

▶ **EMI Analysis and Filter Design Using  
EMI Design Suite**

# **Altair PSIM Tutorial**

## 1. Overview

The EMI Design Suite provides a total solution of conducted EMI analysis and EMI filter design for power converter systems. The EMI Design Suite helps users walk through iteration steps of conducted EMI pre-compliance in a typical a power converter product development cycle. Based on the selected EMI standard, the Design Suite automatically designs the EMI filter with proper attenuations for both Differential Mode (DM) and Common Mode (CM) conducted emission noises, and generates a system that is operational and ready to simulate.

The Design Suite can also be used to quickly design the EMI filter if users can provide measured DM and CM EMI data from hardware experiments.

If users already have the EMI filter pre-designed, the EMI Design Suite can help perform EMI simulation and study how different elements impact the EMI behavior.

To facilitate system study and design, the following blocks essential for EMI analysis are provided for both single-phase and 3-phase systems:

- EMI Filters
- Line Impedance Stabilization Network (LISN) for different EMI standards
- DM/CM EMI Noise Signal Analyzer
- Common-Mode Capacitor Block
- Ground Plane

With the EMI Design Suite, one can put together quickly an EMI pre-compliance testing system that includes circuit models, parasitic components, and necessary blocks for EMI analysis.

The EMI Design Suite offers significant benefit and advantages to engineers in the following ways:

- It can help system engineers evaluate EMI requirements and understand the impacts of parasitic inductances and capacitances among major subsystems such as bus bars (or board traces), semiconductors, heatsinks, etc. It can also help engineers derive detailed hardware/mechanical layout specifications before the hardware development begins, and gain a better insight of the subsystem operations from the EMI perspective.
- It can help hardware engineer carry out hardware component selection and design of an EMI filter to meet the EMI requirements before the actual circuit board layout starts.
- It can help EMI engineers quickly integrate and perform EMI pre-compliance testing.

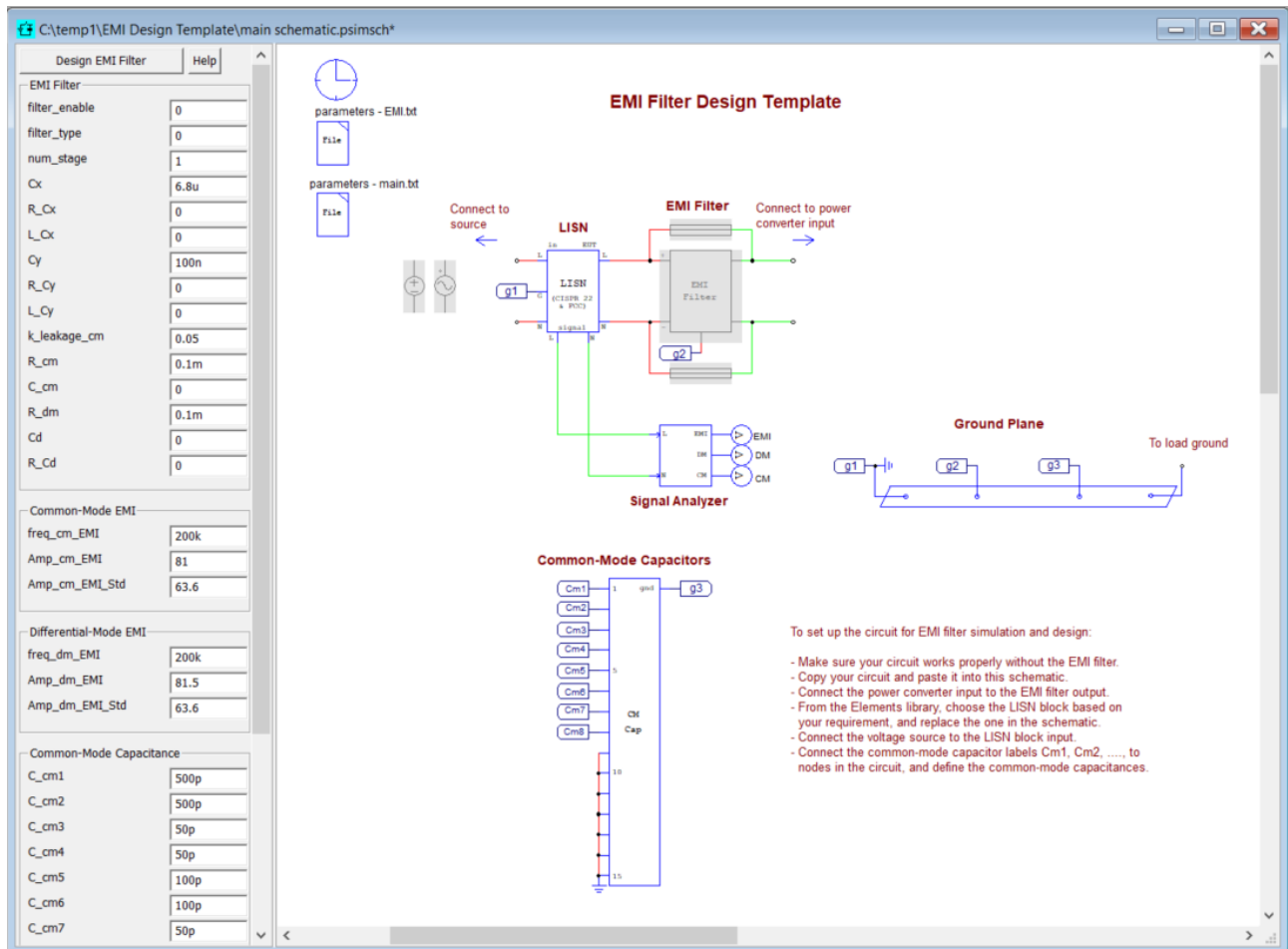
The EMI Design Suite provides a very quick design to the EMI filter development, and helps speed up the EMI pre-compliance process substantially.

Five power converter design templates and one general EMI design template for EMI pre-compliance set up are provided in the EMI Design Suite:

EMI Design Template	General EMI design template which allows users to insert one's own power converter and control circuits.
<b>Buck Converter</b>	CISPR-22 Class B EMI pre-setup of a buck converter.
<b>Boost Converter</b>	Mil-461 440V EMI pre-setup of a boost converter.

<b>Power Factor Correction (PFC) Converter</b>	FCC Class B EMI pre-	setup of a PFC converter.
<b>Phase Shifted Full-Bridge (PSFB) DC-DC Converter</b>	CISPR-25 level 4 EMI pre-converter.	setup of a PSFB dc-dc
<b>PMSM Drive</b>	CISPR-25 level 3 EMI pre-	setup of a PMSM drive.
<b>Vienna Rectifier</b>	CISPR-22 Class B EMI pre-Vienna rectifier.	setup of a 3-phase

A typical EMI pre-compliance setup of a power electronic converter system in PSIM consists of an EMI filter, LISN, DM/CM EMI noise signal analyzer, CM parasitic capacitance block, and a power converter system. The overall structure of the general EMI template is shown below:



After EMI parasitic parameters and intended X-cap, Y-cap values are specified, the entire circuit is ready to be simulated and investigated for EMI performance.

This tutorial describes how to use the EMI templates in the EMI Design Suite. We will use the **Buck Converter** template as an example to illustrate the process.

The buck converter requirements are given as below:

$V_{in} = 120V_{ac}$ ,  $V_o = 12V_{dc}$ ,  $P = 250W$

$C_{link} = 500\mu F$ ,  $L_o = 53\mu H$ ,  $C_o = 6.5mF$

EMI compliance standard: CISPR 22 Class B

The buck converter parasitic parameters are defined as:

DC link capacitor ESR =  $20m\Omega$

Output capacitor ESR =  $10m\Omega$

Power switch ESL =  $5nH$

Bus bars (or board traces) used for power ESL =  $20nH$

CM parasitic capacitances are defined as follows:

$C_{cm1} = 500pF$  (between output positive and ground)

$C_{cm2} = 500pF$  (between output negative and ground)

$C_{cm3} = 50pF$  (between cathode of diode D1 and ground)

$C_{cm4} = 50pF$  (between anode of diode D1 and ground)

$C_{cm5} = 100pF$  (between drain of MOSFET Q1 and ground)

$C_{cm6} = 100pF$  (between dc link capacitor  $C_{link}$  negative and ground)

$C_{cm7} = 50pF$  (between input line and ground)

$C_{cm8} = 50pF$  (between input neutral and ground)

Please note that the CM parasitic capacitance values entered for simulation should reflect the real circuit measurements (if the circuit is already built) or the realistic target values (if circuit is not built yet) based on estimations and past experience so that the EMI pre-compliance testing simulation and study are meaningful.

Level-2 models are used for MOSFET Q1 and Diode D1 to take into account switching transient.

Based on the power requirements, the buck converter operates at a switching frequency of 100 kHz. A peak current inner loop with slope compensation is adapted. The outer voltage PI control loop provides the current reference to the peak current inner loop.

It is important to note that the power converter circuit (with level-2 MOSFET, IGBT, and diode models) must be fully functional before the EMI design process can begin, so that the  $di/dt$  and  $dv/dt$  characteristics of switching power devices truly reflect that of a real circuit.

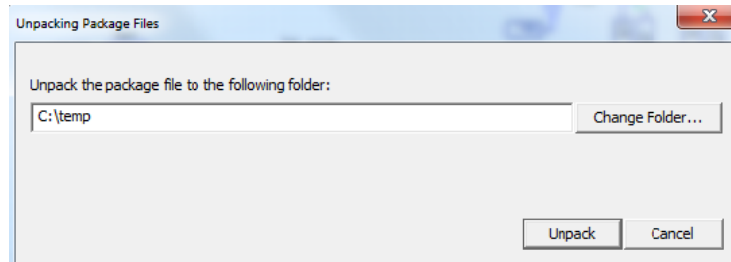
EMI performance evaluation with the EMI Design Suite can be achieved in following three steps:

- Defining system parasitic parameters and some EMI filter parameters.
- Running simulation with the EMI filter disabled. Record and enter the frequencies and amplitudes of both CM and DM as well as the EMI standard levels at the worst point where CM and CM exceed the EMI standard.
- Performing EMI filter design and running simulation again with the EMI filter enabled.

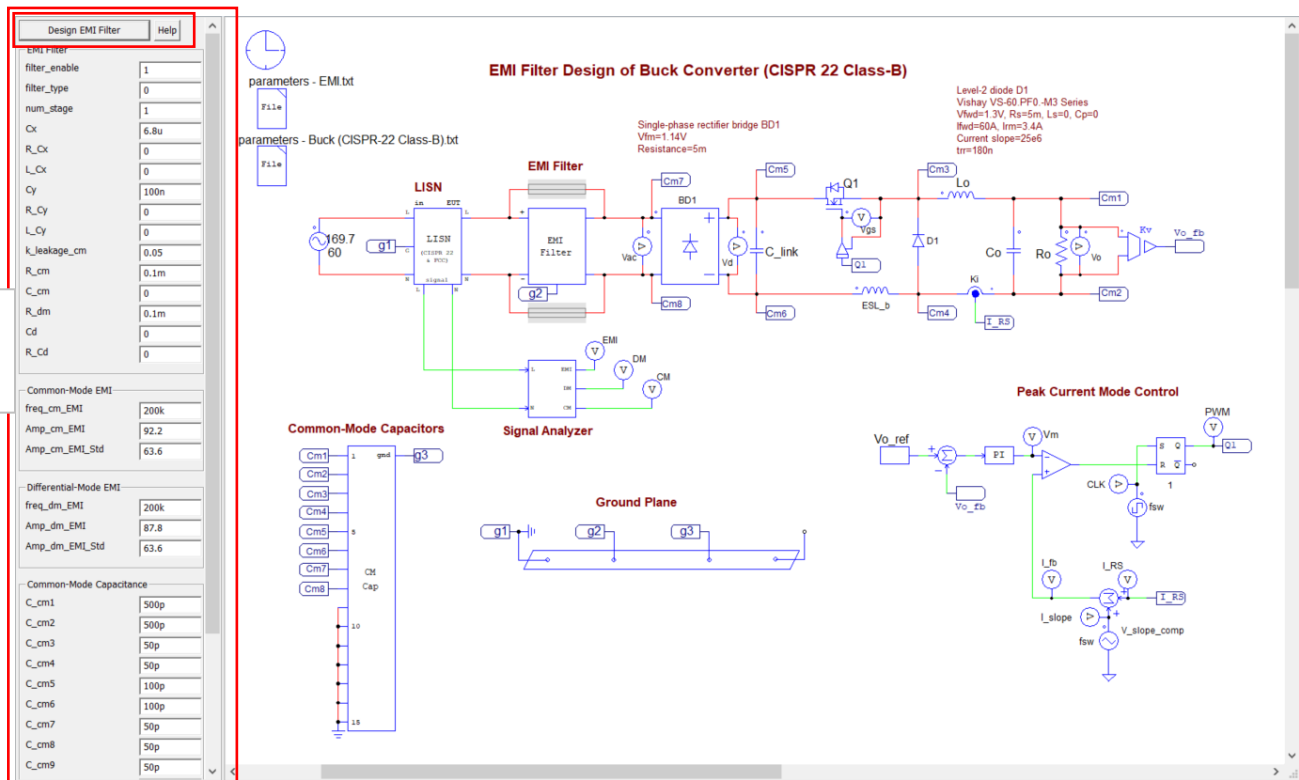
## Step 1: Defining System Parasitic Parameters

To run a EMI template, follow the steps below:

- In PSIM, go to **Design Suites >> EMI Design Suite**, and select one of the sample EMI templates, for example, **Buck Converter (CISPR-22 Class-B)**. A dialog window as shown below will appear. Click on **Unpack** to unpack the files to the default folder. To unpack to a different folder, click on **Change Folder** to browse the folder, or enter the folder name. In this example, the files will be placed in "c:\temp".



- After files are unpacked, a template circuit will be displayed in PSIM as shown below. Enter or modify the design parameters from the Parameter Panel on the left.



At the left of the schematic is the **Input Parameter Panel**. The panel defines the EMI filter related parameters. They include EMI filter enable/disable flag, filter type and number of stages, X-Cap and Y-Cap values, CM inductor and parasitic capacitance values, and damping branch parameters. They also include the frequencies, EMI noise levels, and EMI standard levels for both CM and DM.

At this step, ignore the values under the section **Common-Mode EMI** and **Differential-Mode EMI** as they are not available yet. They will be obtained in Step 2.

For this example, enter the values as below.

<b>EMI Filter:</b>	Value	Comment
filter_enable	0	Filter enable flag (0: disabled; 1: enabled)
filter_type	0	Filter type (0: L-type; 1: pi-type, 2: T-type)
num_stage	1	Filter number of stages
Cx	6.8u	Cx capacitance, in F
R_Cx	0	ESR (equivalent series resistance) of Cx
L_Cx	0	ESL (equivalent series inductance) of Cx, in H
Cy	100n	Cy capacitance, in F
R_Cy	0	ESR of Cy
L_Cy	0	ESL of Cy, in H
K_leakage_cm	0.05	Ratio of L_leakage/L_self of the CM choke
R_cm:	0.1m	CM choke winding resistance
C_cm	0	CM choke capacitance, in F
R_dm	0.1m	DM inductor resistance
Cd	0	Damping capacitance, in F
R_Cd	0	ESR of Cd
<b>Common-Mode EMI:</b>		
freq_cm_EMI	200k	Lowest frequency at which CM noise exceeds standard
Amp_cm_EMI	92.2	CM noise level at this frequency, in dB uV
Amp_cm_EMI_Std	63.6	EMI standard value at this frequency, in dB uV
<b>Differential-Mode EMI:</b>		
freq_dm_EMI	200k	Lowest frequency at which DM noise exceeds standard
Amp_dm_EMI	87.8	DM noise level at this frequency
Amp_dm_EMI_Std	63.6	EMI standard value at this frequency, in dB uV
<b>Common-Mode Capacitances:</b>		
C_cm1	500p	CM capacitance at the node C_cm1
C_cm2	500p	

C_cm3	50p
C_cm4	50p
C_cm5	100p
C_cm6	100p
C_cm7	50p
C_cm8	50p

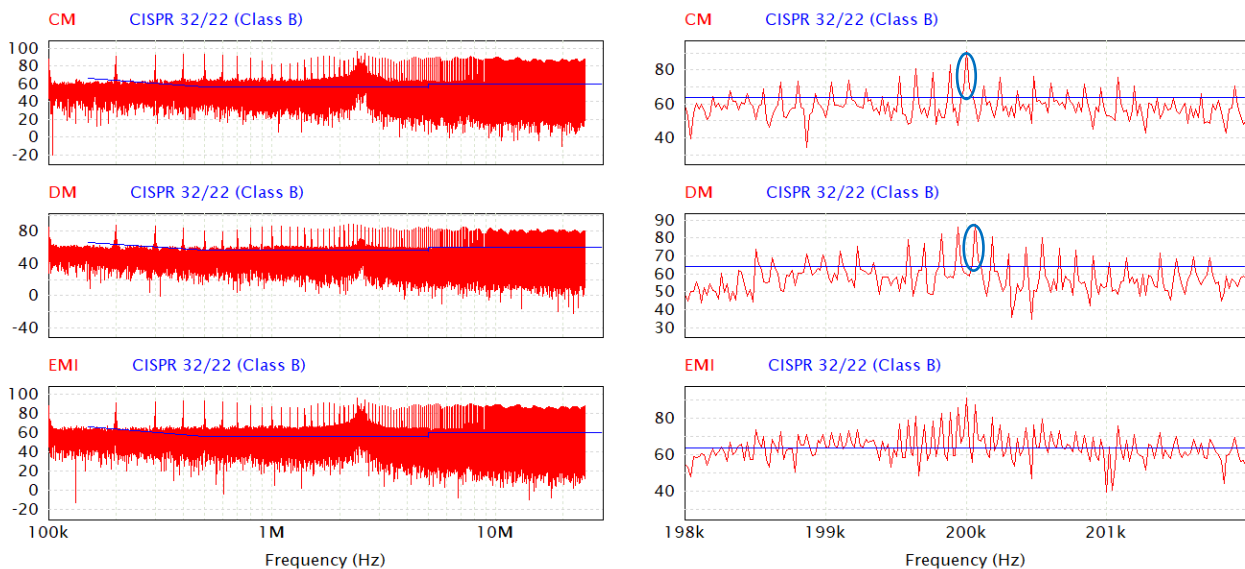
The definitions of these parameters are described in the online help by clicking on the **Help** button in the Parameter Panel.

## Step 2: Running Simulation with the EMI Filter Disabled

After parameters are entered in the Parameter Panel with the EMI filter disabled (with filter\_enable = 0), click on the button **Design EMI Filter** to update the parameter file "parameters-EMI.txt" in the schematic. This parameter file contains the EMI parameters entered by the user and the ones calculated by the EMI Design Suite.

If any of the EMI parameters in the Parameter Panel are changed, the EMI parameter file in the schematic needs to be updated with **Design EMI Filter** button.

After simulation is completed, display CM, DM, and EMI signals in three separate windows and then perform FFT under the **Analysis** menu. Change the **X** Axis range to 100 kHz, and set **Y** Axis scale to dB $\mu$ V (or in SIMVIEW, go to **Options** >> **Default Display Settings**, and select "Y-Axis in dB uV after FFT analysis"). Add the corresponding EMI Standard to the display from the EMI Standards tab in the **Add/Delete Curves** dialog. In this case, add CISPR 32/22 Class B as shown below on the left.



The expanded result display around 200kHz is shown above on the right.

Measure the frequency and amplitude values of CM and DM signals and corresponding EMI standard levels at the point of interest, that is, at the lowest frequency with the highest noise levels

that exceed the EMI standard. In this example, the lowest frequency with the highest CM and DM noise levels that exceed the EMI standard occurs at 200kHz. At this frequency, the CM noise level is 92.2 dB uV, and the DM noise level is 87.8 dB uV. The EMI standard amplitude is 63.6 dB uV. Enter these values in the section **Common-Mode EMI** and **Differential-Mode EMI** in the Parameter Panel:

Amp\_cm\_EMI = 92.2

Amp\_cm\_EMI\_Std = 63.6

Amp\_dm\_EMI = 87.8

Amp\_dm\_EMI\_Std = 63.6

Also, in the Parameter Panel, enable the EMI filter by setting filter\_enable to 1. Select one-stage or two-stage EMI filter type, and choose initial X-Cap and Y-Cap values. The choice of the X-Cap value is mainly dependent on the practical value of the leakage inductance of the CM inductor. The leakage inductance serves as the filter inductance in the DM circuit. If the X-cap value is selected properly, the leakage inductance can be sufficient, and no external DM inductor is needed. The choice of the Y-Cap value is mainly dependent on the safety requirement of the ground leakage current and the practical value of the CM inductance.

After these values are entered, click on **Design EMI Filter** tab to update the parameter file **parameters-EMI.txt**. Open **parameters-EMI.txt**, and select **Edit >> Show Values** to check the inductance values of CM and DM EMI filter to make sure they are reasonable and practical. If they are not reasonable or practical, adjust X-Cap and Y-Cap values, and repeat the process.

In this example, the Y-Cap is selected as  $C_y = 100\text{nF}$  which results in a design with common mode inductance  $L_{cm} = 179\mu\text{H}$  and leakage inductance  $L_{leakage} = 8.9\mu\text{H}$  to provide adequate CM noise attenuation such that the CM noise is below the EMI standard of 63.6 dB uV at 200kHz.

If X-Cap is selected as  $C_x = 6.8\mu\text{F}$ , the CM inductor's leakage inductance  $L_{leakage}$  of 8.9uH is sufficient to provide an adequate DM noise attenuation such that the DM noise is below the EMI standard of 63.6 dB uV at 200 kHz. If X-Cap is selected as  $C_x = 1.0\mu\text{F}$ , for example, an external DM inductor with  $L_{dm} = 1.3\mu\text{H}$  would be needed for adequate DM noise attenuation, resulting a less desirable design.

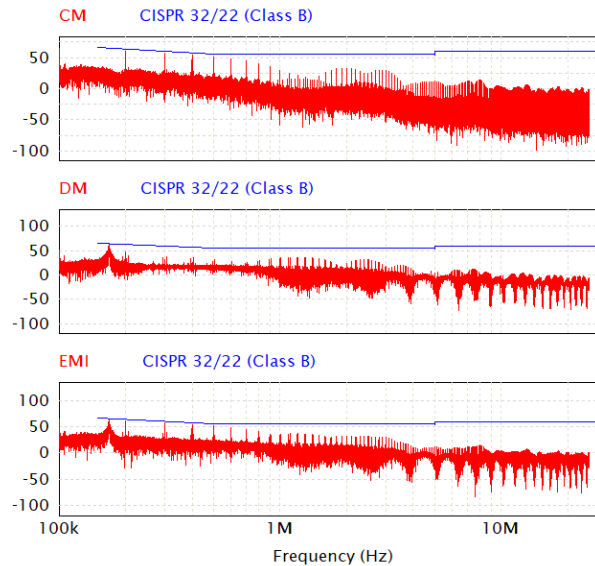
One big advantage of the Design Suite is that parameters of the EMI filter will be calculated automatically for a given EMI standard, saving users the effort and trouble of designing the EMI filter.

### Step 3: Running Simulation with the EMI Filter Enabled

Run simulation with the designed EMI filter enabled. After the simulation is completed, inspect CM/DM EMI signals to make sure they are below the EMI Standard level. If they are not, iterate Step 2 by increasing the values of Amp\_cm\_EMI and/or Amp\_dm\_EMI until satisfactory results are achieved.

The EMI spectrum of this example is shown below. The waveforms show that with the designed EMI filter, the EMI standard CISPR-22 Class-B is met.





Please note that CM, DM, and EMI noises displayed here are peak values, while the EMI standard is the quasi-peak value. Since quasi-peak values are in general lower than peak values, a safety margin is built in the design.

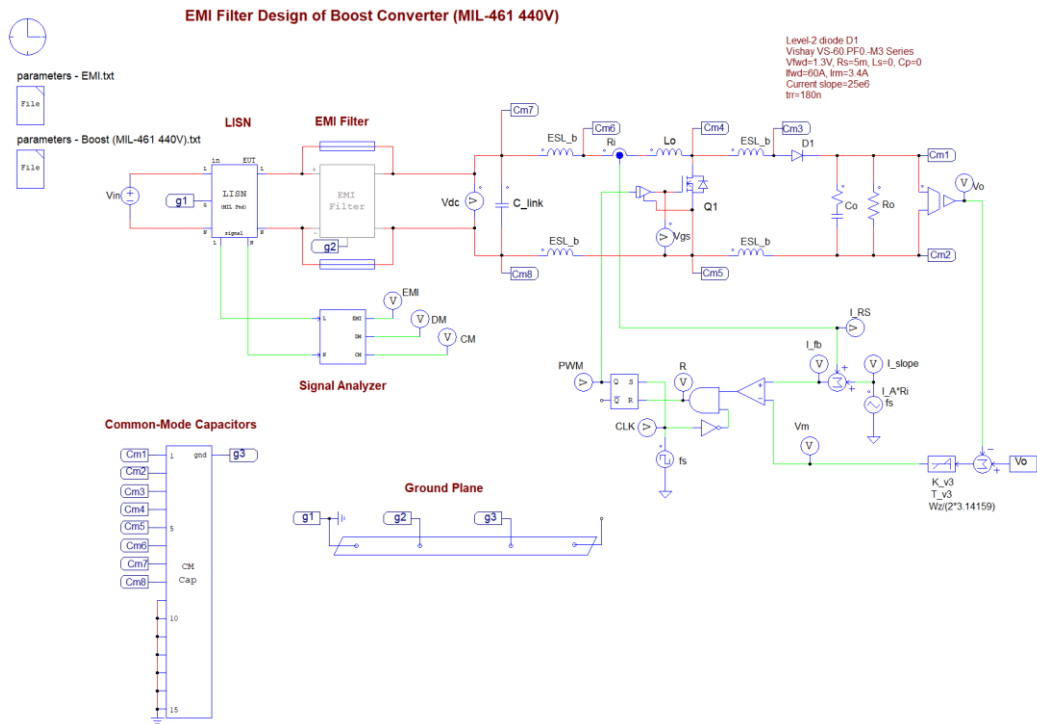
Please also note that the accuracy of EMI simulation is very much dependent on the accuracy of the device models and parasitic component values (especially CM capacitance values). The EMI Design Suite is meant to provide a platform for EMI analysis and a general direction and guideline to the EMI filter design, and it does not replace hardware experiments and testing.

## 2. Other Design Templates

Other power converter design templates for EMI pre-compliance setup are described below.

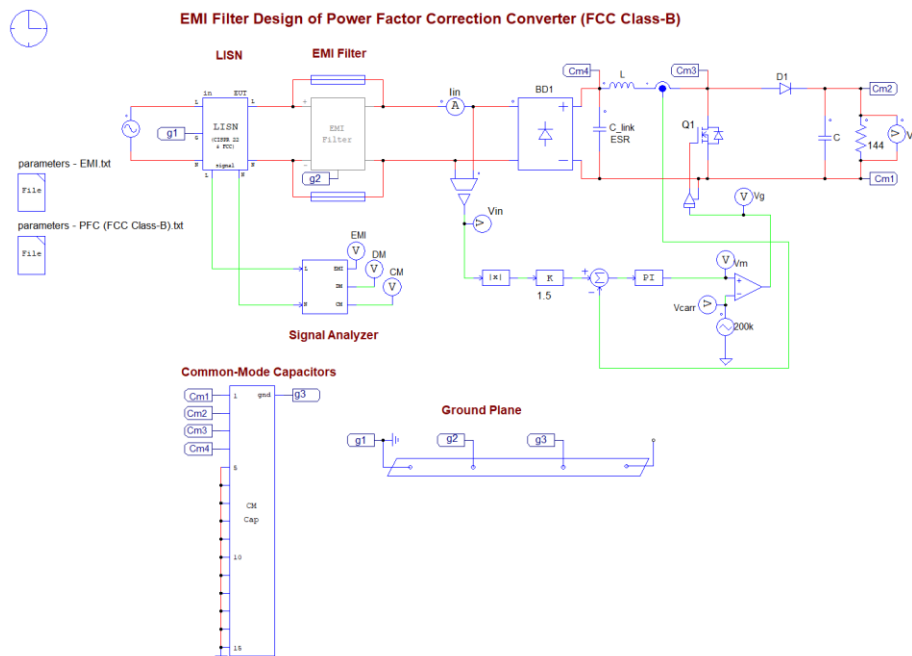
### 2.1 Boost Converter Template

The following figure shows a Boost Converter design template. In this template, the non-isolated boost converter converts 160Vdc input to 320Vdc output with the load power of 500W. The switching frequency is 200 kHz. The EMI standard MIL-461 440V is used. Note that lowest frequency in MIL-461 EMI standard starts at 10 kHz.



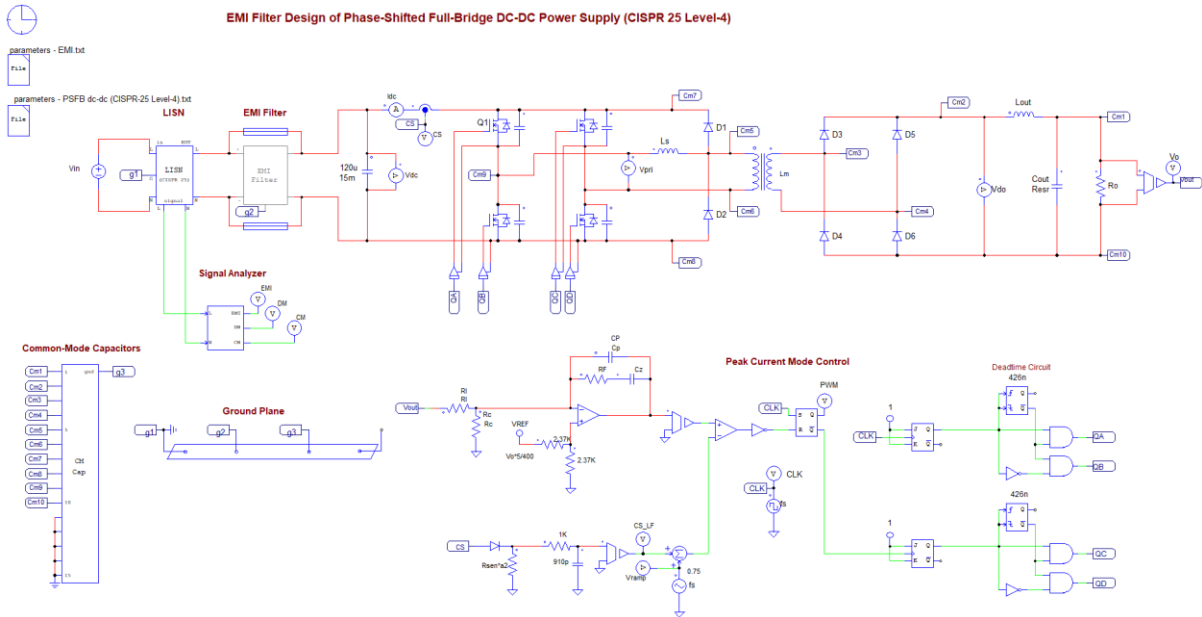
## 2.2 Power Factor Correction (PFC) Converter Template

The following figure shows a PFC Converter template. In this template, the PFC boost converter converts 200Vac input to 288Vdc output with the load power of 576W. The switching frequency is 200 kHz. The EMI standard FCC Class-B is used.



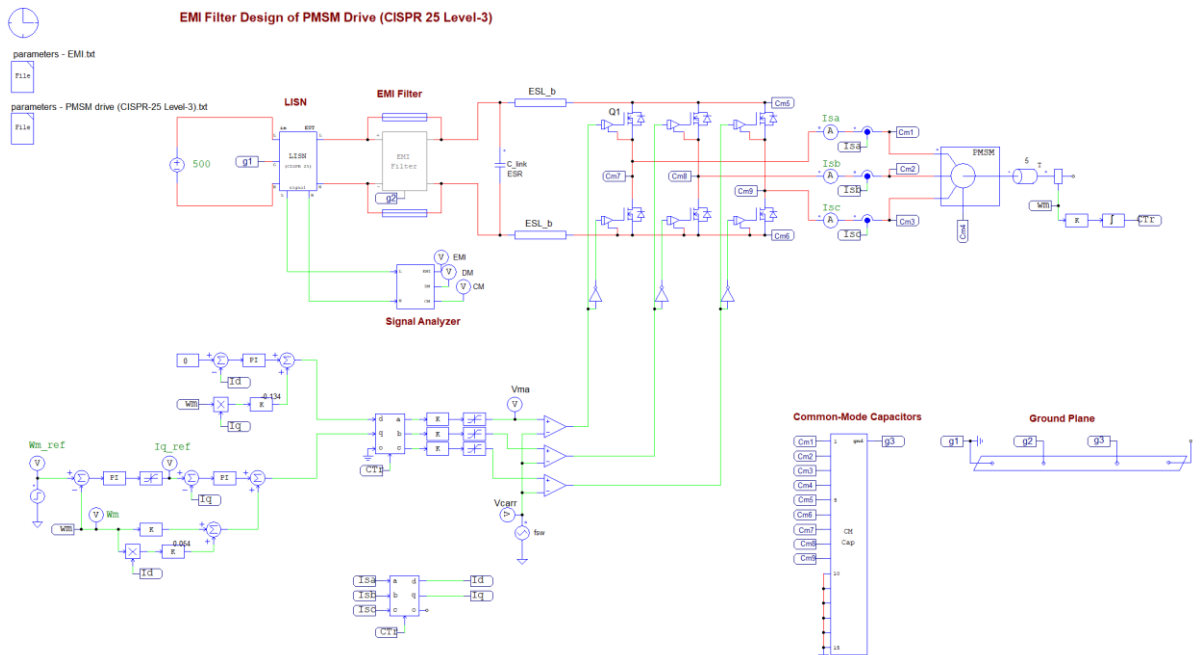
### 2.3 Phase Shifted Full-Bridge (PSFB) DC-DC Converter Template

The following figure shows a PSFB Converter template. In this template, the PSFB Converter converts 720Vdc input to 400Vdc output with the load power of 30 kW. The switching frequency is 140 kHz. The EMI standard CISPR 25 Level 4 is used.



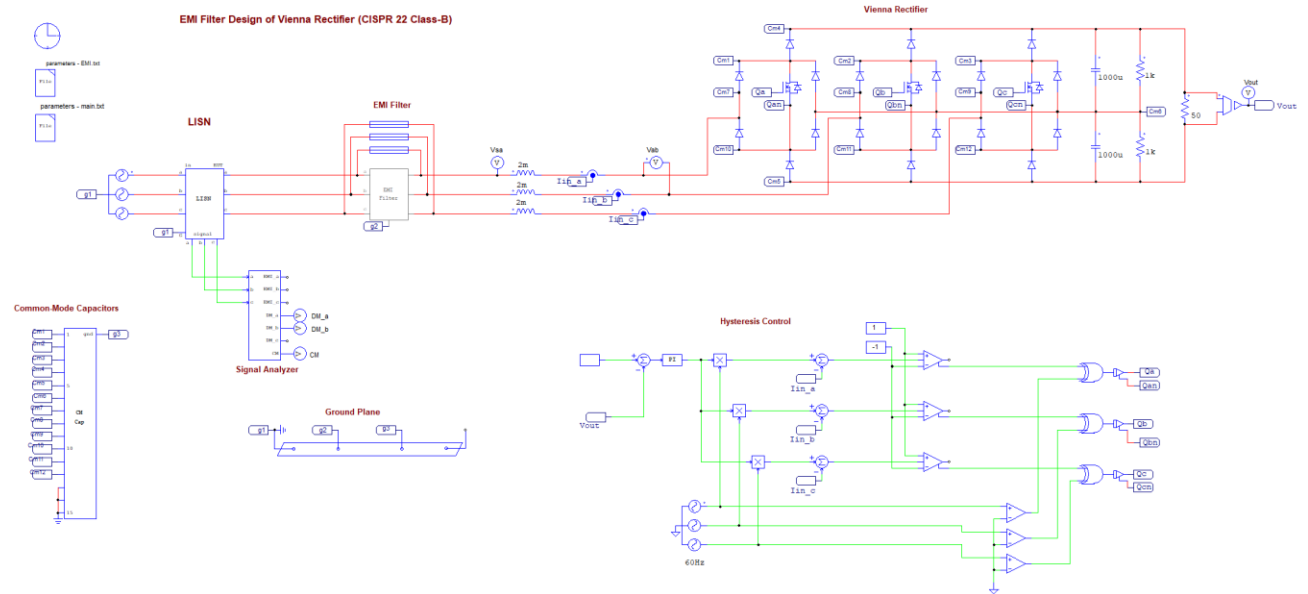
### 2.4 PMSM Drive Template

The following figure shows a PMSM Drive template. In this template, the PMSM inverter converts 500Vdc input to drive a PMSM motor to the speed of 170 Rad/s with the load torque of 5 Nm. The switching frequency is 10 kHz. The EMI standard CISPR 25 Level 4 is used.



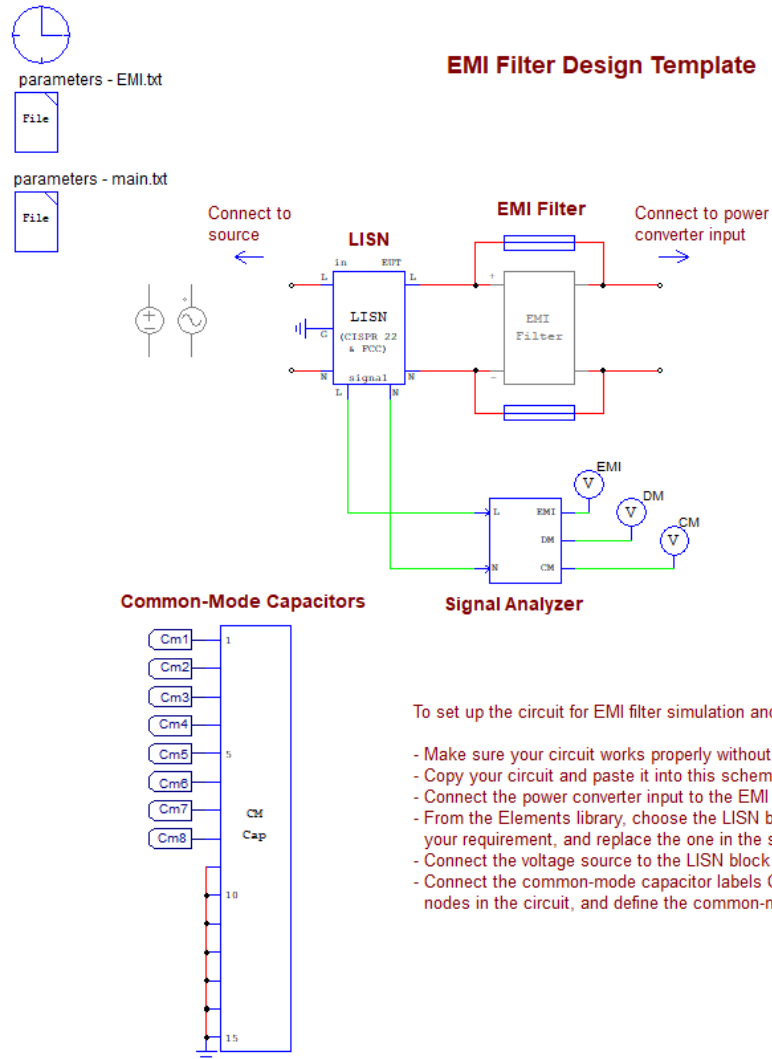
## 2.5 Vienna Rectifier Template

The following figure shows a Vienna rectifier template. Three-phase LISN, EMI Filter, and Signal Analyzer are used in the system. The EMI standard CISPR-22 Class-B is used.



## 2.6 General EMI Design Template

The EMI Design Suite also provides a general EMI design template which allows users to insert their own power converter circuits for EMI compliance simulation. The following figure shows a general EMI design template. In this template, blocks essential to EMI simulation are provided.



To set up the circuit for EMI filter simulation and design:

- Make sure your circuit works properly without the EMI filter.
- Copy your circuit and paste it into this schematic.
- Connect the power converter input to the EMI filter output.
- From the Elements library, choose the LISN block based on your requirement, and replace the one in the schematic.
- Connect the voltage source to the LISN block input.
- Connect the common-mode capacitor labels Cm1, Cm2, ..., to nodes in the circuit, and define the common-mode capacitances.