PSIM

TUTORIAL

EMI Analysis and Filter Design Using EMI Design Suite

February 2021

1. Overview

The EMI Design Suite provides a total solution of conducted EMI analysis and EMI filter design for a power electronic converter system. The EMI Design Suite helps users walk through the typical conducted EMI pre-compliance iteration steps of a typical a power electronics 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 complete 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.

With the capability to put together quickly an EMI pre-compliance testing system that includes circuit models, parasitic components, and circuit blocks essential for EMI analysis, such as EMI filter, Line Impedance Stabilization Network (LISN), and DM/CM EMI noise signal analyzer, the EMI Design Suite offers significant benefit and advantages to engineers in the following ways:

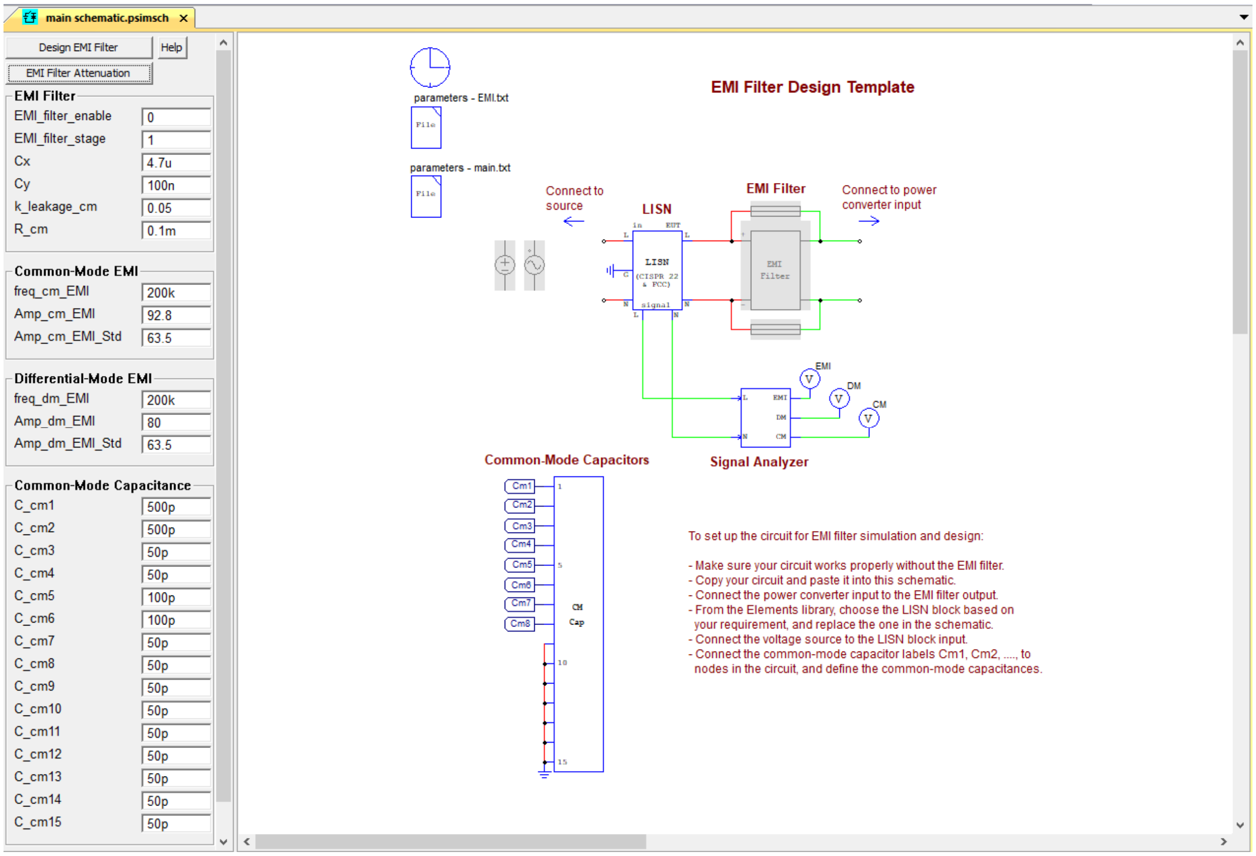
- It can help system engineers evaluate EMI requirements and understand the impacts of parasitic inductances and capacitances among major subsystems such as bus bars (or board traces), semiconductors, heatsinks, etc. It can also help engineers derive detailed hardware/mechanical layout specifications 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 of the system.

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:

Buck Converter	CISPR-22 Class B EMI pre-compliance setup of a buck converter.
Boost Converter	Mil-461 440V EMI pre-compliance setup of a boost converter.
Power Factor Correction (PFC) Converter	FCC Class B EMI pre-compliance setup of a PFC converter.
Phase Shifted Full-Bridge (PSFB) DC-DC Converter	CISPR-25 level 4 EMI pre-compliance setup of a PSFB dc-dc converter.
PMSM Drive	CISPR-25 level 3 EMI pre-compliance setup of a PMSM drive.
General EMI Design	General EMI design template which allows users to insert one's own power converter and control circuits.

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:

Vin = 120Vac, Vo = 12Vdc, P = 250W

C_link = 500uF, Lo = 53uH, Co = 6.5mF

EMI compliance standard: CISPR 22 Class B

The buck converter parasitic parameters are defined as:

DC link capacitor ESR = 20mΩ

Output capacitor ESR = 10mΩ

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 experiences so that the EMI pre-compliance testing simulation and study are meaningful.

A level-2 MOSFET model is used for MOSFET Q1 to take into account the 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 or IGBT model) must be fully functional before the EMI design process can begin, so that the di/di and dv/dt characteristics of switching power devices truly reflect that of a real circuit.

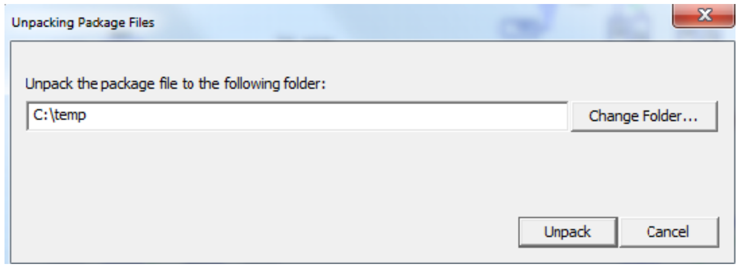
The EMI performance evaluation with EMI Design Suite can be achieved in following three steps:

- 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.

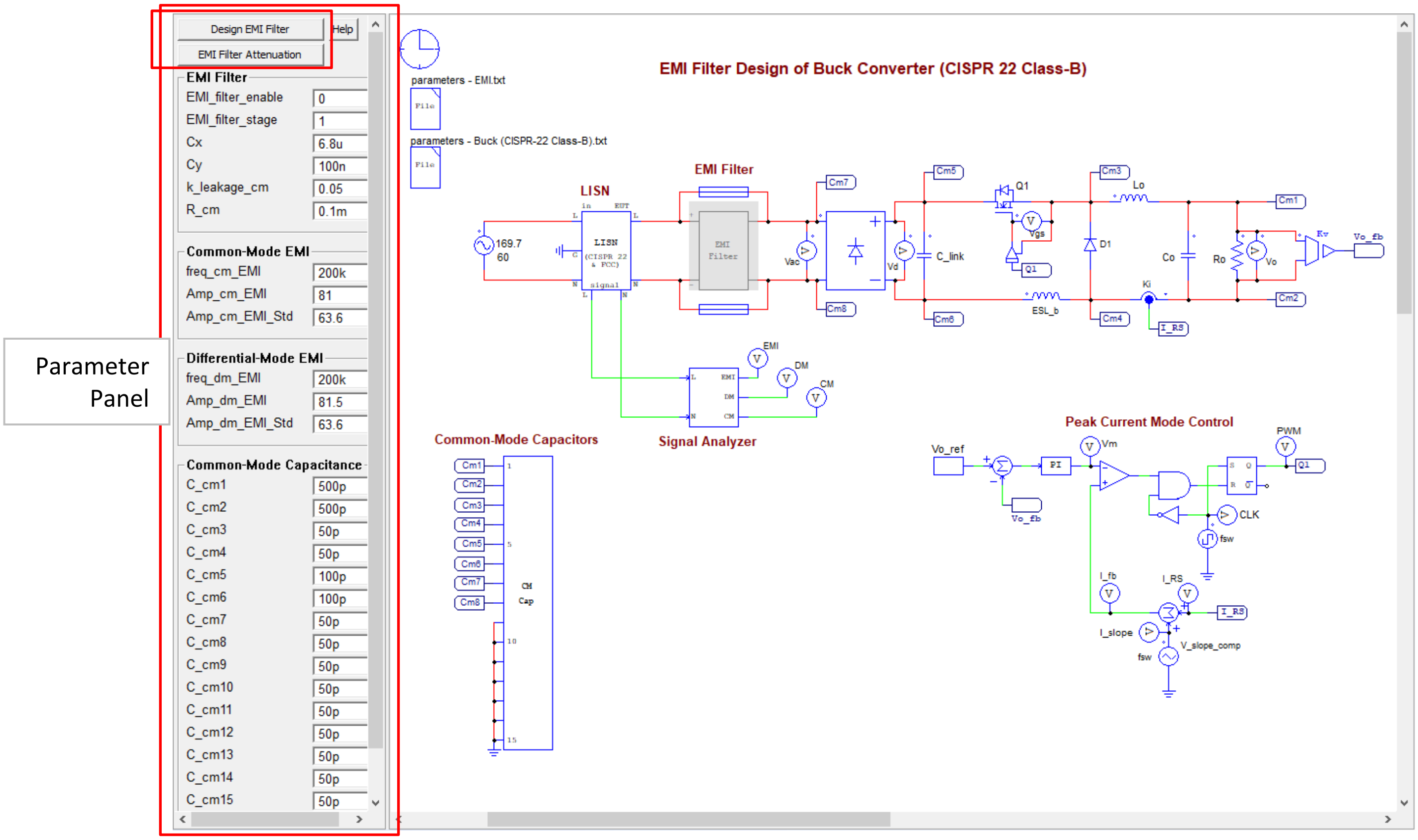
Step I: Defining System Parasitic Parameters

To run the EMI template, follow the steps below:

- In PSIM, go to **Design Suites** >> **EMI Design Suite**, and select one of the sample EMI circuit, 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 (such as enable/disable EMI filter, X-Cap and Y-Cap values, CM inductor parameters), CM parasitic capacitances, and EMI filter attenuation parameters (such as the worst frequencies and amplitudes of both CM and DM as well as EMI standard levels).

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 after Step II.

For this example, enter the values as below.

EMI Filter:	
EMI_filter_enable:	0
EMI_filter_stage:	1
Cx:	6.8u
Cy:	100n
K_leakage_cm:	0.05
R_cm:	0.1m
Common-Mode EMI:	
Freq_cm_EMI:	200k
Amp_cm_EMI:	81
Amp_cm_EMI_Std:	63.6
Differential-Mode EMI:	
Freq_dm_EMI:	200k
Amp_dm_EMI:	81.5
Amp_dm_EMI_Std:	63.6
Common-Mode Capacitances:	
C_cm1:	500p
C_cm2:	500p
C_cm3:	50p
C_cm4:	50p
C_cm5:	100p
C_cm6:	100p
C_cm7:	50p
C_cm8:	50p

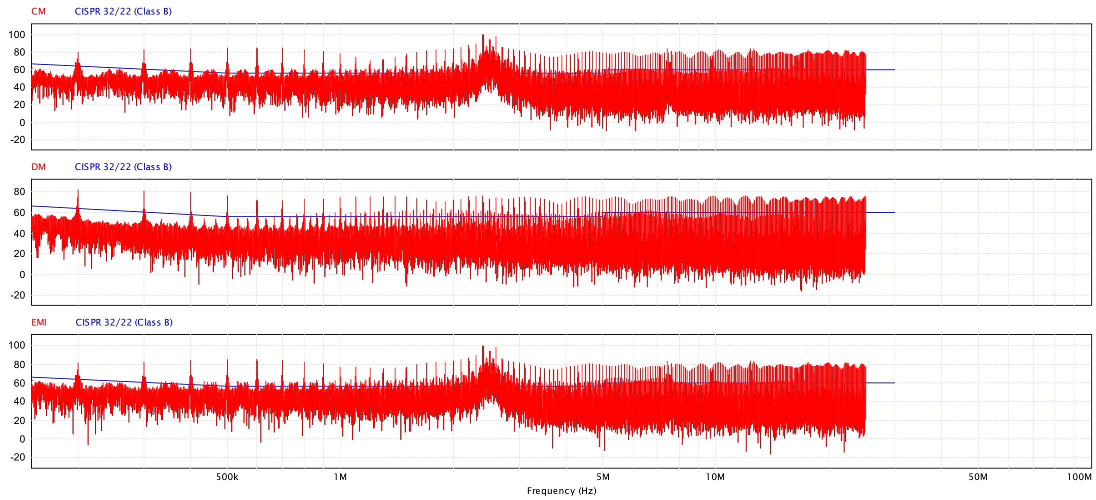
The definitions of these parameters are described in the online help by clicking on the **Help** button in the Parameter Panel.

Step II: Running Simulation with the EMI Filter Disabled

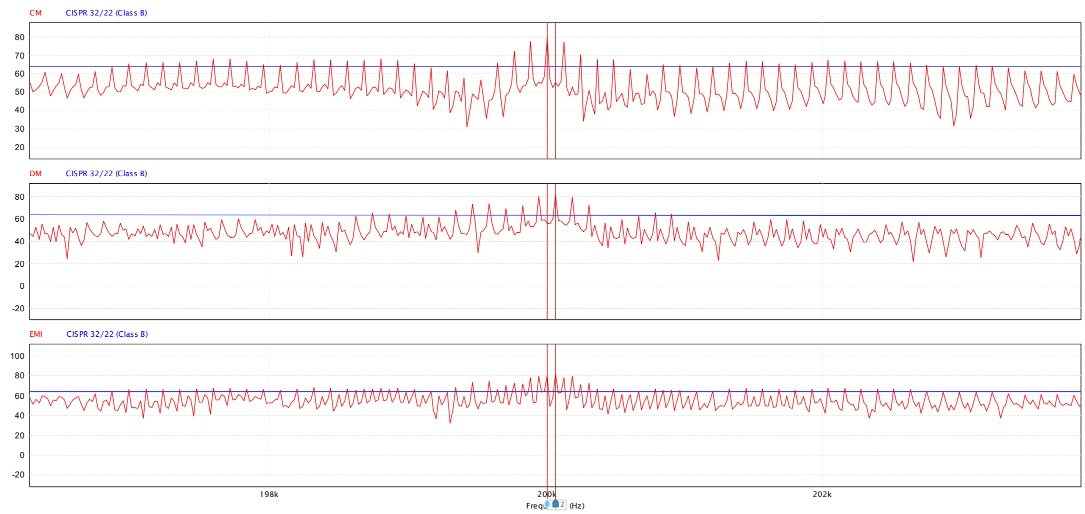
After parameters are entered in the Parameter Panel with the EMI filter disabled (with EMI_filter_enable = 0), click on the button **Design EMI Filter** to update the parameter file "parameters-EMI.txt" in the schematic. This parameter file contains the EMI parameters entered by the user and the ones 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 the 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 as dBµV (or in SIMVIEW, go to **Options** >> **Default Display Settings**, and select “Y-Axis in dB uV after FFT analysis” option). Add the corresponding EMI Standard to the display from the EMI Standards tab in the **Add/Delete Curves** dialog. In this case, CISPR 22 Class B will be added, as shown below.



The expanded result displays are shown below:



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 level above the EMI standard. Then enter them into the Parameter Panel under the section **Common-Mode EMI** and **Differential-Mode EMI**. In this example, the highest CM noise level is 81 dBuV and the highest DM noise level is 81.5 dBuV. They both occur at 200kHz frequency. The EMI standard amplitude is 63.6 dBuV.

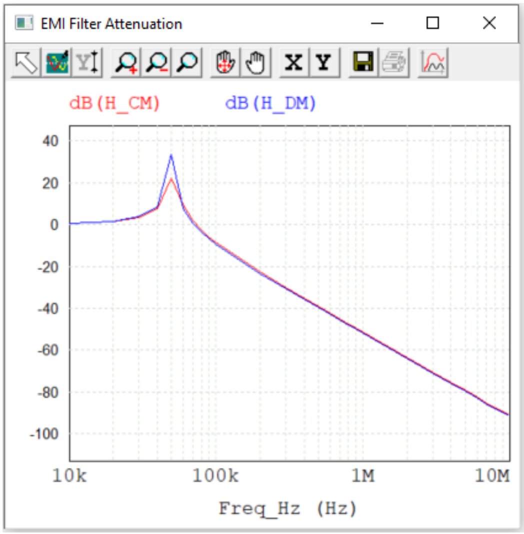
Also, in the Parameter Panel**,** enable the EMI filter by setting EMI_filter_enable to 1. Select one-stage or two-stage EMI filter type, and choose initial X-Cap and Y-Cap values. The choice of the X-Cap value is mainly dependent on the practical value of leakage inductance obtained from the CM inductor. The choice of Y-Cap value is mainly dependent on the safety requirement of the ground leakage current and the practical value of 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.

In this example, the Y-Cap is selected as Cy = 100nF which results in a common mode inductor design with common mode inductance L_cm = 49uH and leakage inductance L_leakage = 2.4uH to provide an adequate CM noise attenuation such that CM noise (81dBuV) is below EMI standard (63.6 dBuV) at 200kHz frequency.

If X-Cap is selected as Cx = 6.8uF, the CM inductor's leakage inductance L_leakage = 2.4uH is sufficient to provide an adequate DM noise attenuation such that DM noise (81.5 dBuV) is below the EMI standard (63.6 dBuV) at the frequency of 200 kHz. If X-Cap is selected as Cx = 1.0uF, for example, the external DM inductor with L_dm = 2.5uH has to be inserted for the adequate DM noise attenuation, resulting a less desirable design.

After the EMI filter is designed and the number of filter stage is determined, in the Parameter Panel, click on the button **EMI Filter Attenuation** to display the CM and DM EMI noise attenuations from the designed EMI filter as shown below.

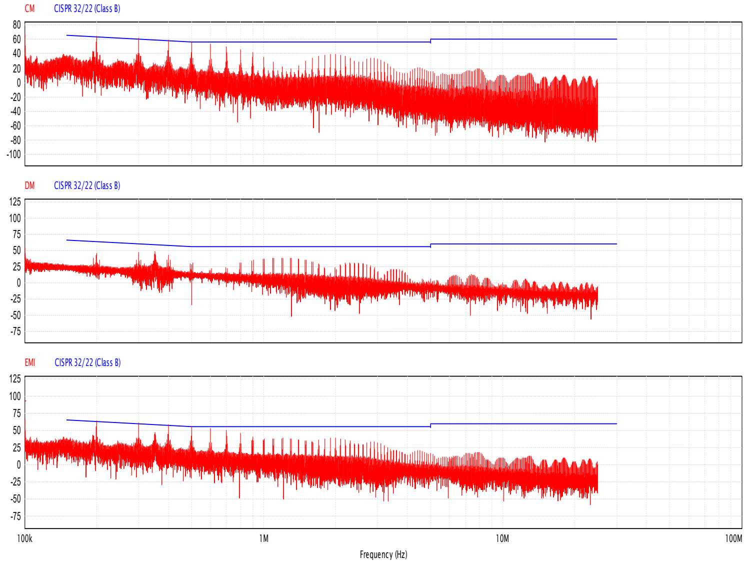


In the figure, dB(H_CM) shows the attenuation of the CM noise, and dB(H_DM) shows the attenuation of the DM noise, both in dB. This tool provides a convenient way to calculate quickly how much attenuation the designed EMI filter will provide to noises at different frequencies.

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 III: Running Simulation with the EMI Filter Enabled

Run the 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 II with different parameters until satisfactory results are achieved as shown below:

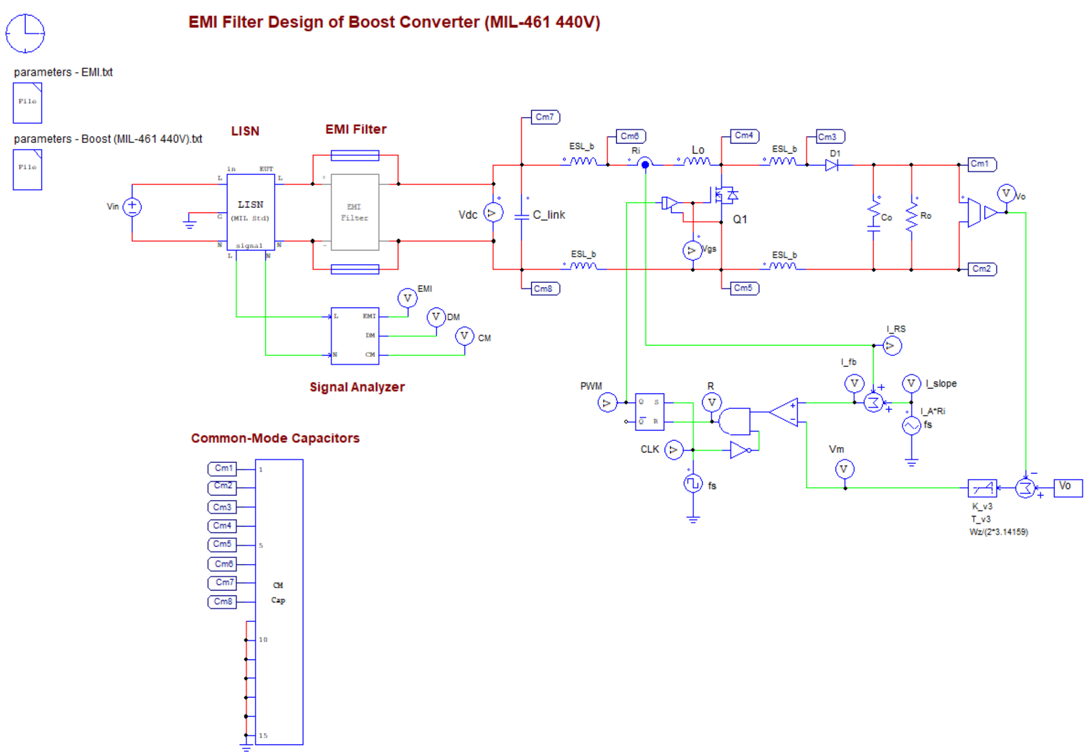


2. Other Design Templates

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

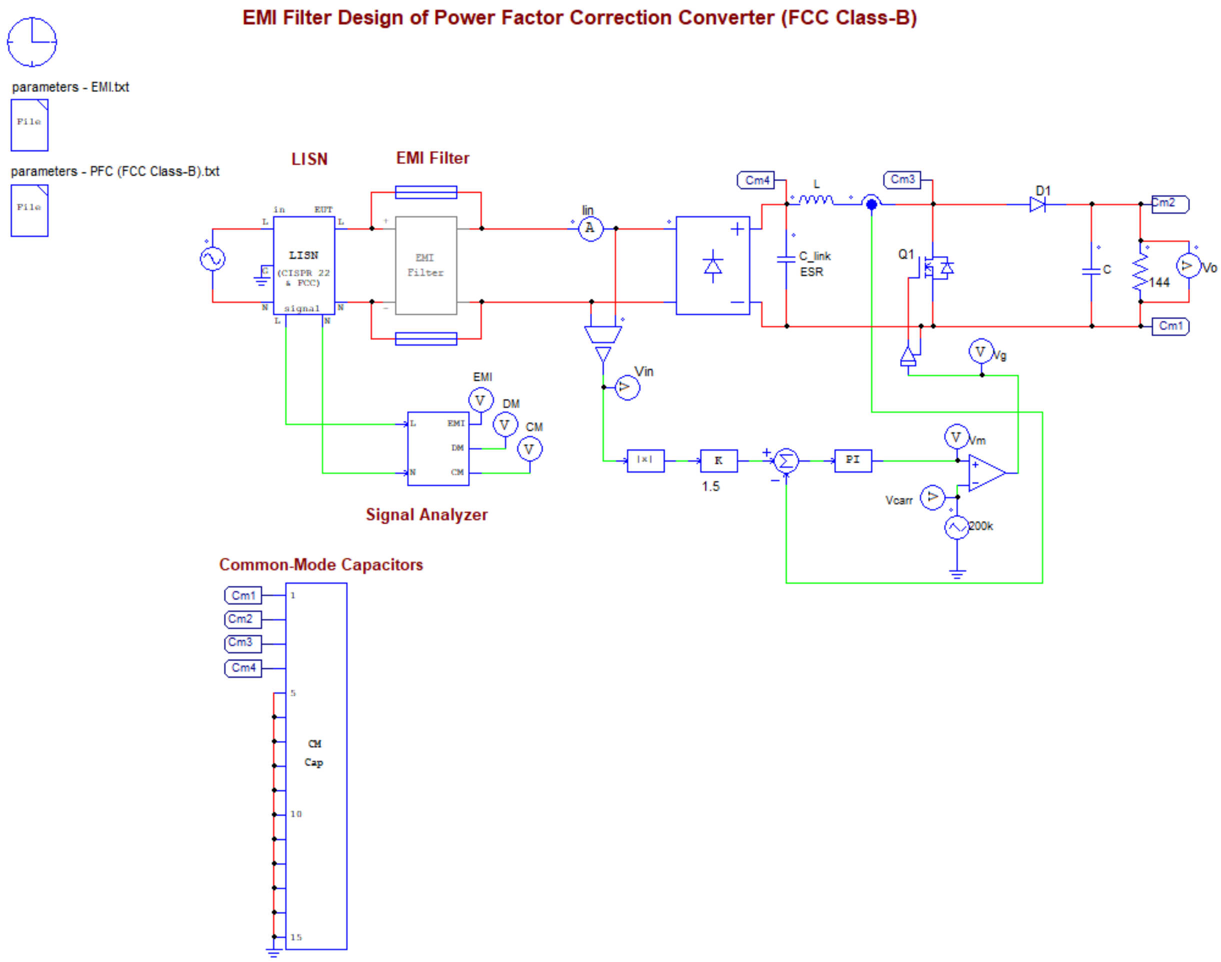
2.1 Boost Converter Template

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. EMI standard MIL-461 440V is used for the EMI compliance. Note that lowest frequency in MIL-461 EMI standard stars at 10 kHz.



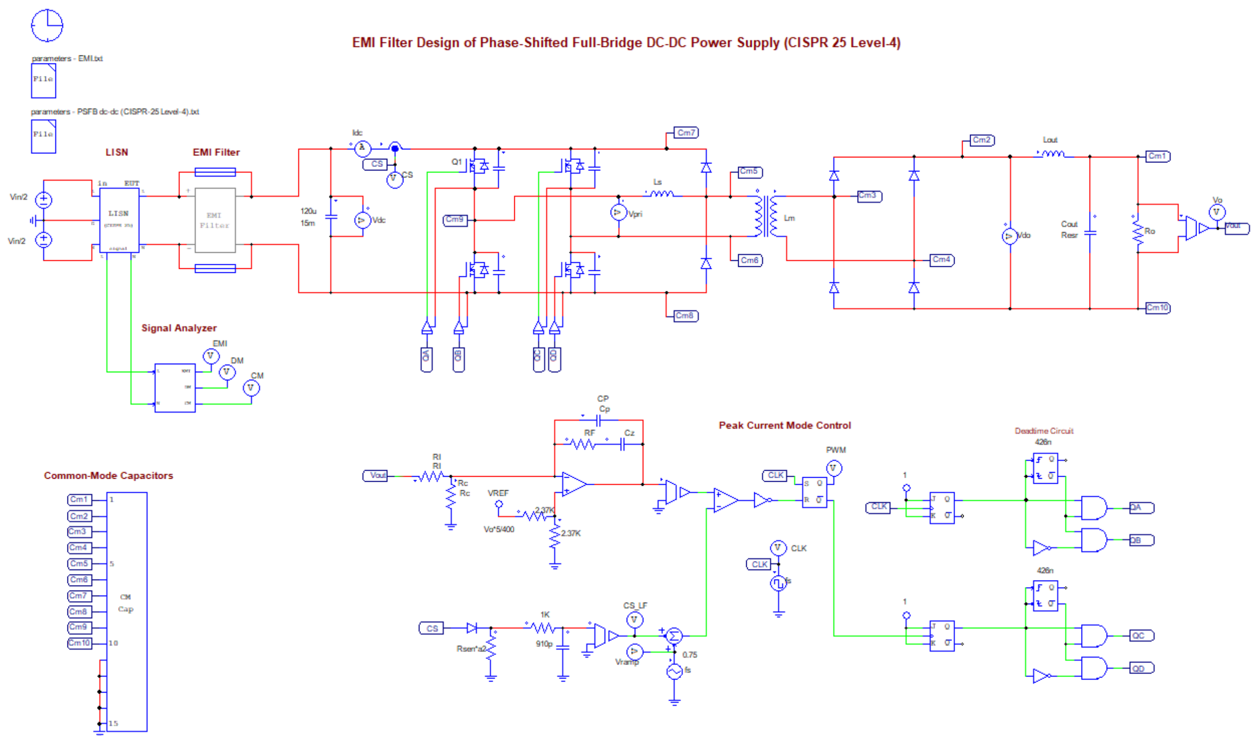
2.2 Power Factor Correction (PFC) Converter Template

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 for the EMI compliances.



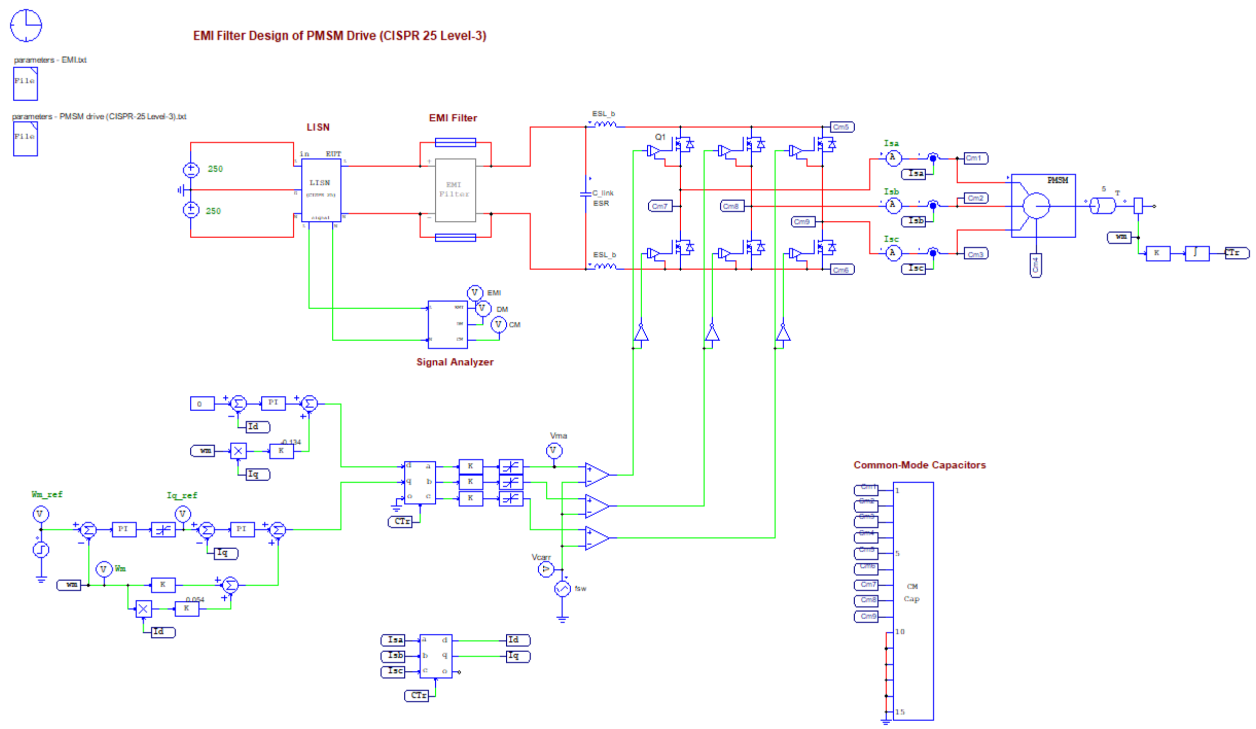
2.3 Phase Shifted Full-Bridge (PSFB) DC-DC Converter Template

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 for the EMI compliances.



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 for the EMI compliances.



2.5 General EMI Design Template

The EMI Design Suite also provides a general EMI design template which allows user to insert one's own power electronic converter circuit for EMI pre-compliance simulation. The following figure shows a general EMI design template. In this template, the essential EMI testing equipment models are provided for user's power electronic converter circuit for EMI pre-compliance simulation.