Thermal Simulation of Power MOSFETs on the P-Spice Platform

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INTRODUCTION

R-C thermal model parameters for Vishay power MOSFETs available under the product information menu offer a simple means to evaluate thermal behavior of the MOSFET under a defined transient operating condition.

Steady state values of thermal impedance, R_{th}(j-a) and R_{th}(j-c) / R_{th}(j-f), along with normalized thermal transient impedance characteristics published in a power MOSFET datasheet, are adequate to analyze the thermal behavior of a part under a regular wave-shaped, single pulse or the periodic power dissipation of known duty cycle.

However, thermal analysis for transient or irregular wave-shaped power profiles requires extending the thermal characterization offered in the datasheet. What is really needed is a thermal model emulating the thermal transient behavior of the power MOSFET on a suitable software platform. The thermal transient impedance characteristics published in a datasheet are a net effect of the thermal resistance and thermal capacitance of the physical structure of a device. Hence the latter can be used for developing a thermal model for the part, but it is necessary to parameterize the thermal characteristics. Incidentally, there exists a direct behavioral analogy between thermal components / parameters and electrical components / parameters; see Table 1.

Table 1

Description	Electrical	Thermal
Ohm's law analogy	R = V / I	R_{th} = °C / W
Resistance	R - Electrical Resistance in Ohms	R_{th} - Thermal Resistance in °C / W
Potential	V - Electrical Potential Difference in Volts	°C - Temperature Difference in Celsius
Energy flow	I - Electrical Current in Ampere	W - Power Dissipation in Watts
Capacitance	C - Electrical Capacitance	C_{th} - Thermal Capacitance

Using the analogy described above, we can use electrical simulation software like P-Spice to analyze thermal behavior by using the corresponding parameters.

This requires a means to obtain the electrical parameters equivalent to the corresponding thermal parameters. Typical thermal characteristics as represented in a datasheet of a power MOSFET are shown in Figure 1.

Curve-fitting techniques can be applied to such time - varying thermal characteristics while using a combination of electrical resistances (R) and capacitances (C) in pairs as variable parameters. The nature of transient thermal characteristics for power MOSFETs necessitates at least four R-C pairs to obtain the best curve fit. These R-C pairs in turn represent thermal model parameters.[1] These pairs can be used on the same OrCAD Capture and P-Spice platform to run electrical simulations and carry out thermal analyses by correctly employing the analogy discussed earlier.

NEW PRODUCT SI7390DP N-CHANNEL 30-V (D-S) FAST SWITCHING WFET®

THERMAL RESISTANCE RATINGS

Parameter		Symbol	Typical	Maximum	Unit
Maximum Junction-to Ambient (MOSFET)[a]	t ≤ 10 sec	R_{thJA}	20	25	*C / W
	Steady State		53	70	
Maximum Junction-to-Case (Drain)	Steady State	R_{thJC}	2.1	3.2	

Notes
a. Surface Mounted on 1" x 1" FR4 Board

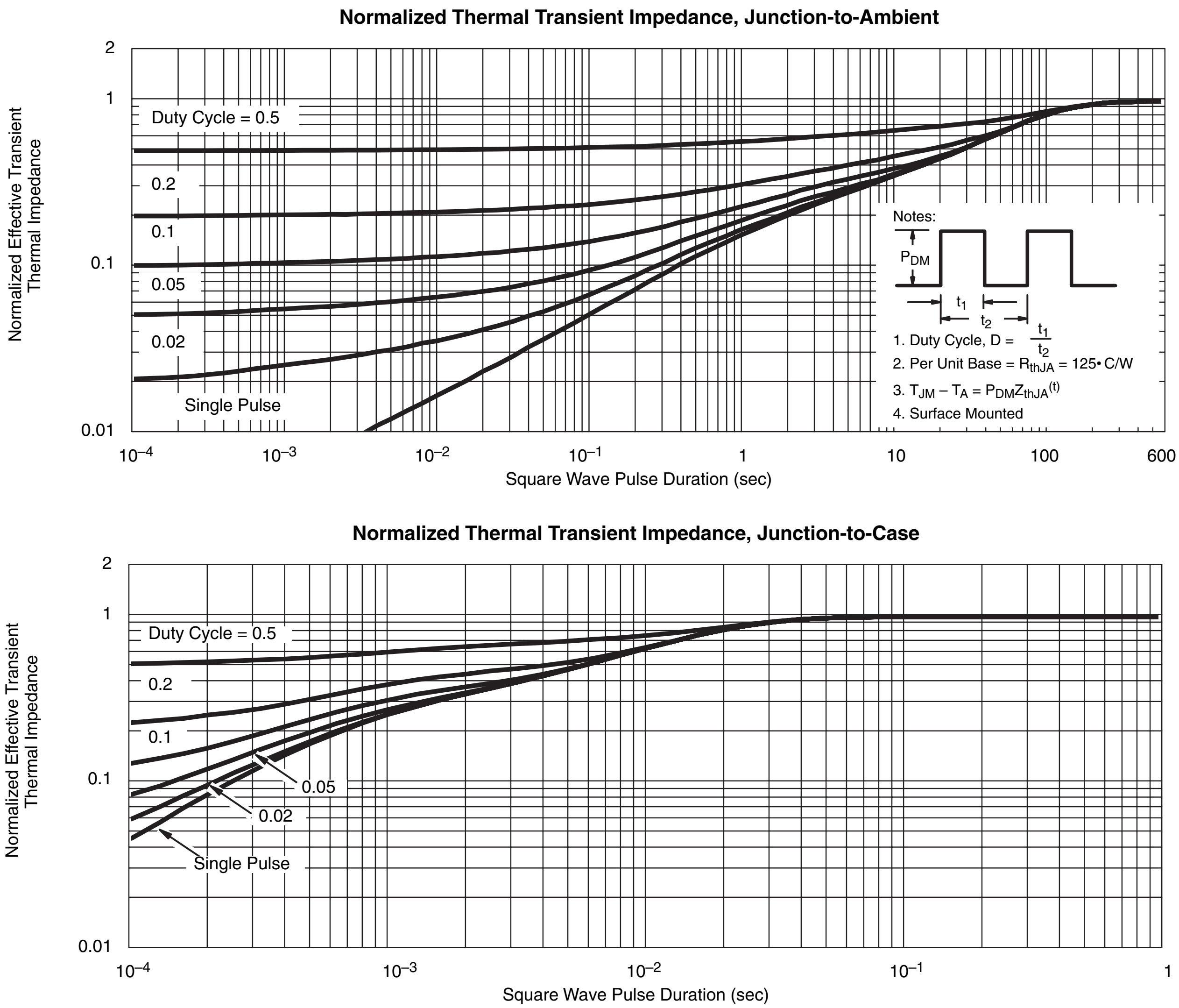


Figure: 1: Datasheet Information

R-C THERMAL MODELS

Two configurations of R-C thermal models offered on the Vishay Web site are a "tank" circuit, Figure 2, and a "filter" circuit, Figure 3. These configurations are also known as Cauer and Foster. Both models are developed using the same database of transient thermal characteristics with curve -fitting techniques, hence closely matching thermal analysis results are obtained.

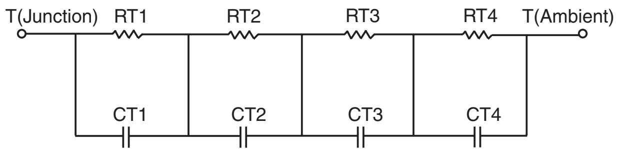


Figure: 2: Tank Circuit Configurations

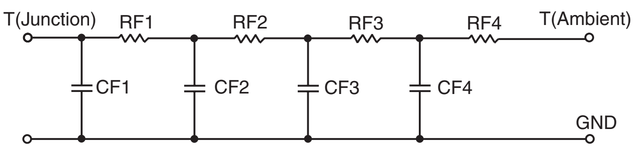


Figure: 3: Filter Circuit Configurations

We can observe from the following expression that, mathematically, the "tank" configuration is very easy to develop.

$$RT(t) = R_1(t) * \left(1 - e^{\left(-t/\tau_1\right)}\right) + R_2(t) * \left(1 - e^{\left(-t/\tau_2\right)}\right) + R_3(t) * \left(1 - e^{\left(-t/\tau_3\right)}\right) + R_4(t) * \left(1 - e^{\left(-t/\tau_4\right)}\right)$$

$$C_x = \frac{\tau_x}{R_x}$$

However, the "filter" configuration requires a complex approach. That is where a linear square integration routine is employed in the curve fitting to obtain R-C values in both configurations. Refer to Appendix A for an example of R-C models developed using this approach. Appendix A is also an illustration of the R-C thermal models offered under the product information menu on the Vishay Web site. The model validation can be observed from close-fitting curves: one curve for the raw data obtained during part characterization and another curve that is produced by a curve-fitting routine using model R-C values. Accordingly, this thermal model represented by R-C electrical parameters can be used for a thermal analysis of a power MOSFET as discussed in the following example.

THERMAL SIMULATION EXAMPLES

(a) Example 1

Aim: Demonstrate the use of a junction to ambient (j-a) model and verify that the junction temperatures obtained by each model configuration are comparable.

We shall estimate the junction temperature of Vishay MOSFET part number Si7390DP with the dissipating power profile described in Table 2.

Table 2

Time (sec)	Power (Watts)
0	0
0.0001	100
0.00099	100
0.001	0.1
0.002	0.1
0.0021	20
0.005	20
0.0051	0
0.1	0

Repeating after every 500 milliseconds.

Ambient temperature = 25 °C

The power profile described in Table 2 can produce high temperature excursions during each cycle and a cumulative temperature rise over a period of 500 milliseconds, which is long enough to produce a temperature rise beyond the part package. Hence, a junction-to-ambient model is useful for this analysis.

Here are the steps to set up and run simulations:

Step 1

Obtain R-C thermal model file Si7390DP_RC from the Vishay Web site; see Appendix A.

Step 2

Start a new project on the OrCAD Capture/P-Spice platform, create a new design folder Tank j-a, and add a schematic page as shown in Figure 4, Tank Configuration.

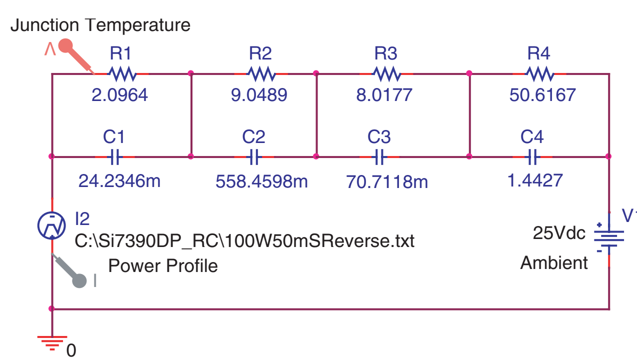


Figure 4: Tank Configuration

Use R-C thermal model values for ambient temperature from the Table 3 R-C values for the tank configuration from Appendix A.

Table 3

R-C VALUES FOR TANK CONFIGURATION			
Thermal Resistance (°C/W)			
Junction to	Ambient	Case	Foot
RT1	2.0964	18.1348 u	N/A
RT2	9.0489	713.7923 m	N/A
RT3	8.0177	1.3126	N/A
RT4	50.6167	1.1896	N/A
Thermal Capacitance (Joules/°C)			
Junction to	Ambient	Case	Foot
CT1	24.2346 m	81.2387 u	N/A
CT2	558.4598 m	673.3554 u	N/A
CT3	70.7118 m	15.6345 m	N/A
CT4	1.4427 m	6.7185 m	N/A

Step 3

Set the property value file of the current source 12 part name IPWL_F_RE_N_TIMES to point to text file C:\Si7390DP_RC\100W50mSReverse.txt, which contains the power profile described earlier.

Step 4

Set the repeat value to 50 in the part property editor.

Step 5

Set the value of voltage source V1 to 25, the value of the ambient temperature.

Step 6

Create a new simulation profile named Tank j-a and set the run time to 600 milliseconds.

Step 7

Run the simulations.

The simulation result in Figure 5 shows that the junction reaches the maximum operating temperature limit of 150 °C in 500 milliseconds.

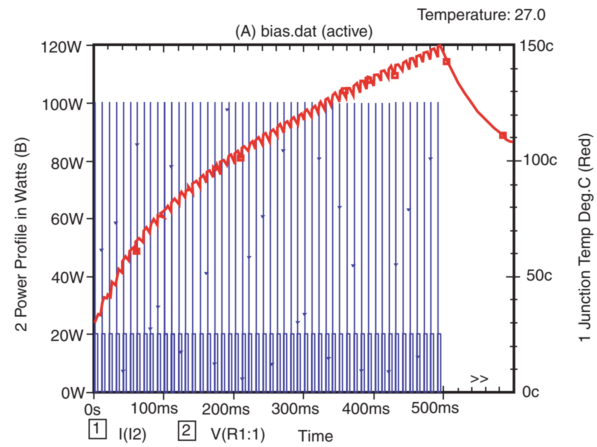


Figure: 5: j-a Tank Simulations
Red: Junction temperature
Blue: Power profile

Figure 6 shows detailed power profile and corresponding temperature excursion for first two cycles

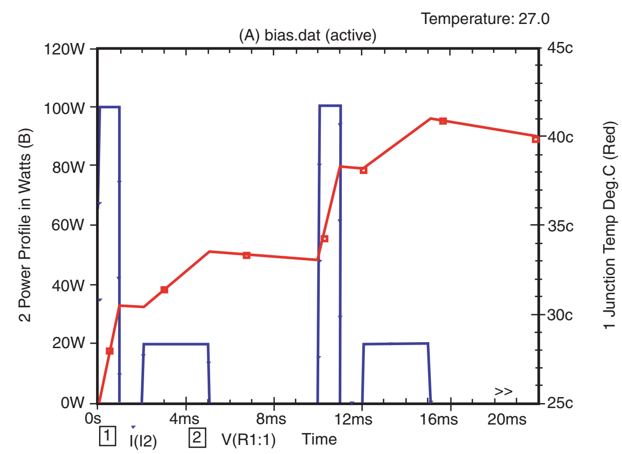


Figure: 6 First Two Cycles

Step 8

Create a new design folder Filter j-a and add a schematic page as shown in Figure 7, Filter Configuration.

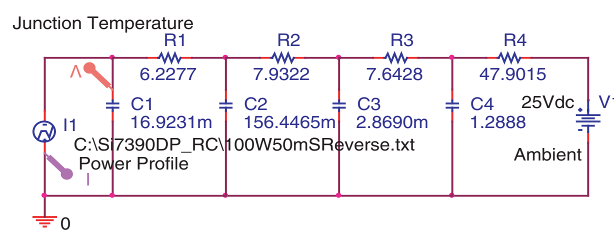


Figure: 7: Filter Configuration

Use R-C thermal model values for the ambient temperature from Table 4, and the R-C values for the filter configuration from Appendix A.

Table 4

R-C VALUES FOR FILTER			
Thermal Resistance (°C/W)			
Junction to	Ambient	Case	Foot
RF1	6.2277	164.8787 n	N/A
RF2	7.9322	888.8177 m	N/A
RF3	7.6428	1.2671	N/A
RF4	47.9015	1.0331	N/A
Thermal Capacitance (Joules/°C)			
Junction to	Ambient	Case	Foot
CF1	16.9231 m	166.0609 u	N/A
CF2	156.4465 m	357.5156 u	N/A
CF3	2.8690 m	4.6473 m	N/A
CF4	1.2888	304.1798 u	N/A

Step 9

Repeat steps 3 through 7 described above and compare the simulation results obtained by using the j-a filter configuration shown in Figure 8 with the simulation results obtained by using the j-a tank configuration in Figure 5.

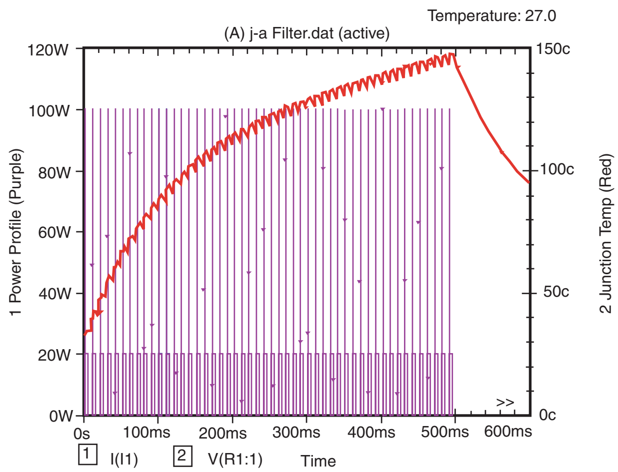


Figure 8: j-a Filter Simulations
Red: Junction temperature
Purple: Power profile

We can observe that the junction temperature value obtained by either configuration is within couple of degrees Centigrade. These results are acceptable for all practical purposes.

(b) Example 2

Aim: Demonstrate the use of the junction-to-ambient (j-c) model and verify that the junction temperatures obtained by each model configuration are comparable.

The transient power profile for high-power, short-duration or even single incidence may exhibit a high temperature rise at the junction before the heat is conducted away from the package. In such cases, j-c or j-f thermal models are useful.

Table 5 describes the single pulse profile to be analyzed.

Table 5:

Time (sec)	Power (Watts)
0	0
10 µs	900
90 µs	900
100 µs	0
1 s	0

Duration = 1 second

Ambient temperature = 25 °C

Follow the same steps as those described in Example 1, except that the R-C values are obtained from the j-c part of the Table 3 and Table 4. The schematic diagram for the j-c tank configuration is shown in Figure 9.

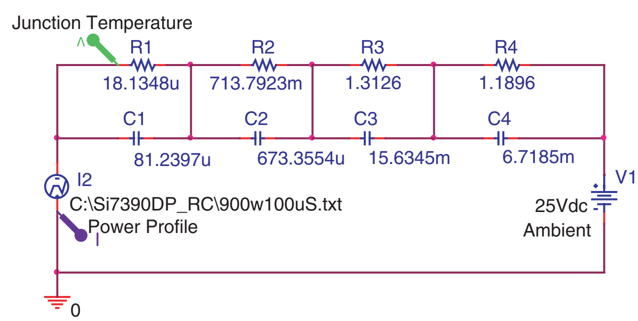


Figure 9: j-c Tank Configuration

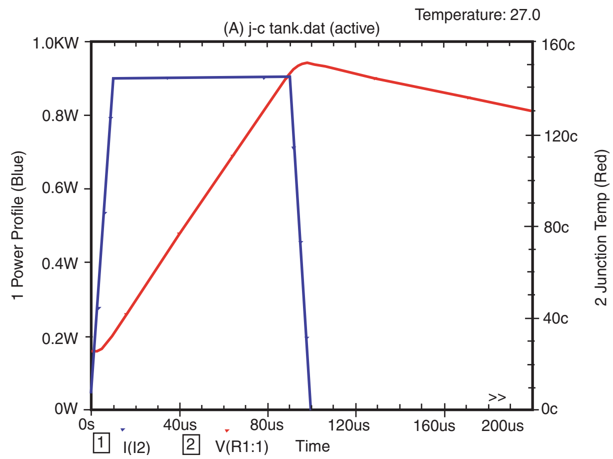


Figure 10: j-c Tank Simulations
Red: Junction temperature
Blue: Power profile

The simulation result shows that the junction temperature rises to 150 °C with just one power pulse.

Next, create a new design folder Filter j-c and add a schematic page as shown in Figure 11, Filter Configuration.

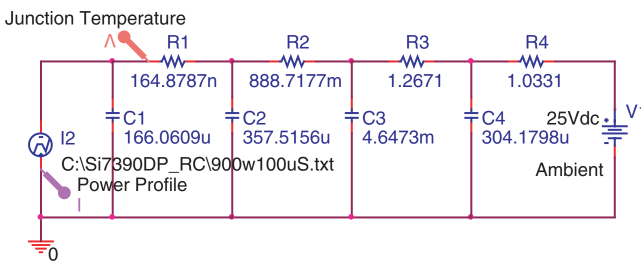


Figure 11: j-c Filter Configuration

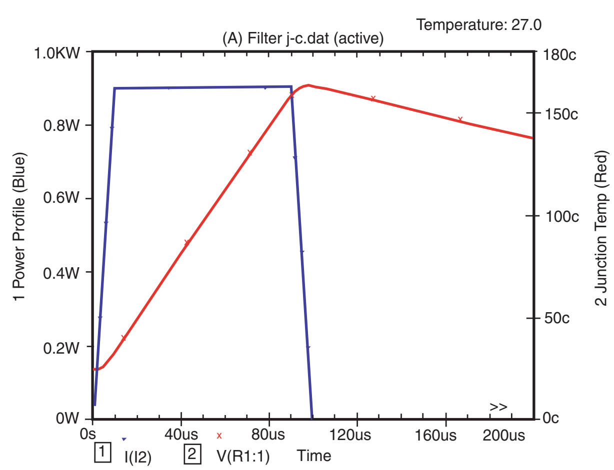


Figure 12: j-c Filter Simulation Results

We can observe that the junction temperature value obtained by either configuration is within 5 to 7 degrees Centigrade. These results are acceptable for all practical purposes.

SUMMARY

R-C thermal model parameters are available for Vishay power MOSFETs under the product information menu. These models can be used on the P-Spice platform to estimate the junction temperature of the MOSFET that is dissipating transient power. The j-a model parameters are employed for repetitive, high peak power and longer duty cycle pulses. All these cases result in residual junction temperatures at the end of each period. On the other hand, the j-c model parameters are employed for single, very high power transients. However, in these cases the junction temperature returns to ambient before the subsequent power pulse is applied. The estimation of junction temperature falls within a practically acceptable range of +/- 5 °C to 7 °C. This approach offers a quick, simple, and very useful alternative to high-end complex thermal modeling tools.

REFERENCES:

[1] "A Simplified Method of Generating Thermal Models for Power MOSFETs, "Kandarp I. Pandya and Wharton McDaniel, March 2002 IEEE SEMI-THERM Proceedings.

[2] "Thermal Modeling for Power MOSFETs in DC/Dc Applications, "Yalcin Bulut and Kandarp Pandya, May 2004 Euro-Sime Proceedings.

[3] "Thermal Analysis of Power MOSFETs Using Rebeca-3D Thermal Modeling Software (From Epsilon Ingenierie) versus Physical Measurements and Possible Extractions, "Kandarp Pandya and Serge Jaunay, April 2005 Euro-Sime Proceedings.

[4] "Rigorous Model and Network for Transient Thermal Problems, "Y.C. Gerstenmaier and G. Wachutka, 7th Therminic Workshop, September 2001.

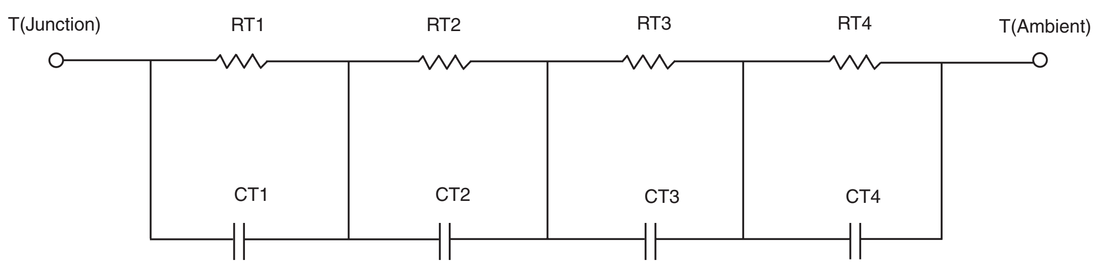
Appendix A

SI7390DP_RC R-C THERMAL MODEL PARAMETERS

DESCRIPTION

The parametric values in the R-C thermal model have been derived using curve-fitting techniques. These techniques are described in "A Simple Method of Generating Thermal Models for a Power MOSFETs"[1]. When implemented in P-Spice, these values have matching characteristic curves to the Single Pulse Transient Thermal Impedance curves for the MOSFET. R-C values for the electrical circuit in the Foster/Tank configuration are included. The corresponding values for the Cauer/Filter configuration are available upon request.

R-C THERMAL MODEL FOR TANK CONFIGURATION



R-C VALUES FOR TANK CONFIGURATION			
Thermal Resistance (°C/W)			
Junction to	**Ambient**	**Case**	**Foot**
RT1	2.0964	18.1348 u	N/A
RT2	9.0489	713.7923 m	N/A
RT3	8.0177	1.3126	N/A
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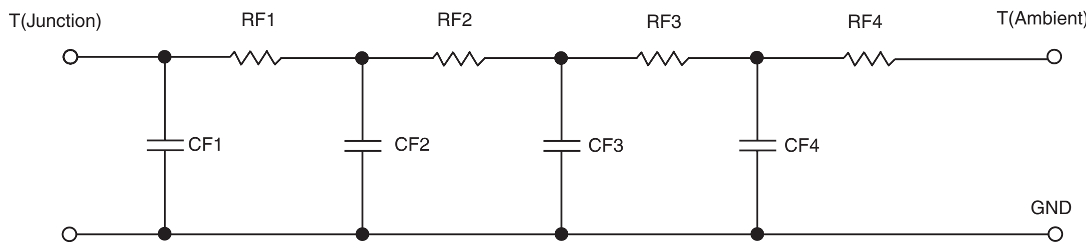
This document is intended as a SPICE modeling guideline and does not constitute a commercial product data sheet. Designers should refer to the appropriate data sheet of the same number for guaranteed specification limits.

R-C THERMAL MODEL FOR FILTER CONFIGURATION



R-C VALUES FOR FILTER CONFIGURATION			
Thermal Resistance (°C/W)			
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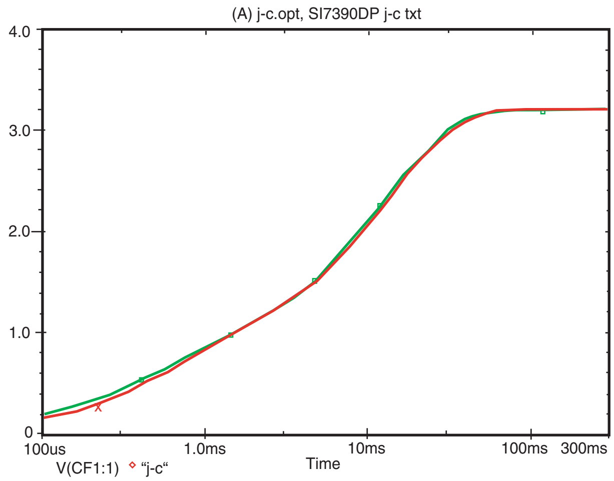
CF2	156.4465 m	357.5156 u	N/A
CF3	2.8690 m	4.6473 m	N/A
CF4	1.2888	304.1798 u	N/A

Note: NA indicates not applicable

For a detailed explanation of implementing these values in P-Spice, refer to Application Note #AN8xx http://www.vishay.com/doc?7xxxxx

Reference:

[1] "A Simple Method of Generating Thermal Models for a Power MOSFET" by Wharton McDaniel and Kandarp Pandya, IEEE / SEMITHERM 2002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4.0
3.0
2.0
1.0
0
100us
1.0ms
10ms
100ms
300ms
Time
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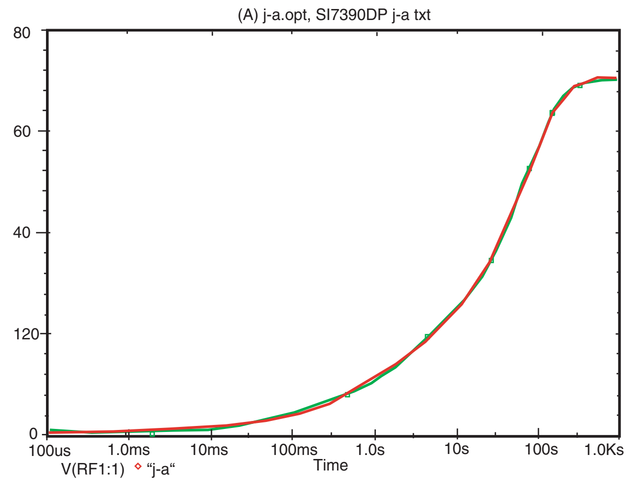
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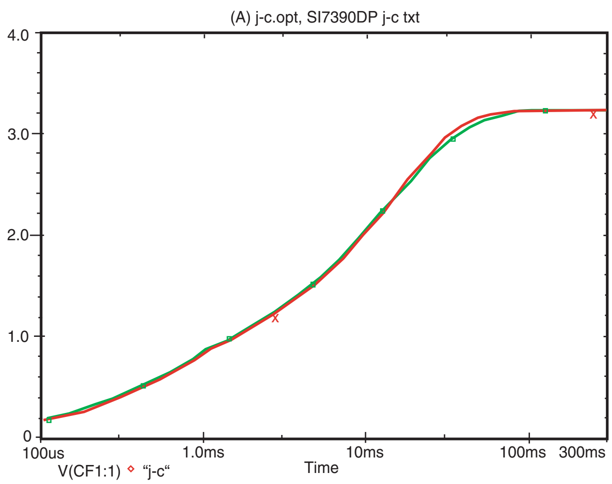
60
40
120
0
100us
1.0ms
10ms
100ms
1.0s
10s
100s
1.0Ks
Time
V(RF1:1) "j-a"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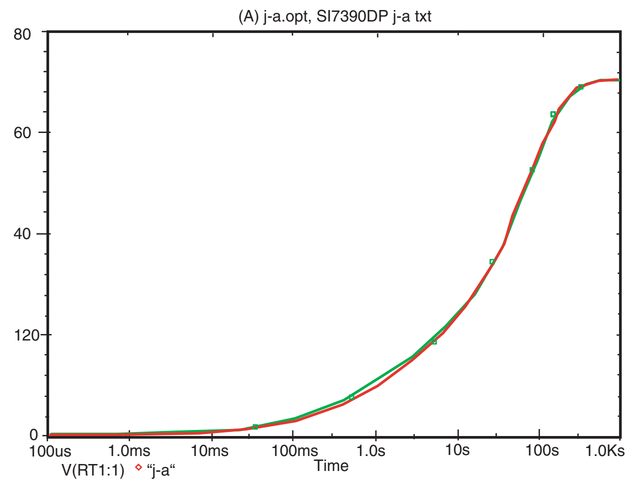
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120
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1.0s
10s
100s
1.0Ks
Time
V(RT1:1) "j-a"