SmartCtrl

User's Guide

Powersim Inc.

SmartCtrl User's Guide

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Chapter 1: Introduction

1.1 Why SmartCtrol?

SmartCtrl is the control designing tool for power electronics. It provides an easy to use interface for designing the control loop of almost any plant.

It includes the predefined transfer functions of some of the most commonly used power electronics plants, such as different DC/DC topologies, AC/DC converters, Inverters and motor drives.

However, it also allows the users to import their own plant transfer function by means of a text file. Therefore, this feature provides flexibility to design an optimized control loop for almost any system.

In order to make easier the first attempt when designing a control loop, an estimation of the stable solutions space is given by the program under the name of "solutions map". Based on the selected plant, sensor and type of regulator, the solutions map provides a map of the different combinations of fc and phase margin that lead to stable systems.

Thus, the designer is able to select one of the points of the stable solutions space and to change the regulator parameters dynamically in order to adjust the system response to the user requirements in terms of stability, transient response, ... Since the program provides, at a glance, the frequency response of the system as well as the transient response and the regulator component values for the open loop given features. All of them are real time updated when any parameter of the system is varied by the designer.

Key Features

- Pre-defined transfer functions of commonly used power electronics plans and sensors.
- Possibility of importing any transfer function by means of txt-file.
- Estimations of the stable solutions space (“Solutions Map”).
- Dynamic variation of the system parameters.
- Real-time updated results of both the frequency response (bode plots) and the system transient response.

1.2 Program Layout

When SmartCtrl is started, all the available options are shown, and the user can select which of them is going to use. The aforementioned window is shown below. It is divided into two sections:

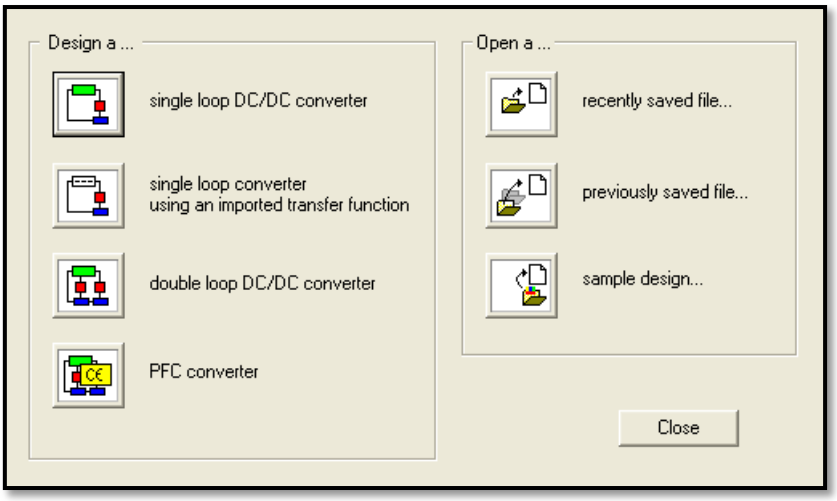
1. **Design a new converter control loop.**

Within this section the available options are the following:

Single loop DC/DC converter.
Single loop converter using an imported transfer function.
Double loop DC/DC converter
PFC Converter

2. **Import a…**

Recently saved file
Previously saved file
Predefined converter



Regardless of the selected option, once the converter is completely defined, the main window of the program is displayed. Different areas are considered within the main window and all of them are briefly described below:

1. There are six drop-down menus, this is:

File It includes all the functions needed in order to manage files, import and export files, establish the printer setup and the print options.

Data SmartCtrl libraries and parametric sweep.

View Allows the user to select which elements are displayed and which are not.

Window Functions to create, arrange and split windows.

Help SmartCtrl Help.

2. The Main Toolbar provides quick access to the most commonly used program functions through left click on the respective icon.

3. The View Toolbar icons allows the user a quick selection of the elements displayed.

4. The Status Bar summarizes the most important parameters of the open loop control design (cross frequency, phase margin and attenuation at the switching frequency).

5. The regulator Design Method Box includes the three calculation methods of the regulator as well as the Solution Map.

6. Graphic and text panels includes the most relevant information of the system: frequency response, polar plot, transient response, input data and the designed regulator components. To access the help topic regarding each panel just right

Chapter 2: Main Menus and Toolbars

2.1 File Menu

New Create a new project (Ctrl+N)

New and initial dialog Create a new project and displays the initial dialog box

Open Open an existing project (Ctrl+O)

Open sample designs Open a sample design from the examples folder

Close Close the current project window

Save Save the current project (Ctrl+S)

Save as... Save the current project to a different file

Open txt files Open any .txt file in Notepad

Import (Merge) Merge data of another file with the data of the existing file for display. The curves of these two files will be combined. (Ctrl+M)

Export The program provide different exporting options. It allows exporting the following.

- Export transfer functions
- Export regulator components to either a txt file, a PSIM parameter file or a PSIM schematic file
- Export transient responses to a file. The available transient responses are: voltage reference step, output current step and input voltage step

Generate report Generates a report to either a .txt file or notepad. It contains information regarding both the input data (steady-state dc operating point, plant input data, ...) and output data (regulator components, cross frequency, phase margin, ...)

Print preview Preview the printout of any of the graphic and text panels (Transfer function modules (dB), Transfer function phase (º), Nyquist diagram, Transients, Data input, Results)

Print Print any of the panels of the main window (bode plots, Nyquist diagram, transient, input data or results)

Printer setup Setup the printer

Exit Exit SmartCtrl program

2.2 Design Menu

The SmartCtrl Design Menu contains the elements that can be used in the SmartCtrl schematic. The library is divided into the following sections:

Predefined Topologies Contains the most commonly used DC/DC plants both in single and double loop configurations, as well as AC/DC plants.

Imported transfer function Allows the use of a generic transfer function by means of the import of a .dat, .txt, or .fra file

Modify Open the schematic window of the current project to modify the parameters

Parametric Sweeps Allows to perform the sensibility analysis of the system parameters. It is divided into two different parametric sweeps: Input Parameters and Regulator Components

Reset all Clears the active window

2.3 View Menu

Comments Opens the comments window. It allows the user to add comments to the design. These comments will be saved together with the designed converter.

Loop Select the loop to be displayed in the active window (inner or outer loop)

Transfer Functions Select the transfer function to be displayed

- Plant transfer function, G(s)
- Sensor transfer function, K(s)
- Regulator transfer function, R(s)
- Sensor-Regulator transfer function, K(s)·R(s)
- Open loop without regulator transfer function, A(s)
- Open loop with regulator transfer function, T(s)
- Closed loop transfer function, CL(s)

Transients Select the transient response to be displayed.
The available transient responses are:

- Input voltage step transient
- Output current step transient
- Reference step transient.

Organize panels Resize all panels and restore the default appearance of the graphic and results panels window.

Enhance Select the panel to be displayed in full screen size

- Bode (modulus) panel (Ctrl+Shift+U)
- Bode (phase) panel (Ctrl+Shift+J)
- Nyquist diagram panel (Ctrl+Shift+I)
- Transient responses panel (Ctrl+Shift+K)
- Input data panel (Ctrl+Shift+O)
- Output (results) panel (Ctrl+Shift+L)

2.4 Window Menu

New Window Create a new window

Maximize active window Maximize the current window

Cascade Arrange the windows in cascade form

Tile horizontal Tile the currently open windows horizontally

Tile vertical Tile the currently open windows vertically

Split Click on the intersection of the lines that delimit the different window panels and drag. This will change the size of the panels

Organize all It restores the default size of the graphic and text panels.

2.5 Main Toolbar

Create a new project

Create a new project and open initial dialogue box

Open an existing project

Open sample design

Close the current project window

Generate report

View document comments

Open the single loop DC/DC data input dialogue box

Import plant transfer function, voltage mode controlled

Import plant transfer function, current mode controlled

Open the double loop DC/DC data input dialogue box

Open the Boost PFC converter data input dialogue box

Save the current project

Export transfer function to a file

Import transfer function from a file to be merged with the current project

Export regulator to PSIM (schematic)

Export regulator to PSIM (parameters file)

Update parameters file of the previously exported regulator

Maximize active window

Tile windows

See all panels

Organizeallpanels

2.6 View Toolbar

Display the frequency response (Bode plot) of the plant transfer function

Display the frequency response (Bode plot) of the sensor transfer function

Display the frequency response (Bode plot) of the open loop without regulator transfer function

Display the frequency response (Bode plot) of the sensor regulator transfer function

Display the frequency response (Bode plot) of the regulator transfer function

Display the frequency response (Bode plot) of the open loop transfer function

	Display the frequency response (Bode plot) of the closed loop transfer function
	Display transient response due to a reference voltage step
	Display the transient response due to an output current step
	Display the transient response due to an input voltage step
	Display inner loop results
	Display outer loop results
	Enables or disables the display of the regulator calculation method toolbox
	Input Parameters Parametric sweep
	Input Parameters Parametric sweep

Chapter 3: Import and Export Transfer Function.

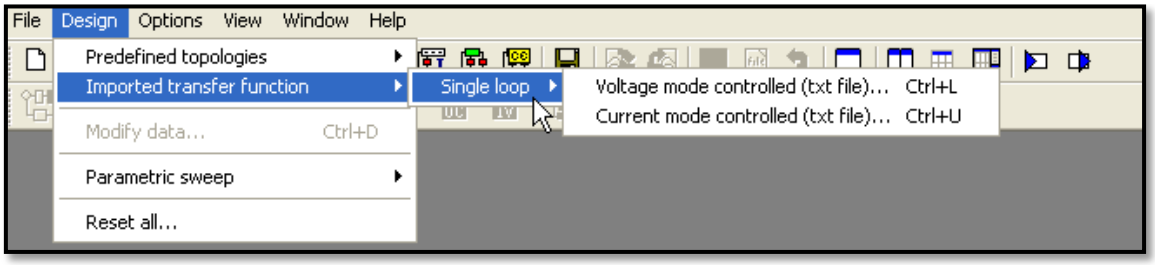
3.1 Import your own transfer function

One of the Key Features of SmartCtrl is the possibility of using a generic plant transfer function imported from a .txt file.

Thanks to this feature, the designer is able to carry out the regulator design and optimization when a generic plant is used. The system average model is not needed, but the plant transfer function, which can be obtained by means of experimental measurements or AC simulation.

To perform the single loop design from an imported plant transfer function just enter the data menu and select imported transfer function. Within this option two options are available:

Current mode controlled
Voltage mode controlled

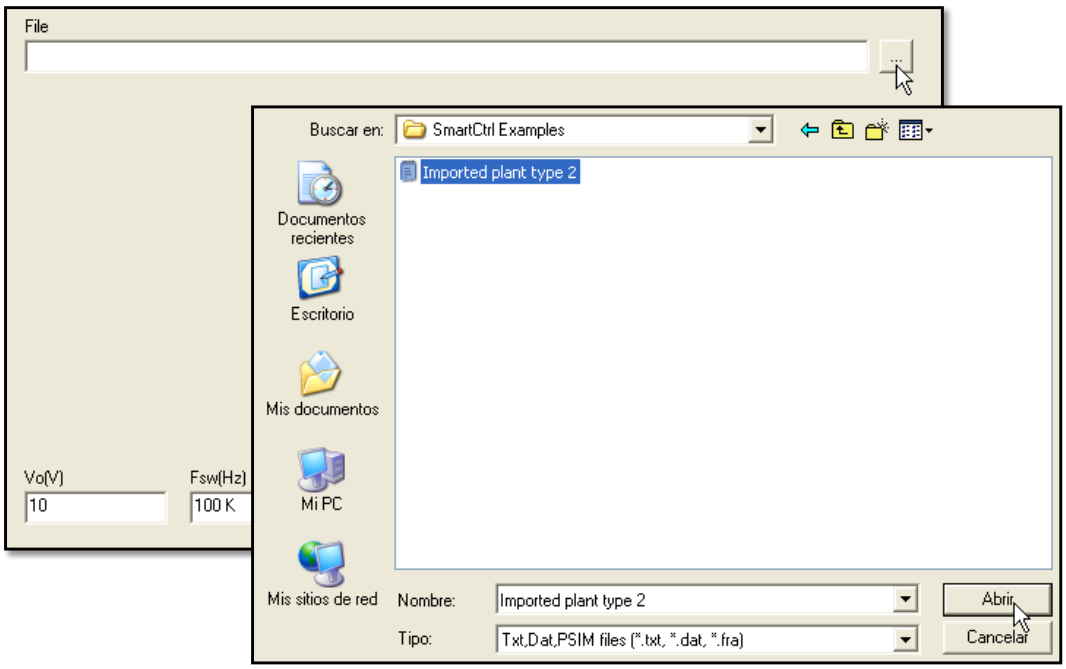


Other available path to access this option are the icons placed within the main toolbar.

Import plant transfer function, voltage mode controlled

Import plant transfer function, current mode controlled

To load the plant from a file follow the instructions below. SmarCtrl is able to load the following file formats: *.dat, *.txt, *.fra

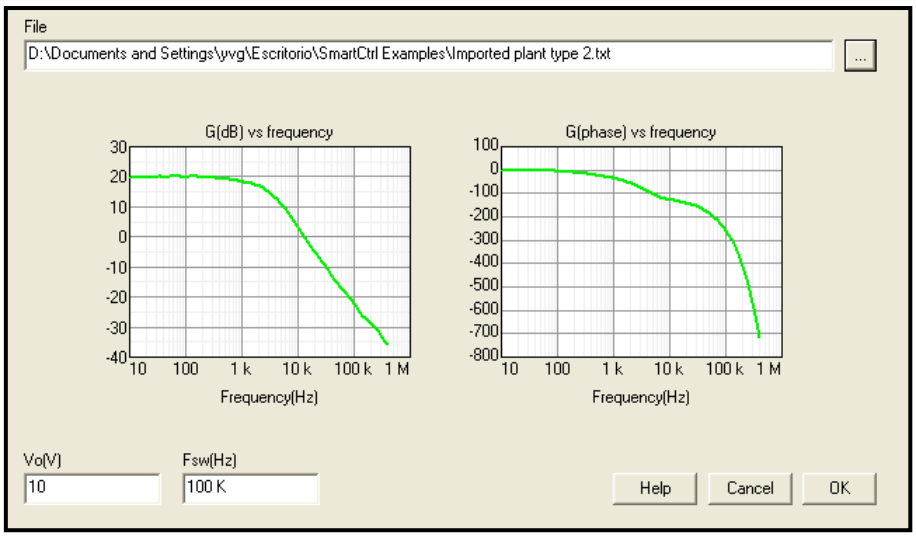


Once the file has been selected, the transfer function is displayed in module and phase.

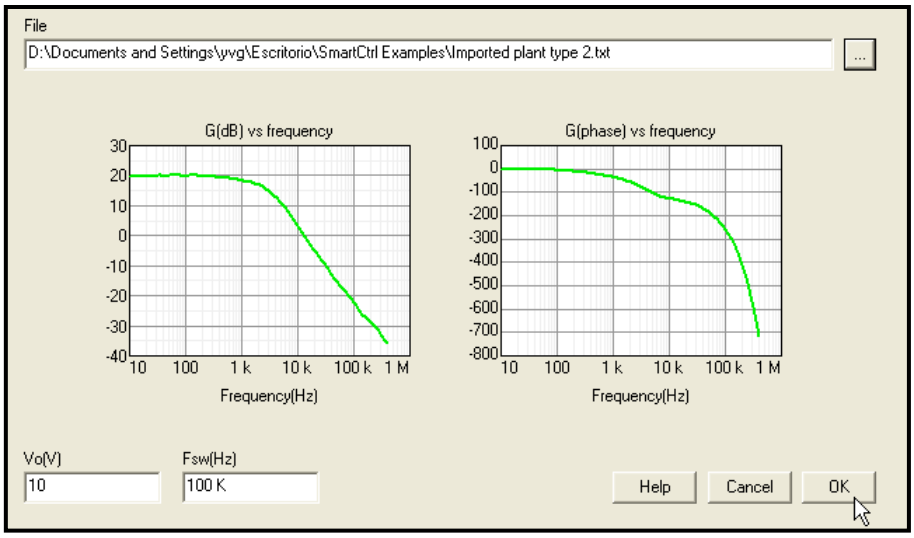
Some additional data must be specified:

The switching frequency (Fsw) in Hertz.

The desired output voltage (Vo) in Volts. (Only if the plant is voltage modecontrolled).



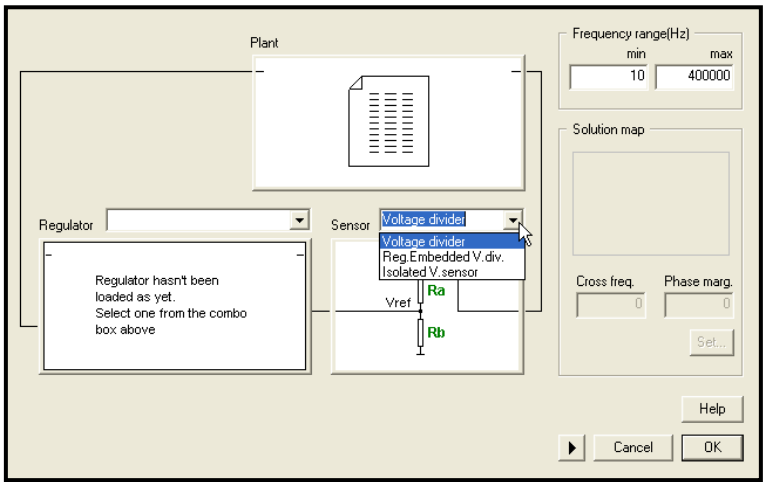
To continue with the single loop design just click OK.



3.1.1 Imported plant single loop design

The single loop is formed by three different transfer functions: plant, sensor and regulator, that must be selected sequentially.Whether the imported plant is voltage mode controlled or current mode controlled, the single loop design process is the same in any case. The only difference are the sensors available in each case.

The imported transfer function has been already loaded. Whether it is a current mode controlled or voltage mode controlled, the available sensors are the following:



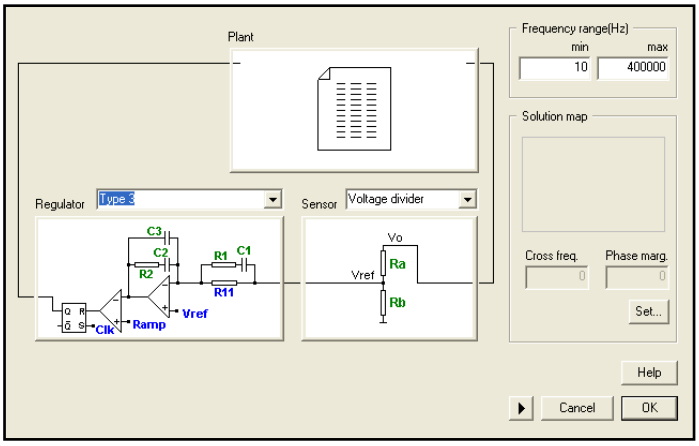
Voltage mode controlled

- Voltage divider
- Reg. Embedded Voltage Divider
- Isolated V sensor.

Current mode controlled

- Current sensor
- Hall effect sensor

Finally, the regulator is selected.

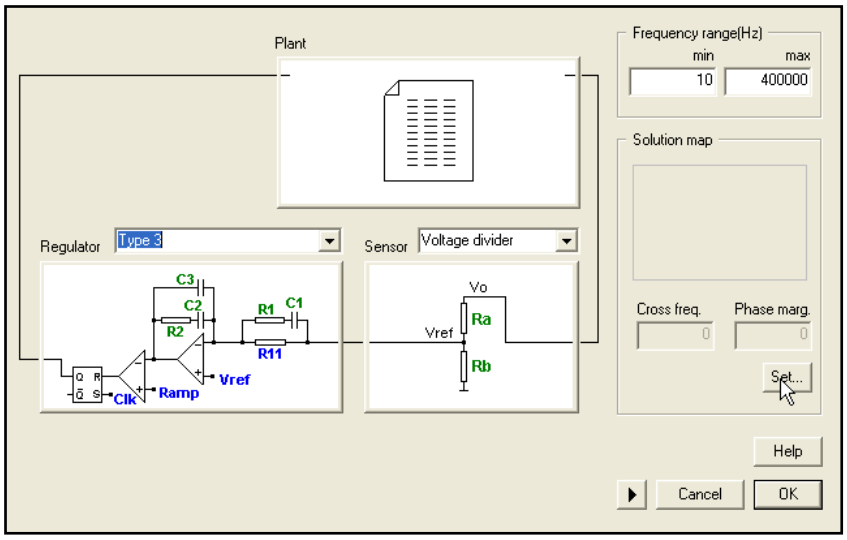


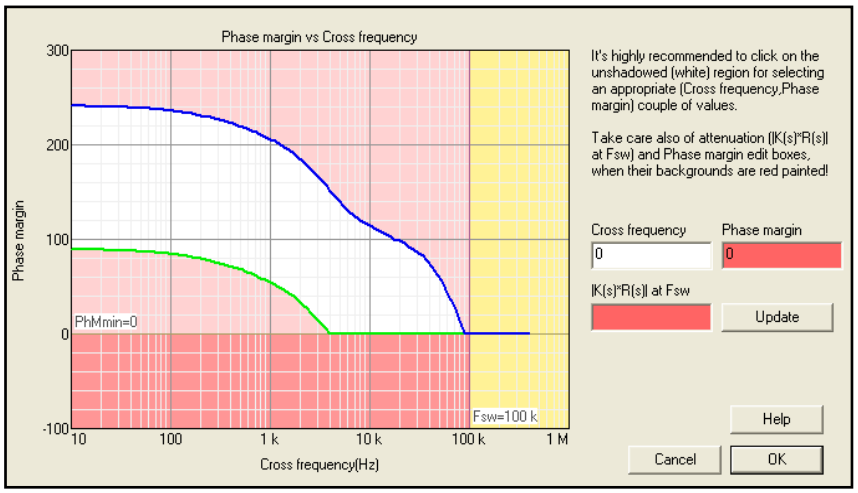
Regulator types:

- Type 3 Unattenuated
- Type 2
- Type 2 unattenuated
- PI
- PI unattenuated
- Single Pole
- Single Pole unattenuated

Once the system has been defined, SmartCtrl calculates the stable solution space in which all the possible combinations of crossover frequency and phase margin that lead to stable solutions are shown graphically. It is called Solutions Map.

The designer is asked to select a point within the solution space to continue. To do that, just click on Set and select a point within the white zone.



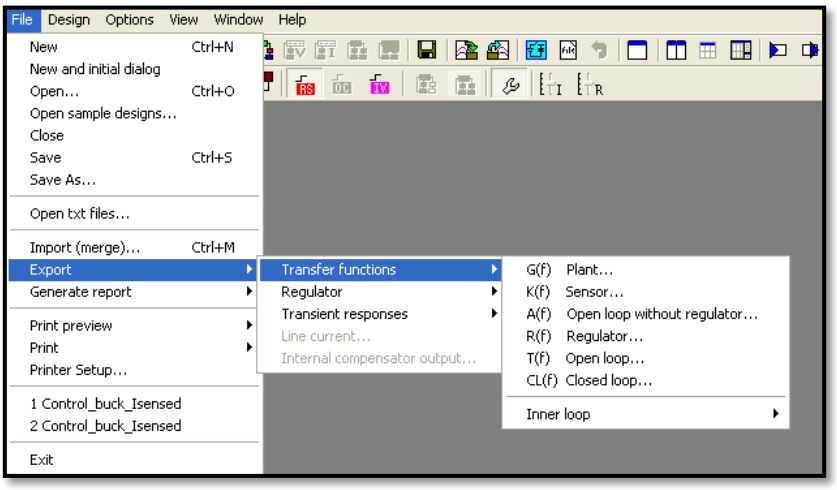


Now accept the selected point and confirm the design, the program will automatically show the performance of the system in terms of frequency response, transient response. (See Graphic and text panels window for detailed information)

3.2 Export

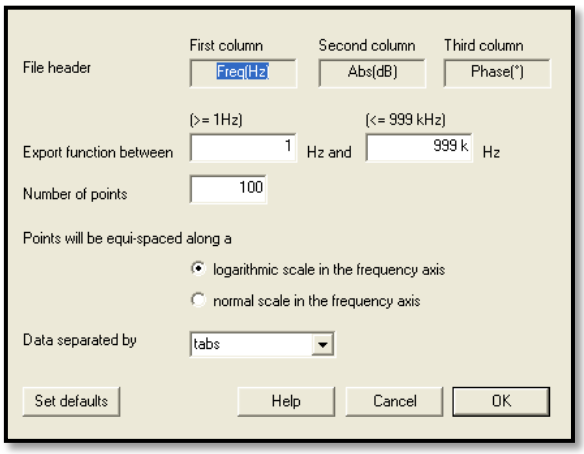
3.2.1 Export transfer function

SmartCtrl provide three different exporting options which are available under the export item of the File Menu. The first of the exporting options is export transfer functions which is also available through left click on the icon placed in the main toolbar.
Any of the transfer functions available can be exported to a .txt file. To do that, the designer must select the function to export within the available list and set the options of the file in the corresponding dialogue box.



The addressed file is formed by three columns containing the frequency vector, the module in dB and the phase in degrees respectively.

The file options and characteristics are contained in the "Exporting transfer function dialogue box" and they are described below:



File Header	It contains the name of the three columns of the file.
Exportfunctionbetween	The designer is able to set the frequency range of the exported transfer function
Number of points	Number of points to be saved in the file

Points will be equi-spaced along a:

Logarithmic scale in the frequency axis
Decimal scale in the frequency axis

Data separated by:

tabs
spaces
commas

3.2.2 Export regulator to PSIM

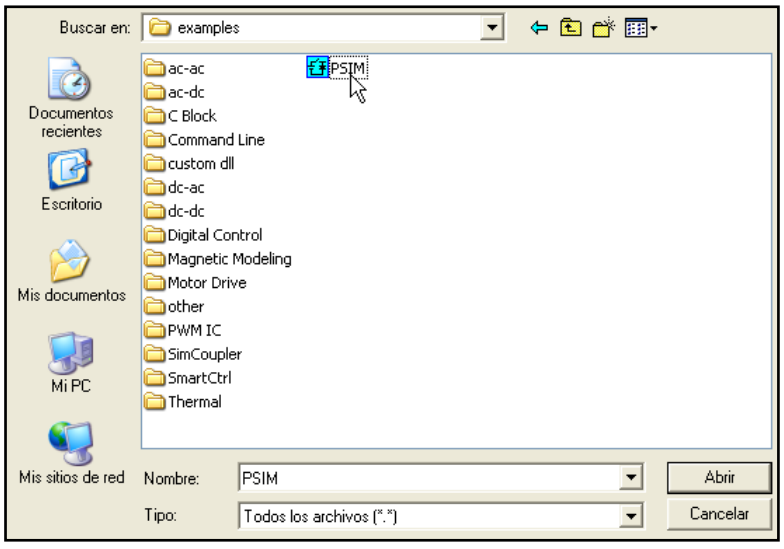
Another of the exporting options provided by SmartCtrl allows to communicatethe program itself with PSIM software.

Once the regulator has been designed, it can be exported easily to PSIM in order to carry out a simulation.

There are three different options for exporting the regulator which are briefly described below:

- **Export regulator to PSIM (schematic)**

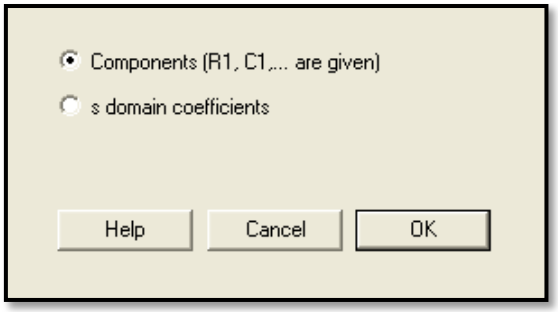
The designer is able to export the designed regulator to PSIM in an schematic form. This is, the user will be asked to select the PSIM file in which the regulator schematic will be inserted.



Two different schematics are available:

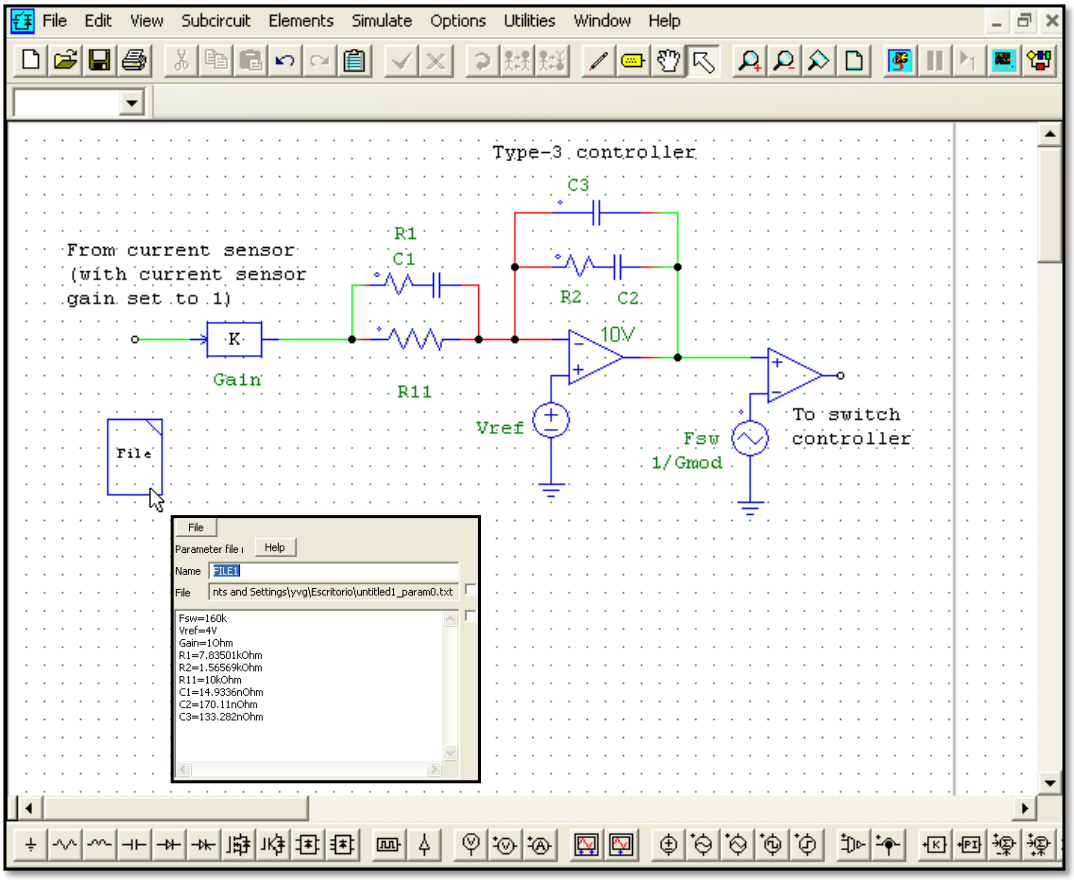
- ✓ Components (R1, C1, ...)
- ✓ s domain coefficients

The user will be asked to select one of them:

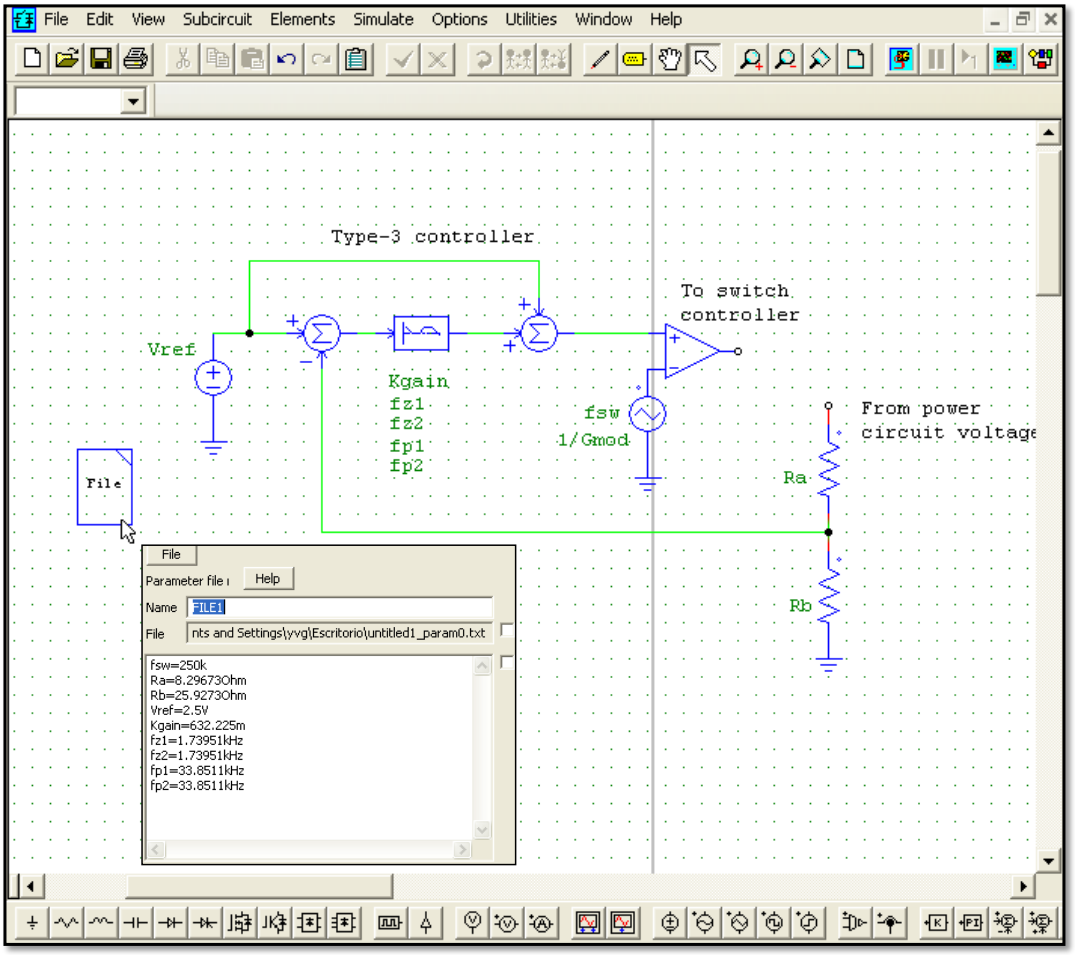


Finally, the regulator is inserted in the selected Psim schematic file:

- ✓ Components (R1, C1, ...)



- ✓ s domaincoefficients



In this case, only the parameters file will be exported to PSIM. Similarly to the previous option, SmartCtrl will ask the designer to select the PSIM schematic to which the parameters file must be exported.

- **Export regulator to PSIM (parameters file)**

  In this case, only the parameters file will be exported to PSIM. Similarly to the previous option, SmartCtrl will ask the designer to select the PSIM schematic to which the parameters file must be exported.

  Two different schematics are also available:

  - ✓ Components (R1, C1, ...)
  - ✓ s domain coefficients

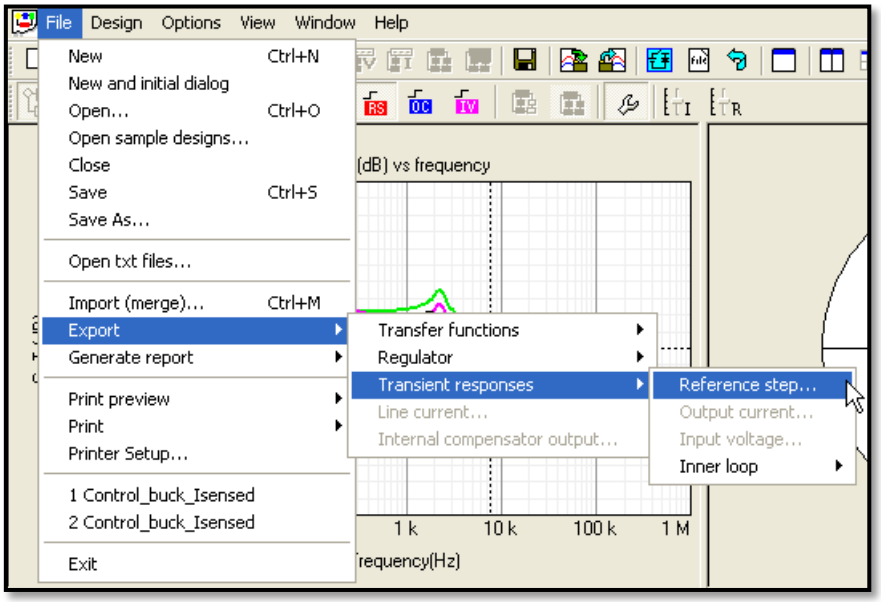
- **Update parameters file**

  Once one of the previously described options have been performed, only the updating of the existing parameter file is needed.

When the designer click on this option, the previously inserted parameter file will be updated automatically.

3.2.3 Export transient responses

SmartCtrl provides three different exporting options which are available under the export item of the File Menu. The third of the exporting options is "export transient functions" which export any of the available transient responses to a file.

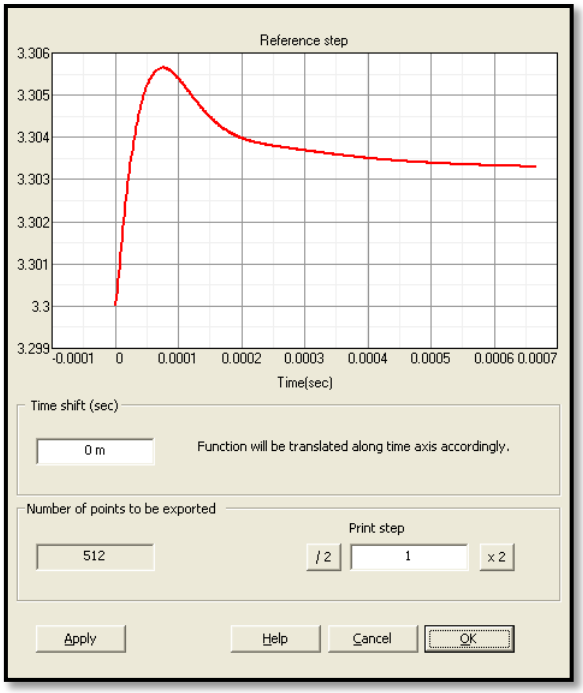


This option is also available through right click on the transient response graphic panel. The corresponding dialogue box is displayed below. It shows the transient response to be exported as well as the following parameters:

Time shift The user is able to set a customized time shift (in seconds) if necessary, and the transient response will be translated accordingly along the time axis.

N. of points to be exported SmartCtrl shows the total number of points of the graph.

Print step Its default value is 1 and it means that every data point will be exported to the file. If it is 4, only one out of 4 points will be saved. This helps to reduce the size of the resultant file. The two buttons placed at both sides of the pint step box allow to increase (x2) or decrease (/2) the print step easily.



Click Apply to update the parameters and OK to continue. At this point, the program will ask you the name and location of the file.

3.3 Import (Merge)

Import (Merge) data of another file with the data of the existing file for display. The curves of these two files will be combined. The Merge function is available within the File Menu and through click on . Itis oriented to the comparison of frequency response curves (Bode plots).
The file to be merged with the current one can be either a .tro file, a .txt file or a .fra. This is, the comparison of the current file results can be compared with the results previously saved by the SmartCtrl Program, with any transfer function saved in a .txt format or with a PSIM frequency AC analysis, respectively.

Neither the .tro file or the .fra file need to be formatted in order to be used by the merge function. However, if a .txt file is going to be used the following considerations must be taken into account:

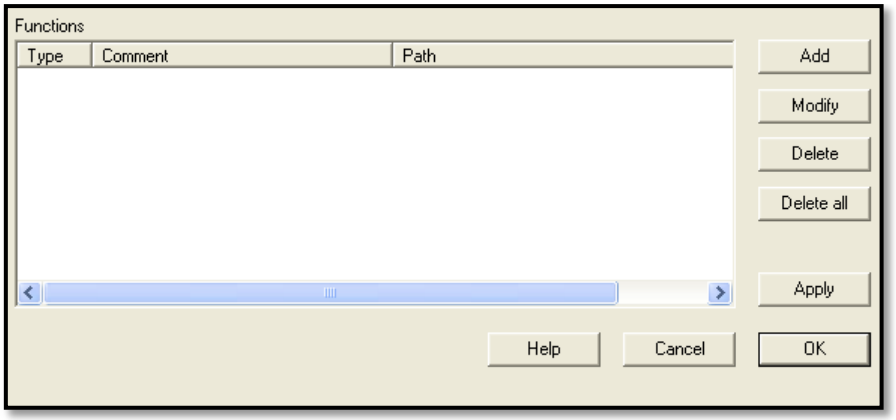
The file must be organized in three columns (from left to right)

First column corresponds to the frequency values
Second column correspond to the module in dB
Third column correspond to the phase in degrees
The first line of the file corresponds to the columns headings

The next steps will guide you to add, modify or delete transfer functions to/from the comparison, either from a .tro file or a .txt file.

1. Merge

You can select the Merge function both from the File Menu or through left click on from the main toolbar.



2. Available actions

You can choose among the following available actions:

Add Adds a new transfer function to the comparison

Modify Modify the settings of a previously added transfer function (change color, file of origin...)

Delete Deletestheselectedfunction

Deleteall Deleteallthefunctions

Apply Applythecurrentsettings

OK Apply the current settings and close the merge window

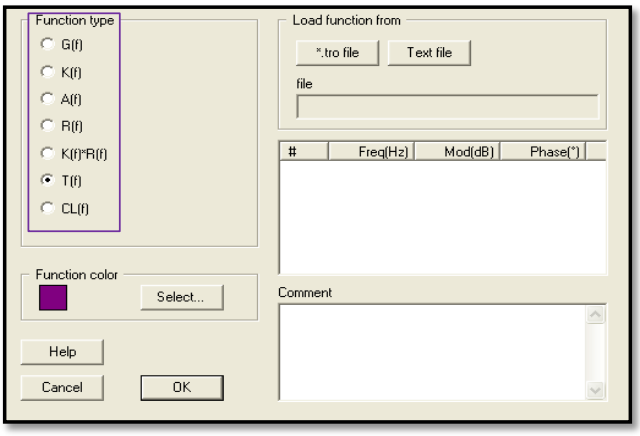
Cancel Close the Merge window but don't apply any change

Help Displaythehelpwindow

3.3.1 Add Function

The Add function to merge allows the user to add a new transfer function to the comparison.

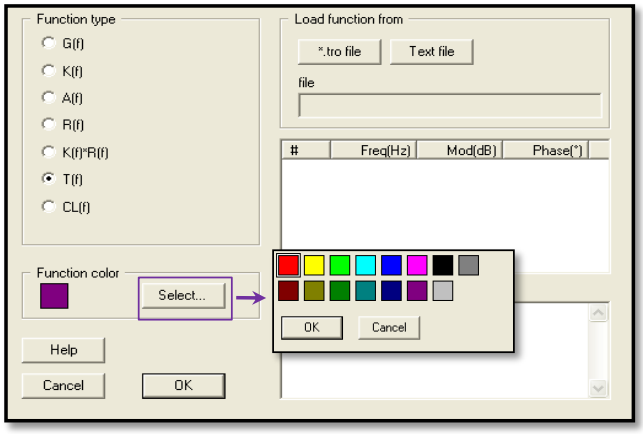
1. SelecttheFunctionType



Where:

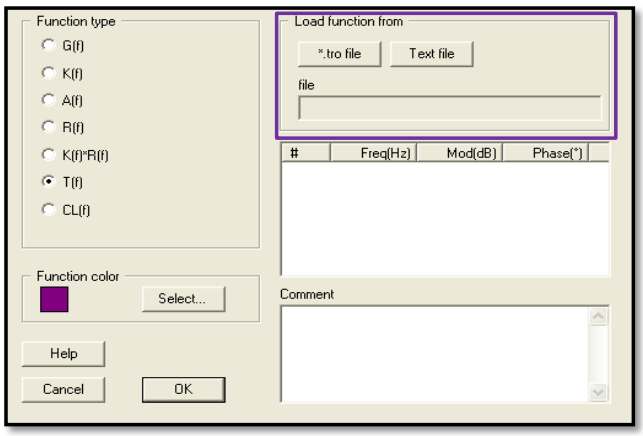
- **G(s)** Plant Transfer Function
- **K(s)** Sensor Transfer Fucntion
- **A(s)** = G(s)·K(s)
- **R(s)** Regulator Transfer Function
- **K(s)·R(s)**
- **T(s)** = A(s)·R(s) Open loop transfer function
- **CL(s)** Closed loop transfer function

2. Selectthe color



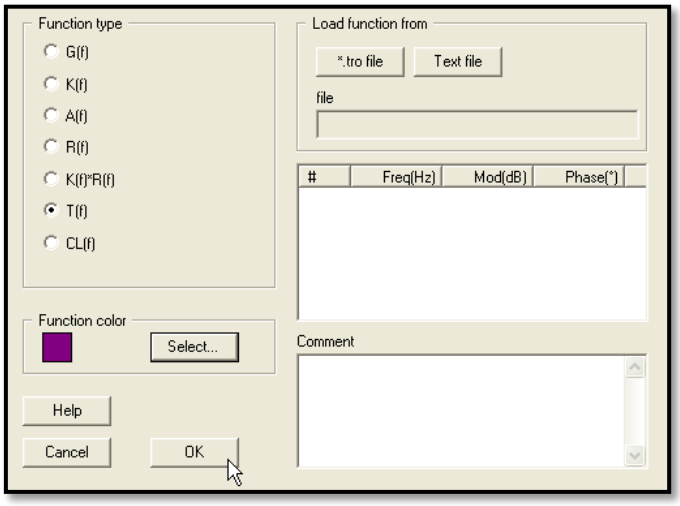
3. Load function from .tro or .txt file

   Load function from either a .tro file or a text file (.txt)



4. OK

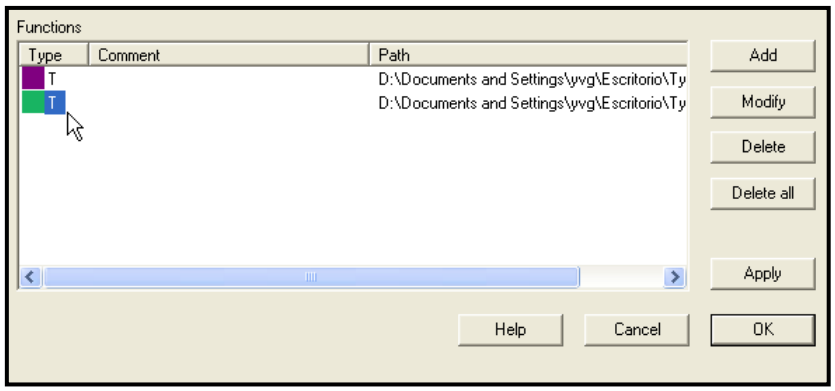
   And the transfer function will be added to the module and phase panels of the Bode Plots.



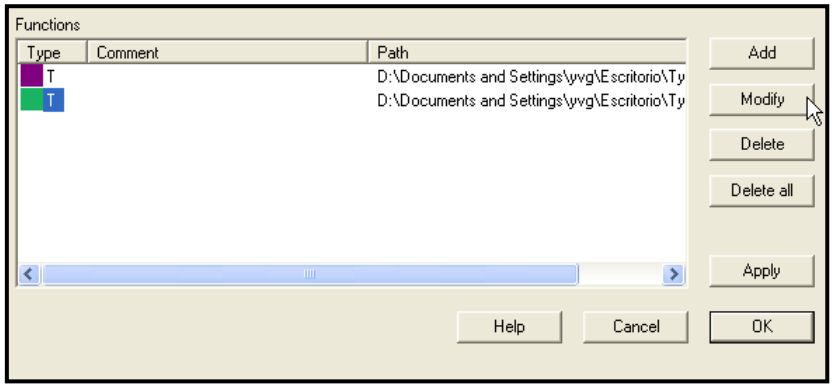
3.3.2 Modify Function

The Modify function allows the user to Modify the settings of a previously merged transfer function (change color, file of origin...)

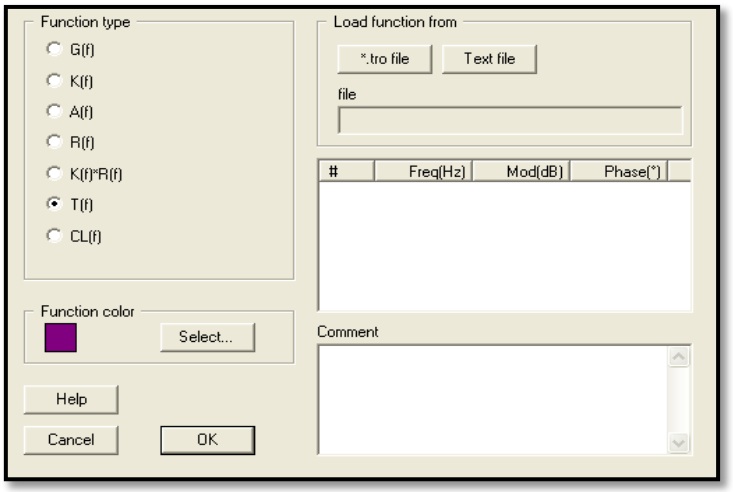
1. Select the Function to be modified



2. Click on the Modify button



3. Modifysettings



The user is able to modify the following parameters:

- Load a new file
- Change the trace color

However, if the user modifies the function type, a new file must be loaded

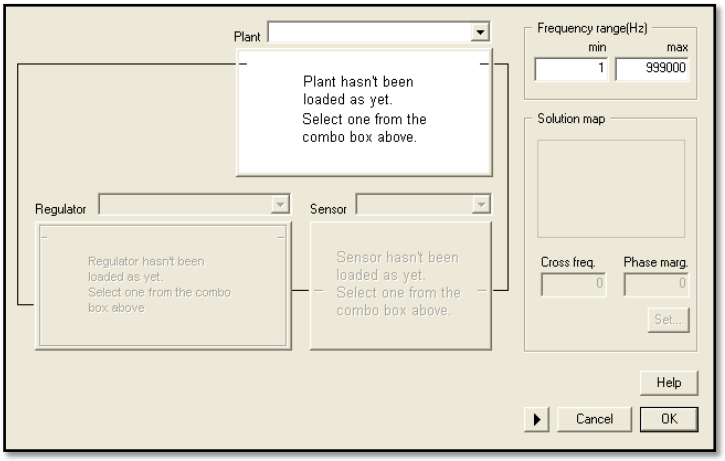
Chapter 4: Sensors, plants and regulators.

4.1 DC / DC Converters

4.1.1 Single Loop

The single loop is formed by three different transfer functions: plant, sensor and regulator, that must be selected sequentially.

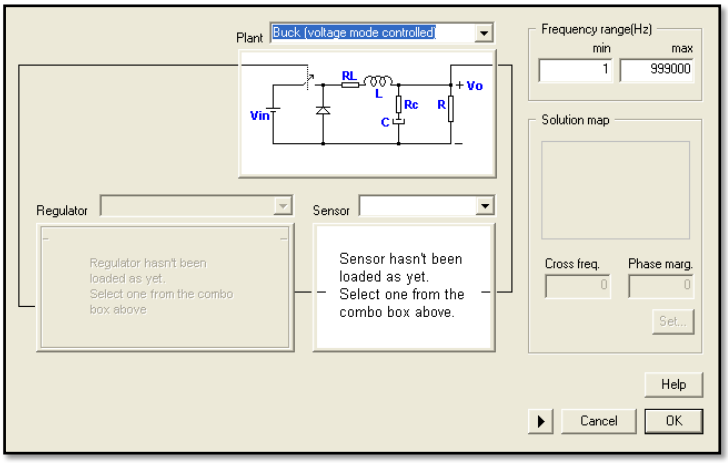
The first step to define the system is the selection of the plant.The plant can be either a pre-defined one or a user own one. This is, the user can import a generic transfer functionby means of a .txt file or select one of the pre-defined topologies.



The predefined DC/DC plants are the following:

- Buck
- Buck-Boost
- Boost
- Flyback
- Forward

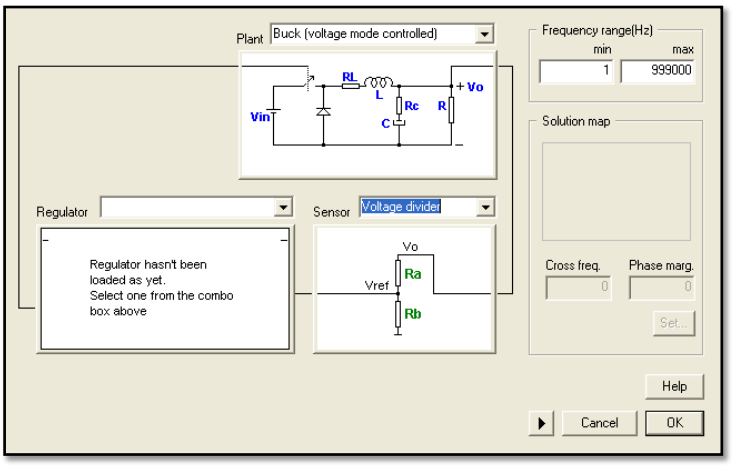
Once the plant has been selected, regardless the magnitude to be controlled is voltage or current, the program will display the appropriate type of sensor.



The different sensors available are the following:

- Voltage Divider.
- Regulator Embedded Voltage Divider.
- Isolated Voltage Sensor.
- Current Sensor.
- Hall Effect Sensor.

Finally, the regulator is selected. SmartCtrl provides different regulators as well as the possibility of importing the transfer function of a new one through a text file.

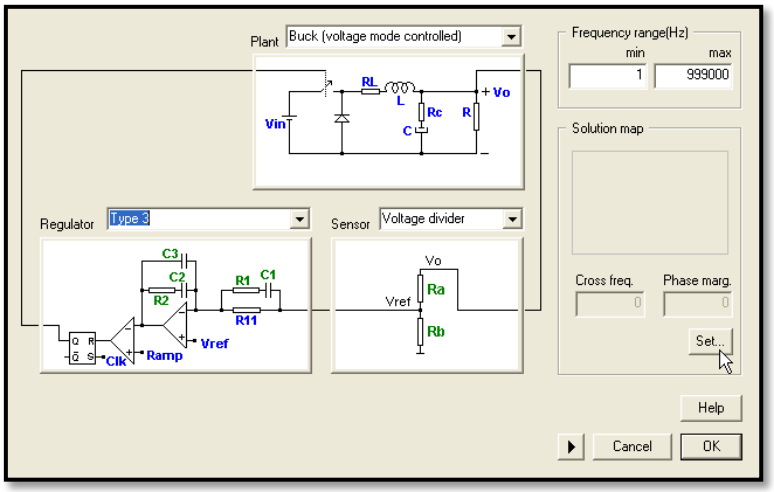


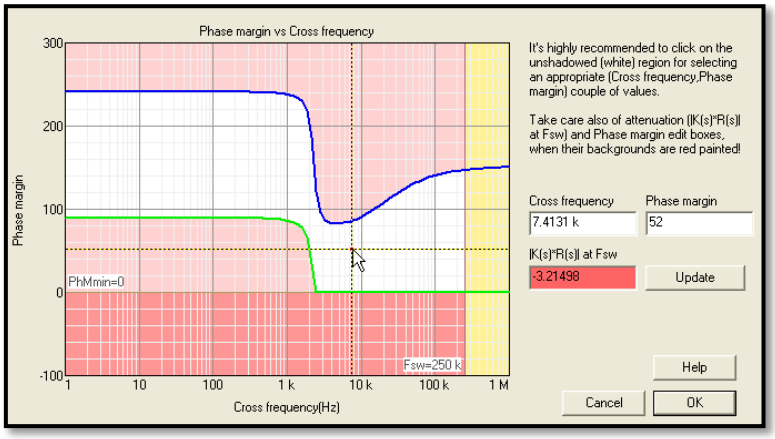
Regulator types:

- Type 3
- Type 3 Unattenuated
- Type 2
- Type 2 unattenuated
- PI
- PI unattenuated
- Single Pole
- Single Pole unattenuated

Once the system has been defined, SmartCtrl calculates the stable solution space in which all the possible combinations of crossover frequency and phase margin that lead to stable solutions are shown graphically. It is called Solutions Map.

The designer is asked to select a point within the solution space to continue. To do that, just click on Set and select a point within the white zone.



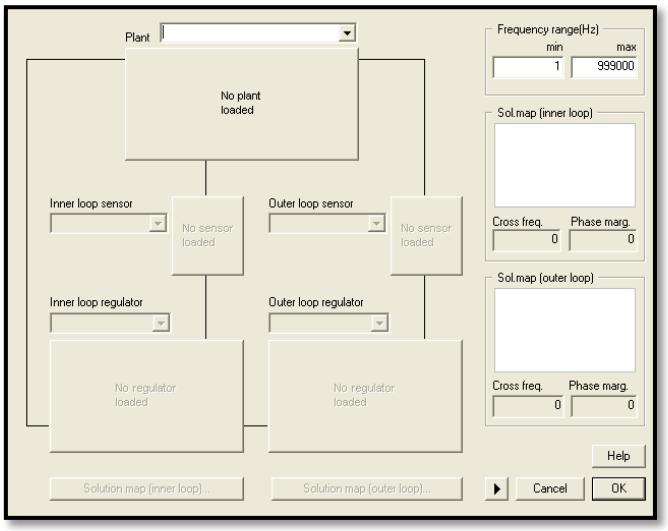


Now accept the selected point and confirm the design, the program will automatically show the performance of the system in terms of frequency response, transient response. (See Graphic and text panels windowfor detailed information)

4.1.2 Double Loop

The double loop option is formed by an inner current loopand an outer voltage mode loop. As well as the single loop, the double loop setup must be built sequentially. The program will guide you to built it, enabling the following step and keeping everything else disabled.

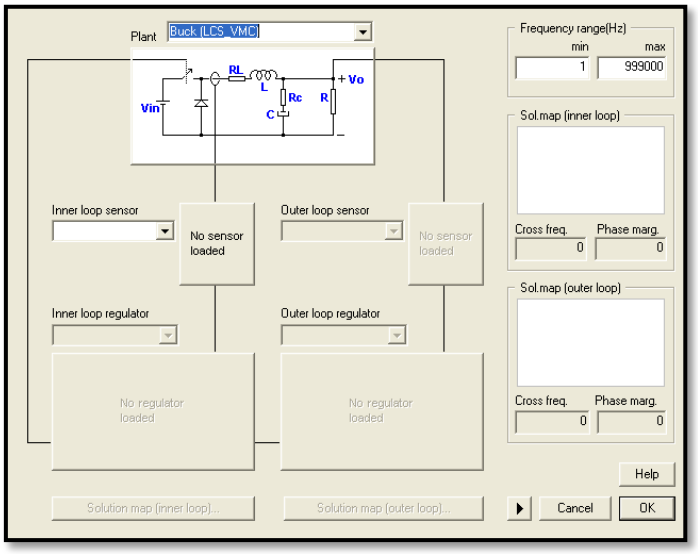
In all the available plants, the outer loop is a voltage mode control (VMC), while the inner loop is a current controlled one. Depending on the selected plant, the current is sensed either on the inductance (LCS) or on the diode (DCS). The DC/DC plant must be selected among the following list.



The predefined DC/DC plants are the following:

- Buck (LCD-VMC)
- Buck-Boost (LCS-VMC)
- Boost (LCS-VMC)
- Boost (DCS-VMC)
- Flyback (DCS-VMC)
- Forward(LCS-VMC)

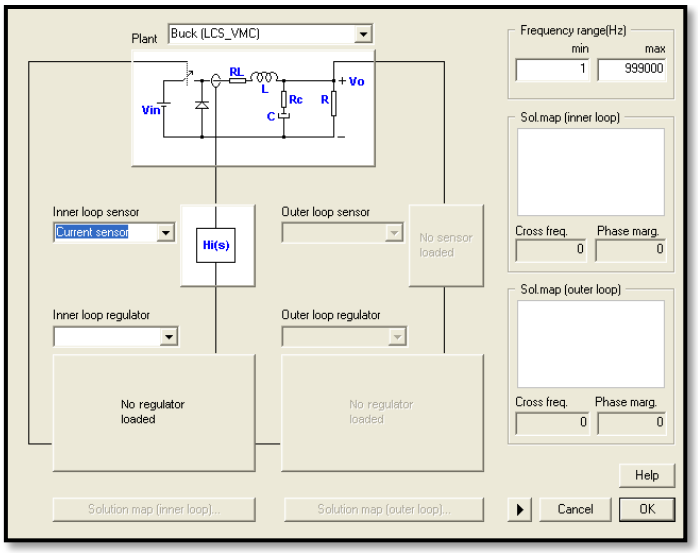
Next, the inner control loop will be configured. This is, the current sensor and the regulator type must be selected.



The available current sensors are the following:

- Current Sensor
- Hall Effect Sensor

Finally, the inner loop regulator is selected.

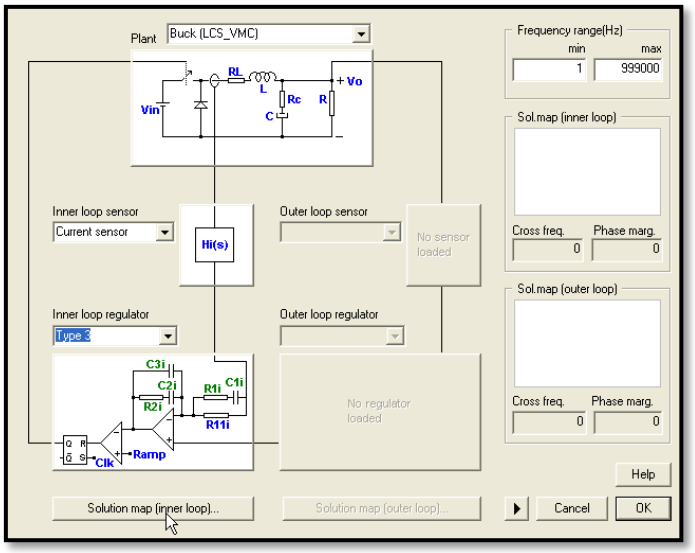


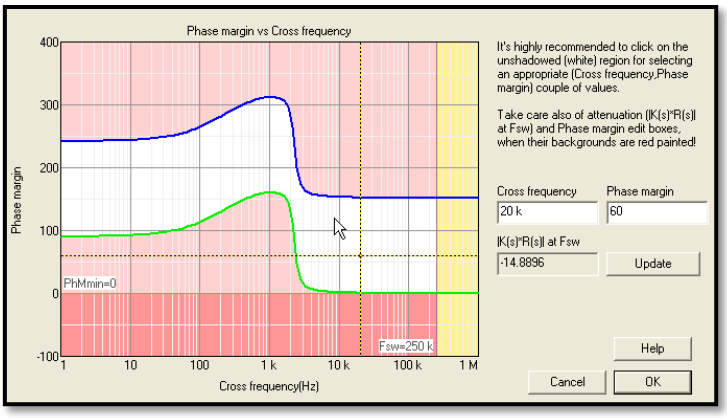
Regulator types:

- Type 3
- Type 2
- PI
- Single Pole

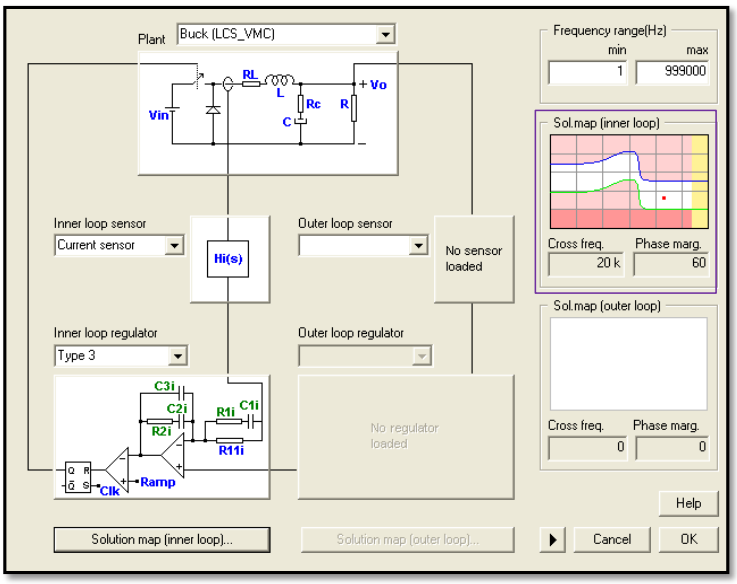
Once all the inner loop transfer functions have been defined, The cut off frequency and the phase margin must be selected. Under the name of Solution Map, SmartCtrl provides the stable solution space in which all the possible combinations of cut off frequency and phase margin that lead to stable solutions are shown graphically. Just clicking on the "Solutions map (inner loop)" button the solution map corresponding to the inner loop is displayed.

The designer is asked to select the crossover frequency and the phase margin just by clicking within the white zone to continue.



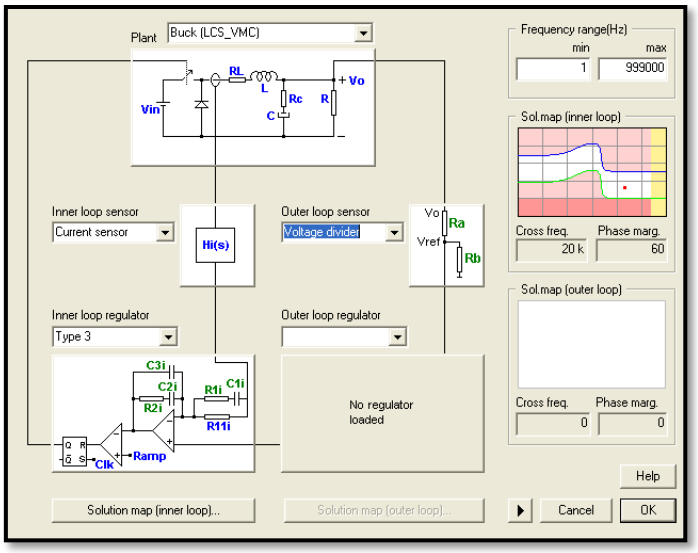


Once the cut off frequency and the phase margin have been selected, the solution map will be shown on the right of the side of the DC/DC double loop input data window. If, at any time, the two aforementioned parameters need to be changed, just click on the shown solution map. (Seenext figure).



Now, the outer loop can be defined.

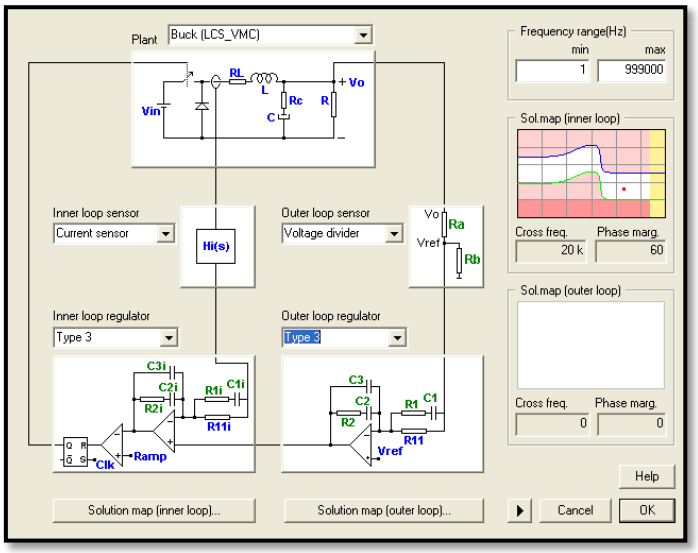
First, the voltage sensor must be selected.



The different sensors available are the following:

- Voltage Divider
- Regulator Embedded Voltage Divider

Next, the outer loop regulator must be selected.



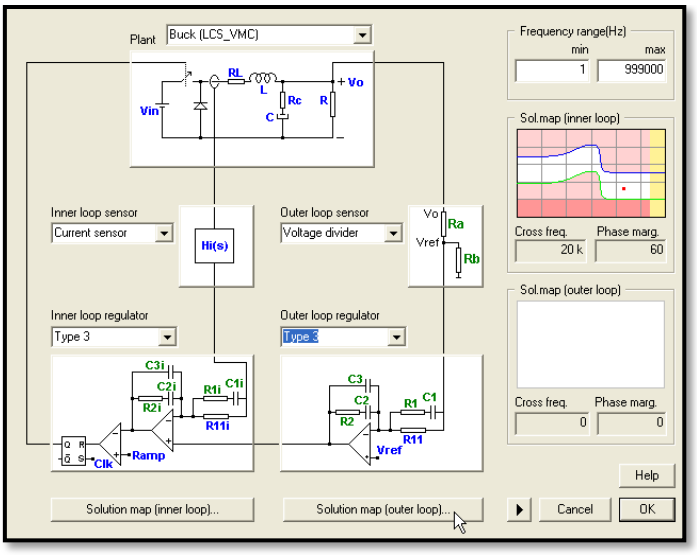
Regulator types:

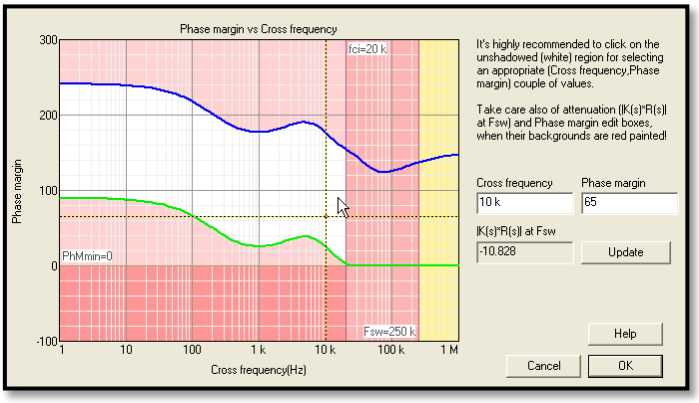
- Type 3
- Type 3 Unattenuated
- Type 2
- Type 2 unattenuated
- PI
- PI unattenuated
- Single Pole
- Single Pole unattenuated

As well as in the case of the inner loop, the cut off frequency and the phase margin must be selected. Also in this case, the solution map is available to help the selection of an stable solution.

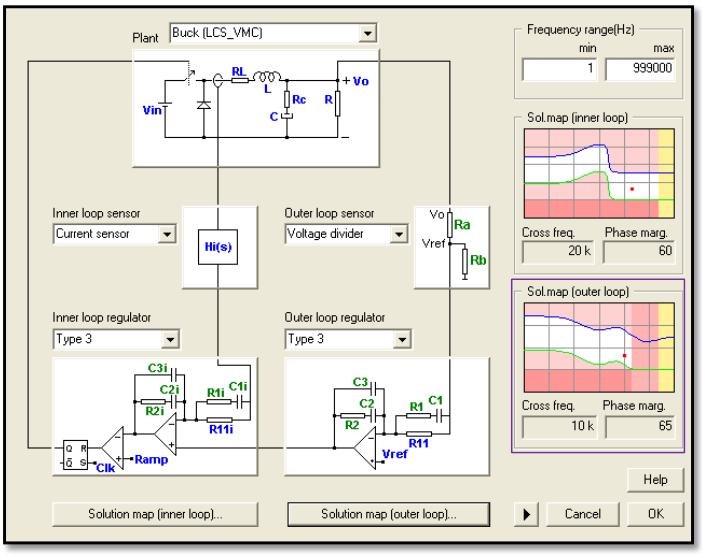
Press the "Solution map (outer loop)" button and the solution map will be displayed. Then select a point just by clicking within the white area.

It should be remarked that, due to stability constraints, the crossover frequency of the outer loop cannot be greater than the crossover frequency of the inner loop. In order to prevent the selection of an outer loop fc greater than the inner loop one, a pink shadowed area has been included in the solutions map of the outer loop.





Once the crossover frequency and the phase margin have been selected, the solution map will be shown on the right of the side of the DC/DC double loop input data window. If, at any time, the two aforementioned parameters need to be changed, just click on the shown solution map. (Seenext figure)

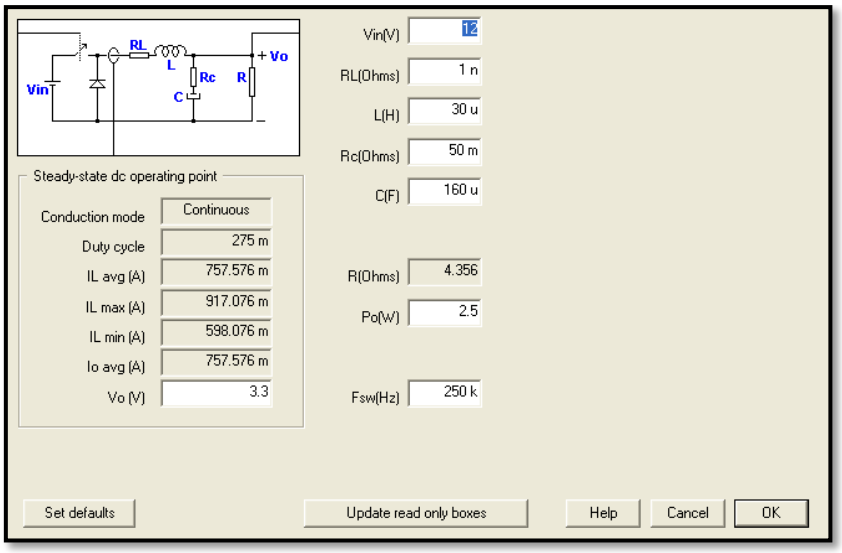


Now accept the selected configuration and confirm the design, the program will automatically show the performance of the system in terms of frequency response, transient response.(See Graphic and text panels windowfor detailed information).

4.1.3 DC / DC Plants

For every DC/DC converter, the input data window allows the user to select the desired input parameters and also provides useful information such as the steady state dcoperating point. For any of the considered DC/DC topologies, the input data correspond to the white shadowed boxes, and the additional information provided by the program will be shown in the grey shadowed boxes.

Lets consider any of the available converters. In the following picture it can be seen that the parameters which define the steady-state dc operating point are placed right below the converter image. Depending on the topology considered in each case, some of them will be input data and some others will be output data.

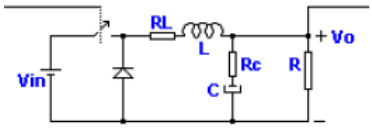


The DC/DC available plants are the following:

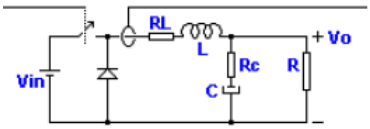
Buck
Boost
Buck-Boost
Flyback
Forward
Text File

4.1.3.1 Buck

When a single loop control scheme is used, the magnitude to be controlled in a buck converter can be either the output voltage or the inductance current. Both possibilities have been included in SmartCrl. The schematics are shown below:

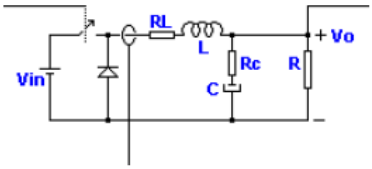


VoltageModeControlledBuck



L-CurrentSensedBuck

In the case of a double loop control scheme, two magnitudes must be sensed simultaneously, a current and the output voltage. Theresultantbuckschemeisthefollowing:

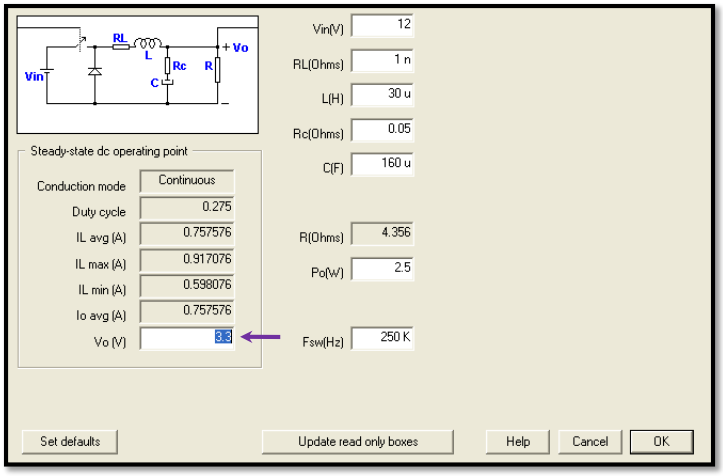


Buck (LCS-VMC)

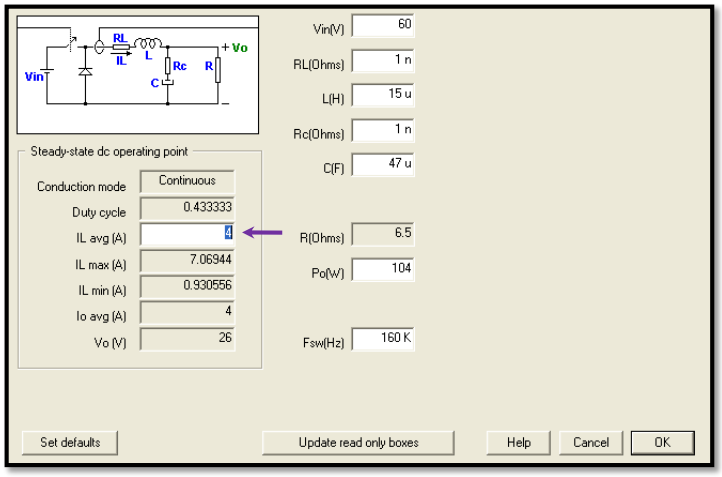
Theinput data windowallows the user to select the desired input parameters and provides useful information such as the steady state dc operating point. This information is placed right below the converter image.

Two examples of the input data window are shown below, in each of them, the white shadowed boxes correspond to the input data boxes while the grey shadowed ones correspond to the additional information provided by the program.

Please, note that the input data is different in case of a voltage controlled plant (output voltage is an input) or a current controlled plant (in this case the current to be controlled is the input data). An example of the input data windows is provided below:



Input Data Window of a Voltage Mode Controlled Buck



Input Data Window of a Current Mode Controlled Buck

The parameters shown in the input data windows are defined below:

Steady-state dc operating point

Conduction Mode It can be Continuous or Discontinuous

Duty Cycle t_{on}/T of the active switch

IL avg Inductance average current (A)

IL max Maximum value of the inductance switching ripple (A)

IL min Minimum value of the inductance switching ripple (A)

Io avg Output average current (A)

Vo Output voltage (V)

Other parameters of the converter

V_{in} Input Voltage (V)

R_L Equivalent Series Resistor of the Inductance (Ohms)

L Inductance (H)

Rc Equivalent Series Resistor of the output capacitor (Ohms)

C Output Capacitor (F)

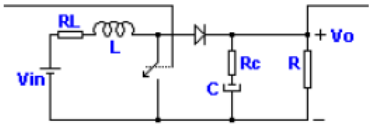
R Load Resistor (Ohms)

P_o Output Power (W)

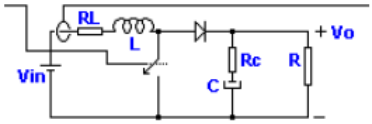
F_{SW} Switching frequency (Hz)

4.1.3.2 Boost

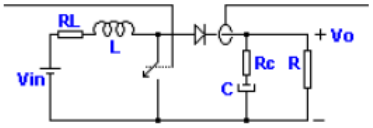
There are three possible magnitudes to be controlled in the boost converter when a single loop control scheme isselected, this is the output voltage, the inductor current and the diode current. Therespectiveschematics are thefollowing:



Voltage Mode Controlled Boost Converter

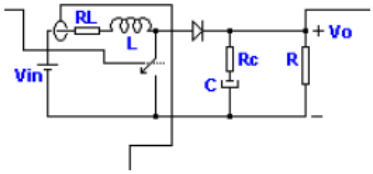


L-current sensed Boost Converter

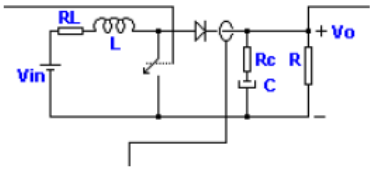


Diode Current Sensed Boost Converter

In the case of a double loop control scheme, the output voltage and a current must be sensed simultaneously. The available plants for double loop designs are included below:



Boost (LCS-VMC)

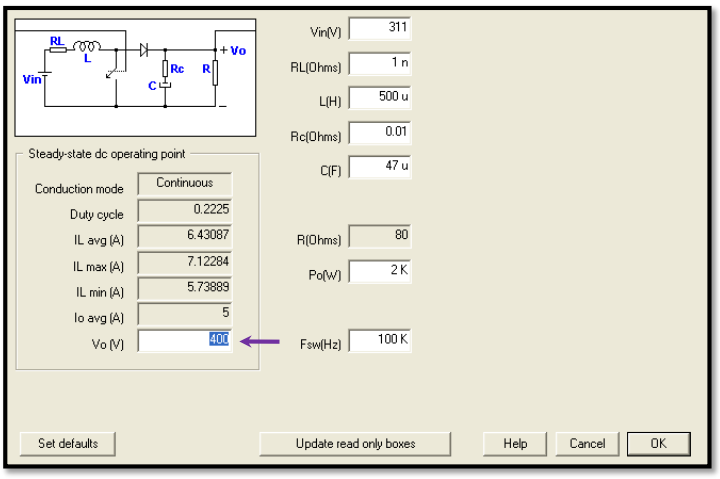


Boost (DCS-VMC)

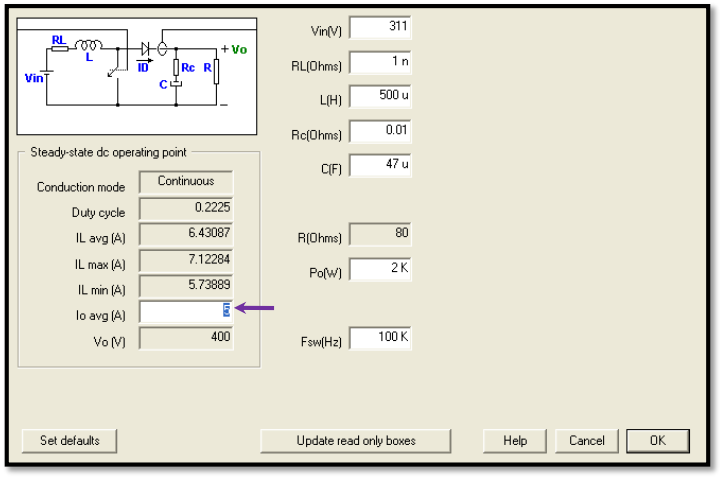
Theinput data windowallows the user to select the desired input parameters and provides useful information such as the steady state dc operating point. This information is placed right below the converter image.

Two examples of the input data window are shown below, in each of them, the white shadowed boxes correspond to the input data boxes while the grey shadowed ones correspond to the additional information provided by the program.

Please, note that the input data is different in case of a voltage controlled plant (output voltage is an input) or a current controlled plant (in this case the current to be controlled is the input data). An example of the input data windows is provided below:



Input Data Window of a Voltage Mode Controlled Boost



Input Data Window of a Current Mode Controlled Boost

The parameters shown in the input data windows are defined below:

Steady-state dc operating point

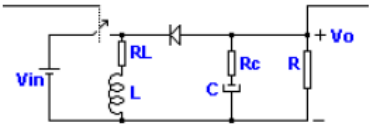
Conduction Mode	It can be Continuous or Discontinuous
Duty Cycle	t_{on}/T of the active switch
IL avg	Inductance average current (A)
IL max	Maximum value of the inductance switching ripple (A)
IL min	Minimum value of the inductance switching ripple (A)
Io avg	Output average current (A)
Vo	Output voltage (V)

Other parameters of the converter

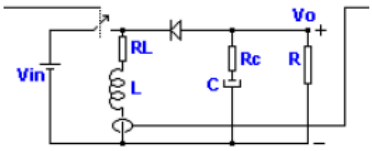
V_{in}	Input Voltage (V)
R_L	Equivalent Series Resistor of the Inductance (Ohms)
L	Inductance (H)
Rc	Equivalent Series Resistor of the output capacitor (Ohms)
C	Output Capacitor (F)
R	Load Resistor (Ohms)
P_o	Output Power (W)
F_{SW}	Switching frequency (Hz)

4.1.3.3 Buck-Boost

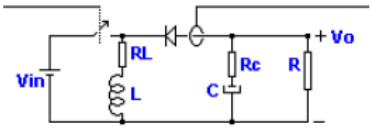
In a single loop control scheme there are three possible magnitudes to be controlled in the buck-boost converter. This is the output voltage, the inductor current and the diode current. Therespectiveschematics are thefollowing:



Voltage Mode Controlled Buck-Boost Converter

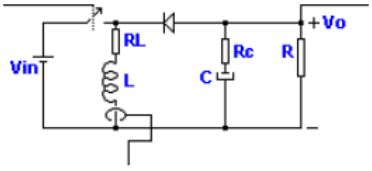


L-current sensed Buck-Boost Converter



Diode Current Sensed Buck-Boost Converter

In the case of a double loop control scheme, the magnitudes sensed are the output voltage and the L current.

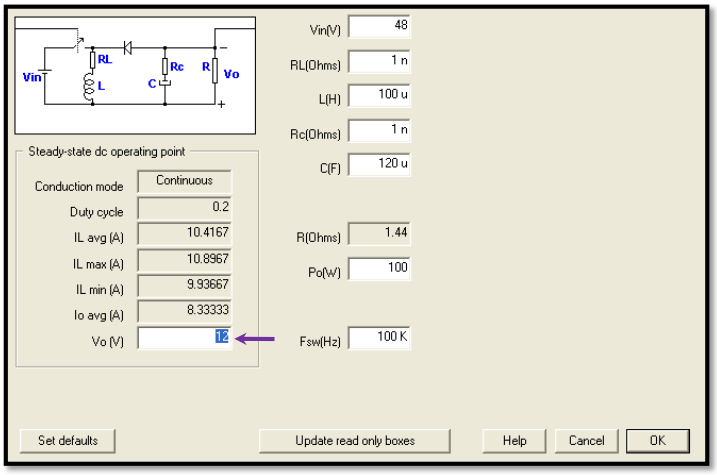


Buck-Boost (LCS-VMC)

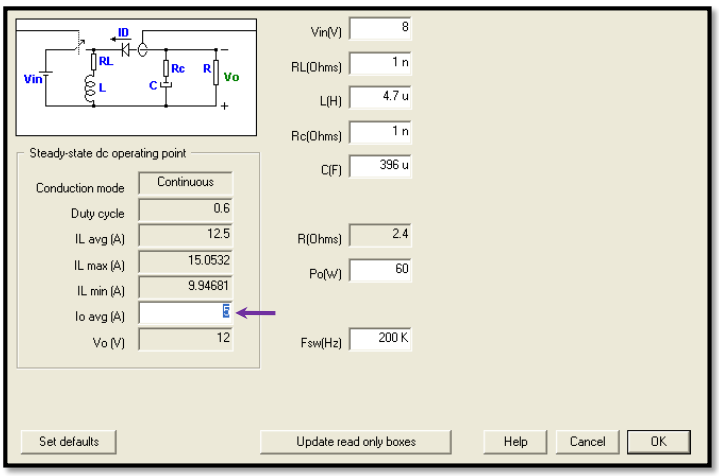
Theinput data windowallows the user to select the desired input parameters and provides useful information such as the steady state dc operating point. This information is placed right below the converter image.

Two examples of the input data window are shown below, in each of them, the white shadowed boxes correspond to the input data boxes while the grey shadowed ones correspond to the additional information provided by the program.

Please, note that the input data is different in case of a voltage controlled plant (output voltage is an input) or a current controlled plant (in this case the current to be controlled is the input data). An example of the input data windows is provided below:



Input Data Window of a Voltage Mode Controlled Buck-Boost



Input Data Window of a Current Mode Controlled Buck-Boost

The parameters shown in the input data windows are defined below:

Steady-state dc operating point

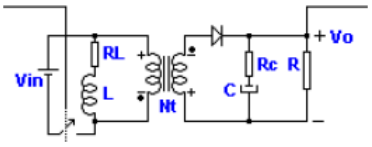
Conduction Mode	It can be Continuous or Discontinuous
Duty Cycle	t_{on}/T of the active switch
IL avg	Inductance average current (A)
IL max	Maximum value of the inductance switching ripple (A)
IL min	Minimum value of the inductance switching ripple (A)
Io avg	Output average current (A)
Vo	Output voltage (V)

Other parameters of the converter

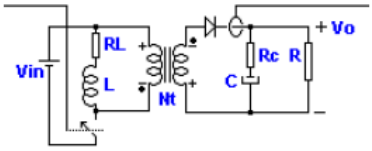
V_{in}	Input Voltage (V)
R_L	Equivalent Series Resistor of the Inductance (Ohms)
L	Inductance (H)
Rc	Equivalent Series Resistor of the output capacitor (Ohms)
C	Output Capacitor (F)
R	Load Resistor (Ohms)
P_o	Output Power (W)
F_{SW}	Switching frequency (Hz)

4.1.3.4 Flyback

In a single loop control scheme, the magnitude to be controlled in a Flyback converter can be either the output voltage or the diode current. Both possibilities have been included in SmartCrl. The schematics are shown below:

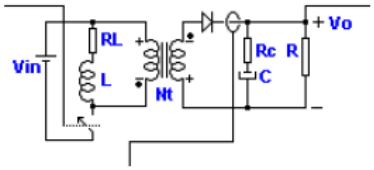


VoltageModeControlledFlyback



DiodeCurrentSensedFlyback

In the case of a double loop control scheme, the magnitudes sensed are the output voltage and the diode current.

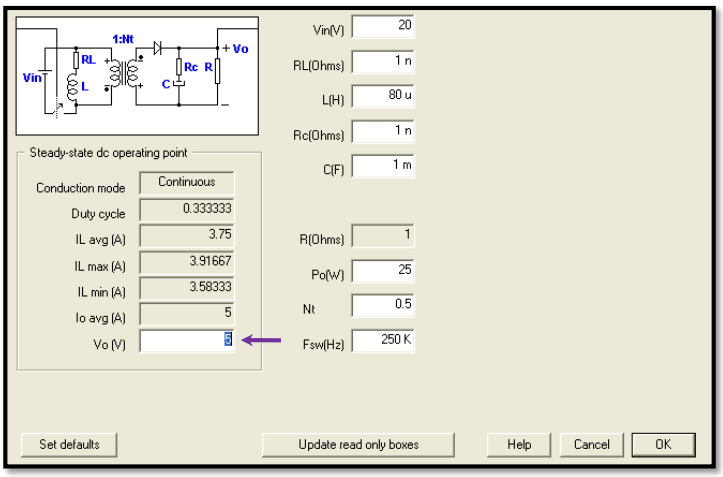


Flyback (DCS-VMC)

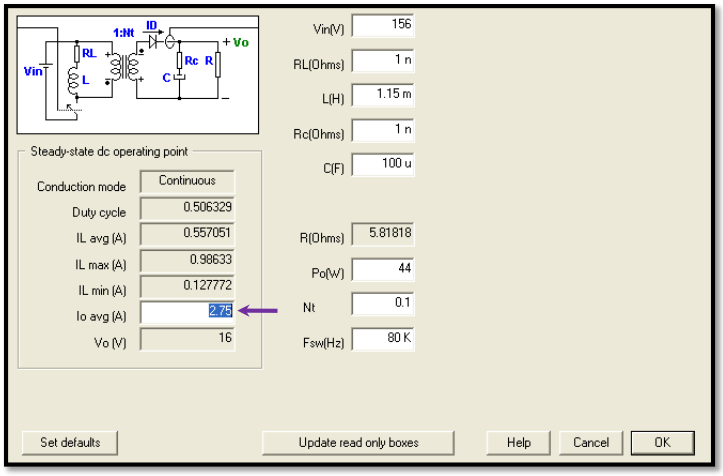
Theinput data windowallows the user to select the desired input parameters and provides useful information such as the steady state dc operating point. This information is placed right below the converter image.

Two examples of the input data window are shown below, in each of them, the white shadowed boxes correspond to the input data boxes while the grey shadowed ones correspond to the additional information provided by the program.

Please, note that the input data is different in case of a voltage controlled plant (output voltage is an input) or a current controlled plant (in this case the current to be controlled is the input data). An example of the input data windows is provided below:



Input Data Window of a Voltage Mode Controlled Flyback



Input Data Window of a Current Mode Controlled Flyback

The parameters shown in the input data windows are defined below:

Steady-state dc operating point

Conduction Mode It can be Continuous or Discontinuous

Duty Cycle t_{on}/T of the active switch

IL avg Inductance average current (A)

IL max Maximum value of the inductance switching ripple (A)

IL min Minimum value of the inductance switching ripple (A)

Io avg Output average current (A)

Vo Output voltage (V)

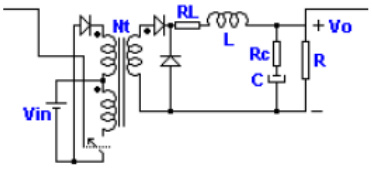
Other parameters of the converter

V_{in}	Input Voltage (V)
R_L	Equivalent Series Resistor of the Inductance (Ohms)
L	Inductance (H)
Rc	Equivalent Series Resistor of the output capacitor (Ohms)
C	Output Capacitor (F)
R	Load Resistor (Ohms)
P_o	Output Power (W)
F_{SW}	Switching frequency (Hz)

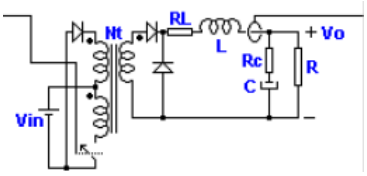
(*)N2 is the transformer secondary side number of turns
N1 is the transformer primary side number of turns

4.1.3.5 Forward

The magnitude to be controlled in a Forward converter can be either the output voltage or the inductance current. Both possibilities have been included in SmartCrl. The schematics are shown below:

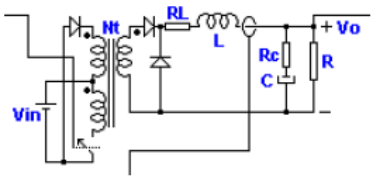


VoltageModeControlled Forward



L-CurrentSensed Forward

In the case of a double loop control scheme, the magnitudes sensed are the output voltage and the L current.

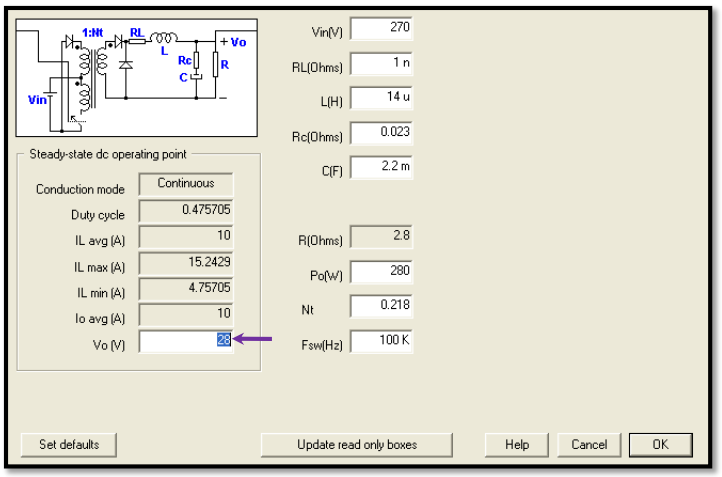


Forward (LCS-VMC)

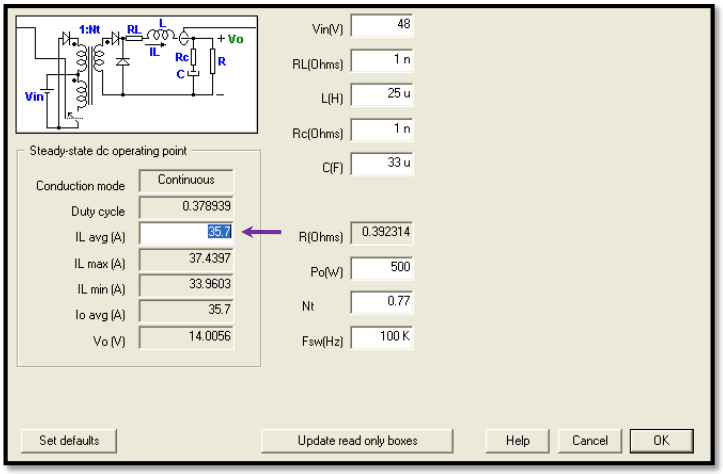
Theinput data windowallows the user to select the desired input parameters and provides useful information such as the steady state dc operating point. This information is placed right below the converter image.

Two examples of the input data window are shown below, in each of them, the white shadowed boxes correspond to the input data boxes while the grey shadowed ones correspond to the additional information provided by the program.

Please, note that the input data is different in case of a voltage controlled plant (output voltage is an input) or a current controlled plant (in this case the current to be controlled is the input data). An example of the input data windows is provided below:



Input Data Window of a Voltage Mode Controlled Forward



Input Data Window of a Current Mode Controlled Forward

The parameters shown in the input data windows are defined below:

Steady-state dc operating point

Conduction Mode	It can be Continuous or Discontinuous
Duty Cycle	t_{on}/T of the active switch
IL avg	Inductance average current (A)
IL max	Maximum value of the inductance switching ripple (A)
IL min	Minimum value of the inductance switching ripple (A)
Io avg	Output average current (A)
Vo	Output voltage (V)

Other parameters of the converter

V_{in}	Input Voltage (V)
R_L	Equivalent Series Resistor of the Inductance (Ohms)
L	Inductance (H)
Rc	Equivalent Series Resistor of the output capacitor (Ohms)
C	Output Capacitor (F)
R	Load Resistor (Ohms)
P_o	Output Power (W)
F_{SW}	Switching frequency (Hz)

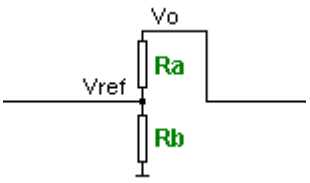
(*)N2 is the transformer secondary side number of turns.
N1 is the transformer primary side number of turns.

4.2 Boost PFC converter

For more details see chapter 9.

4.3 Sensors

4.3.1 Voltage Divider



The Voltage Divider measures and adapts the output voltage level to the regulator voltage reference level.

Its transfer function corresponds to the following equation:

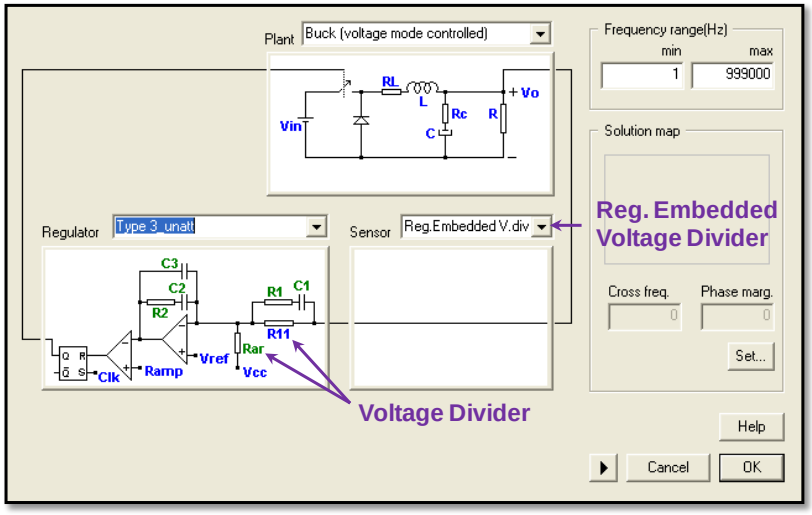
$$K(s) = \frac{Vref}{Vo}$$

Where:

V_{ref} is the regulator reference voltage
V_o is the DC/DC converter output voltage

4.3.2 Reg. Embedded voltage divider

The two resistors that form the voltage divider (R11,Rar) are embedded within the regulator. So, no sensor is represented in the corresponding box. And the voltage divider resistors are highlighted in the regulator figure:

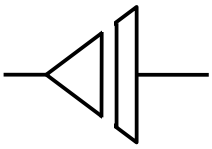


Given the desired output voltage, the regulator reference voltage and the value of R11, SmartCtrl calculates the resistor R_{ar}. the transfer function of the voltage divider at 0Hz is the following:

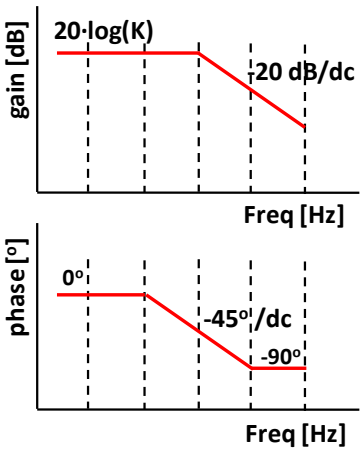
$$\frac{Vo}{Vref} = \frac{Rar}{Rar + R_{11}}$$

4.3.3 Isolated Voltage Sensor

The Isolated voltage sensor is a voltage sensor that provides electrical isolation. Its transfer function is described below. It is available for the flyback and the flyback DC/DC topologies.



$$K(s) = \frac{Gain}{1 + \frac{s}{2 \cdot \pi \cdot fpK}}$$



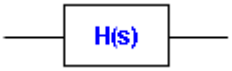
Where:

Gain is the sensor gain at 0dB, its given by the output and the reference voltage.

$$Gain = \frac{Vo}{Vref}$$

fpK is the pole frequency in Hertz

4.3.4 Current Sensor



The current sensor is represented by a generic transfer function box. Internally, the transfer function corresponds to a constant gain in V/A.

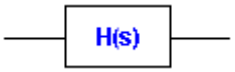
$$K(s) = Gain$$

For example, if the current is sensed using a resistor Rs, the current sensor gain will be the value of this resistor:

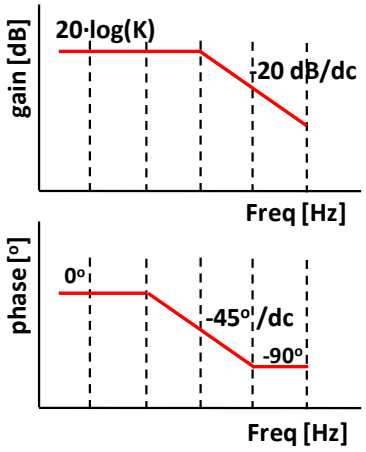
$$K(s) = Rs$$

4.3.5 Hall effect sensor

The Hall effect is a current sensor represented through a generic transfer function box. Internally, its transfer function corresponds to the following equation:



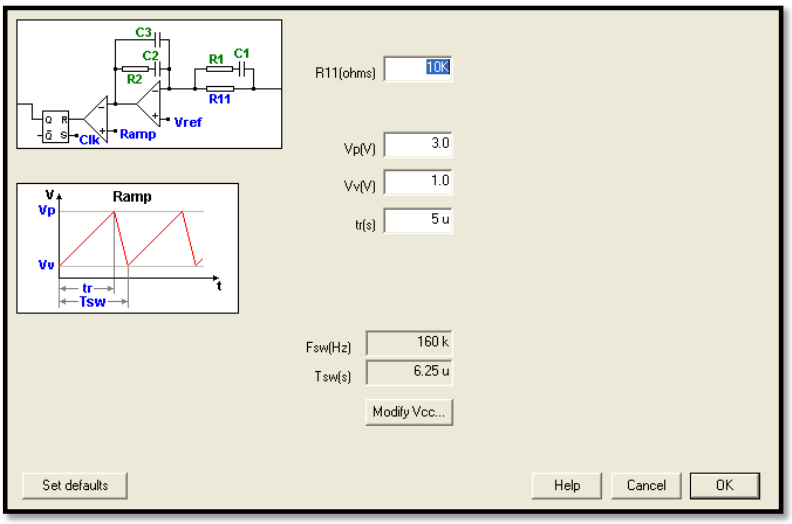
$$K(s) = \frac{Gain}{1 + \frac{s}{2 \cdot \pi \cdot fpK}}$$



Where:
Gain is the sensor gain at 0dB.
fpK is the pole frequency in Hertz

4.4 Regulators

4.4.1 Type 3 regulator



Input Data

R11 Its default value is $10\,k\Omega$

Vp(v) Peak value of the ramp voltage (carrier signal of the PWM modulator)

Vv(v) Valley value of the ramp voltage

Tr(s) Rise time of the ramp voltage

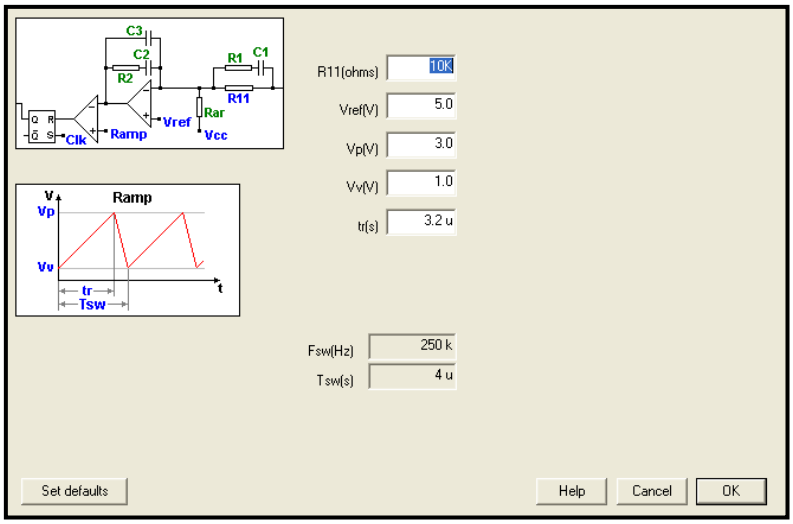
Tsw Switching period

Output Data

The regulator components values (*C1*, *C2*, *C3*, *R1*, *R2*) are calculated by the program and displayed in the correspondingtext panel

4.4.2 Type 3 regulator unattenuated

The voltage divider needed in order to adapt the sensed output voltage to the reference voltage is embedded within the regulator. It corresponds to R_{11} and R_{ar}. This regulator configuration eliminates the attenuation due to the external voltage divider.



Input Data

R11 Its default value is $10\,k\Omega$

Vp(v) Peak value of the ramp voltage (carrier signal of the PWM modulator)

Vv(v) Valley value of the ramp voltage

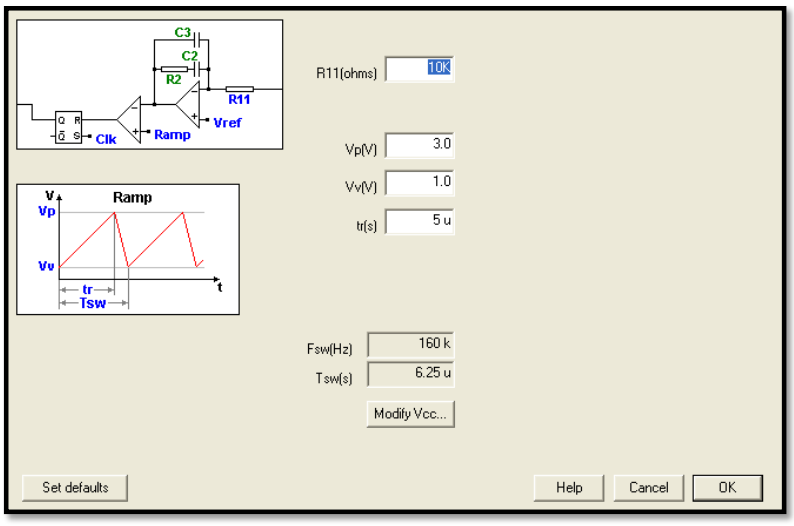
Tr(s) Rise time of the ramp voltage

Tsw Switching period

Output Data

The regulator components values (*C1, C2, C3, R1, R2*) and the resistor $R_{ar}$are calculated by the program and displayed in the correspondingtext panel

4.4.3 Type 2 regulator



Input Data

R11 Its default value is $10\,k\Omega$

Vp(v) Peak value of the ramp voltage (carrier signal of the PWM modulator)

Vv(v) Valley value of the ramp voltage

Tr(s) Rise time of the ramp voltage

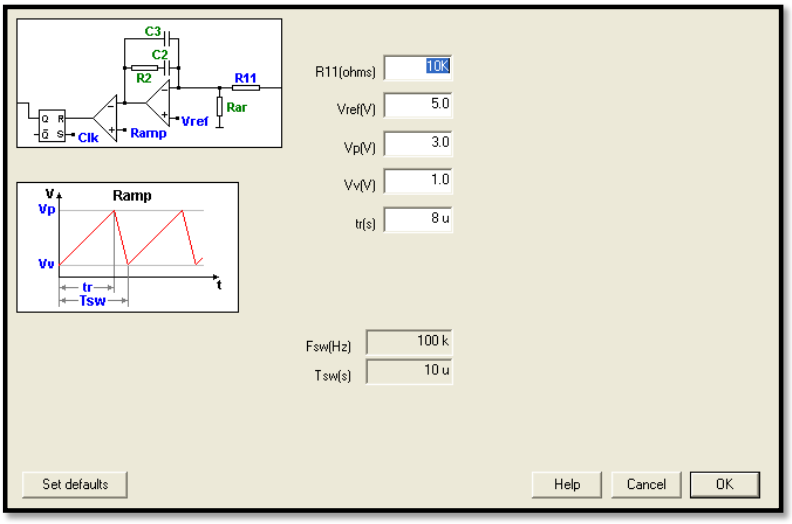
Tsw Switching period

Output Data

The regulator components values (*C2, C3, R2*) and the resistor R_{ar} are calculated by the program and displayed in the corresponding text panel.

4.4.4 Type 2 regulator unattenuated

The voltage divider needed in order to adapt the sensed output voltage to the reference voltage is embedded within the regulator. It corresponds to R_{11} and R_{ar}. This regulator configuration eliminates the attenuation due to the external voltage divider.



Input Data

R11 Its default value is $10\,k\Omega$

Vp(v) Peak value of the ramp voltage (carrier signal of the PWM modulator)

Vv(v) Valley value of the ramp voltage

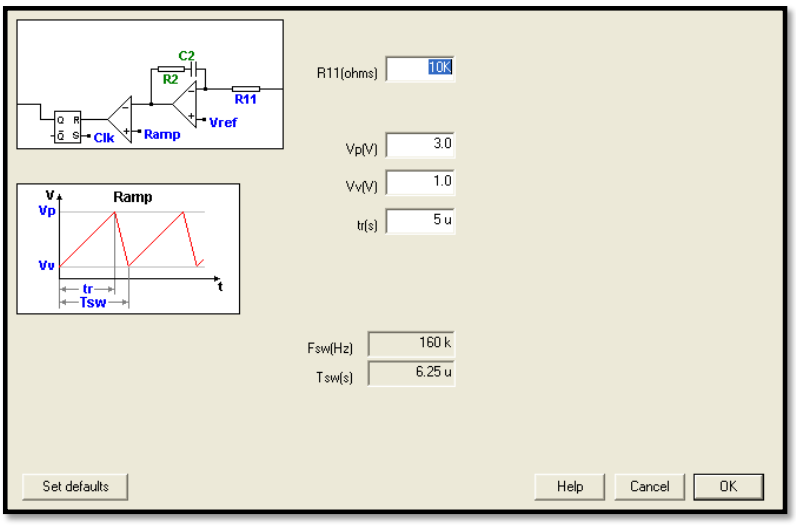
Tr(s) Rise time of the ramp voltage

Tsw Switching period

Output Data

The regulator components values (*C1*, *C2*, *C3*, *R1*, *R2*) and the resistor R_{ar} are calculated by the program and displayed in the corresponding text panel

4.4.5 PI regulator



Input Data

R11 Its default value is $10\,k\Omega$

Vp(v) Peak value of the ramp voltage (carrier signal of the PWM modulator)

Vv(v) Valley value of the ramp voltage

Tr(s) Rise time of the ramp voltage

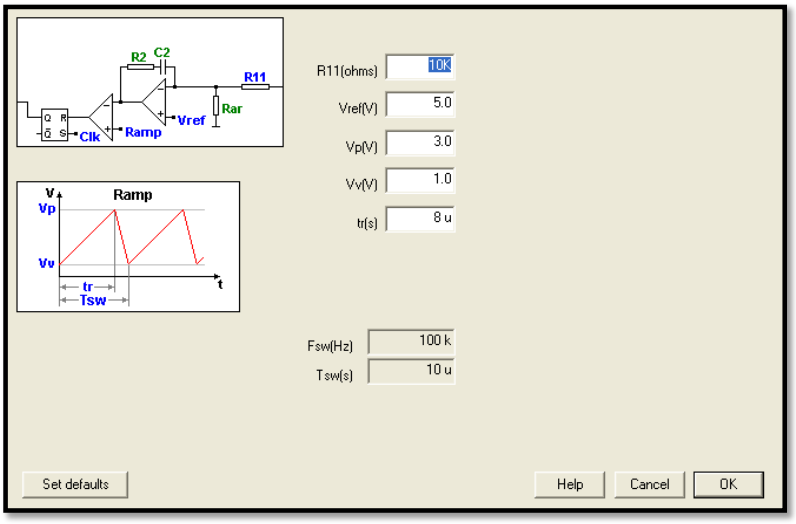
Tsw Switching period

Output Data

The regulator components values (*C2*, *R2*) are calculated by the program and displayed in the correspondingtext panel.

4.4.6 PI regulator unattenuated

The voltage divider needed in order to adapt the sensed output voltage to the reference voltage is embedded within the regulator. It corresponds to R_{11} and R_{ar}. This regulator configuration eliminates the attenuation due to the external voltage divider.



Input Data

R11 Its default value is $10\,k\Omega$

Vp(v) Peak value of the ramp voltage (carrier signal of the PWM modulator)

Vv(v) Valley value of the ramp voltage

Tr(s) Rise time of the ramp voltage

Tsw Switching period

Output Data

The regulator components values (C2, R2) and the resistor R_{ar} are calculated by the program and displayed in the corresponding text panel.

Chapter 5: Graphic and text panels

The window is divided in six different panels. Four of them are graphic panels and the two other are text panels.

The graphic panels are:

- Bode plot Module (dB)
- Bode plot Phase (º)
- Polar plot
- Transient response plot

The text panels are:

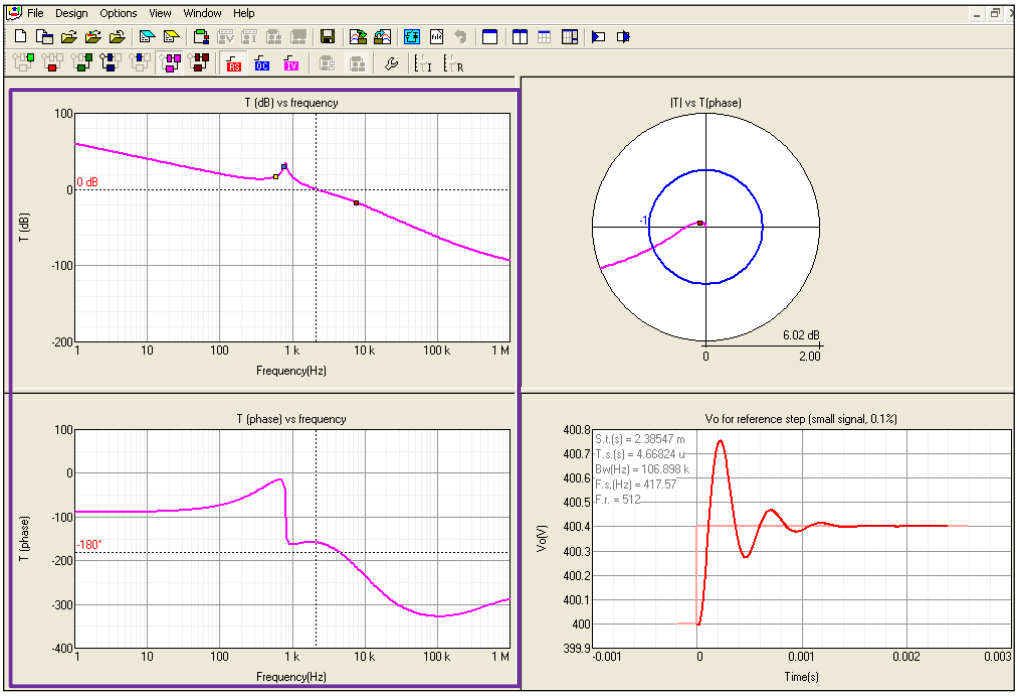
- Input Data
- Output Data

5.1 Bode plots

The Bode plot is used to characterize the frequency response of the system. It consists of two different graphs, the gain or module plot and the phase plot versus frequency. Frequency is plotted in a log axe.

Module plot (dB) Plots the module of a given transfer function in decibels (dB) versus frequency. It is represented in the upper left panel of the SmartCtrl window.

Phase plot (º) Plots the phase of a given transfer function in degrees versus frequency. It is represented in the bottom left panel of the SmartCtrl window.



In SmartCtrl there are seven different transfer functions that can be plotted in the Bode plot. To represent any of them, just click on the corresponding icon of the View Toolbar or select the corresponding transfer function within the View Menu.

Manual placement of poles and zeros

Additionally, when a type 3 or type 2 is used, poles and zeros of the compensator are represented by means of three little squares.

Yellow corresponds to fz
Red corresponds to fp
Blue corresponds to fi

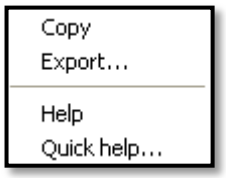
The placement of the aforementioned zeros and poles can be varied by the designer just by clicking and dragging on each square. To enable this option manual method tag in the design method box must be selected.

Cross frequency

The cross frequency of the open loop is shown by means of a pair of dashed lines on the open loop transfer function of the system.

Click on right button

By right clicking on each plot a new window is opened with some additional options.



Copy Copy de Bode Plot to clipboard

Export This option allows exporting the data of the all frequencies response in several formats.

Help Link to the on-line SmartCtrl help

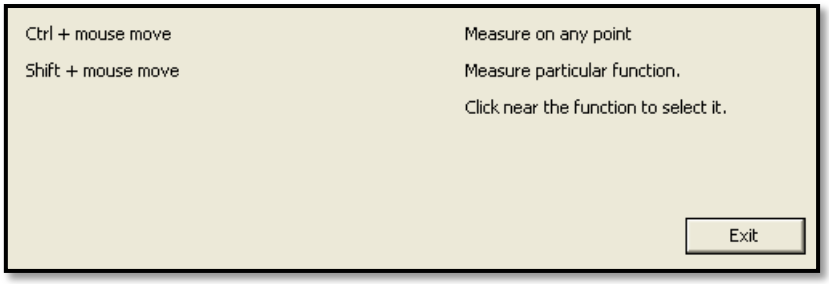
Quick Help Shows a short explanations about how to measure directly on the plot

Measurement tools

Two different types of cursors are available:

Ctrl + mouse Keep the Ctrl key pressed and move the mouse. Two crossed red lines are displayed and the two coordinates of the point on which the mouse is placed are given. You can measure at any point within the graph area.

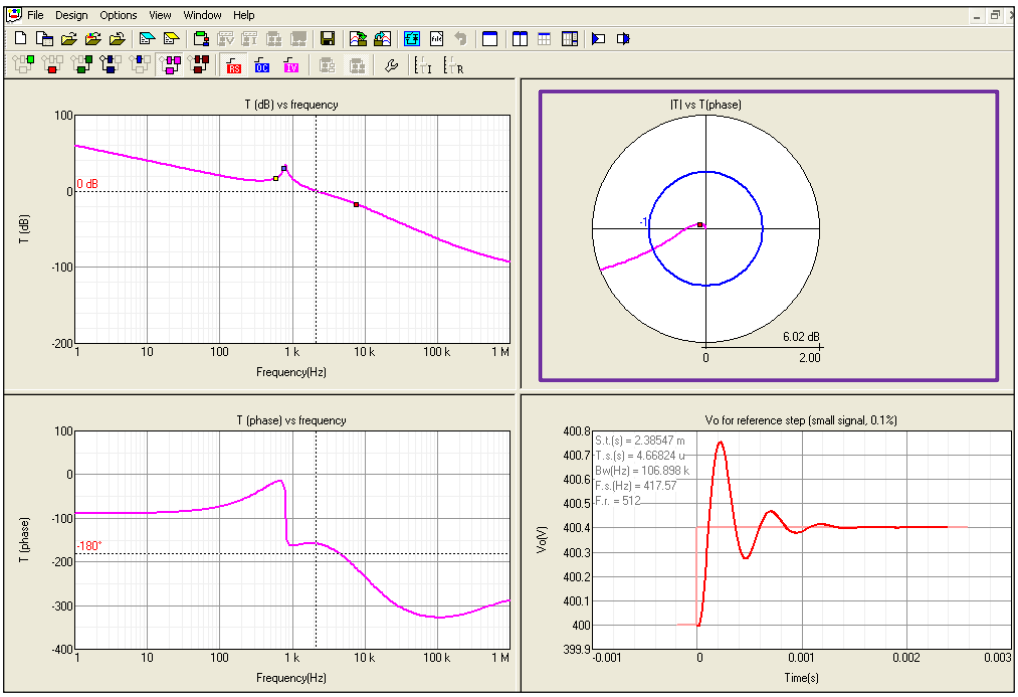
Shift+mouse Keep the Shift key pressed and place the mouse near one of the displayed module traces. The cursor will track itself to that trace, and the cursor will measure simultaneously the phase and module of the tracked trace.
If you want to track the cursor to other trace, just left click on that trace.
Additionally, if the selected trace is open loop transfer function, SmartCtrl will measure simultaneously on both Bode plots (module and phase) and on the Nyquist diagram.



5.2 Polar Plots

The Nyquist diagram, together with the Bode plots, is a graphical representation of the frequency response of a linear system.

For each ω, the resulting open loop transfer function is represented as Im(T) vs R(T). So, the gain at this ω is the distance from the represented point to the origin, and the phase is the corresponding angle.



In terms of stability, the polar Nyquist diagram provides a graphic and easy to evaluate criterion of the closed loop system stability based on the open loop system frequency response. This is, if the open loop transfer function is stable (no RHP poles), the closed loop system will be unstable for any encirclement of the point (-1, j0).

In SmartCtrl the designer can determine the system stability at a glance since a unity circle is provided (in blue).

Poles and zeros

Poles and zeros of the compensator are represented by means of three little squares.

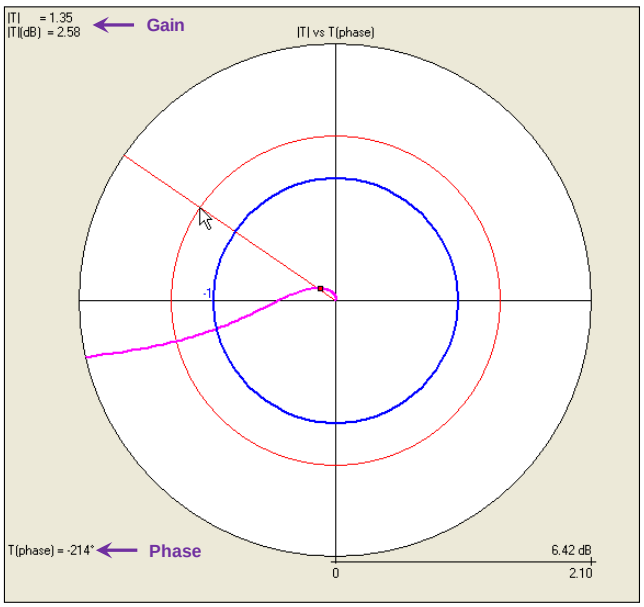
Yellow corresponds to fz
Red corresponds to fp
Blue corresponds to fi

However, unlike in the Bode plots, they cannot be placed manually.

Measurement tool

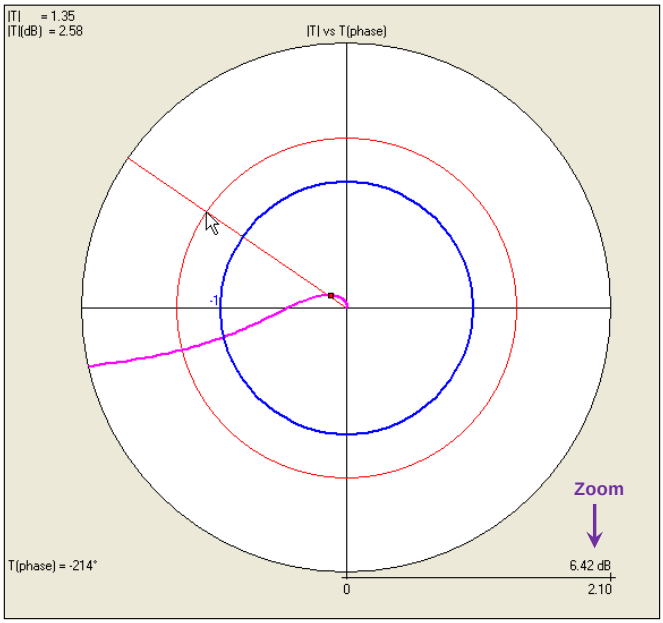
In order to ease the determination of the gain and phase of any point within the polar plot, a measurement tool has been implemented.

If the Ctrl key is press while the mouse arrow is pointing to any point of the open loop transfer function a polar cursor will be shown, which measures both the gain and the phase. These are given numerically in the upper left corner of the polar plot panel and in the lower left corner of the polar plot, respectively. Gain is given both in natural scale and in dB, and phase is given in degrees.



Zoom

A zoom-in and zoom-out tool has been implemented by left-clicking and dragging the mouse within the white area of the polar plot. The relative scale is given by the radio of the outer circle both in dB and natural scale.

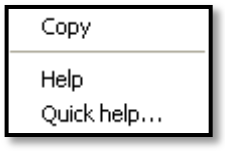


Copy to clipboard

The same way as in the Bode plots and the transient response plots, a copy to clipboard option is available through right click on the polar plot are that will allow the user to copy the current graph to the clipboard.

Click on right button

By right clicking on each plot a new window is opened with some additional options.



Copy Copy de Bode Plot to clipboard

Help Link to the on-line SmartCtrl help

Quick Help Shows a short explanations about how to measure directly on the plot

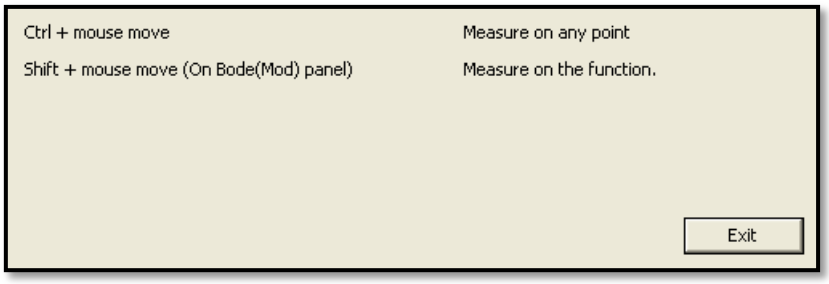
Measurement tools

Two different types of cursors are available:

Ctrl + mouse Keep the Ctrl key pressed and move the mouse. Two crossed red lines are displayed and the two coordinates of the point on which the mouse is placed are given. You can measure at any point within the graph area.

Shift+mouse Keep the Shift key pressed and place the mouse near one of the displayed module traces. The cursor will track itself to that trace, and the cursor will measure simultaneously the phase and module of the

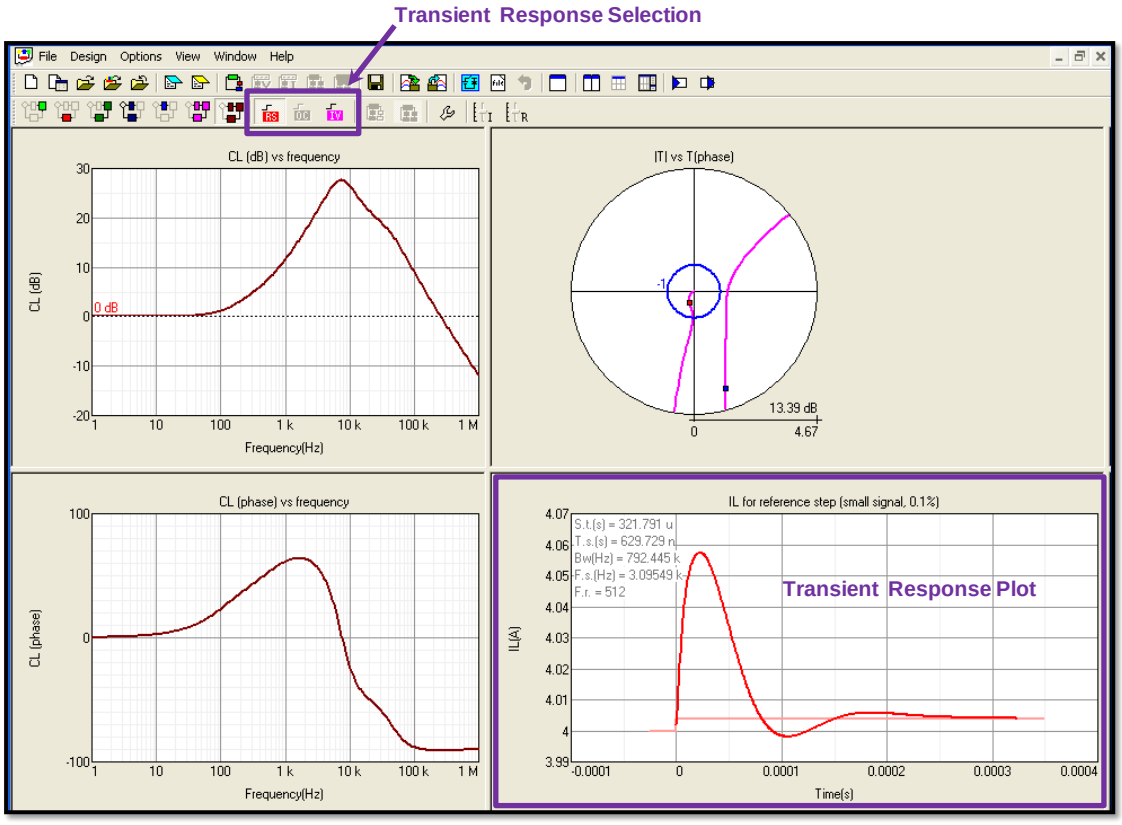
tracked trace.
If you want to track the cursor to other trace, just left click on that trace.
Additionally, if the selected trace is open loop transfer function, SmartCtrl will measure simultaneously on both Bode plots (module and phase) and on the Nyquist diagram.



5.3 Transient response plot

Transient response specifications, such as setting time and voltage peak transient values, are usually critical specifications when designing the control stage of a power converter. Therefore, providing a quick view to the transient response of the converter may greatly help the designer during the design process.

In SmartCtrl the three most significant transient responses have been developed. They can be plotted just by clicking on the corresponding icons of the View Toolbar or selecting the corresponding transient response within the View Menu.



By right clicking on the transient response plot, the following options are displayed.

Export

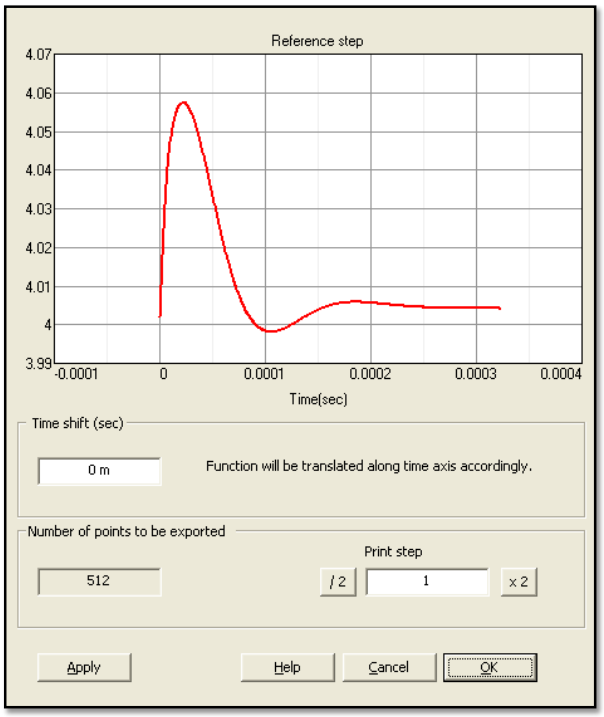
This option allows the user to export the current transient responses to a file which could be either .txt or .smv format. It is placed within the menu displayed through right click on the transient response panel.

Time shift:

This options allows the user to shift the time axis

Print step:

This option allows modifying the number of points to be exported. If the print step is multiplied by 2, only one point per two ones will be saved. This helps to reduce the size of the output file.



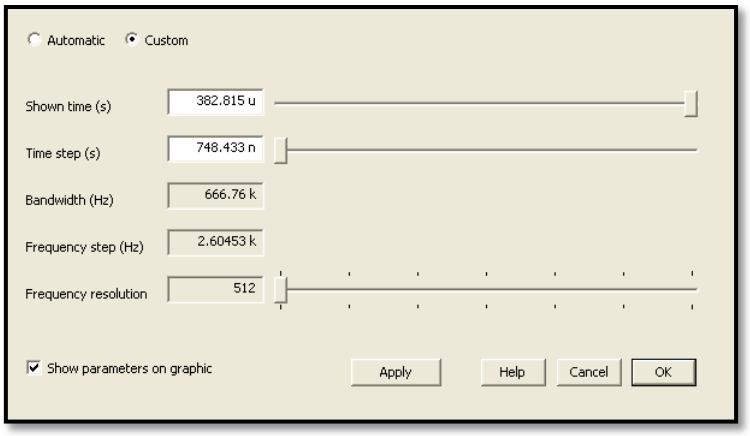
Copy

This allows the user to copy the current graphs in the clipboard

Modify transient parameters

This option allows the user to customize the transient response plot as well as the parameters of the computation algorithm

SmartCtrl makes an automatic selection of the parameters as the user modifies his design. By right clicking on the transient plot and selection the Custom option, a set of sliders are displayed so that the user is able to customize the settings listed bellow.

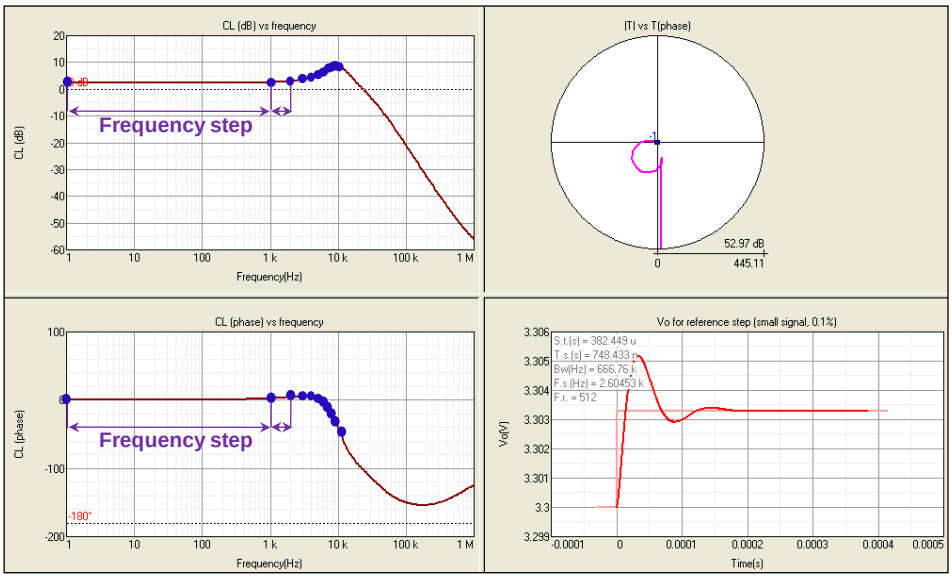


Time step: This option allows modifying the time interval between data points.

Frequency resolution: The transient response computation is based on sampling the frequency response of the power converter. The higher the resolution, the higher the number of sampled points, which means higher accuracy but also longer computational time. Therefore, the trade-off can be considered by the user.

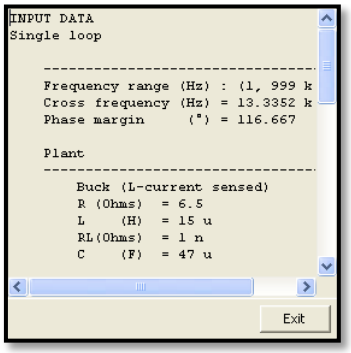
Shown time: This option allows the user to modify the time period displayed in the window. The maximum value is limited by the time step multiplied by the frequency resolution.
A zoom effect could be obtained by decreasing the "shown time", decreasing also the "time step" parameter and finally increasing the "frequency resolution" if necessary.
In addition, the following information is displayed for informative purposes.

Frequency step: The frequency separation between two sampled frequency points. It is determinate by the frequency resolution and the bandwidth. An excessive high frequency step may lead to an incorrect transient plot.
Bandwidth: It determinates the maximum sampled frequency and is directly related to the time step selected by the user. An excessively low value may lead to an incorrect transient plot.

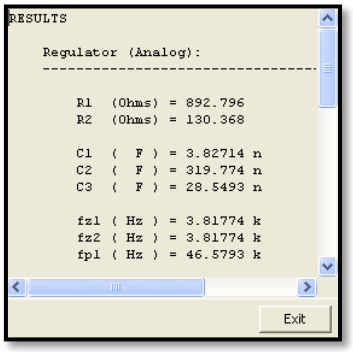


5.4 Text panels

There upper right and lower right panels are the input data panel and output data panels respectively.



Input Data panel.



Output Data panel

The input data panel summarizes the input parameters of the system such as the plant parameters, the steady-state dc operating point, the regulator parameters, etc...

The output data panel shows the regulator resistors and capacitors values as well as the frequencies of poles and zeros and the most important open loop characteristics. This is, the phase margin, gain margin and attenuation at the switching frequency.

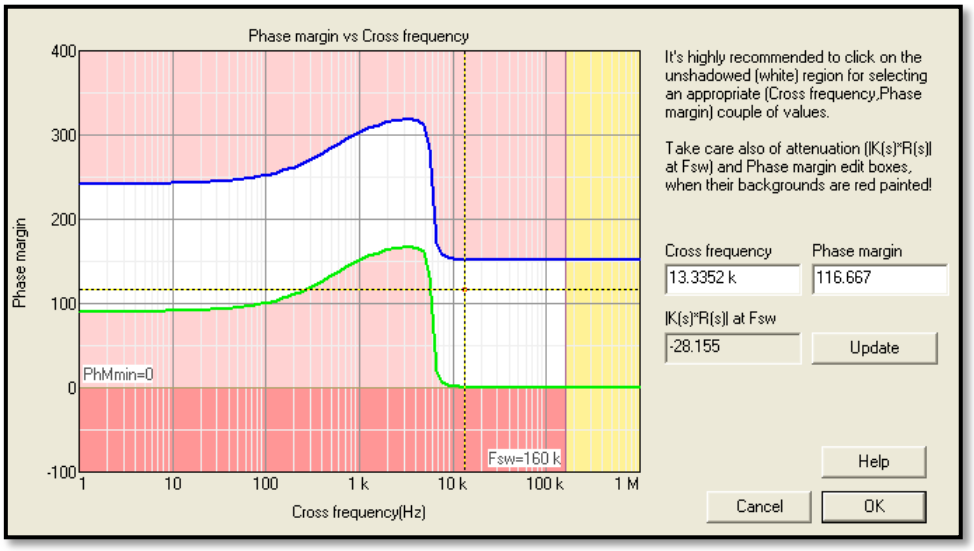
Chapter 6: Solutions Maps

The appropriate selection of f_{cross} and PM is one of the key issues for loop optimization.

In order to ease the first attempt when designing a control loop, an estimation of the stable solutions space has been developed under the name of solutions map. Based on the selected plant, sensor and type of regulator, the solutions map provides a "safe operating area" of the different combinations of f_{cross} and PM that lead to stable systems. The two parameters involved are represented as PM vs frequency.

- Just by clicking within the white area, a set of (f_{cross} and PM) that lead to an stable solution is selected.
- The input boxes (white background) are automatically updated
- And so is the attenuation achieved at f_{sw} box. It is an output parameter (grey background) and represents the attenuation achieved by the open loop at the switching frequency.

Additionally, when any of the three aforementioned values is uncommonly low or high, the boxes background are red-colored in order to draw the designer attention.



Boundaries

The boundaries, which determine the valid area (white area), represent the maximum and minimum phase margin that can be achieved for any kind of compensator.

- The simple integrator is a particular case of any regulator, therefore it provides the lower PM limit by adding 90 degrees to the phase of the open loop transfer function without regulator (plant, sensor and modulator) (green line).
- The upper limit of the solution map is given by the maximum phase boost provided by each kind of compensator (blue line).

In terms of frequency, the solutions space is limited by the switching frequency, f_{sw}.

When the first design point has been selected within the “Solution Map”, SmartCt shows its main screen. In the main screen the solutions Map will be shown as a floating window. The position of this window can be changed by the user by right clicking on the Solution Map window plus mouse move. Important Warning messages will be shown in the bottom part of the Solution Map window.

Chapter 7: Design Methods

The design method box is enabled or disabled by clicking on the icon of theView Toolbar.

The design method box includes the following utilities:

Design method tags

Each tag correspond to one of the three different design methods available for the regulator calculation, this is:

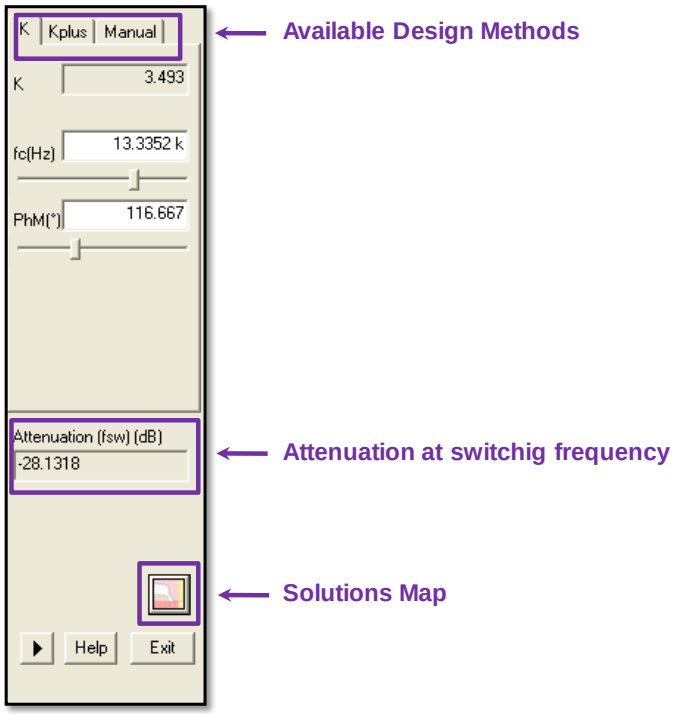
K-method
K plus method
Manual

Attenuation at switching frequency

This output box displays the attenuation achieved by the open loop transfer function at the switching frequency.

Solutions map

Based on the selected plant, sensor and type of regulator, the solutions map provides an estimation if the stable solutions space that lead to stable solutions. The two parameters involved are represented as PM vs frequency.

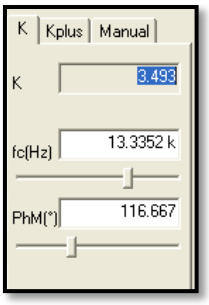


Two change the considered cross frequency and the phase margin, the designer can either change their values in the white-coloured boxes, use the sliders or just click on a different point within the solutions map.

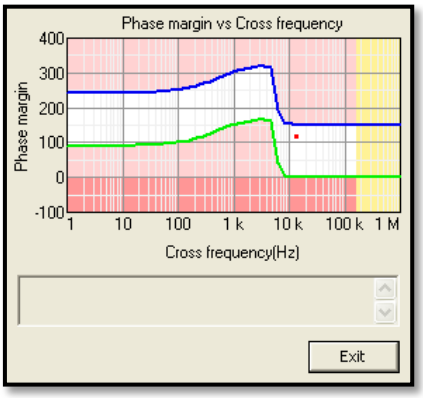
7.1 K-factor Method

The K factor allow the designer to choose a particular open loop cross-over frequency and phase margin, and then determine the necessary component values to achieve these results. In SmartCtrl, the regulator component values are displayed within theresults text panel.

The two input parameters of the K factor (f_c, PM) can be easily changed in the K method tag of the design method box.



They can be also modified by clicking on the solutions map and the K method will recalculate the regulator to fit the new values. Remember that the stable solutions area is the white one.



In SmartCtrl it is possible to use the K method for both, the Type 2 and Type 3 regulators.

K factor for Type 3 regulator

A Type 3 regulator is formed by two zeroes, two poles and a low frequency pole. When a Type 3 regulator is chosen, the K factor method assumes that a double pole and a double zero must be placed to design the compensator.

- The double zero is placed at $\frac{f}{\sqrt{K}}$ frequency
- The double pole is placed at $f \cdot \sqrt{K}$ frequency

Where K is defined as the ratio of the double pole frequency to the double zero frequency and the frequency f is the geometric mean between the frequency of the double zero and the frequency of the double pole.

So, the maximum open loop phase boost is achieved at frequency *f*, and it is assumed that the regulator is designed so that the open loop cross-over occurs at frequency *f* also.

K factor for Type 2 regulator

A Type 2 regulator is formed by a single zero, a single pole and a low frequency pole. When a Type 2 regulator is selected the pole and the zero are placed as follows:

- The zero is placed at $\frac{f}{K}$
- The pole is placed at $f \cdot K$

Where the K factor is defined as the square root of the ratio of the pole frequency to the zero frequency and*f* is the geometric mean of the zero frequency and the pole frequency.

The maximum phase boost from the zero-pole pair occurs at frequency *f*, and it is assumed that the regulator is designed so that the open loop cross-over occurs at frequency *f* also.

7.2 Kplus Method

The Kplus method is based on the K-factor and the inputs are the same:

- The desired cross-over frequency (f_c)
- The target phase margin (PM)

However, unlike K-factor method, cross-over frequency is no longer the geometric mean of the zeroes and the poles frequencies.

The Kplus method provides an additional design freedom degree with respect to the conventional Kfactor method, since the Kplus method places the double zero frequency f_z a factor "α" below f_{cross} ($f_Z = \frac{f_C}{\alpha}$) and the poles a factor "β" above f_{cross} ($f_Z = f_C \cdot \beta$).

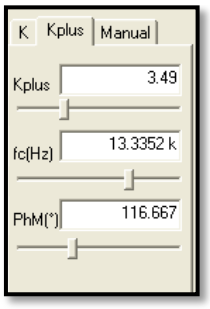
Where "α" is set from f_{cross} and phase margin. This parameter allows the designer to select the exact frequency in which the zeroes will be placed. After that, "β" is automatically calculated.

The additional degree of freedom obtained with Kplus can be used as follows:

- *If "α" is set to be lower than K* (from the K-factor method), higher gain at low frequencies but less attenuation at switching frequency (f_{sw}) are obtained.
- On the contrary, *if "α" is set higher than K* (from the K-factor method), the control loop has less gain at low frequency but more attenuation at f_{sw}. It should be remarked that the phase margin is the same in all cases.
- When *"α" is equal to K,* both methods are equivalent.

Therefore, the Kplus method can be used to improve the overall performance of the control loop in those cases where a slightly larger high frequency ripple could be admitted at the input of the PWM modulator.

In the same way as the K method, when the Kplus tag is selected, the user can easily change the input parameters, phase margin and cross-over frequency And also an additional parameter, Kplus, which corresponds to the aforementioned "α" factor.



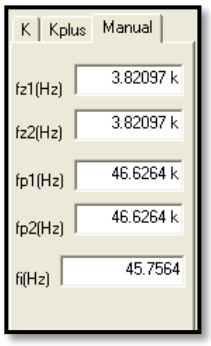
They can also be modified by clicking on the solutions map and the Kplus method will recalculate the regulator to fit the new values. Remember that the stable solutions area is the white one.

7.3 Manual

This method allows placing poles and zeroes independently from each other. It is used when the designer would like to refine the results obtained from the K and Kplus methods or when these automatic methods do not provide a valid solution.

The manual method is provided for both the type 3 and type 2 regulators. Their poles and zeroes frequencies can be varied by directly dragging and dropping them in the Bode plots.

Or typing the frequencies of poles and zeroes in corresponding input boxes of the design methods box.



In the case of a **Type 3 regulator**, the designer can adjust the frequency values of:

- The two zeroes,
- The two poles
- And the low frequency pole

In the case of a **Type 2 regulator**, the available frequencies are:

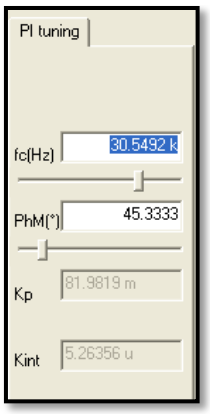
- The zero
- The pole
- And the low frequency pole

7.4 PI tuning

The PI tuning method input parameters are the same as in the K-factor method:

- Phase margin
- Cross-over frequency

From these two input parameters, SmartCtrl calculates the both the proportional (K_p) and integral (K_{int}) gains and shows them in the corresponding output boxes.

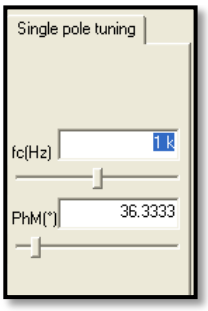


The same as in the other automatic calculation methods, the phase margin and cross-over frequency can be set directly by clicking in the solutions map.

7.5 Single Pole tuning

The I tuning method is the equivalent of the manual method but for integral regulators.

The simple integrator is formed by a single pole, which frequency must be selected by the designer. Given this frequency, the associated phase margin is automatically calculated by the program.



The solutions map of an integrator is a single line that represents the addition of 90º to the open loop without regulator transfer function. So, the designer can also determine the cross-over frequency by clicking in the solutions map, the same way as in the other design methods.

Chapter 8: Parametric Sweep

The parametric sweep can be accessed either through the Data Menu or the View Toolbar icons. The SmartCtrl program distinguish among two different parametric sweeps:

Input Parameters Parametric Sweep .
It allows the variation of all the input parameters of the system. These are:

- General Data
- Plant
- Sensor
- Regulator

Regulator Components Parametric Sweep **.**
It allows to vary the component values of the regulator. This is, the resistor an capacitor values that conform the regulator.

8.1 Input Parameters Parametric

To access the input parameters parametric sweep the user can either click must click on the button , placed within the View toolbar**or** through the Data Menu > Parametric Sweep > Input parameters.

The functions available within the input parameters parametric sweep are the following:

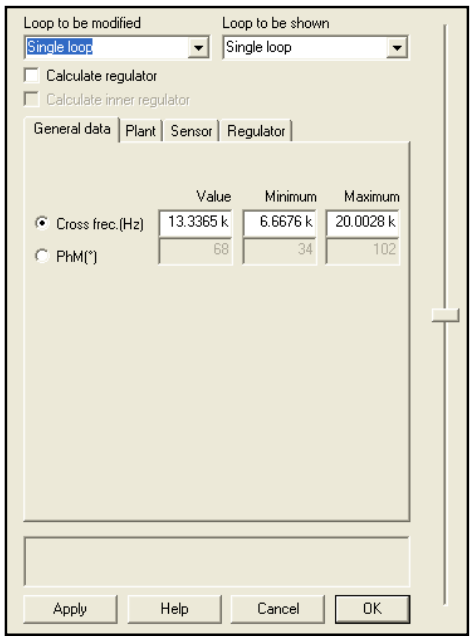
Loop to be modified Select which loop would you like to modify. This option is only available in the case of a double loop design, where the designer can select amongst the inner loop or the outer loop

Tick box "calculate regulator" When this box is selected, the regulator is recalculated for each new set of parameters along the parametric sweep.
If it not selected, the regulator is fixed to the last one calculated

Loop to be shown Select which loop results would you like to display. This option is only available in the case of a double loop design, where the designer can select amongst the inner loop or the outer loop.
The parameters to be varied are related to the open loop parameters. The designer is asked to provide a range of variation. The available parameters are:

- Cross Frequency (Hz)
- Phase Margin (º)

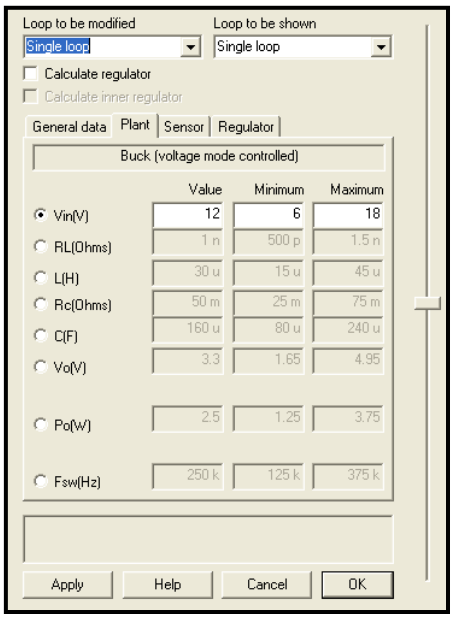
Cross Frequency (Hz)
Phase Margin (°)



Tag "General Data"

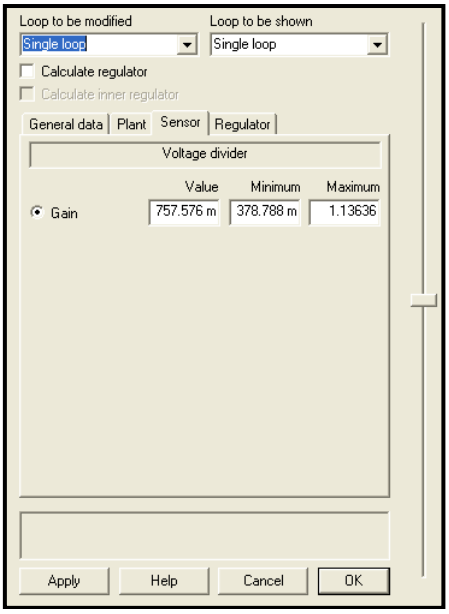
The parameters to be varied are related to the open loop parameters. The designer is asked to provide a range of variation. The available parameters are:

- Cross Frequency (Hz)
- Phase Margin (º)



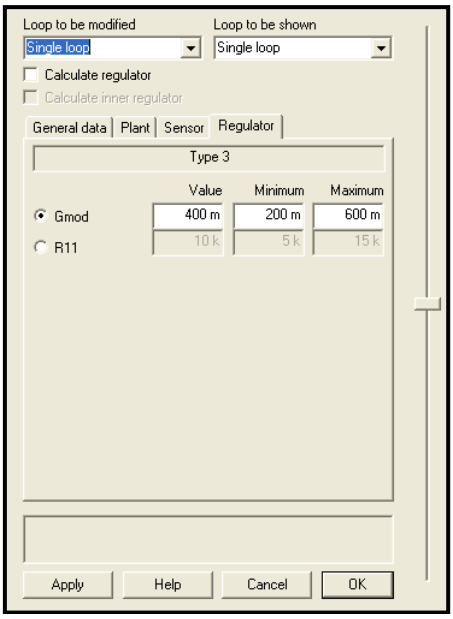
Tag "Plant"

The parameters available for variation are related to the plant input parameters. The user must introduce a minimum and a maximum value for the variable selected, in order to provide its range of variation. Only one parameter can be varied at a time



Tag "Sensor"

Two different sensor are available for variation. The voltage divider and the Hall effect sensor. The parameter to be varied in the voltage divider is its voltage gain (V_{ref}/V_o). In the case of the Hall effect sensor there are to available parameters: its gain at 0Hz and the pole frequency.



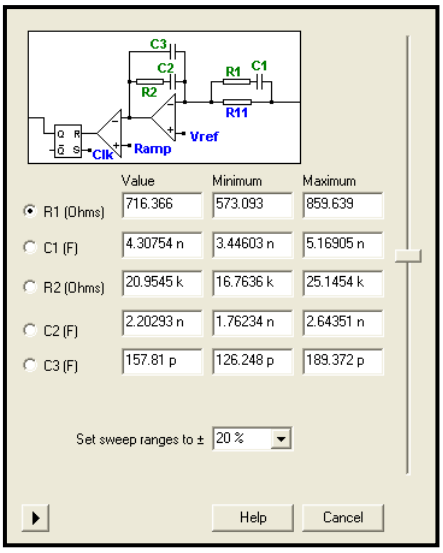
Tag "Regulator"

The parameters available correspond to the modulator gain and the Resistor R11.

8.2 Regulator Components Parametric Sweep

To access the regulator components parametric sweep the user can either click on the button , placed within the view toolbar or through the Data Menu > Parametric Sweep >Regulator components.

The regulator components parametric sweep is oriented to the variation of the resistors an capacitors values that conform the regulator. The parametric sweep is available for Type 3 and Type2 regulators.

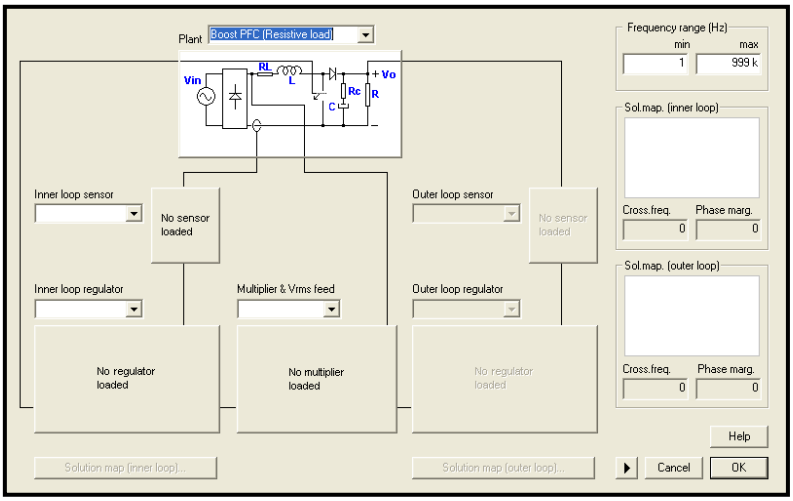


Chapter 9: Power Factor Corrector

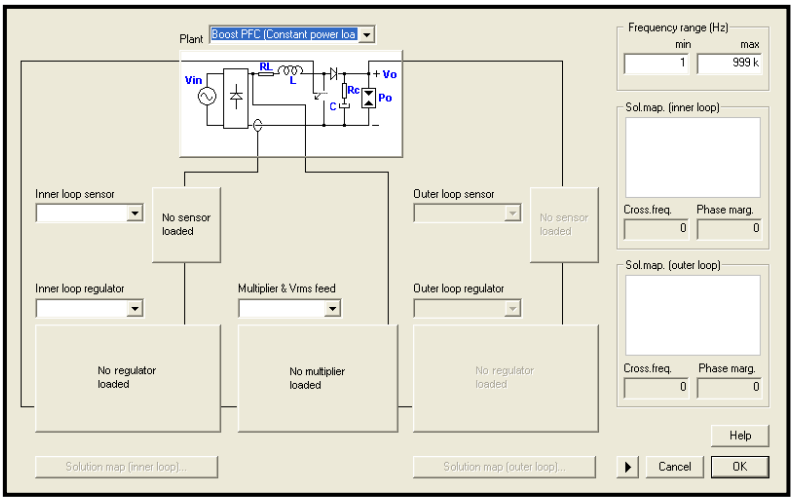
The power factor corrector based on a boost topology has a double control loop, formed by an inner current loopand an outer voltage mode loop. The double loop setup must be built sequentially. The program will guide you to build it, enabling the following step and keeping everything else disabled.

The available plant is a boost converter. The outer loop is a voltage mode control, while the inner loop is a current controlled one, and the current is sensed on the inductance.

The predefined plants are the following:

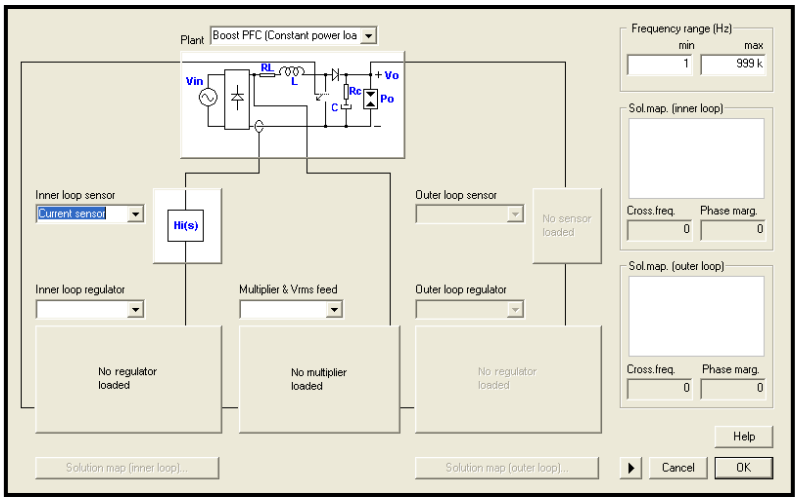


Boost PFC (Resistive load)



Boost PFC (Constant power load)

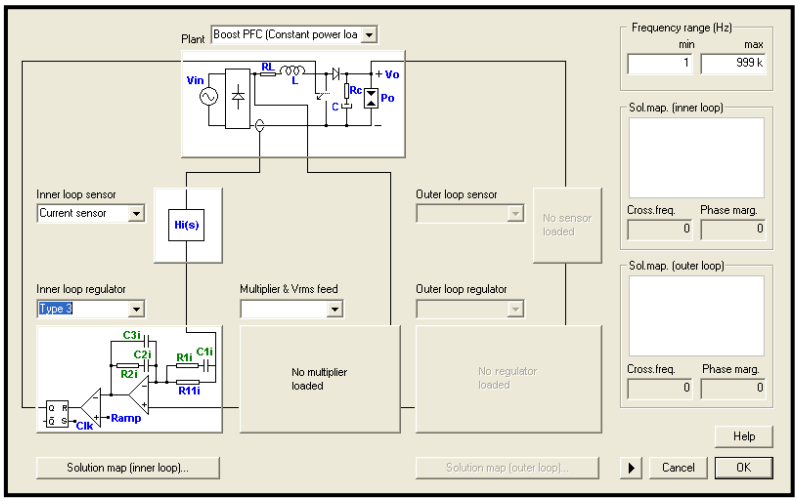
Next, the inner control loop will be configured: the current sensor and the regulator type must be selected.



The available current sensors are the following:

- Current Sensor
- Hall Effect Sensor

Finally, the inner loop regulator is selected.

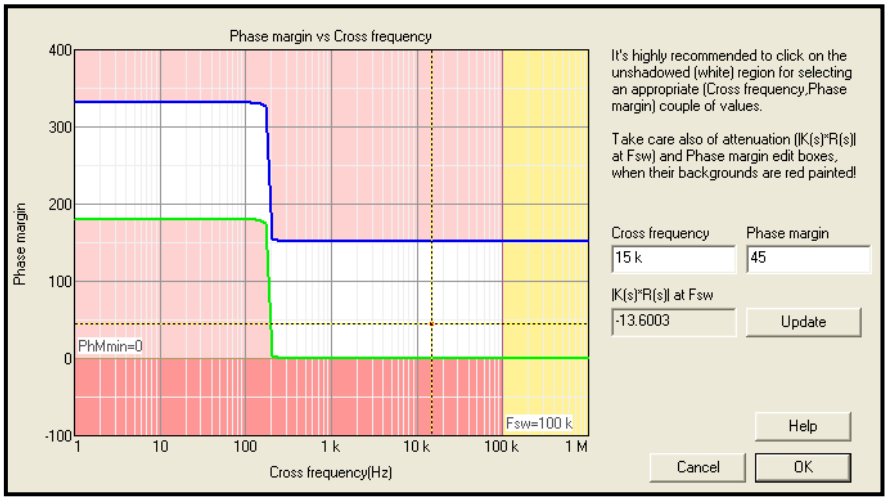


Regulator types:

- Type 3
- Type 2
- PI regulator
- Single Pole

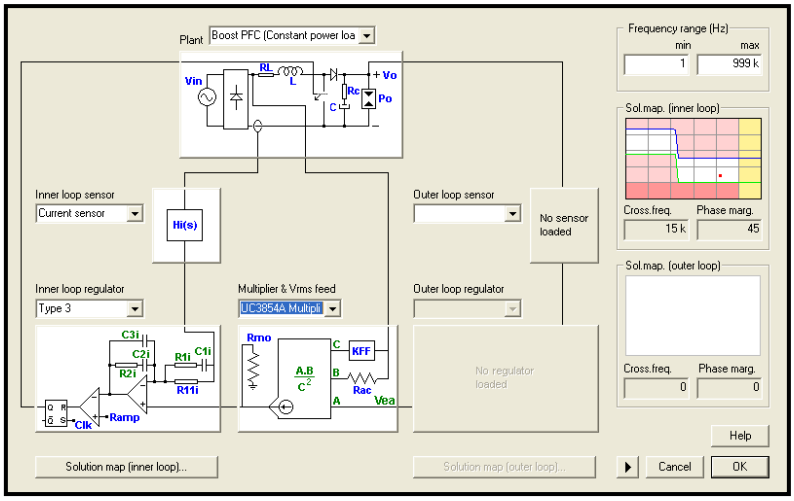
Once all the inner loop transfer functions have been defined, the cut off frequency and the phase margin must be selected. Under the name of Solution Map, SmartCtrl provides the stable solution space in which all the possible combinations of cut off frequency and phase margin that lead to stable solutions are shown graphically. Just clicking on the "Solutions map (inner loop)" button the solution map corresponding to the inner loop is displayed.

The designer is asked to select the crossover frequency and the phase margin just by clicking within the white zone to continue.



Once the cut off frequency and the phase margin have been selected, the solution map will be shown on the right of the side of the AC/DC PFC Boost converter input data window. If, at any time, the two aforementioned parameters need to be changed, just click on the shown solution map. (Seenext figure)

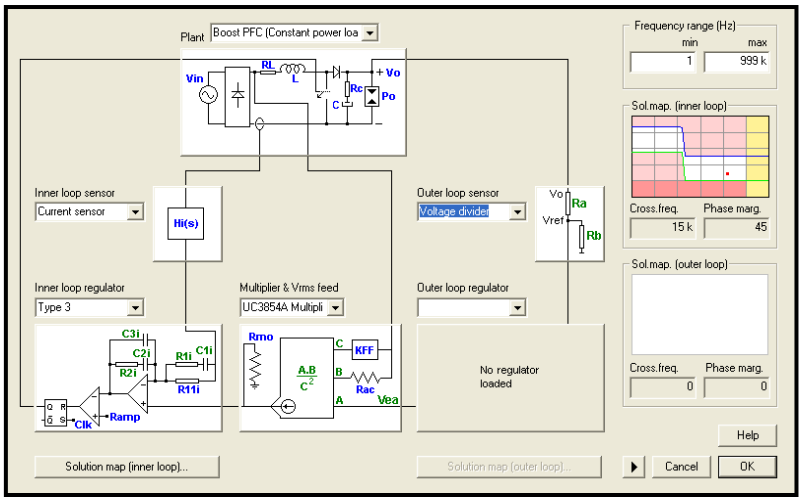
The next step is to determine the parameters of the multiplier that will be used:



Options for the multiplier and Vrmsfeedforward:

- Multiplier
- UC3854A Multiplier

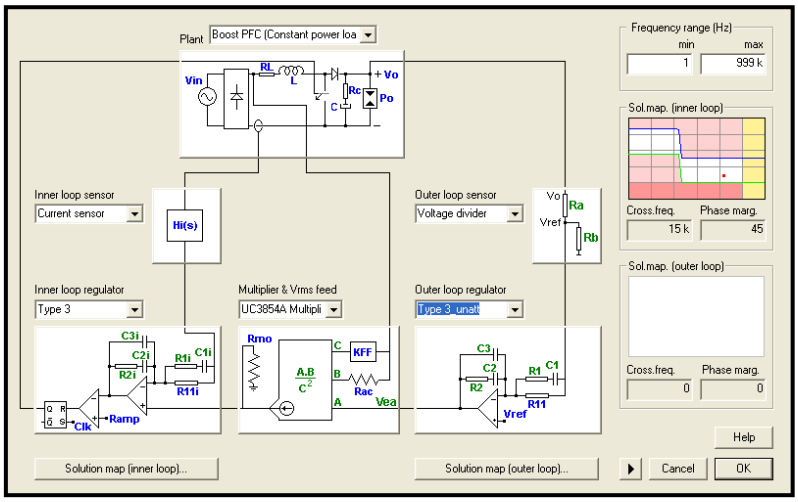
Now, the outer loop can be defined. First, the voltage sensor must be selected.



The different sensors available are the following:

- Voltage Divider
- Regulator Embedded
- Voltage Divider

Next, the outer loop regulator must be selected.

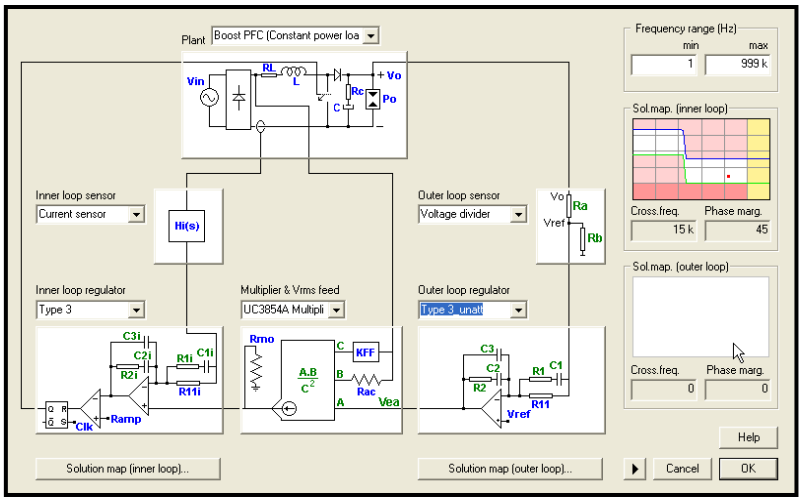


Regulator types:

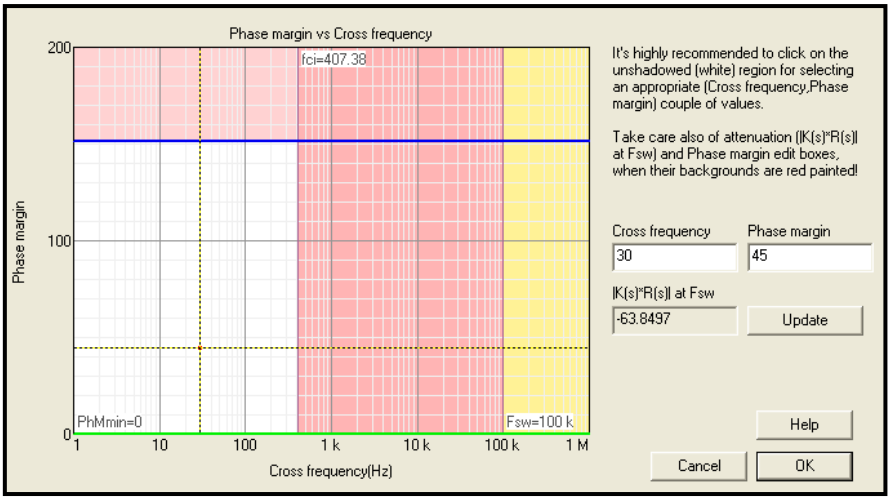
- Type 3
- Type 3 Unattenuated
- Type 2
- Type 2 unattenuated
- PI
- PI unattenuated
- Single Pole
- Single Pole unattenuated·

As well as in the case of the inner loop, the cut off frequency and the phase margin must be selected. Also in this case, the solution map is available to help the selection of a stable solution.

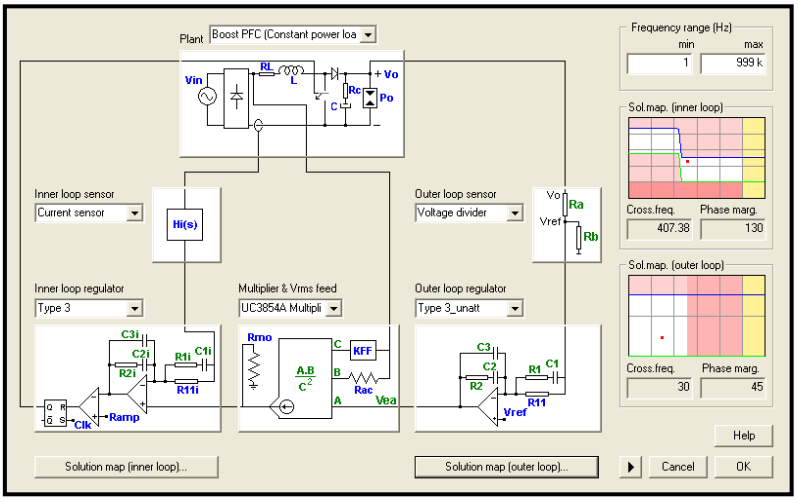
Press the "Solution map (outer loop)" button and the solution map will be displayed. Then select a point just by clicking within the white area.



It should be remarked that, due to stability constraints, the crossover frequency of the outer loop cannot be greater than the crossover frequency of the inner loop. In order to prevent the selection of an outer loop fc greater than the inner loop one, a pink shadowed area has been included in the solutions map of the outer loop.



Once the crossover frequency and the phase margin have been selected, the solution map will be shown on the right of the side of the DC/DC double loop input data window. If, at any time, the two aforementioned parameters need to be changed, just click on the shown solution map. (See next figure)



Now accept the selected configuration and confirm the design, the program will automatically show the performance of the system in terms of frequency response, line current shape... (See Graphic panels window for detailed information).

Once the design has been generated, two possible warning messages can appear in the solution map window:

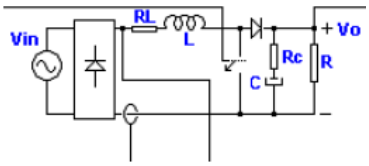
- In the case of a single pole compensator in the outer loop, which is a typical compensator for power factor correctors, the gain at low frequency may be low. A warning appears when the estimated Vo (shown in the method panel) differs from the specified one in more than 10%.In these cases, a compensator with a higher gain at low frequency is recommended.
- The line current waveform is calculated assuming that the current loop follows perfectly well the reference generated by the outer loop. However, in some occasions there is a zero-cross distortion and the actual line current would differ from the one represented. In these cases, a warning message appears. The cross-frequency of the inner loop compensator should be increased to minimize this problem.

In the method panel, additional information is provided both for the inner loop and the outer loop:

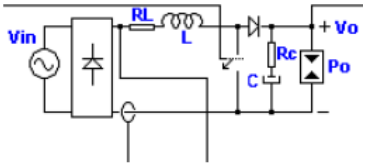
- Attenuation (fsw)(dB). This is the attenuation in dB achieved by the open loop transfer function at the switching frequency. It should be low for the inner loop and the outer loop.
- Attenuation (2fl)(dB) . This is the attenuation in dB achieved by the open loop transfer function at twice the line frequency (100 Hz or 120 Hz). It should be high for the inner loop and low for the outer loop.
- Estimated Vo (V). This is the estimated output voltage of the converter. This parameter is important because, if the frequency gain of the open loop transfer function is not high enough, there will be a steady-state error and the estimated output voltage can be different from the specified output voltage. As mentioned above, if the estimated Vo (shown in the method panel) differs from the specified one in more than 10%, there is a warning.

9.1 Power Stage

The Boost PFC is based on a double loop control scheme, and therefore the output voltage and a current through the inductor aresensed simultaneously. There are two options for the plant, depending on the load:



Boost PFC (Resistive load)



Boost PFC (Constant power load)

The current loop is designed considering a piecewise linear model of the plant: using quasi-static assumption, the small signal model for each operating point is calculated as in a DC/DC boost converter.

The input data variables are listed and defined below:

Input data

V_{in}(rms)	Input Voltage (V)
R_L	Equivalent Series Resistor of the Inductance (Ohms)
L	Inductance (H)
Rc	Equivalent Series Resistor of the output capacitor (Ohms)
C	Equivalent Series Resistor of the output capacitor (Ohms)
V_o	Output Voltage (W)
R	Load Resistor (Ohms)
P_o	Output Power (W)
Wta	Line angle(º). The current loop is designed considering the plant calculated for this operating point. This line angle is indicated as a red dot in the output panel that represents the Rectified voltage and external compensator output(See Graphic and text panels window for detailed information)
F_{SW}	Switching frequency (Hz)
Line frequency	Line frequency (Hz)

9.2 Graphic panels

The window is divided in six different panels:

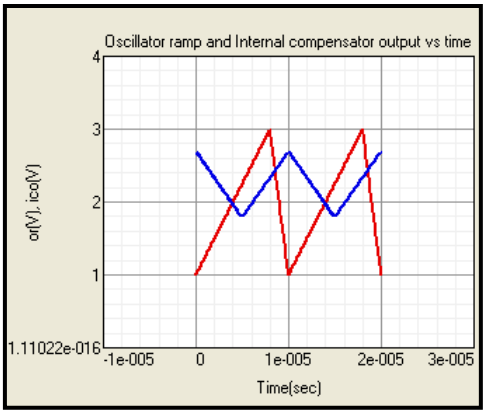
The graphic panels are:

- Bode plot Module (dB)
- Bode plot Phase (º)
- Polar plot
- Line current
- Oscillator ramp and internal compensator
- Rectified voltage and external compensator output

9.2.1 Oscillator ramp and internal compensator

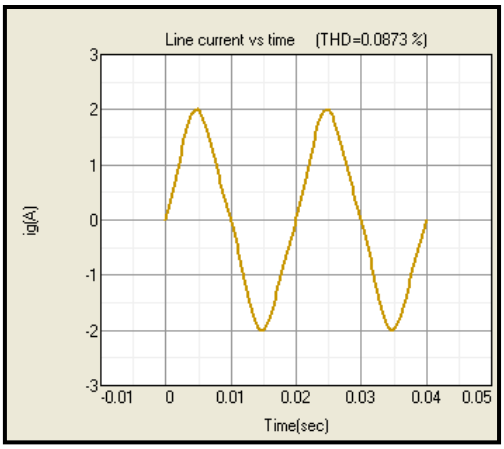
This graphic panel provides information about the output of the inner control compensator (blue line) compared to the oscillator ramp (red line). The output of the internal compensator is represented for the line angle corresponding to the maximum current ripple through the inductor. This line angle is identified by means of a blue dot in the Rectified voltage and external compensator output graphical panel.

This comparison can be useful to determine whether there could be oscillations. If the slopes of both functions are too similar, there could be more than one intersection per period.



9.2.2 Line Current

This graphic panel provides information about the line current and its harmonic distortion. The line current waveform is calculated assuming that the current loop follows perfectly the reference generated by the outer loop. However, in some occasions there is a zero-cross distortion and the actual line current would differ from the one represented. In these cases, a warning message would appear in the solution map window.

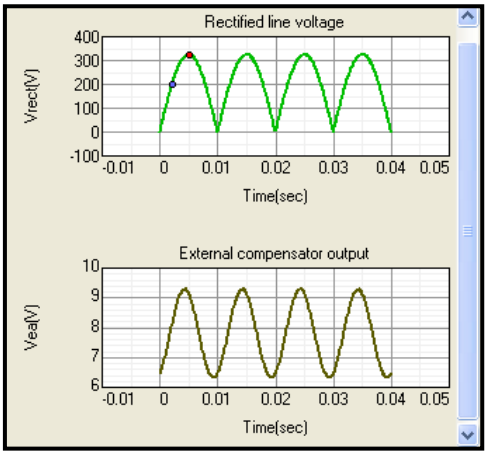


9.2.3 Rectified voltage and external compensator output

This graphic panel provides information about the external compensator output voltage. Its phase shift compared to the rectified voltage can be assessed. If the compensator output voltage has not an appropriate phase shift compared to the rectified voltage (reference), the line current distortionwill increase.

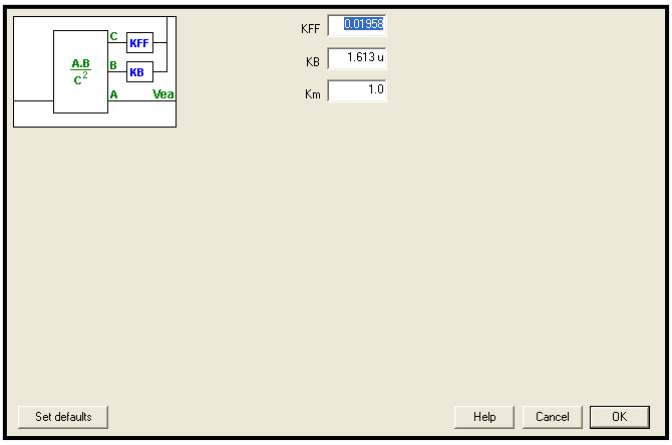
The current loop is designed considering a piecewise linear model of the plant.The current plant represented in the Bode plot panels (seeGraphic panels window) corresponds to the operating point marked with a red dot in the rectified voltage. The small signal model for the plant is calculated as in a DC/DC boost converter for this operating point. This dot can be moved by clicking and dragging with the mouse, resulting in a variation of the operating point. As the dot changes its position, the Bode plot corresponding to the inner loop varies, as well as the attenuation information in the K-factor panel refreshes according to the indicated operating point.

The blue dot in the rectified voltage represents the operating point that corresponds to the maximum current ripple through the inductor. The graphics in theOscillator ramp and internal compensator panel have been represented for this operating point.



9.3 Multipliers

9.3.1 Multipliers



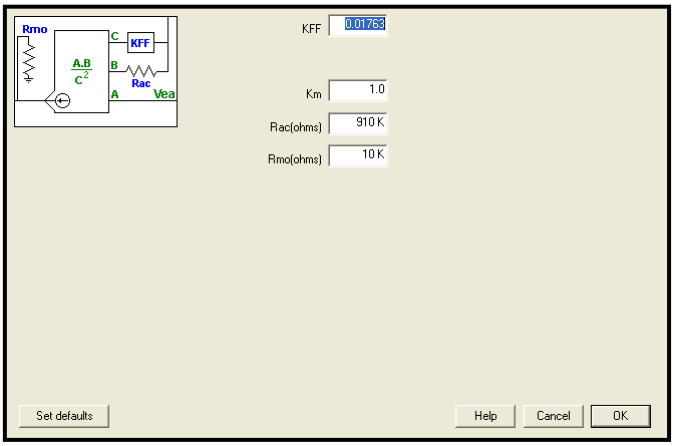
The multiplier has the following parameters:

KFF Gain of the feed-forward. It is the ration between the rms input voltage and the average input voltage to the multiplier.

KB Gain of the current reference for the inner loop.

Km Multiplier gain.

9.3.2 UC3854 Amplifiers



The **UC3854A multiplier** has the following parameters.

KFF Gain of the feed-forward. It is the ration between the rms input voltage and the average input voltage to the multiplier.

Rac Resistance to introduce the current reference for the inner loop (Ohms)

Rmo Resistance to convert the multiplier output current into a voltage reference for the inner compensator (Ohms)