

PLECS

*DEMO MODEL*

## Half-Bridge LLC Converter with Analysis Tools

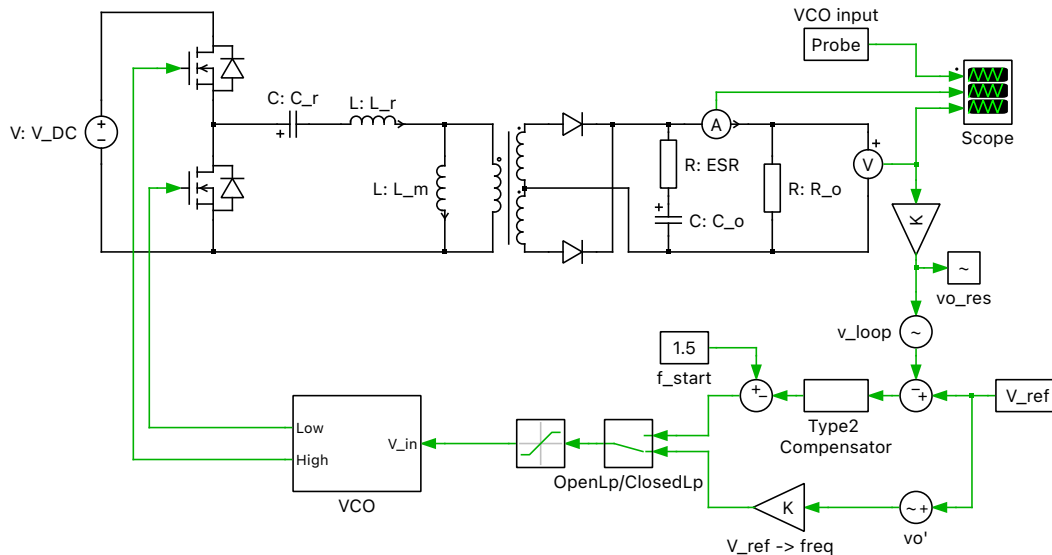
Last updated in PLECS 4.7.1

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# 1 Overview

This demonstration shows a half-bridge LLC resonant converter operated with open-loop and closed-loop frequency control using a voltage-controlled oscillator (VCO). Further, Multitone Analysis is used in the open-loop system to design the compensator and to check the stability of the closed-loop system.



**Figure 1: Half-bridge LLC resonant converter operated with open-loop and closed-loop frequency control**

**Note** This model contains model initialization commands that are accessible from:

*PLECS Standalone:* The menu **Simulation + Simulation Parameters... + Initializations**

*PLECS Blockset:* Right click in the **Simulink model window + Model Properties + Callbacks + InitFcn\***

## 2 Model

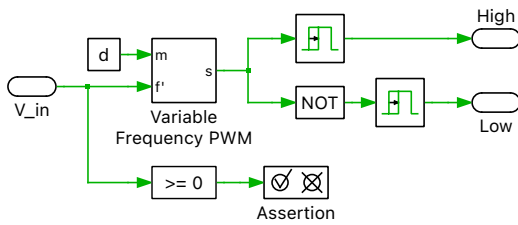
### 2.1 Power circuit

The LLC converter is a DC/DC converter and in this case uses a front end half-bridge. The AC-side of the half-bridge is connected to the primary side of a high-frequency transformer via a series-connected resonant inductor and capacitor. The magnetizing inductance of the transformer, along with the inductor and capacitor, form the LLC resonant tank. The secondary side of the transformer is connected to a full-wave diode rectifier to convert the AC transformer output to a high ripple DC voltage that is then filtered to provide a low ripple DC voltage output.

### 2.2 Voltage-controlled oscillator

The VCO block converts a voltage signal into a PWM signal. It is shown in Fig. 2. The frequency of the PWM signal is proportional to the input voltage. This voltage is passed to the Variable Frequency PWM block to generate the gate signals. The Turn-on Delay block inserts a blanking time between the high and low side switches.

The VCO enables the variable-frequency control of the half-bridge LLC resonant converter.



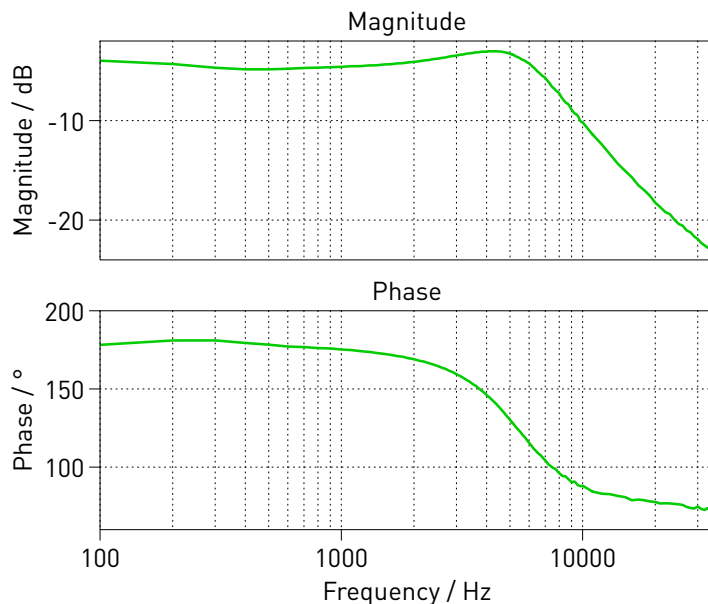
**Figure 2: Voltage-controlled oscillator for the half-bridge LLC resonant converter**

## 2.3 Analysis

The model can be run either as an open-loop or closed-loop controlled system. Double-clicking on the Manual Switch “OpenLp/ClosedLp” toggles the model configuration.

In the compensator design process, the open-loop plant transfer function is used to verify the analytical model of the plant. With the model as is, execute the following steps for either PLECS Standalone or PLECS Blockset:

- *Standalone:* Choose **Analysis tools...** from the **Simulation** menu. Run the Multitone Analysis for the “OpenLoopAnalysis” analysis. This provides the transfer function for the open-loop system. The result is shown in Fig. 3.
- *Blockset:* Run a Multitone Analysis by double-clicking on the **Multitone Analysis** block to open the dialog and click on the **Start analysis** button. The progress of the analysis can be configured for display in the MATLAB Command Window. When the analysis has finished a new Bode plot will be displayed showing the corresponding transfer function.



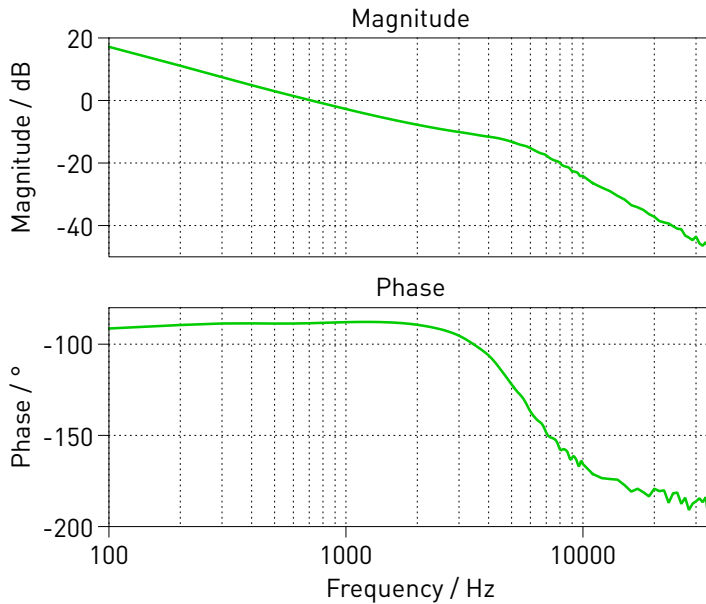
**Figure 3: Open-loop transfer function for the half-bridge LLC resonant converter**

Observe the Bode plot generated by the analysis. The double pole due to the inductor and output capacitor is at approximately 4 kHz. Further, the zero due to the output ESR is at approximately 8 kHz. The slope of the gain at DC is about 0 dB per decade, which may introduce steady-state tracking error for the closed-loop system.

A Type 2 compensator is used for output voltage regulation. The integrator introduced in the system by the compensator ensures there is no steady-state tracking error. The zero of the Type 2 compensator is used to cancel one of the double-poles due to the inductor and output capacitor. The pole of the Type

2 compensator is used to cancel the zero due to the output capacitor ESR. The DC-gain increases the system bandwidth.

Double-click on the Manual Switch “OpenLp/ClosedLp” to configure the model for closed-loop control operation. Run the “ClosedLoopAnalysis” in PLECS Standalone (or “Loop Gain” analysis on the Simulink level for PLECS Blockset) to obtain the open-loop transfer function of the closed-loop system. The result is shown in Fig. 4. Analyze the Bode plot generated by the analysis. The cross-over frequency is about



**Figure 4: Closed-loop transfer function for the half-bridge LLC resonant converter**

700 Hz, the slope of the gain is close to  $-19$  dB per decade, and the gain and phase margins are about 34 dB and  $91^\circ$ , respectively. Thus, this system is stable.

### 3 Simulation

In this demonstration, a 380 VDC input is stepped down to maintain an output voltage of 12 VDC. The converter output voltage is regulated by controlling the converter switching frequency. To obtain an output voltage of 12 VDC, the converter is switched at about 130 kHz. For the closed-loop system, the frequency modulation starts at 150 kHz and as the output voltage reaches the voltage set point the modulation frequency is regulated to 130 kHz.

**Note** For converters with variable-frequency control a Multitone Analysis should be used for generating the frequency response. The AC Sweep tool employs the Steady-State Analysis, that needs the information of the system period, which for variable-frequency controlled converters, is not known prior to the simulation.

### References

- [1] Huang, H. “Designing an LLC Resonant Half-Bridge Power Converter”, TI Power Supply Design Seminar, SEM1900, Topic 3, 2010.

## Revision History:

PLECS 4.3.1	First release
PLECS 4.7.1	Using the new Variable Frequency PWM library block

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