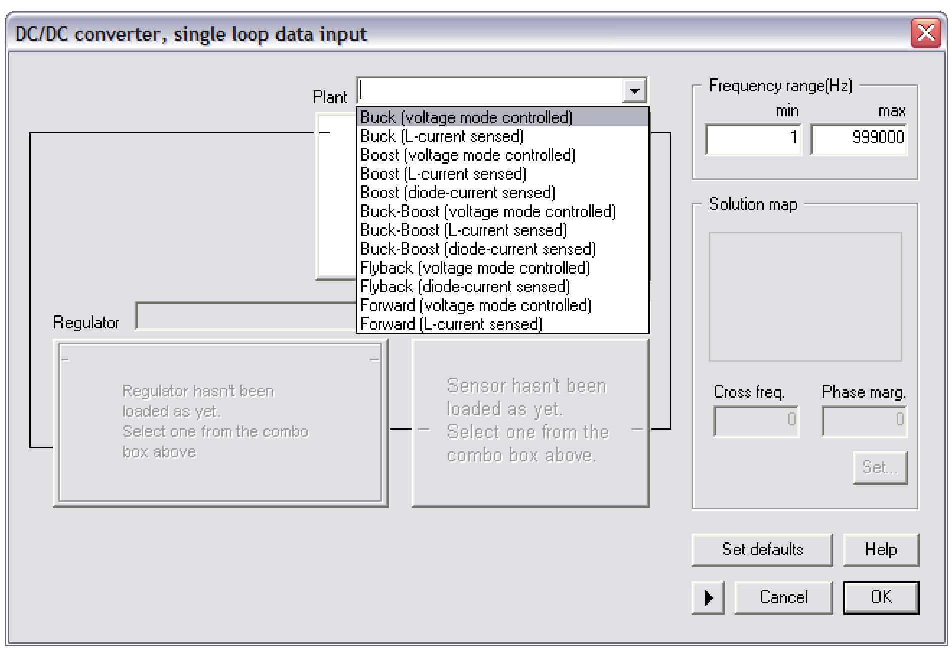
Converter parameters:

- Input voltage: 16V
- Output voltage: 10V
- Reference voltage: 2.5V
- Output inductance: 200uH
- Output capacitance: 30uF
- Switching frequency: 100kHz

The procedure of designing the voltage loop regulator is described below.

1. Define the converter

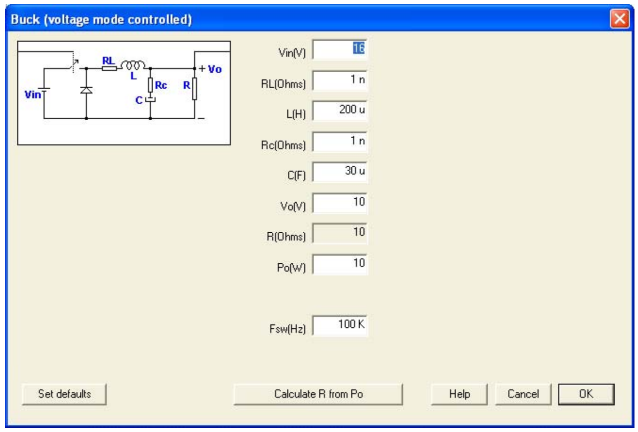
   To begin the design process in this example, in SmartCtrl, click on the icon , and a dialog window will appear, as shown below. From the dialog window, select the **Plant** drop-down menu and choose **Buck (voltage mode controlled)**.



[1] SmartCtrl is copyright in 2010 by Carlos III University of Madrid, GSEP Power Electronics Systems Group, Spain

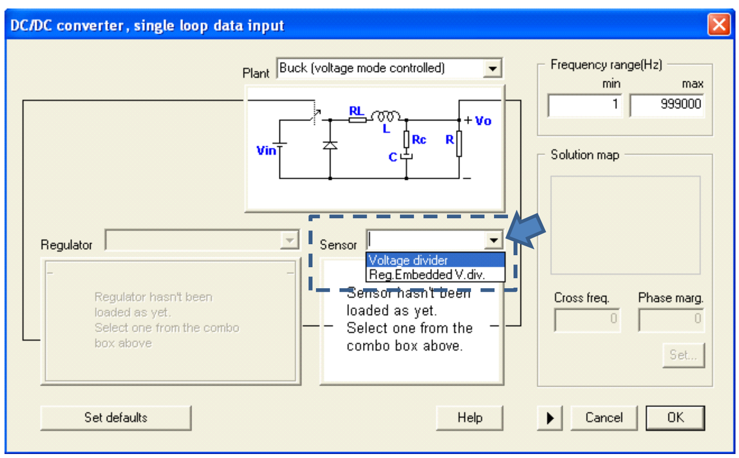
Or from the **Data** menu, choose **Predefined topologies** -> **DC/DC converters** -> **Single loop** -> **Buck** -> **Voltage mode controlled**.

Complete the parameters of the plant, and click OK to continue.

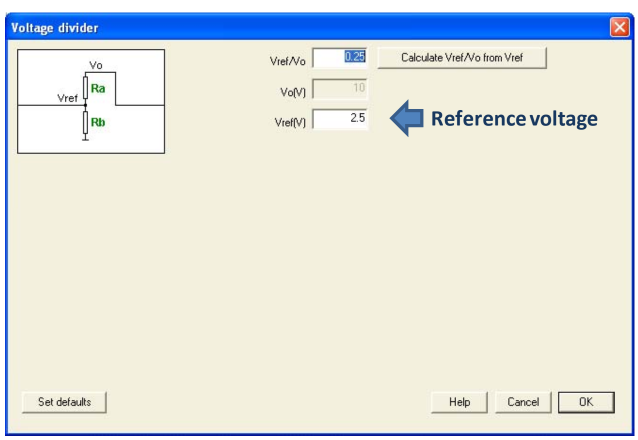


2. Select the sensor

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



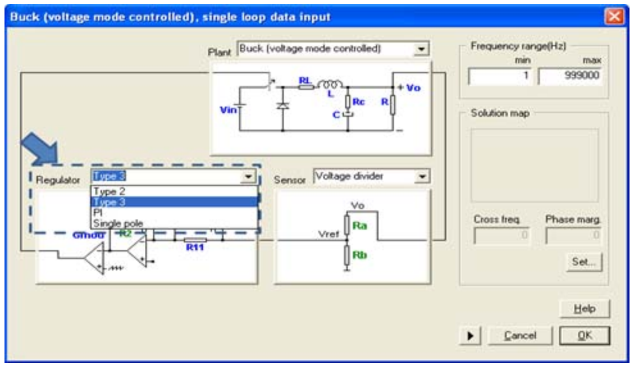
In the case of a voltage divider, one must enter the reference voltage. SmartCtrl will automatically calculate the sensor gain. In this example, the reference voltage is set at 2.5V. The figure below shows the sensor input data window.



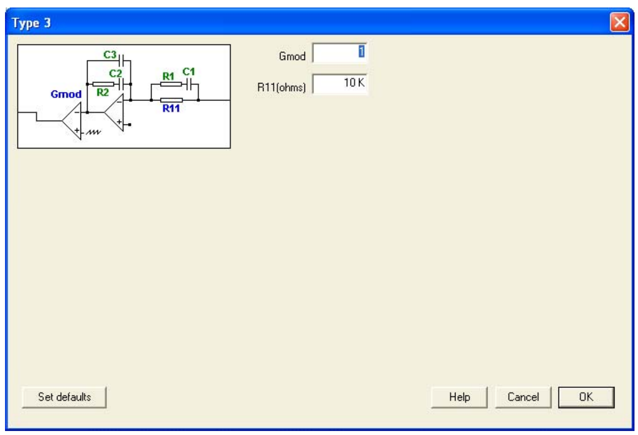
Note that the design will be carried out using this gain, and the resistor values to implement the voltage divider will be listed by SmartCtrl together with the regulator component values.

3. Select the regulator type

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

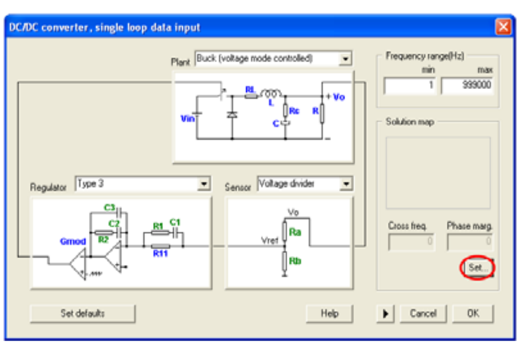


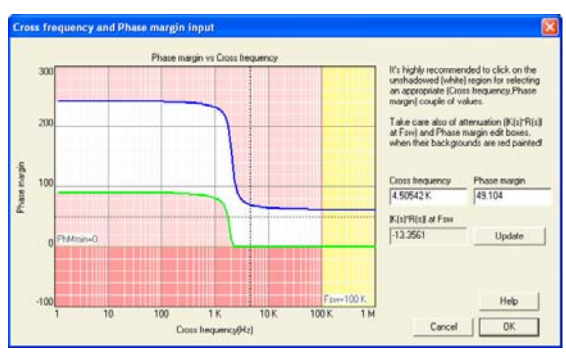
The type of regulator depends on the plant controlled. In this example, since the plant is a second order system, the best choice is a Type 3 regulator in order to obtain the proper phase margin and enough bandwidth. Select the Type 3 regulator, and enter the parameters as shown below, where Gmod is the modulator gain.



4. Select the crossover frequency and the phase margin

SmartCtrl provides a guideline and an easy way of selecting the crossover frequency (sometimes also referred to as the bandwidth) and the phase margin through the ***Solution Map***. Click on the **Set** button, and the Solution Map will be shown as below.





The x-axis of the Solution Map is the crossover frequency and the y-axis is the phase margin. Based on the converter parameters and the type of regulator selected, SmartCtrl will generate a safe design area as shown in the white area in the Solution Map. Any selection of the crossover frequency and the phase margin within this white area will lead to a stable solution.

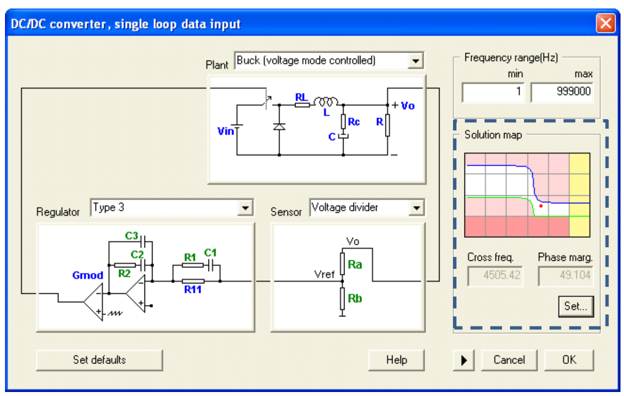
One can select the desired crossover frequency and the phase margin by entering the values in the edit boxes, and click on the **Update** button, or left click directly on the Solution Map. The selected design appears as a red point in the Solution Map.

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, in general, a crossover frequency of 1/10 of the switching frequency and a phase margin of 45 to 60 deg. are a good initial guess. In this example, we set the crossover frequency at 4.4436kHz and the phase margin at 49.1 deg, and the design is well within the white safe design area. Click OK to continue.

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



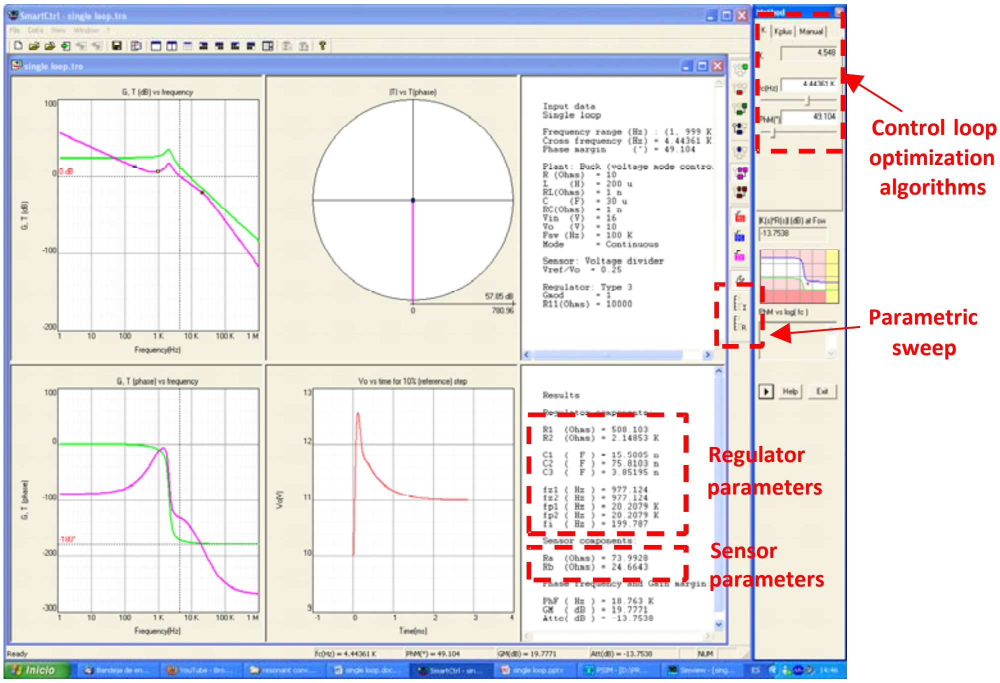
Now click OK to confirm the design, and the program will automatically show the performance of the system in terms of the Bode plots , polar plot, transient response, etc.

5. Perform control loop analysis and optimization

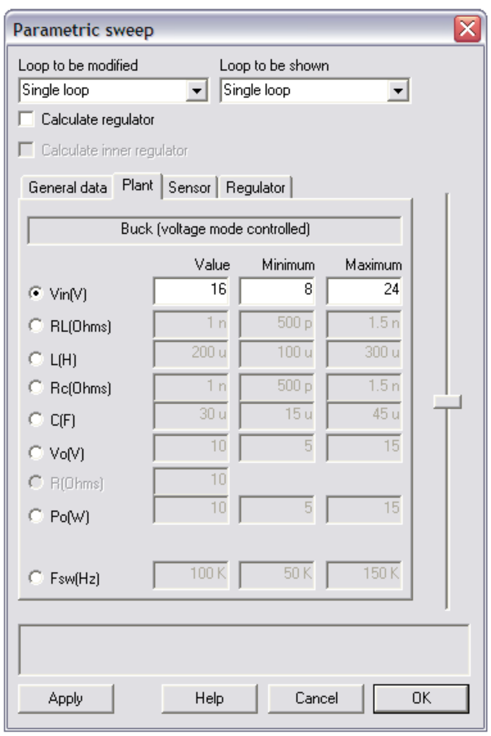
Once the crossover frequency and the phase margin are selected, the regulator parameters will be calculated, and the control loop performance can be evaluated. SmartCtrl provides a very intuitive and straightforward way of examining the control loop performance through Bode plots, the polar plot, and transient time-domain responses, as shown in the figure below.

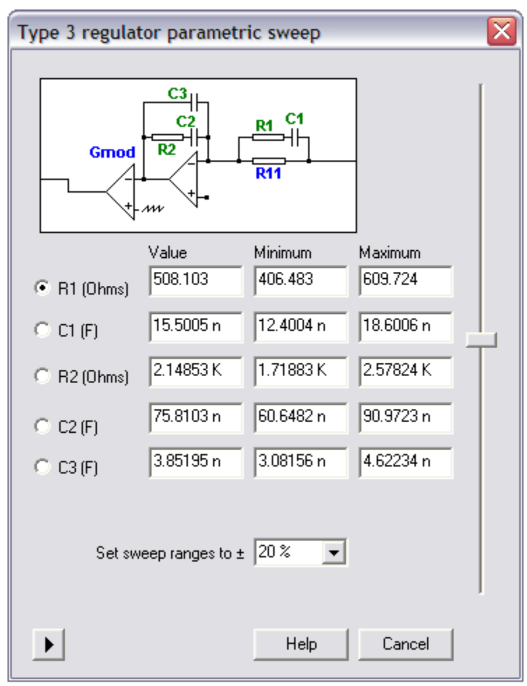
From the **View** menu, or from the toolbar on the right, one can display the Bode plots of the plant, the regulator, the open-loop and closed-loop transfer functions, as well as the input/output step response and the reference step response, etc.

Depending on the regulator type, various methods are provided to calculate the regulator parameters. In this example, for the Type 3 regulator, three methods are provided: K factor method, Kplus method (an improved version of the K factor method), and the manual pole/zero placement method. By adjusting the slide bars, one can see the Bode plots and time-domain responses being updated instantly, and see how the change of a particular control parameter affect the control loop performance.



Additionally, by selecting **Data** -> **Parameter sweep** -> **Input parameters** or **Regulator components** in SmartCtrl, one can perform sensitivity analysis. The figure below shows the dialog windows of the parameter sweep for input parameters and regulator parameters.





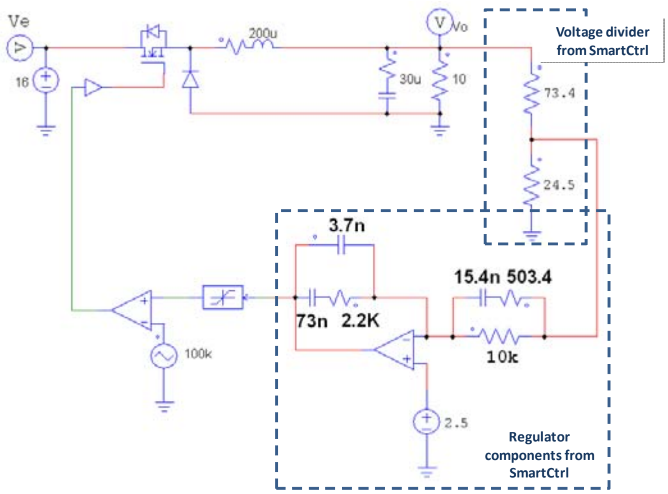
After selecting a particular parameter, one can change the slide bar and see instantly how the change of this parameter affects the control loop performance.

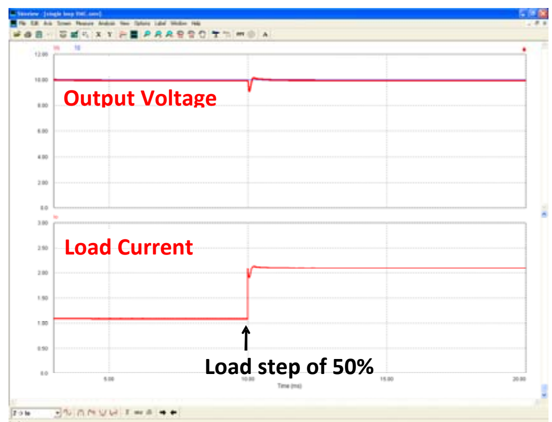
6. Validate the regulator design

   After the design is completed, SmartCtrl provides the component values for the sensor and the regulator. One can export the regulator circuit and parameters by selecting **File** -> **Export** -> **Regulator** -> **To PSIM (schematic)** (or clicking on the icon *Export to PSIM* (*schematic*)), and perform a time-domain transient simulation in PSIM to validate the design.

   The PSIM schematic of this example is shown below. The component values from SmartCtrl are rounded to the nearest values for implementation.

   To check the control loop performance, a load step change of 50% is applied. The simulation waveforms below show that the control loop responds very well to the change, with small overshoot and short settling time.





The example illustrates that SmartCtrl in combination with PSIM provide a fast and powerful platform for the design and validation of power converter control.