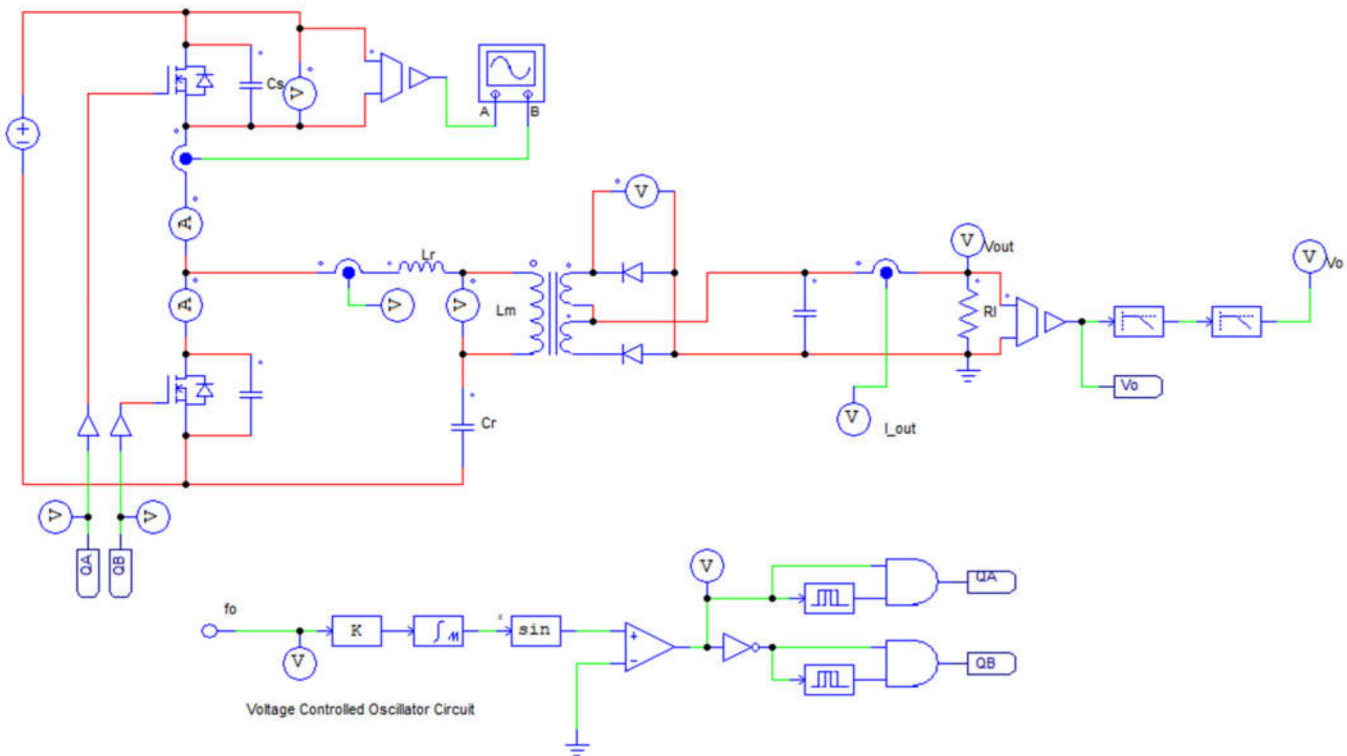
LLC Resonant Converter Design with Scripting

This example circuit uses scripting to determine the minimum magnetics ratio of magnetizing/resonant, Ln = Lm/Lr, to provide the desired gain and output power of an LLC resonant converter.

This application note will explain the scripting example and outputs but will not go into the theory of a resonant converter. This LLC design is based on an app note from Texas Instruments and there are links to it at the bottom of the page and within the text.



Half Bridge LLC schematic

The script runs constant loads across 2 decades of frequency centered on the resonant frequency Fr. The script runs 3 nested loops: the outer loop sweeps different Ln, the middle loop sweeps different loads (Qe), and the inner loop sweeps the frequency.

The LLC converter circuit is based on an application note published by *Texas Instruments – Designing an LLC Resonant Converter (slup 263)* which is a supporting document for their *UCC25600*, 8-Pin High-Performance Resonant Mode LLC Controller.

The loads are defined by the Quality factor Qe which defined inscript as:

Qe = ((Lr/Cr)^0.5)/Re; //Quality factor equation (22)

The output is compiled to represent the gain of each load vs a normalized frequency. Essentially the script investigates the impact of changing the parameters *Lm* and *Rl* with multiple frequency inputs *fo* in the schematic above.

In order to achieve an efficient simulation, the script optimizes the timestep and simulation time for each frequency input. If the resonant frequency is 100KHz, the lowest frequency that will be run is 10KHz and the fastest frequency is 1MHz. With a fixed timestep and simulation length, the 10KHz simulation would dictate the simulation length while the 10MHz simulation would dictate the timestep:

- Period of 10MHz = 100ns vs Period of 10KHz = 100us
- 60 cycles @ 10MHz = 6us vs 60 cycles @ 10KHz = 6ms

Given the above information a constant timestep and simulation time would need the worst case situation: period of 100ns and simulation time of 6ms. Which would then mean at the 10KHz simulation we would need:

- timestep = 100ns/400 = .25ns
- simulation time = 6m seconds
- Total datapoints = .36/.25n = 24M

Using 24M datapoints is completely unnecessary if the script simply optimizes the timestep for the frequency of interest for each simulation performed. For the script 400 datapoints per cycle and 60 cycles is used for optimal resolution of the switching transitions and to allow the converter plenty of time to hit steady state in open loop. This is built into the script and means every simulation will have the same number of data points for the 10KHz case:

- timestep = 100u/400 = 250ns
- simulation time = 6ms
- Data points = 6m/250n = 24k

24k datapoints is a much more reasonable number for each simulation and the following lines of code in the script ensure that it is the same for each simulation

```
period = 1/fo;
// the simulation and time step is dynamically declared based on the frequency to be used.
length = period*60; //assume steady state by 60 cycles;
stepsize = period/400; //400 data points per cycle
```

where “fo” above is the frequency defined for the simulation.

The script saves each simulation to a unique results file for post simulation analysis while calculating and plotting the gain curves for each load vs frequency.

Qe= 5 Fn= 132629 Ln= 2 LLC_script_out.smv	4/17/2018 3:55 PM	PSIM Document	4,328 KB
Qe= 5 Fn= 129976 Ln= 2 LLC_script_out.smv	4/17/2018 3:55 PM	PSIM Document	4,328 KB
Qe= 5 Fn= 124671 Ln= 2 LLC_script_out.smv	4/17/2018 3:55 PM	PSIM Document	4,328 KB
Qe= 5 Fn= 127323 Ln= 2 LLC_script_out.smv	4/17/2018 3:55 PM	PSIM Document	4,328 KB
Qe= 5 Fn= 122018 Ln= 2 LLC_script_out.smv	4/17/2018 3:55 PM	PSIM Document	4,328 KB

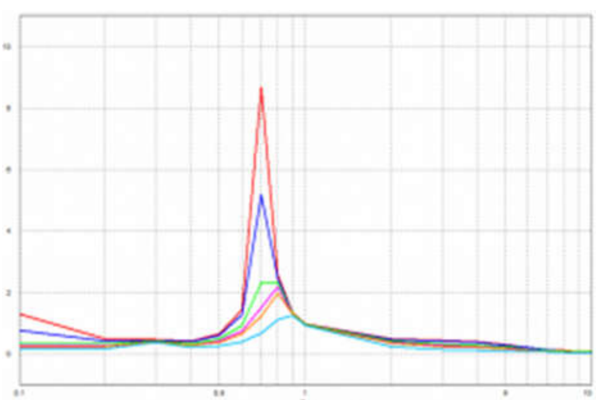
The above screenshot of some of the results shows that each file has a unique name and the size of the files are all the same, showing that the timestep and simulation time is being optimized for each scenario.

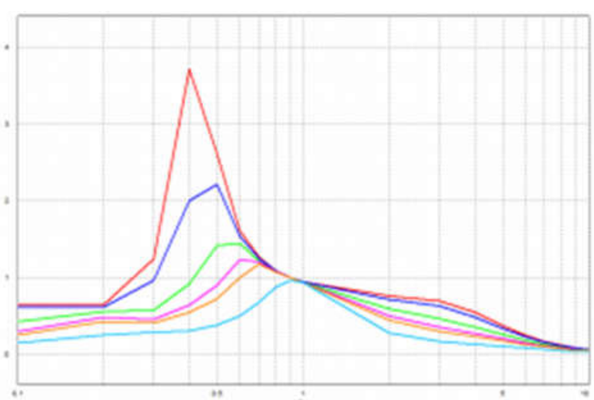
The script performs 342 open loop simulations and computes the gain for each simulation. On the test computer it took 2 minutes and 55 seconds to complete.

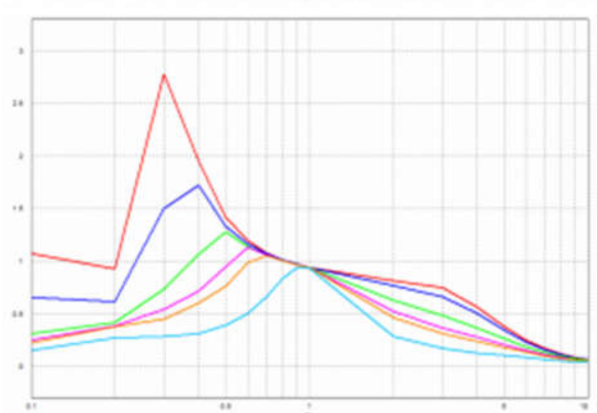
Qe, Ln and Fo are swept through:

- Qe = { .1, .2, .5, .8, 1, 2}
- Ln ratio = {1, 5, 10}
- Frequency multipliers = {0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9,1,2,3,4,5,6,7,8,9,10};

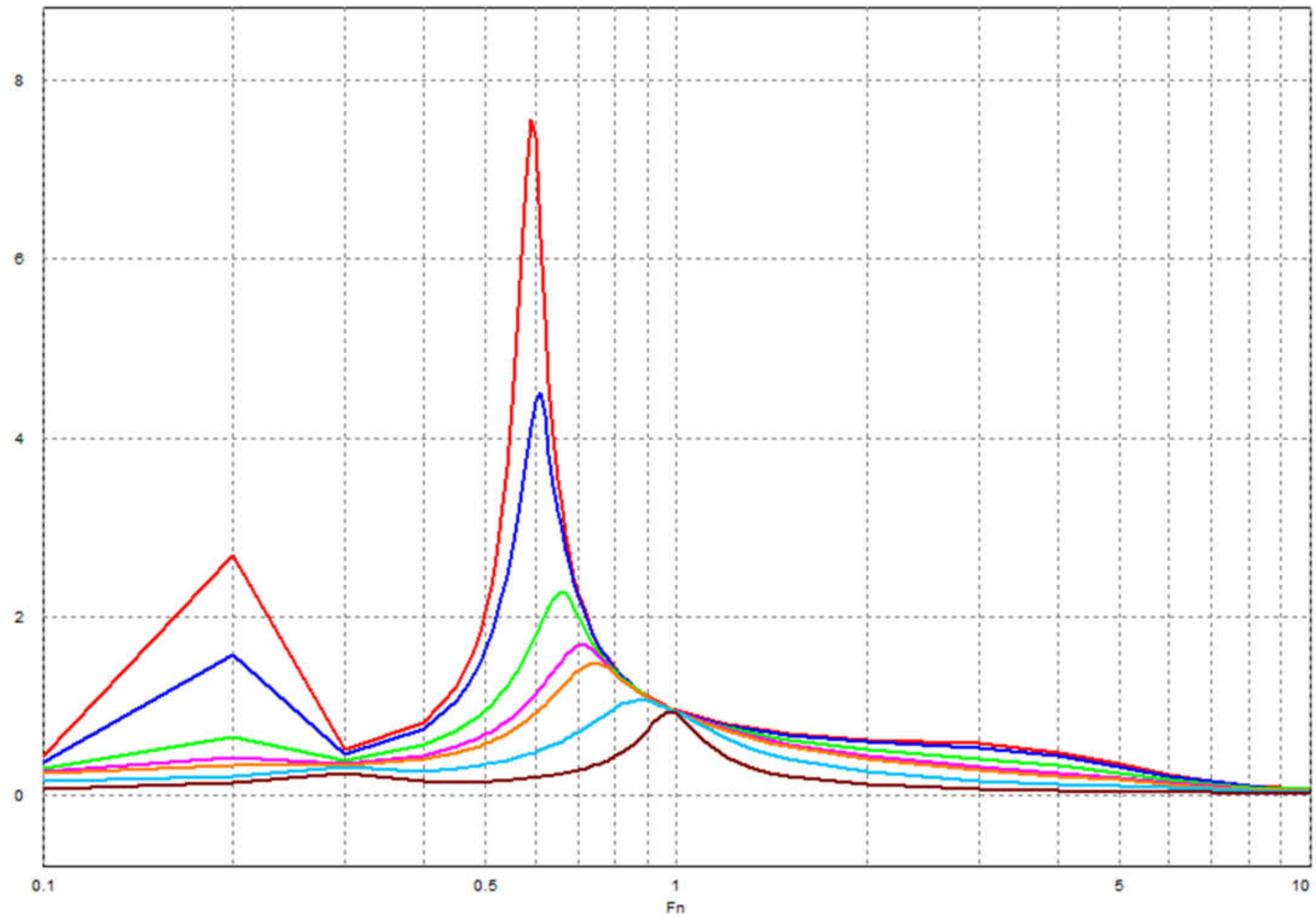
The script compiles 3 plots which show the gain across various loads with a particular magnetics ratio. The plots for Ln = 1, 5, and 10 are below.







Another set of simulations was run focusing on Ln = 2, with more resolution in the frequency. This plot is made up of 400 simulations and shows the gains achieved with an Ln = 2.



These gain plots are important during the design of an LLC resonant converter as it is critical to identify the operating frequency range and required Ln ration to provide enough gain over the load range for the design. The example files are available below for download or from the PSIM examples folder in "\examples\scripts\LLC converter". If you download from below please save the files in the same folder.