

Title: Magnetic Core and BH Curve

Product: OrCAD PSpice A/D, OrCAD PSpice AA and AMS Simulator

Summary: This application note shows how to build inductors with magnetic cores and how to plot the BH curve of a core in PSpice Probe Window. The model parameters of a core can be edited in Model Editor and the BH curve can also be plotted into it.

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1 Introduction

A magnetic core is a piece of magnetic material with high permeability used to confine and guide magnetic fields in electrical and electromechanical devices such as electromagnets, transformers, electric motors and inductors. The magnetic field can be created by a coil of wire around the core that carries a current. The presence of the core can highly increase the magnetic field of a coil of what it would be without the core. [3]

There are many PSpice models for magnetic cores. A nonlinear magnetic core can be used to build e.g. an inductor and the BH curve can be plotted in PSpice Probe Window. The PSpice model of a core can be easily modified and the BH curve can also be plotted using Model Editor.

- PSpice supports two models of magnetic core:
- Jiles-Atherton model (level 2)
- Spice Plus model (level 3)

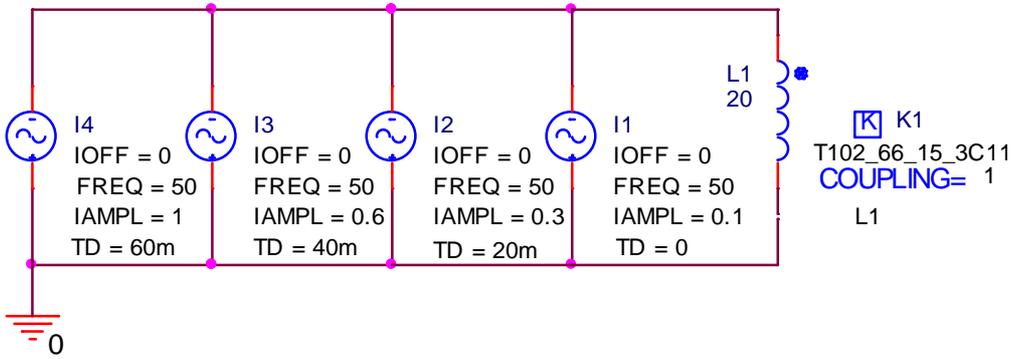
The Jiles-Atherton model parameters are listed below:

Model parameters	Description	Units	Default
<i>A</i>	Thermal energy parameter	amp/meter	1E+3
<i>AREA</i>	Mean magnetic cross-section	cm ²	0.1
<i>C</i>	Domain flexing parameter		0.2
<i>GAP</i>	Effective air-gap length	Cm	0
<i>K</i>	Domain anisotropy parameter	amp/meter	500
<i>LEVEL</i>	Model index		2
<i>MS</i>	Magnetization saturation	amp/meter	1E+6
<i>PACK</i>	Pack (stacking) factor		1.0
<i>PATH</i>	Mean magnetic path length	Cm	1.0

This model parameters are accessible in the Model Editor.

2 Building an Inductor

A simple demo circuit in the project Core_BH.opj is created as follows:



In this circuit, L1 and K1 are coupled to form an inductor. The nonlinear magnetic core T102_66_15_3C11 comes from the library magnetic.olb and is a Jiles-Atherton model. This is a ring core (toroid), and has the default coupling factor value of 1.

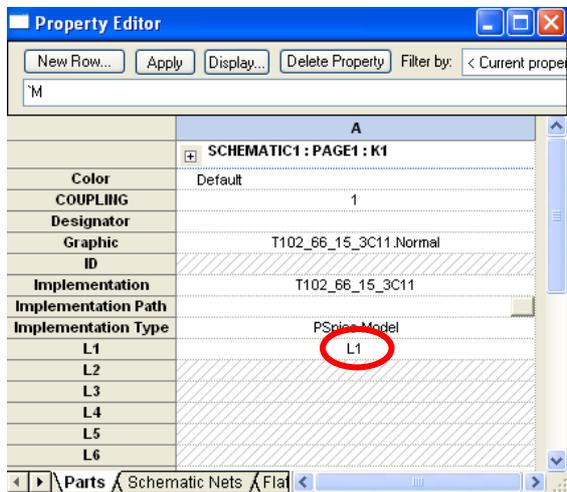
Note:

In PSpice, the coupling factor **COUPLING** must have a value from -1 to +1.

The name of a core, e.g. T102_66_15_3C11, is defined as follows:

- T core type
- 102_66_15 core size, here
 - outer diameter = 102 mm
 - inner diameter = 66 mm
 - height = 15 mm
- 3C11 core material

In order to couple 'L1' to 'K1', open the Property Editor for this magnetic core and enter 'L1' as the value for the property of the first coupled inductor L1. This property can also be displayed in Capture schematic by clicking **Display...**



In our example we just couple L1 which has 20 turns.

Note:

Per default, up to 6 different inductors (L1 – L6) can be coupled using a nonlinear core. The first L property, L1, must have a value (a RefDes of an inductor) and the other L properties may be left blank. The value of an inductor is set to the number of turns. In comparison to nonlinear magnetic core, linear coupling (K_Linear) must be applied to two or more inductors and the values of the affected inductors are set to values in Henries. Furthermore, the property IMPLEMENTATION has no core model assigned.

3 BH Curve in Probe Window

In order to plot a BH curve in Probe Window, a transient analysis is needed. To do this, create a PSpice Profile, set the simulation time to e.g. 80ms and run the simulation. The x-axis in Probe Window can be set to the magnetic field strength H through **Plot >> Axis Settings... >> X Axis >> Axis Variable... >> H(K1)** (Trace Expression).

Now the curve B(K1) can be added in Probe Window.

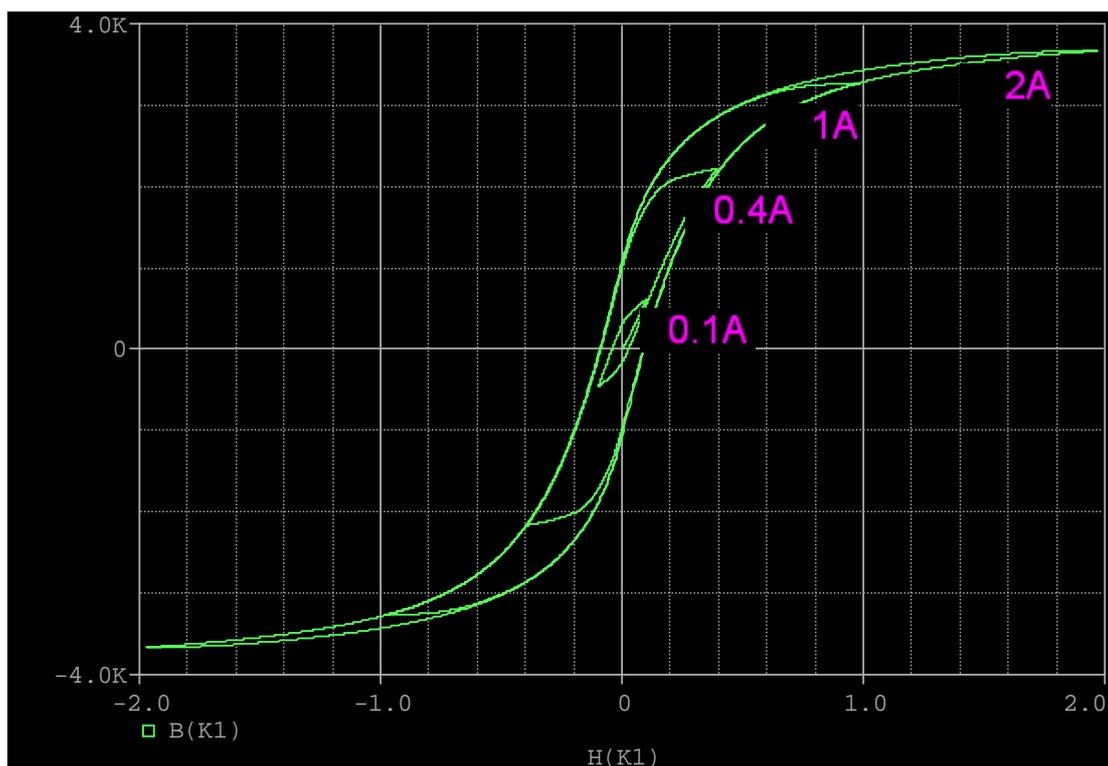


Fig. 2: BH curve in Probe Window

There are 4 loops, one for each of the 4 different currents which flow through the inductor.

In PSpice, the unit for the magnetic field strength H is Oersted and for the magnetic flux density B is Gauss.

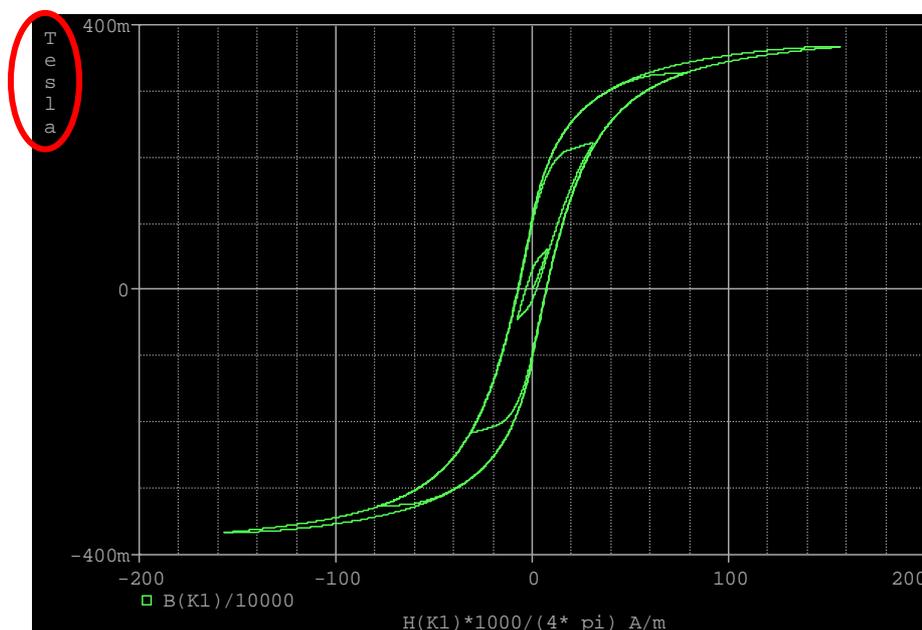
Note:

Many manufacturers show H in A/m and B in Tesla. Because

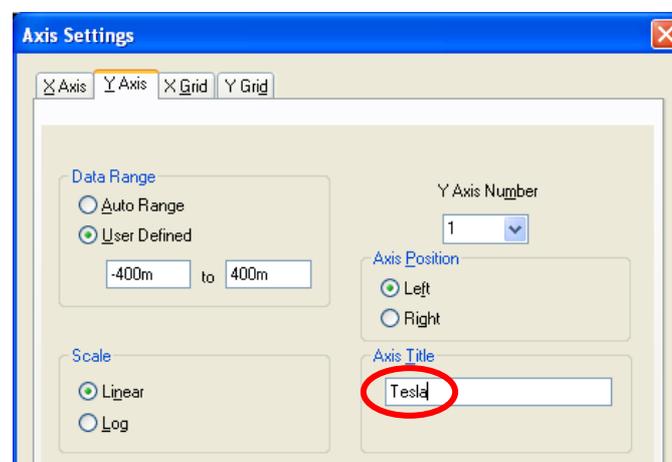
$$1\text{Oersted} = \frac{1000}{4\pi} \text{ A/m} \approx 79.577 \text{ A/m}$$

$$1\text{Gauss} = \frac{1}{10000} \text{ Tesla}$$

We can also display the BH curve with SI units as follows:

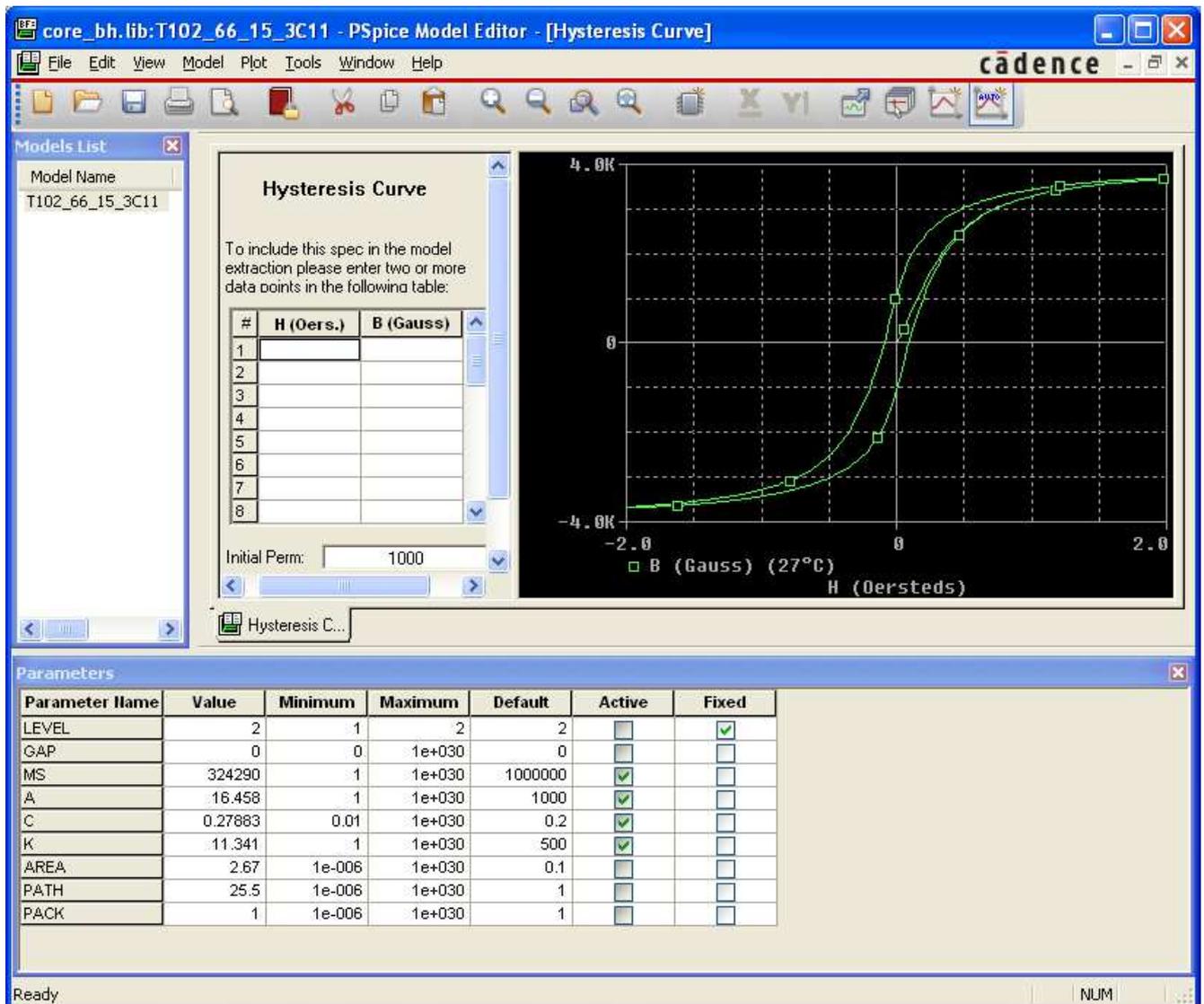
**Note:**

The X or Y-axis can be labelled by clicking **Plot >> Axis Settings... >>** (e.g.) **Y Axis >> Axis Title** and in this example entering **Tesla**.



4 BH Curve in Model Editor

The BH curve of the same magnetic core can also be plotted in Model Editor. To do so, save the model in a PSpice library e.g. core_bh.lib and then open it using Model Editor. If you only see the text model definition, the **Hysteresis Curve** window can be activated through **View >> Extract Model**



The BH curve in Model Editor is the same as the BH curve in Fig. 2.

4.1 Edit the Model Parameters

In the **Parameters** window, the active parameters can be modified to get a new magnetic core model.

Copy the model T102_66_15_3C11 into the same library core_bh.lib (**Model -> Copy From...**) and rename the model to e.g. my_K_T102_66_15_3C11. Change the value of K from 11.341 to e.g. 50 and the BH curve is changed correspondingly after selecting **Tools -> Extract Parameters** as follows:

The screenshot shows the PSpice Model Editor interface. The main window is titled "core_bh.lib:my_K_T102_66_15_3C11 - PSpice Model Editor - [Hysteresis Curve]". The "Hysteresis Curve" window is active, showing a graph of B (Gauss) vs H (Oersteds) with a hysteresis loop. The graph has a y-axis from -4.0K to 4.0K and an x-axis from -2.0 to 2.0. A table for data points is visible, with columns for #, H (Oers.), and B (Gauss). Below the table, the "Initial Perm:" is set to 1000.

The "Parameters" window is also open, showing a table of model parameters. The value of K is highlighted with a red circle and set to 50.

Parameter Name	Value	Minimum	Maximum	Default	Active	Fixed
LEVEL	2	1	2	2	<input type="checkbox"/>	<input checked="" type="checkbox"/>
GAP	0	0	1e+030	0	<input type="checkbox"/>	<input type="checkbox"/>
MS	324290	1	1e+030	1000000	<input checked="" type="checkbox"/>	<input type="checkbox"/>
A	16.458	1	1e+030	1000	<input checked="" type="checkbox"/>	<input type="checkbox"/>
C	0.27883	0.01	1e+030	0.2	<input checked="" type="checkbox"/>	<input type="checkbox"/>
K	50	1	1e+030	500	<input checked="" type="checkbox"/>	<input type="checkbox"/>
AREA	2.67	1e-006	1e+030	0.1	<input type="checkbox"/>	<input type="checkbox"/>
PATH	25.5	1e-006	1e+030	1	<input type="checkbox"/>	<input type="checkbox"/>
PACK	1	1e-006	1e+030	1	<input type="checkbox"/>	<input type="checkbox"/>

Note:

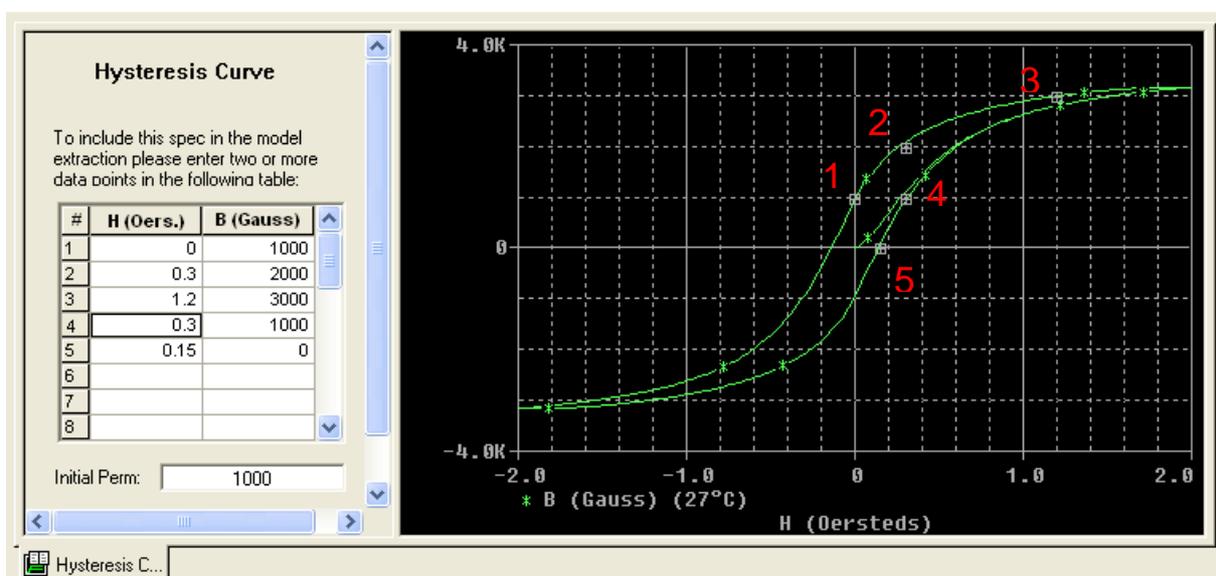
The LEVEL=2 is fixed for Jiles-Atherton model and we recommend to activate the parameters MS, A, C and K.

5 Edit the BH Curve according to Data Sheet Specifications

If you have a datasheet, you can enter some points in the specification entry according to the BH curve and extract the corresponding Jiles-Atherton model parameters for a magnetic core.

Copy the model T102_66_15_3C11 into the same library core_bh.lib and rename the model to e.g. data_T102_66_15_3C11. In the **Hysteresis Curve** entry, enter the initial permeability e.g. 1000 and some value points in the first quadrant as follows:

#	H(Oers.)	B(Gauss)	Comment
1	0	1000	y-axis intercept
2	0.3	2000	a point at the upper limb for the same x-axis value
3	1.2	3000	a point where the limbs converge
4	0.3	1000	a point at the lower limb for the same x-axis value
5	0.15	0	x-axis intercept



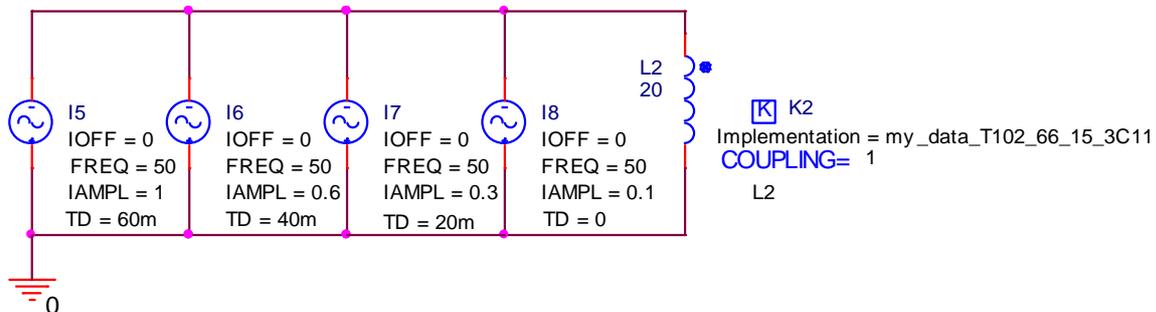
Note:

More data points can be entered in the **Hysteresis Curve** entry in order to get a more precise BH curve.

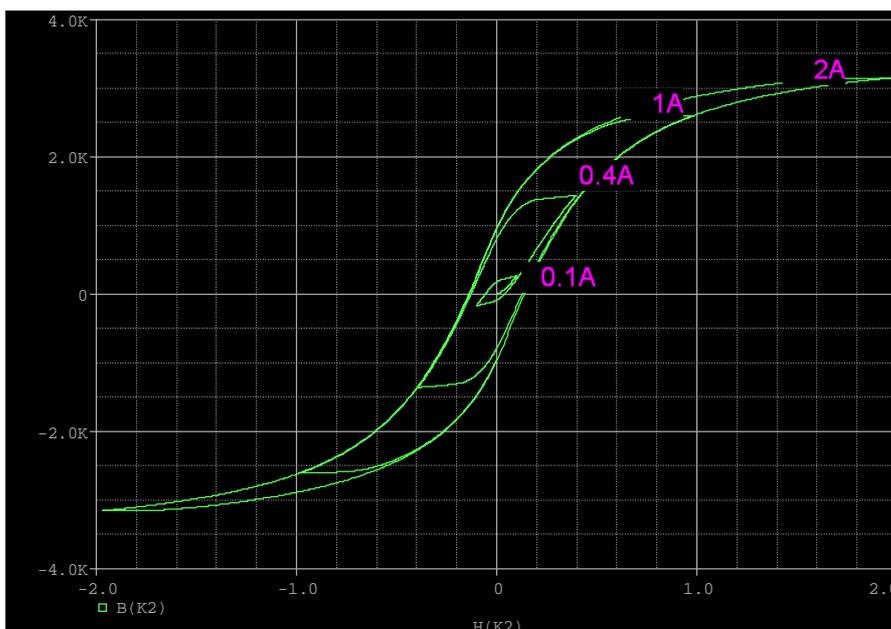
After entering the data points, the model parameters can be extracted through **Tools >> Extract Parameters**. The updated parameters are then displayed in the **Parameters** window and the points from the hysteresis Curve Table are marked in the curve Window.

Parameter Name	Value	Minimum	Maximum	Default	Active	Fixed
LEVEL	2	1	2	2	<input type="checkbox"/>	<input checked="" type="checkbox"/>
GAP	0	0	1e+030	0	<input type="checkbox"/>	<input type="checkbox"/>
MS	299518.0696	1	1e+030	1000000	<input checked="" type="checkbox"/>	<input type="checkbox"/>
A	27.73255056	1	1e+030	1000	<input checked="" type="checkbox"/>	<input type="checkbox"/>
C	0.101917104	0.01	1e+030	0.2	<input checked="" type="checkbox"/>	<input type="checkbox"/>
K	14.02650347	1	1e+030	500	<input checked="" type="checkbox"/>	<input type="checkbox"/>
AREA	2.67	1e-006	1e+030	0.1	<input type="checkbox"/>	<input type="checkbox"/>
PATH	25.5	1e-006	1e+030	1	<input type="checkbox"/>	<input type="checkbox"/>
PACK	1	1e-006	1e+030	1	<input type="checkbox"/>	<input type="checkbox"/>

Using the same test circuit to plot a BH curve of this customized magnetic core, the Implementation of a nonlinear core e.g. K2 is set to my_data_T102_66_15_3C11 correspondingly.



Finally, run a transient simulation for e.g. 80ms, and plot the BH curve of K2 in PSpice Probe Window:



If you compare the BH curve in Fig. 3, you will notice that they are the same.

6 Bibliography

- [1] PSpice User's Guide, Cadence
- [2] OrCAD Capture User's Guide, Cadence
- [3] http://en.wikipedia.org/wiki/Magnetic_core
- [4] Elektromagnetische Felder und Netzwerke (Anwendungen in Mathcad und PSpice),
Otfried Georg, Springer Verlag