Non-linear inductor SPICE simulation

The simulation files of the Non-linear inductor will run on ORCAD 9.2 evaluation version (Lite Edition). In case of difficulty pleas contact at:

sby@ee.bgu.ac.il or morp@ee.bgu.ac.il

The main folder (name: non-linear inductor) includes four subfolders (Buck, Buck_Average, Behavior and Param_Mod), each folder contains one simulation project for the corresponding simulation circuit. The inductor data refers to a 77254-A7 iron powder core (Kool Mu) characteristics, drawn from MAGNETICS data sheets.

Technical data: http://www.mag-inc.com/pdf/MAGNETICS_Powder_Core_Technical_Data.pdf.

Core data: http://www.mag-inc.com/pdf/MAGNETICS_Powder_Core_Data.pdf.

77254-A7, core characteristics:

- Permeability (Kool Mu): 125
- Path length: l_e = 9.84 cm
- Window area: A_w = 4.27 cm^2
- Area product: A_p = 4.58 cm^4
- Effective area: A_e = 1.072cm^2
- Inductance per 1000 turns: 168mH
- Number of turns: n = 130, provide initial inductance of 2.8mH

All characteristics assigned as parameters using 'PARAM' element.

Simulation projects description:

1. Folder: Behavior. Project name: Non_Linear_Inductor

Non-linear inductor dependence on the DC current.

Schematics page description:

The simulation page contains two circuits of the non-linear inductor, one for each method mentioned in the article [1]:

Experimental method – denoted by the letter A:

The non-linear inductor model is subjected to a small signal AC source in series with a DC current source. The inductor's non-linear behavior is described as a table of the inductance as a function of the DC current, as obtained by measurements.

Manufacturer's data – denoted by the letter B:

The non-linear inductor model is subjected to a small signal AC source in series with a DC current source. The inductor's non-linear behavior is described as an expression of the inductance as a function of the magnetic force (H).

Probe window (Window> Display Control> behavior):

Displays three plots: Two lower plots - The inductance value (of both methods) observed from the input, $L = \frac{X_L}{2\pi \cdot \text{frequency}}$, where X_L is measured by: $X_L = \frac{V_{in}}{I_{in}}$, Evaluation for different bias current is set with the parameter "I_bias" as the sweep global parameter, (AC, Simulation settings > parametric sweep).

Upper plot - Performance analysis, inductance value as a function of the bias current.

Bias current sweep: 0 – 6ADC in 0.1ADC steps.

2. Folder: Buck. Project name: Buck_non_linear_L

Cycle-by-Cycle, transient simulation of a buck converter.

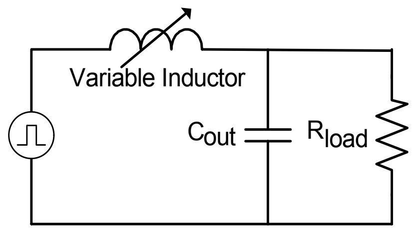

Figure 1. Simplified Buck converter.

Schematics page description:

The simulation page contains two circuits of a simplified buck converter, cycle-by-cycle model and an average model.

Buck Cy-by-Cy:

Simplified Cycle-by-Cycle simulation of an open loop buck converter (a pulsed voltage source is fed to the buck LC filter).

The inductor's non-linear behavior is described as an expression of the inductance as a function of the magnetic force (H).

Buck-average:

An average behavioral model of an open loop buck converter [2, 3].

The inductor's non-linear behavior is described as an expression of the inductance as a function of the magnetic force (H).

Analysis: TRAN, Power-on transient V_{in} = 400V, D_0 = 0.5, $I_L(0)$ =0, run time: 10ms

Sweep parameter: Rload

Probe window (Window> Display Control> cy_by_cy):

Displays two plots, one graph in each; upper plot: inductor current of the average model, lower plot: inductor current of the cycle-by-cycle model. Evaluation for different load values is set with Rload as the sweep global parameter (TRAN, Simulation settings > parametric sweep). Rload values are: 20Ω, 50Ω and 100Ω.

3. Folder: Buck_Average. Project name: Buck_average
   Small-signal simulation of a buck converter.

Schematics page description:

Buck_average:

An average behavioral model of a buck converter, open loop simulation. D_0=0.5
AC sources: d
Parametric sweep: parameter: Rload

Probe window (Window> Display Control> ac):

Displays the open loop gain (V_{out}/d) of the average simulation [2, 3]. Evaluation for different load values is set with Rload as the sweep global parameter (AC, Simulation settings > parametric sweep). Rload values are: 20Ω, 50Ω and 100Ω.

4. Folder: Param_Mod. Project name: Parametric_mod

Schematics page description:

Parametric_modulation:

Performing modulation on an input signal by changing the circuit parameters. I_carrier is the high frequency carrier signal and the current sensed by Vs_pm is the modulating signal (fed thru a bias winding - see Fig. 2) [4]. Inductance changes as a function of the current sensed in Vs_pm, causes the circuit to change its parameters.

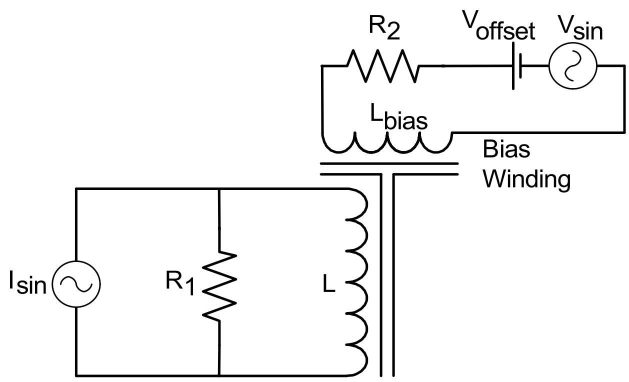

Figure 2. Parametric Modulation circuit.

Probe window (Window> Display Control> param_mod):

1. TRAN – transient simulation, displays two plots, one graph in each plot upper plot: inductor voltage, lower plot: inductor value (1mV=1mH).

References

[1] S. Ben-Yaakov and M.M. Peretz, "Simulation bits: A SPICE behavioral model of non-linear inductors", *IEEE Power Electronics Society Newsletter*, Fourth Quarter, 9-10, 2003.

[2] S. Ben-Yaakov, "Average simulation of PWM converters by direct implementation of behavioral relationships". *IEEE Applied Power Electronics Conference*, APEC-93, 510-516, San-Diego, 1993.

[3] I. Zafrani, S. Ben-Yaakov, “Generalized switched inductor model (GSIM):accounting for conduction losses”. *IEEE Trans. Aerospace and Electronic Systems,*vol. 38, pp. 681-687, 2002.

[4] D. Medini, and S. Ben-Yaakov, “A current controlled variable inductor for high frequency resonant power circuits”. *IEEE Applied Power Electronics Conference*, APEC-94, pp. 219-225, Orlando, 1994.