Dynamic Model of Power Inductors and High Dielectric Constant Type Chip Monolithic Ceramic Capacitors

v1.01　2015/6

Dynamic Model of Power Inductors

Necessity of a Dynamic Model

Q. Why is a dynamic model required?

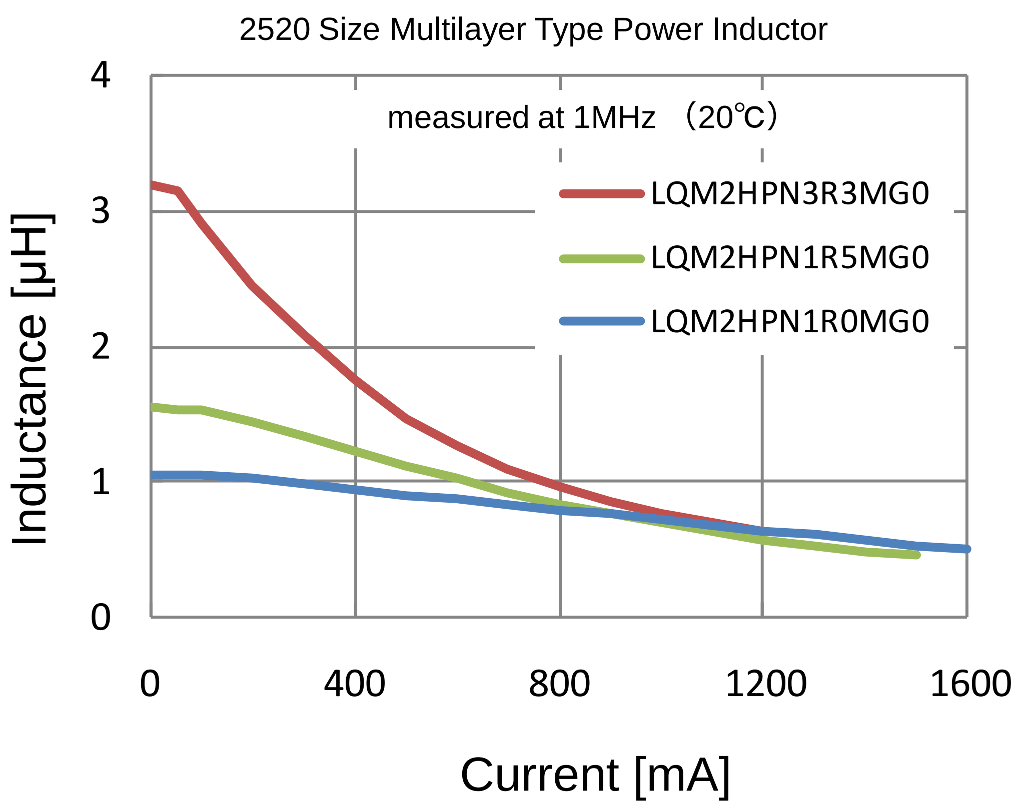
A. In a static model, the simulation results that reflect the inductance which changes in real time cannot be acquired.

In a circuit where a power inductor is used, the current which flows into the power inductor is not constant.

||

The inductance value is not constant during operation.

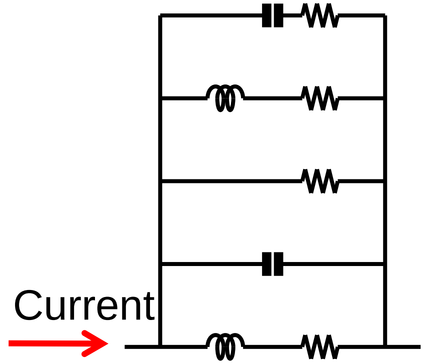
Example of Power Inductor Current - Inductance Characteristics



=> In ferrite based power inductors, when a large current flows through, since the ferrite approaches magnetic saturation, the permeability decreases during the process. The inductance also decreases because the inductance is proportional to the permeability. The above figure shows the characteristics (DC superposition characteristics) when a direct current flows through a power inductor.

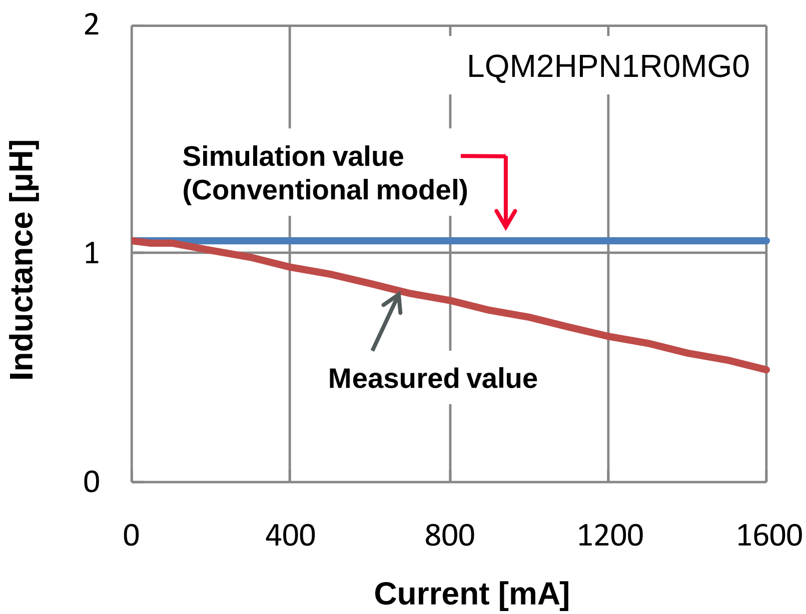
Comparison between Murata's Conventional Models and Actual Measurement Value

(1) Murata's conventional equivalent circuit model of an inductor (Example)



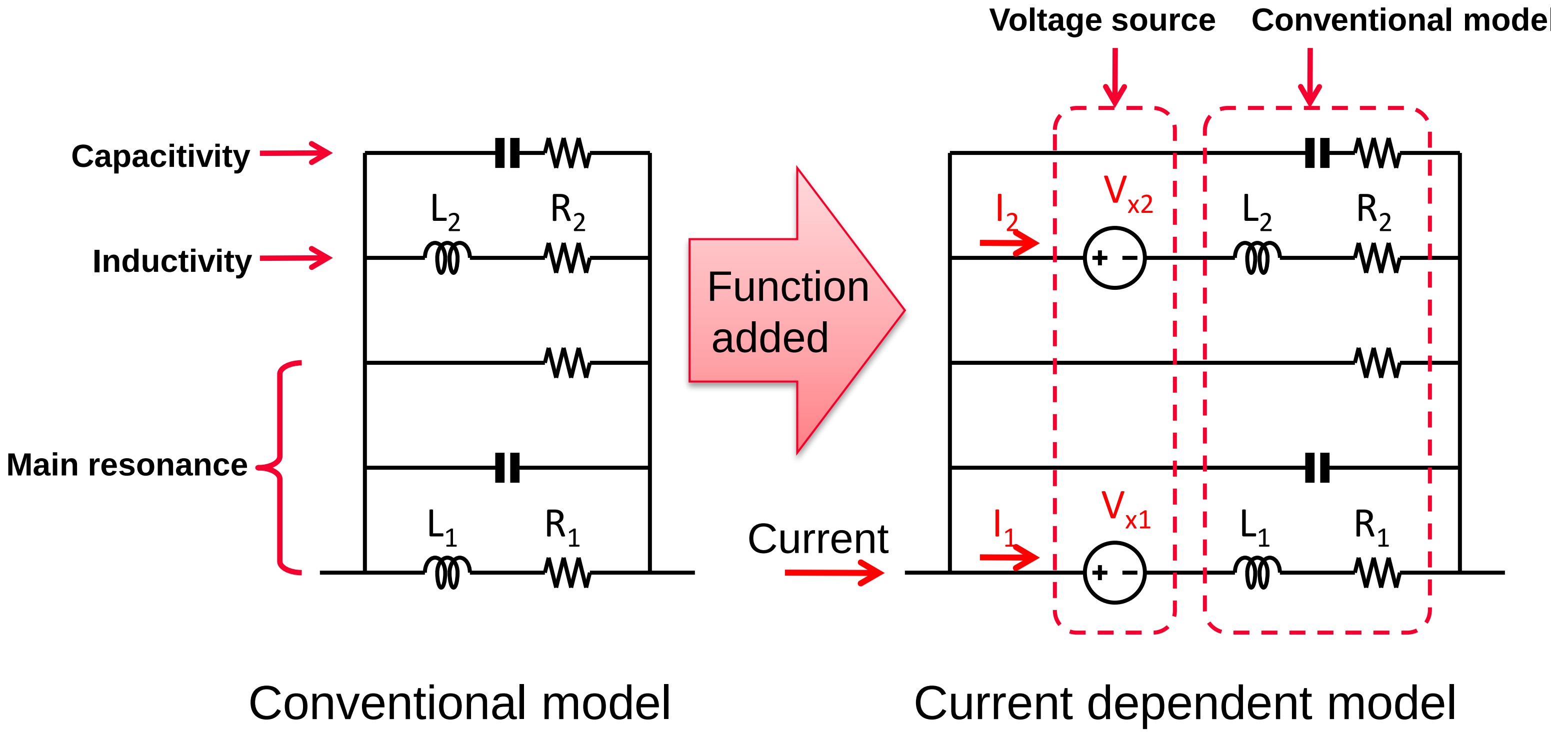
=> Even when the current changes, the constant of each component does not change (DC superposition characteristics are not reflected)

(2) Comparison between conventional model and actual measurement value



=> The DC superposition characteristics are not reflected in the (1) conventional model.

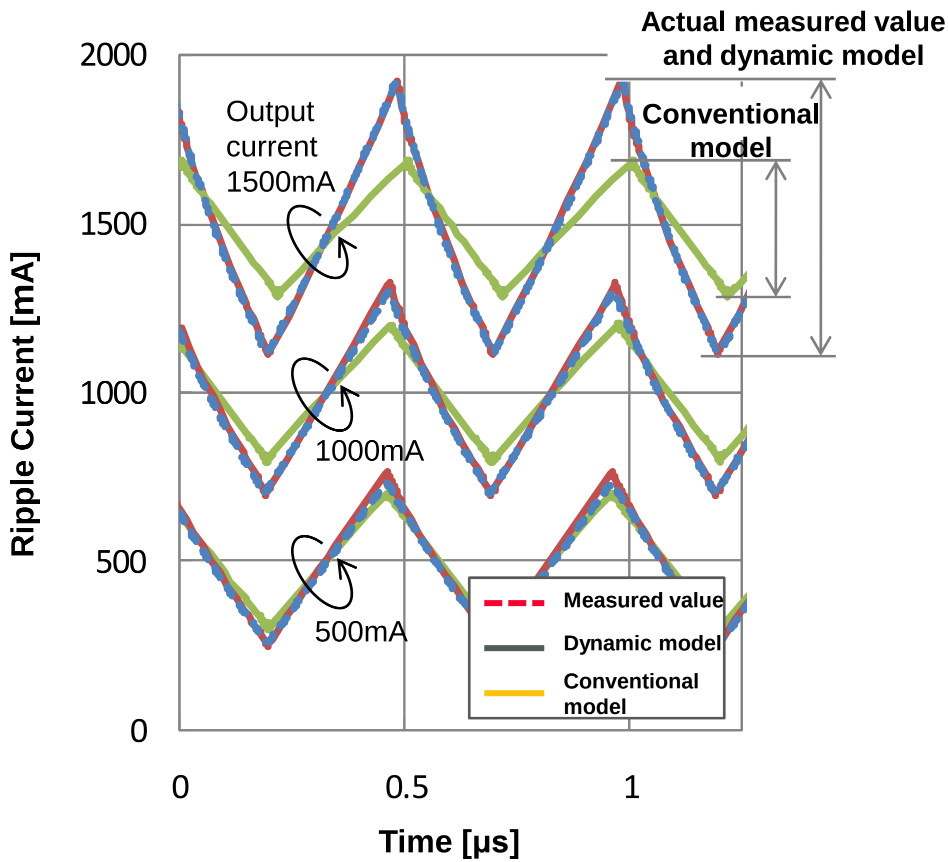
Proposal of Current Dependent Model (Dynamic Model)



=> Adding current dependency to several components of a conventional model, realized a dynamic model which responds to the change of inductance along with the change of the real time current.

Comparison between Dynamic Model and Actual Measurement Value (1/2)

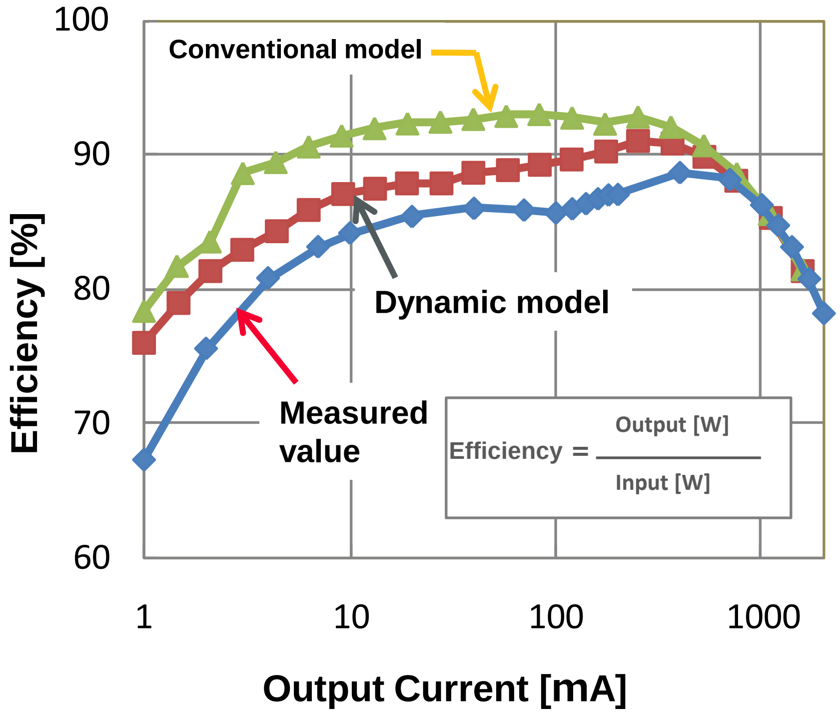
Example of verification: Comparison of the ripple current in a DC-DC converter



=> In a conventional model, since the current dependent characteristics of an inductor are not reflected, the simulation results deviate from the measured value.
On the other hand, in a dynamic model, results close to the actual measured value could be acquired.

Comparison between Dynamic Model and Actual Measurement Value (2/2)

Example of verification: Comparison of the power supply efficiency in a DC-DC converter



=> In the simulation by a dynamic model, results closer to the actual measured value could be acquired.

* Since there are factors other than the dynamic model of an inductor, the simulation and actual measured value do not conform completely.

Downloading of Dynamic Models of Murata's Inductors

This model is released in the Library of Murata's Web site.

- ■ Cadence® PSpice®
  http://www.murata.com/en-global/tool/library/pspice

- ■ Cadence® Spectre®
  http://www.murata.com/en-global/tool/library/spectre

- ■ Synopsys HSPICE®
  http://www.murata.com/en-global/tool/library/hspice

- ■ Linear Technology LTspice®
  http://www.murata.com/en-global/tool/library/ltspice

[Contained Products]
Power inductor: LQMxxP Series, etc.

* Cadence, PSpice and Spectre are registered trademarks or trademarks of Cadence Design Systems, Inc. in the United States and other countries.
* HSPICE is a registered trademark or trademark of Synopsys, Inc. in the United States and other countries.
* LTspice is a registered trademark or trademark of Linear Technology Corporation in the United States and other countries.

Usage Example of Dynamic Model of Murata's Power Inductor - PSpice® -

LQM2MPNR24MGH_P - Notepad

File Edit Format View Help

```
**$ENCRYPTED_LIB
**$PARTIAL
* ---------------------------------------------------------------------
*  PSPICE Model generated by Murata Manufacturing Co., Ltd.
*  Copyright(C) Murata Manufacturing Co., Ltd.
*  Murata P/N : LQM2MPNR24MGH
*  Description : Size 2 * 1.6 * 0.9mm / L = 0.24uH / Imax = 3.4A / Rdc = 0.02ohm
*  Frequency Range : 679.7kHz - 30.0MHz
*  Voltage Condition : DC-DC Converter, Input Voltage = 3.6V, Output Voltage = 1.8V
*  Model generated 2014/04/14(Ver 1.05), measured 2014/04/01
*  A patent has been applied for
* ---------------------------------------------------------------------
*  Encrypted Netlist
* ---------------------------------------------------------------------

.subckt LQM2MPNR24MGH port1 port2
$CDNENCSTART
eee8c5c7a[illegible]303678664e7916da0bae22e8cb0bba041dd67c69ce448ea70148a9ac1670c892
6a46f4e4a[illegible]a78d3c8f2104a6a3f8d859eb3553d9a91294fd429388bcb1ddedb571d6878eeec
fd0d27d8b[illegible]a04097ae60587568e99bb4c24f00abf73b59eb73958667b0549088555add448d
```

Input/output node

Part No.

Circuit data

◎Usage Example

PSPICE_main_L - Notepad

File Edit Format View Help

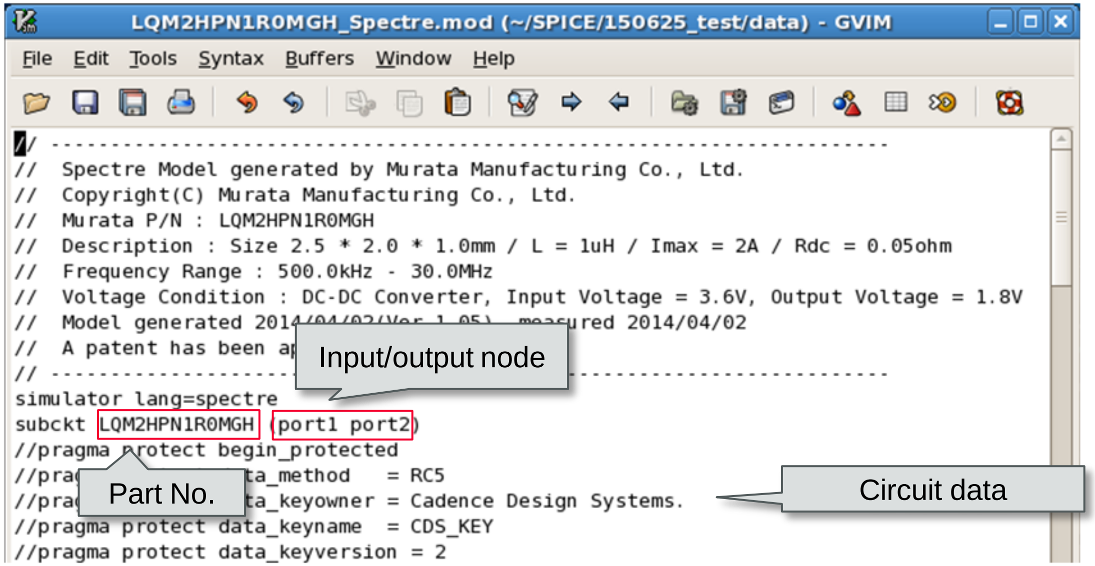
```
.inc ./data/LQM2MPNR24MGH_P.mod

.ac dec 41 500e3 30e6
.probe
.param Ibias=3.4

I1 0 N001 DC {Ibias} AC 1 0
XL1 N001 0 LQM2MPNR24MGH

.end
```

Added mod file to be used

The DC superposition current value is automatically detected.

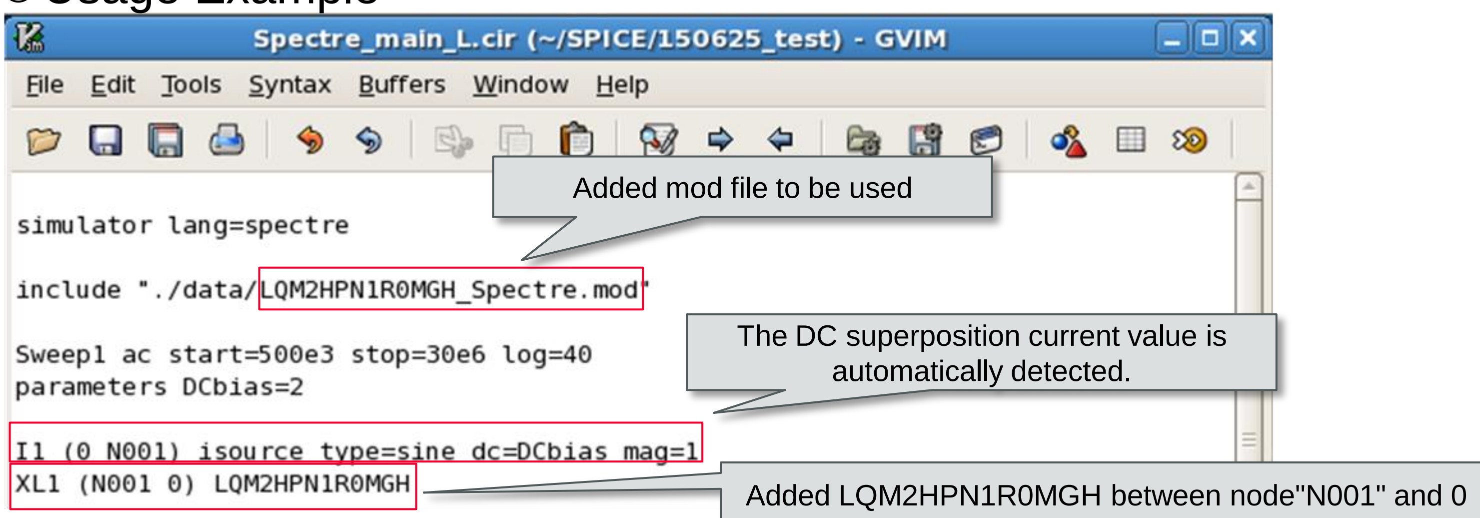
Added LQM2MPNR24MGH between node "N001" and 0

Usage Example of Dynamic Model of Murata's Power Inductor - Spectre® -




```
// ----------------------------------------------------------------------------
//  Spectre Model generated by Murata Manufacturing Co., Ltd.
//  Copyright(C) Murata Manufacturing Co., Ltd.
//  Murata P/N : LQM2HPN1R0MGH
//  Description : Size 2.5 * 2.0 * 1.0mm / L = 1uH / Imax = 2A / Rdc = 0.05ohm
//  Frequency Range : 500.0kHz - 30.0MHz
//  Voltage Condition : DC-DC Converter, Input Voltage = 3.6V, Output Voltage = 1.8V
//  Model generated 2014/04/02(Ver.1.05)  measured 2014/04/02
//  A patent has been ap
// ----------------------------------------------------------------------------
simulator lang=spectre
subckt LQM2HPN1R0MGH (port1 port2)
//pragma protect begin_protected
//pra      ta_method    = RC5
//pra      ta_keyowner = Cadence Design Systems.
//pragma protect data_keyname   = CDS_KEY
//pragma protect data_keyversion = 2
```

◎Usage Example




```
simulator lang=spectre

include "./data/LQM2HPN1R0MGH_Spectre.mod"

Sweep1 ac start=500e3 stop=30e6 log=40
parameters DCbias=2

I1 (0 N001) isource type=sine dc=DCbias mag=1
XL1 (N001 0) LQM2HPN1R0MGH
```

Usage Example of Dynamic Model of Murata's Power Inductor - HSPICE® -

LQM2MPNR24MGH_H - WordPad

```
*
------------------------------------------------------------------------
*  HSPICE Model generated by Murata Manufacturing Co., Ltd.
*  Copyright(C) Murata Manufacturing Co., Ltd.
*  Murata P/N : LQM2MPNR24MGH
*  Description : Size 2 * 1.6 * 0.9mm / L = 0.24uH / Imax = 3.4A
/ Rdc = 0.02ohm
*  Frequency Range : 679.7kHz - 30.0MHz
*  Voltage Condition : DC-DC Converter, Input Voltage = 3.6V,
Output Voltage = 1.8V
*  Model generated 2014/04/14(Ver 1.05), measured 2014/04/01
*  A patent has been applied for
*
------------------------------------------------------------------------
*  Encrypted Netlist
*
------------------------------------------------------------------------
.subckt LQM2MPNR24MGH port1 port2
.PROT ddl1
A9(8S#Uc(1Y)E-U>9%j;x5I#'%S$b-,(2/E5bVWc'F:9h]Uc:Xj5EJh>(%j)7-
U#/JS:b-T:'%EP$V.c'/25bl+):Fi5h8
```

Part No.

Input/output node

Circuit data

◎Usage Example

HSPICE_main_L - Notepad

```
.option post=2

.inc ./data/LQM2MPNR24MGH_H.mod

.ac dec 41 500e3 30e6
.print ac vr(V1) vi(V1)
.param Ibias=1.8

I1 N001 0 DC=Ibias AC=1,0
XL1 N001 0 LQM2MPNR24MGH

.end
```

Added mod file to be used

The DC superposition current value is automatically detected.

Added LQM2MPNR24MGH between node"N001" and 0

Usage Example of Dynamic Model of Murata's Power Inductor - LTspice® -

■ Symbol file (Ext.asy)

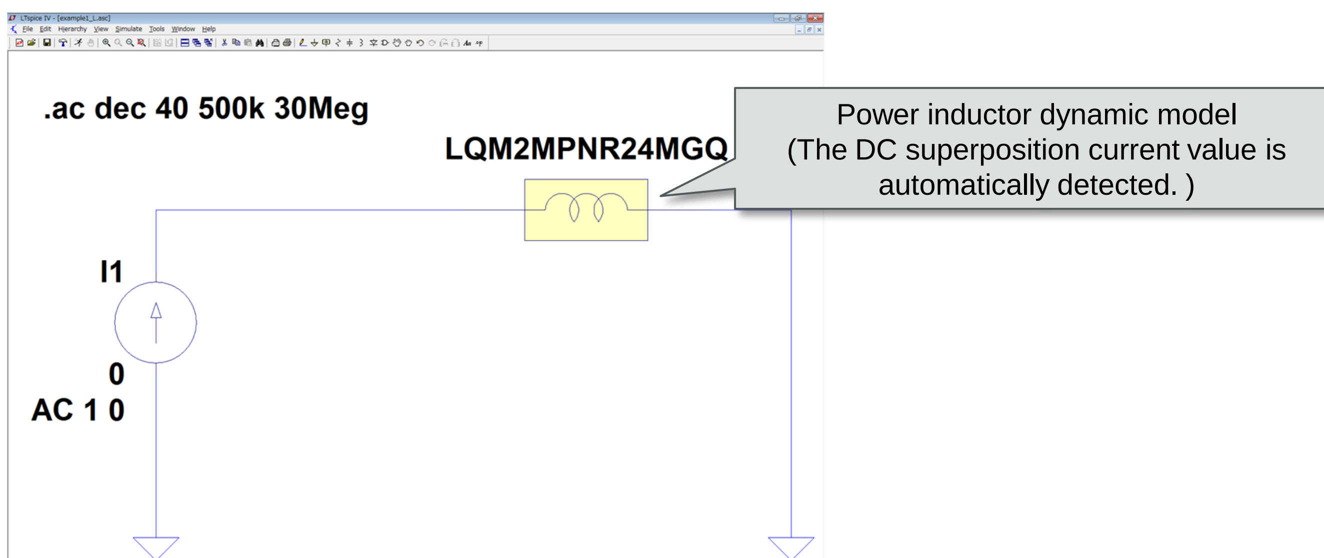
Create and save any folder after the "sym" folder in the folder where LTspice is installed.
Example) C:\Program Files (x86)\LTC\LTspiceIV\lib\sym\murata_Inductor\

■ Encrypted nonlinear SPICE file (Ext.mod)

Directly save the mod file after the "sub" folder in the folder where LTspice is installed.
Example) C:\Program Files (x86)\LTC\LTspiceIV\lib\sub\

* The mod file in the same folder as the circuit (e.g.: test1.asc) of the reference source can also be saved.
* When saving the file to other folders, use the command ".inc" to refer to a folder.

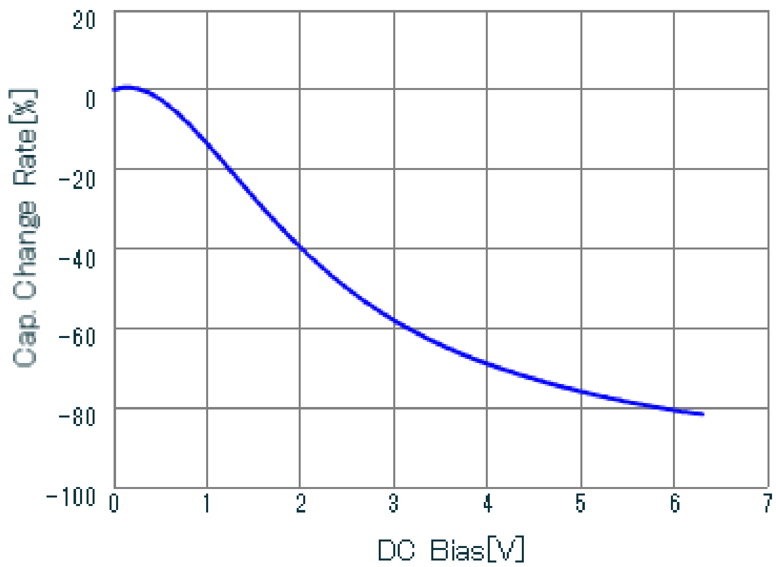
Select the file saved by clicking Edit in Menu → Component



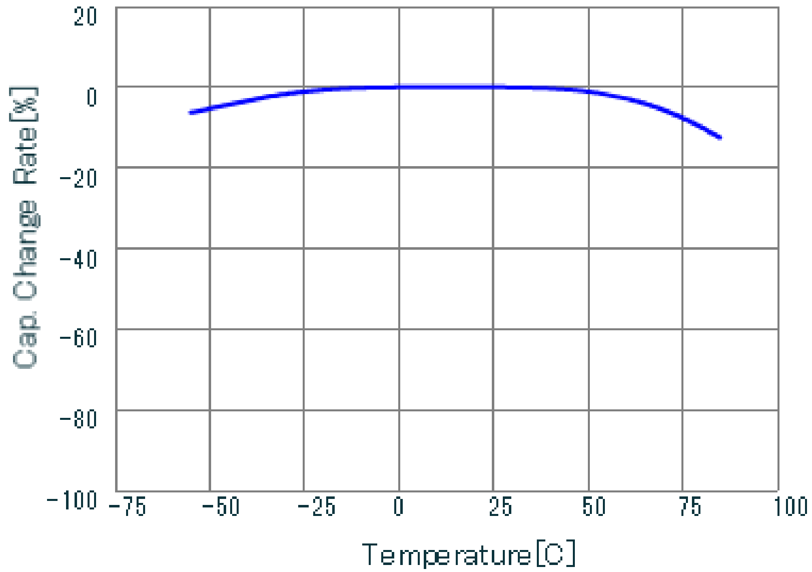
Dynamic Model of High Dielectric Constant Type Chip Monolithic Ceramic Capacitors

Change of Capacitance by DC Bias/Temperature in High Dielectric Constant Type MLCC (1/2)

Example:
Capacitance change rate - DC bias characteristic



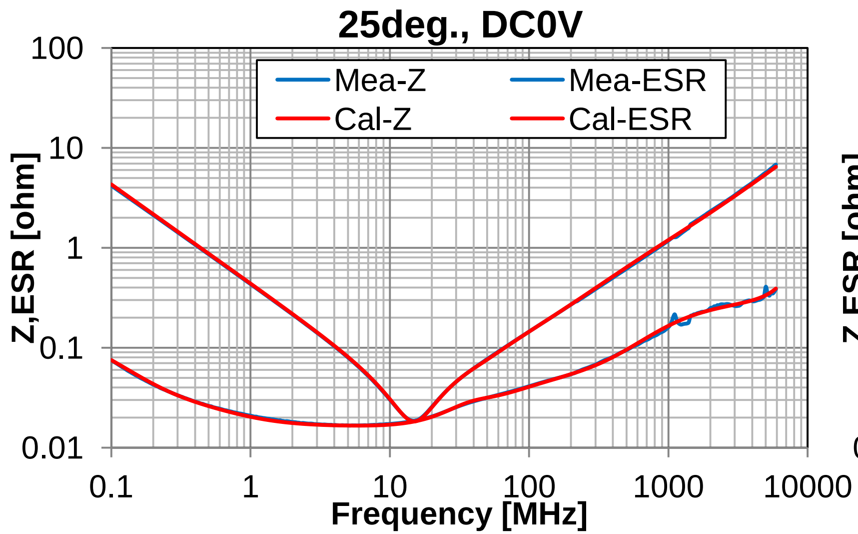
Example:
Capacitance change rate - Temperature characteristic

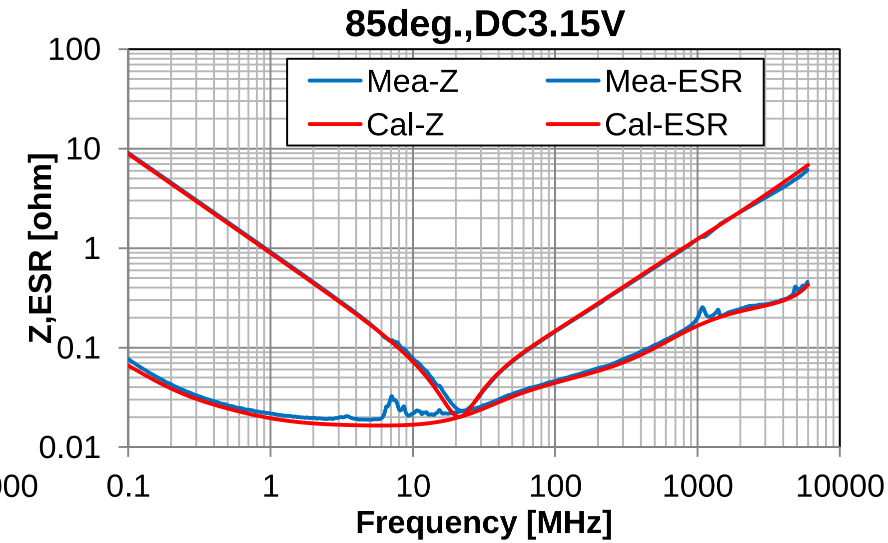


MLCC: 0603 size / R6 Temp. characteristic / 0.47 uF / rated 6.3V

=> As shown in the above figure, the capacitance of the high dielectric constant type monolithic ceramic capacitor (MLCC) changes with the DC bias and temperature. Accordingly in the circuit design, there were cases where a deviation occurred between the simulation results and the actual measured value.

Change of Capacitance by DC Bias/Temperature in High Dielectric Constant Type MLCC (2/2)





0603 size / R6 Temp. characteristic / 0.47 uF / rated 6.3V

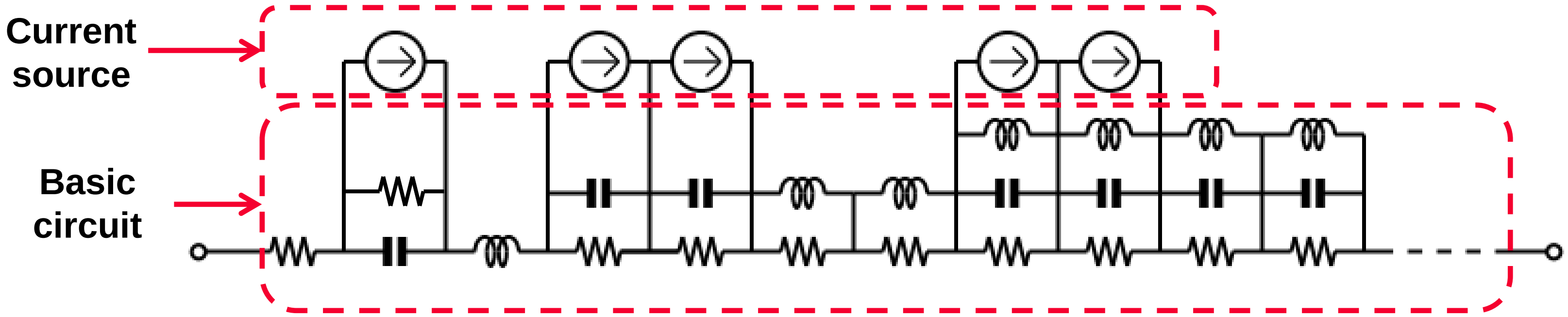
Red line: Calculated Value (Cal);
Blue line: Actual Measured Value (Mea)

=> In order to reduce the deviation between the simulation and the actual measured value, Murata provides a SPICE model in which the DC bias and temperature can be specified as 1 condition in our design support tool "SimSurfing" (*).

* It can be used in "Enhanced SimSurfing" of my Murata (https://my.murata.com/en/web/mymurata/simsurfing_c).
Only the DC bias condition can be specified in the normal version of "SimSurfing" (http://www.murata.com/simsurfing/).

The figure on the upper left shows the comparison between the calculated value and the actual measured value of Z and ESR acquired from the SPICE model in the conditions of DC bias 0V/room temperature, and the figure on the upper right shows the values acquired from the SPICE model in which the conditions of DC bias/temperature are reflected. Both graphs show similar results.

Dynamic Model in High Dielectric Constant Type MLCC

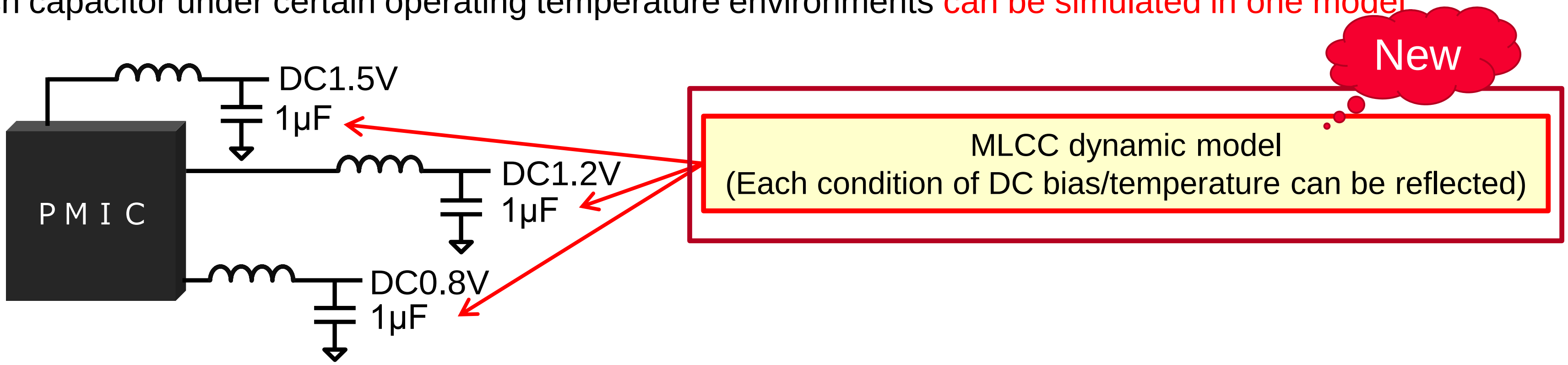


Example of SPICE model in which DC bias dependency and temperature dependency are reflected

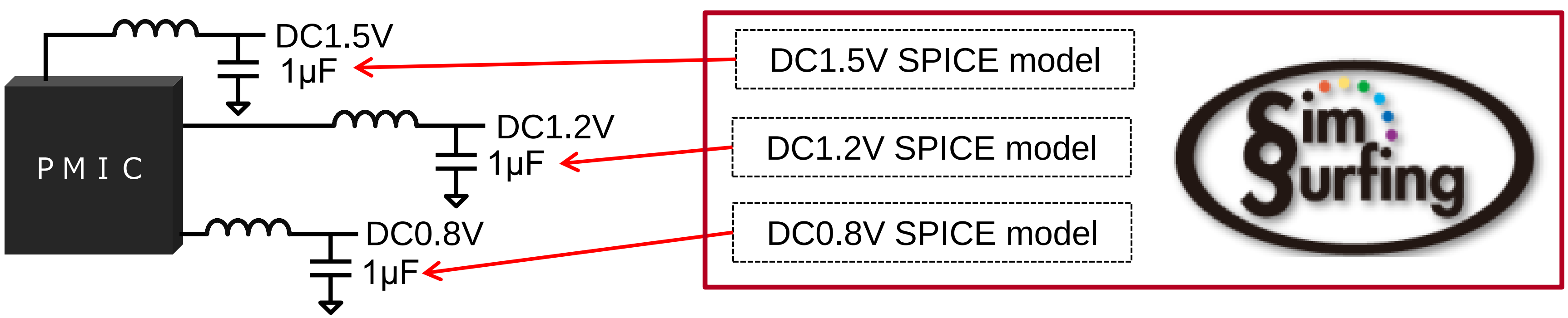
=> This SPICE model realized a dynamic model that corresponds to the changes of the DC bias and temperature, by adding the dependency of DC bias and temperature to several components in a basic equivalent circuit model.

Merits of using Dynamic Models

◎When a dynamic model is used (SPICE model with DC bias automatic setting / specifiable temperature)
Using the following circuit as an example, the characteristics according to the DC bias voltage applied to each capacitor under certain operating temperature environments can be simulated in one model.



<Reference> When a SPICE model downloaded from myMurata "SimSurfing" is used
The SPICE model will be downloaded by model where each DC bias/temperature is set.
When performing the same simulation as the above, it is necessary to prepare models set with three different types of DC bias.



Downloading of Dynamic Models of Murata's MLCC

This model is released in the Library of Murata's Web site.

■ Cadence® PSpice®

http://www.murata.com/en-global/tool/library/pspice

■ Synopsys HSPICE®

http://www.murata.com/en-global/tool/library/hspice

■ Linear Technology LTspice®

http://www.murata.com/en-global/tool/library/ltspice

[Contained Products]
MLCC: Each series of GRM/GCD/GCM/GJ4/GJ8/LLL/LLR

* Cadence and PSpice are registered trademarks or trademarks of Cadence Design Systems, Inc. in the United States and other countries.
* HSPICE is a registered trademark or trademark of Synopsys, Inc. in the United States and other countries.
* LTspice is a registered trademark or trademark of Linear Technology Corporation in the United States and other countries.

Usage Example of Dynamic Models of Murata's MLCC - PSpice® -

muRata INNOVATOR IN ELECTRONICS

GRM219B31A226MEA0_P - Notepad

File Edit Format View Help

```
**$ENCRYPTED_LIB
**$PARTIAL
*--------------------------------------------------------------------------
* PSPICE Model generated by Murata Manufacturing Co., Ltd.
* Copyright(C) Murata Manufacturing Co., Ltd.
* Description : 2012/B/22uF/10V (Capacitor)
* MURATA P/N : GRM219B31A226MEA0
* Property : C = 22 [uF]
*--------------------------------------------------------------------------
* Applicable Conditions:
*   Frequency Range = 100Hz - 6GHz
*   Temperature = -25 degC - 85 degC
*   DC Bias Voltage = 0V - 10V
*   Small Signal Operation
*--------------------------------------------------------------------------
* Encrypted Netlist
*--------------------------------------------------------------------------
.subckt GRM219B31A226MEA0 Port1 Port2 PARAMS:temperature=25
$CDNENCSTART
eee8c5c7a2bc4b0 3664e7916da0bae22e8cb0bba041dd67c69ce448ea70148
3b33857aaa06aa9 e9923a241a839a9452a9d8dbe5ad9087facd679cc2a47c
e47652bdde991f48d6085d4ffa1a7c798dbe5ad9087facd679cc2a47c0f7e607fefa20b60
```

Input/output node

Definition of temperature specification method
This is the default value with no specified temperature when called

Part No.

Circuit data

◎Usage Example

PSPICE_main_C - Notepad

File Edit Format View Help

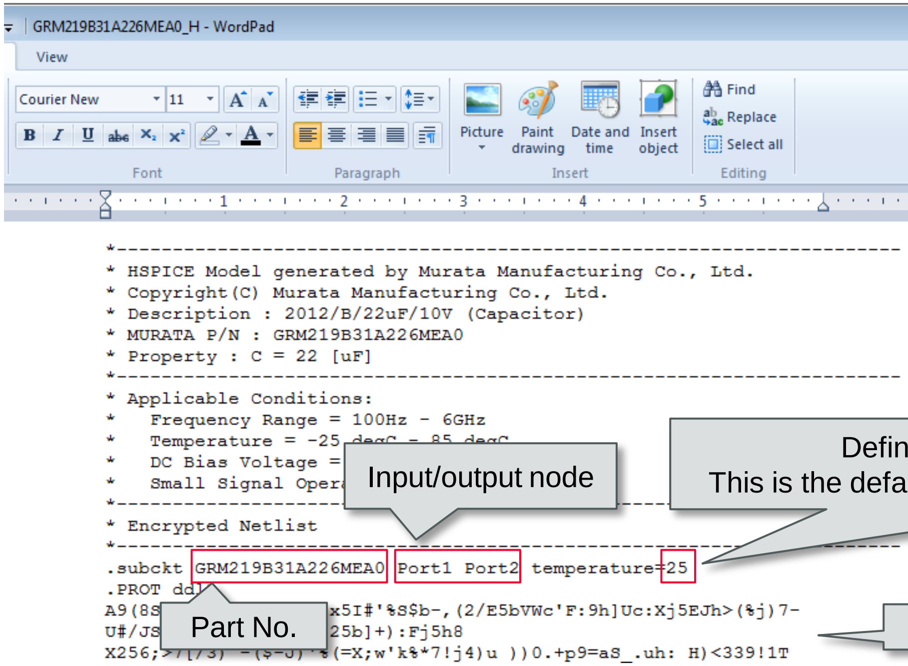
```
.inc ./data/GRM219B31A226MEA0_P.mod

.ac dec 41 100 6000000000
.probe
.param DCbias=0

V1 N001 0 DC {DCbias} AC 0.1 0
XC1 N001 0 GRM219B31A226MEA0 PARAMS:temperature=125

.end
```

Added mod file to be used

The DC superposition current value is automatically detected.

Added GRM219B31A226MEA0 between node"N001" and 0
Set “temperature=125” as a parameter

Usage Example of Dynamic Models of Murata's MLCC - HSPICE® -



```
*-----------------------------------------------------------------------
* HSPICE Model generated by Murata Manufacturing Co., Ltd.
* Copyright(C) Murata Manufacturing Co., Ltd.
* Description : 2012/B/22uF/10V (Capacitor)
* MURATA P/N : GRM219B31A226MEA0
* Property : C = 22 [uF]
*-----------------------------------------------------------------------
* Applicable Conditions:
*   Frequency Range = 100Hz - 6GHz
*   Temperature = -25 degC - 85 degC
*   DC Bias Voltage = …
*   Small Signal Opera…
*-----------------------------------------------------------------------
* Encrypted Netlist
*-----------------------------------------------------------------------
.subckt GRM219B31A226MEA0 Port1 Port2 temperature=25
.PROT ddl
A9(8S…x5I#'%S$b-,(2/E5bVWc'F:9h]Uc:Xj5EJh>(%j)7-
U#/JS…25b]+):Fj5h8
X256;…(=X;w'k%*7!j4)u ))0.+p9=aS_.uh: H)<339!1T
```

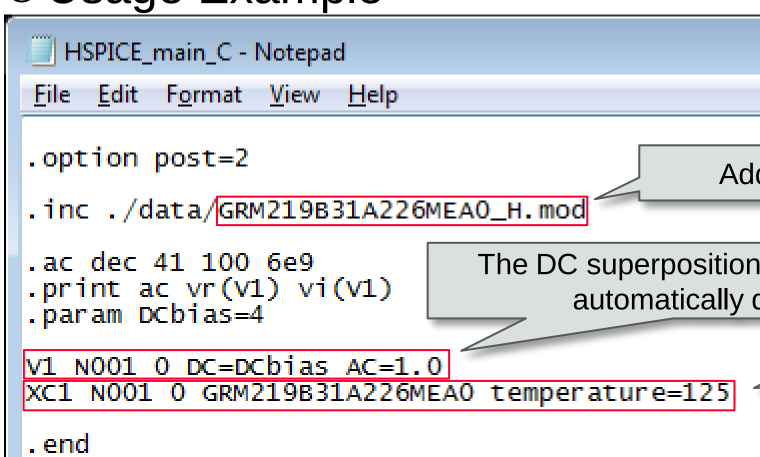
Input/output node

Definition of temperature specification method
This is the default value with no specified temperature when called

Part No.

Circuit data

◎Usage Example



```
.option post=2
.inc ./data/GRM219B31A226MEA0_H.mod

.ac dec 41 100 6e9
.print ac vr(V1) vi(V1)
.param DCbias=4

V1 N001 0 DC=DCbias AC=1.0
XC1 N001 0 GRM219B31A226MEA0 temperature=125

.end
```

Added mod file to be used

The DC superposition current value is automatically detected.

Added GRM219B31A226MEA0 between node "N001" and 0
Set “temperature=125” as a parameter

Usage Example of Dynamic Models of Murata's MLCC - LTspice® -

■ Symbol file (Ext.asy)

Create and save any folder after the "sym" folder in the folder where LTspice is installed.
Example) C:\Program Files (x86)\LTC\LTspiceIV\lib¥sym\murata_MLCC\

■ Encrypted nonlinear SPICE file (Ext.mod)

Directly save the mod file after the "sub" folder in the folder where LTspice is installed.
Example) C:\Program Files (x86)\LTC\LTspiceIV\lib\sub\

* The mod file in the same folder as the circuit (e.g.: test1.asc) of the reference source can also be saved.
* When saving the file to other folders, use the command ".inc" to refer to a folder.

Select the file saved by clicking Edit in Menu → Component