# Resistive Thermal Interconnect interconnectrt

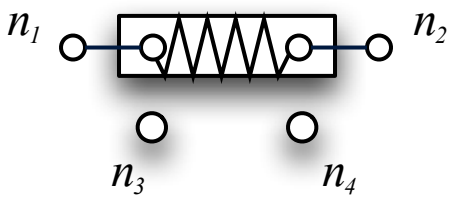


Figure 1: interconnectrt — Resistive electro-thermal interconnect element.

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Description:
This element implements an interconnect line as an electro-thermal resistor. effects.

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*Form:* `interconnectrt:`⟨`instance name`⟩ $n_1$ $n_2$ $n_3$ $n_4$ ⟨`parameter list`⟩
instance name is the model name,
$n_1$, $n_2$, $n_3$ and $n_4$ are the element terminals,
$n_1$ and $n_2$ are element electrical terminals,
$n_3$ and $n_4$ are element thermal terminals,
$n_2$ is the element local reference node,
$n_4$ is the element thermal reference node.

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*Parameters:*

| Parameter | Type | Default value | Required? |
|---|---|---|---|
| l: Length of interconnect line (m) | DOUBLE | n/a | yes |
| w: Width of interconnect line (m) | DOUBLE | 1 $\mu m$ | no |
| tm: Thickness of interconnect line (m) | DOUBLE | 0.3 $\mu m$ | no |
| rho: Resistivity of metal ($\Omega - m$) | DOUBLE | n/a | no |
| metal: Metal (Silver, Copper, Gold, Aluminum) | STRING | copper | no |
| t: System temperature ($^0C$) | DOUBLE | 20 | no |
| tnom: Initial system temperature ($^0C$) | DOUBLE | 20 | no |
| tc: Temperature coefficient ($1/^0C$) | DOUBLE | 0 | no |
| pdr: Thermal element flag | BOOLEAN | false | no |

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*Example:*

```
interconnectrt: irt1 2 0 3 "tref"  l = 20u  metal = "copper"
```

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*Details:*
The resistive thermal interconnect is modeled as resistive only, the metal line is made by a kind of metal,

which includes silver, copper, gold, and aluminum that are predefined in the model.

This is an electro-thermal element is modeled differently depending on the setting of the Parameter `pdr`.

`pdr` = false/true.

When `pdr` is false (the default) the interconnect line is calculated as a resistor by giving length and resistivity or metal selection.
When `pdr` is true, the interconnect line is modeled as electro-thermal resistor by giving length, resistivity or metal selection, and system temperature. Resistance calculation is based on the electrical parameters and system temperature. The power dissipation and heat flux are modeled with thermal terminals.

Resistance of the interconnect line:

$$R = \frac{\rho \cdot l}{A}$$

Electro-thermal resistance of the interconnect with temperature coefficient:

$$R = \frac{\rho \cdot l}{A} \cdot [1 + \beta \cdot (t - t_0)]$$

```
interconnectrt: irt1 2 0 3 "tref" l = 20u  metal = "copper"
```

Here terminals '0' and 'tref' are the local reference terminals of the element. Terminal '0' is the global ground. Terminal 'tref' is a thermal local reference terminal of the element. An example netlist is:

```
.ref "tref"
.ref 0

vsource 1 0 vac = 1 f = 5GHz
res:r1 1 2 r=50
interconnectrt:irt1 2 0 1000 "tref" l = 1m metal = "copper" pdr=1
```

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*References:*


1. Houssam S.Kanj. fREEDA element ResistorT, "$elements\backslash r\backslash ResistorT$".
2. Tony Mulder, Travis Lentz. fREEDA element CmosInvT, "$elements\backslash c\backslash CmosInvT$"


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Example of Transient Analysis (.TRAN2) Fixed times steps, time-stepping nonlinear analysis.
netlist file: interconnectrt.net:

```
*** Transient InterconnectRT test

*** Transient Analysis
.tran2 tstop=4e-6 tstep=10e-9 out_steps=5

.options InitTmp=300

.ref "tref"
```

```
.ref 0

*** Sources
vpulse:Vp 1 0 v1=1 v2=5 per=2e-6 pw=1e-6 tr=0.05e-6 tf=0.05e-6

*** Network
resistor:rs 1 2 r=2k
interconnectrt:irt1 2 0 1000 "tref" l=1e-3 metal="copper" pdr=1
*interconnectrt:irt1 2 0 1000 "tref" l=1e-3 rho=1.83e-8 tc=0.004041 pdr=1

*** Thermal network
resistor:rt1 1000 1001 r=6e3
vsource:vt1 1001 "tref" vdc=InitTmp
capacitor:ct1 1000 1001 c=1e-12

*** Transient Output
.options gnuplot
*.out plot term 2 vt  in "trans_input.out"
.out plot term 2 vt element "interconnectrt:irt1" 0 it div in "trans_res.out"
*.out plot element "interconnectrt:irt1" 0 it in "trans_current.out"
.out plot element "interconnectrt:irt1" 1 ut in "trans_temp.out"

.end
```

The output log file is

```
**********  fREEDA 1.3 running on Thu Apr 17 22:25:28 2008  **********

**  Environment variables: **
FREEDA_HOME = /Users/Jerry/freeda
FREEDA_LIBRARY = /Users/Jerry/freeda/library
FREEDA_PROJECTS = /Users/Jerry/freeda/projects
FREEDA_PATH = /Users/Jerry/freeda/freeda
FREEDA_BIN = /Users/Jerry/freeda/freeda/bin
FREEDA_SIMULATOR = /Users/Jerry/freeda/freeda/simulator
FREEDA_ELEMENTS = /Users/Jerry/freeda/freeda/simulator/elements
FREEDA_DOCUMENTATION = /tmp
FREEDA_WEB_DOCUMENTATION = http://www.freeda.org/doc
FREEDA_BROWSER = firefox

*** Transient InterconnectRT test

*** Transient InterconnectRT test

*** Transient Analysis
.tran2 tstop=4e-6 tstep=10e-9 out_steps=5

.options inittmp=300

.ref "tref"
.ref 0
```

```
*** Sources
vpulse:vp 1 0 v1=1 v2=5 per=2e-6 pw=1e-6 tr=0.05e-6 tf=0.05e-6

*** Network
resistor:rs 1 2 r=2k
interconnectrt:irt1 2 0 1000 "tref" l=1e-3 metal="copper" pdr=1
*interconnectrt:irt1 2 0 1000 "tref" l=1e-3 rho=1.83e-8 tc=0.004041 pdr=1

*** Thermal network
resistor:rt1 1000 1001 r=6e3
vsource:vt1 1001 "tref" vdc=inittmp
capacitor:ct1 1000 1001 c=1e-12

*** Transient Output
.options gnuplot
*.out plot term 2 vt  in "trans_input.out"
.out plot term 2 vt element "interconnectrt:irt1" 0 it div in "trans_res.out"
*.out plot element "interconnectrt:irt1" 0 it in "trans_current.out"
.out plot element "interconnectrt:irt1" 1 ut in "trans_temp.out"


   *** Starting analysis ...

-------------------------------------------------------------------------------
   Matrix size = 6
   Matrix nnz = 12
   equed = 1.42812e-306
   recip_pivot_growth = 1
   1 / Condition number = 0.297426
   info = 0
   ferr = 2.85551e-307
   berr = 1
   No of nonzeros in factor L = 12
   No of nonzeros in factor U = 12
   No of nonzeros in L+U = 18
   L\U MB 0.000 total MB needed 0.001 expansions 0
   Using line search method.
   Nonlinear analysis tolerance (ftol) = 6.12865e-06
   Maximum number of nonlinear iterations per time-point (maxit) = 250
   Using Lee and Lee's quasi-Newton updates.
   --- Starting transient simulation ...

   Number of nonlinear state variables: 2
-------------------------------------------------------------------------------
   |  Step  |    Time (s)  |   Residual   |  Recent Max   |     Max      |
-------------------------------------------------------------------------------
   |      0 | 0.000000e+00 | 3.303597e-06 | 3.303597e-06  | 3.303597e-06 |
   |      5 | 5.000000e-08 | 3.170376e-06 | 3.204794e-06  | 3.303597e-06 |
   |     10 | 1.000000e-07 | 2.053913e-15 | 2.358213e-07  | 3.303597e-06 |
   |     15 | 1.500000e-07 | 1.871533e-06 | 2.138801e-06 *| 3.303597e-06 |
```

|      20 | 2.000000e-07 | 1.871421e-06 | 1.871423e-06 *| 3.303597e-06 |
|      25 | 2.500000e-07 | 1.871421e-06 | 1.871421e-06 *| 3.303597e-06 |
|      30 | 3.000000e-07 | 1.871421e-06 | 1.871421e-06 *| 3.303597e-06 |
|      35 | 3.500000e-07 | 1.871421e-06 | 1.871421e-06 *| 3.303597e-06 |
|      40 | 4.000000e-07 | 1.871421e-06 | 1.871421e-06 *| 3.303597e-06 |
|      45 | 4.500000e-07 | 1.871421e-06 | 1.871421e-06 *| 3.303597e-06 |
|      50 | 5.000000e-07 | 1.871421e-06 | 1.871421e-06 *| 3.303597e-06 |
|      55 | 5.500000e-07 | 1.871421e-06 | 1.871421e-06 *| 3.303597e-06 |
|      60 | 6.000000e-07 | 1.871421e-06 | 1.871421e-06 *| 3.303597e-06 |
|      65 | 6.500000e-07 | 1.871421e-06 | 1.871421e-06 *| 3.303597e-06 |
|      70 | 7.000000e-07 | 1.871421e-06 | 1.871421e-06 *| 3.303597e-06 |
|      75 | 7.500000e-07 | 1.871421e-06 | 1.871421e-06 *| 3.303597e-06 |
|      80 | 8.000000e-07 | 1.871421e-06 | 1.871421e-06 *| 3.303597e-06 |
|      85 | 8.500000e-07 | 1.871421e-06 | 1.871421e-06 *| 3.303597e-06 |
|      90 | 9.000000e-07 | 1.871421e-06 | 1.871421e-06 *| 3.303597e-06 |
|      95 | 9.500000e-07 | 1.871421e-06 | 1.871421e-06 *| 3.303597e-06 |
|     100 | 1.000000e-06 | 1.871421e-06 | 1.871421e-06 *| 3.303597e-06 |
|     105 | 1.050000e-06 | 1.871421e-06 | 1.871421e-06 *| 3.303597e-06 |
|     110 | 1.100000e-06 | 3.202763e-06 | 3.219358e-06  | 3.303597e-06 |
|     115 | 1.150000e-06 | 5.551115e-17 | 5.007632e-09  | 3.303597e-06 |
|     120 | 1.200000e-06 | 4.924549e-07 | 5.627811e-07 *| 3.303597e-06 |
|     125 | 1.250000e-06 | 4.924256e-07 | 4.924261e-07 *| 3.303597e-06 |
|     130 | 1.300000e-06 | 4.924256e-07 | 4.924256e-07 *| 3.303597e-06 |
|     135 | 1.350000e-06 | 4.924256e-07 | 4.924256e-07 *| 3.303597e-06 |
|     140 | 1.400000e-06 | 4.924256e-07 | 4.924256e-07 *| 3.303597e-06 |
|     145 | 1.450000e-06 | 4.924256e-07 | 4.924256e-07 *| 3.303597e-06 |
|     150 | 1.500000e-06 | 4.924256e-07 | 4.924256e-07 *| 3.303597e-06 |
|     155 | 1.550000e-06 | 4.924256e-07 | 4.924256e-07 *| 3.303597e-06 |
|     160 | 1.600000e-06 | 4.924256e-07 | 4.924256e-07 *| 3.303597e-06 |
|     165 | 1.650000e-06 | 4.924256e-07 | 4.924256e-07 *| 3.303597e-06 |
|     170 | 1.700000e-06 | 4.924256e-07 | 4.924256e-07 *| 3.303597e-06 |
|     175 | 1.750000e-06 | 4.924256e-07 | 4.924256e-07 *| 3.303597e-06 |
|     180 | 1.800000e-06 | 4.924256e-07 | 4.924256e-07 *| 3.303597e-06 |
|     185 | 1.850000e-06 | 4.924256e-07 | 4.924256e-07 *| 3.303597e-06 |
|     190 | 1.900000e-06 | 4.924256e-07 | 4.924256e-07 *| 3.303597e-06 |
|     195 | 1.950000e-06 | 4.924256e-07 | 4.924256e-07 *| 3.303597e-06 |
|     200 | 2.000000e-06 | 4.924256e-07 | 4.924256e-07 *| 3.303597e-06 |
|     205 | 2.050000e-06 | 3.170377e-06 | 3.204658e-06  | 3.303597e-06 |
|     210 | 2.100000e-06 | 1.665335e-16 | 2.358209e-07  | 3.303597e-06 |
|     215 | 2.150000e-06 | 1.871531e-06 | 2.138800e-06 *| 3.303597e-06 |
|     220 | 2.200000e-06 | 1.871420e-06 | 1.871422e-06 *| 3.303597e-06 |
|     225 | 2.250000e-06 | 1.871420e-06 | 1.871420e-06 *| 3.303597e-06 |
|     230 | 2.300000e-06 | 1.871420e-06 | 1.871420e-06 *| 3.303597e-06 |
|     235 | 2.350000e-06 | 1.871420e-06 | 1.871420e-06 *| 3.303597e-06 |
|     240 | 2.400000e-06 | 1.871420e-06 | 1.871420e-06 *| 3.303597e-06 |
|     245 | 2.450000e-06 | 1.871420e-06 | 1.871420e-06 *| 3.303597e-06 |
|     250 | 2.500000e-06 | 1.871420e-06 | 1.871420e-06 *| 3.303597e-06 |
|     255 | 2.550000e-06 | 1.871420e-06 | 1.871420e-06 *| 3.303597e-06 |
|     260 | 2.600000e-06 | 1.871420e-06 | 1.871420e-06 *| 3.303597e-06 |
|     265 | 2.650000e-06 | 1.871420e-06 | 1.871420e-06 *| 3.303597e-06 |
|     270 | 2.700000e-06 | 1.871420e-06 | 1.871420e-06 *| 3.303597e-06 |

```
   |    275 | 2.750000e-06 | 1.871420e-06 | 1.871420e-06 *| 3.303597e-06 |
   |    280 | 2.800000e-06 | 1.871420e-06 | 1.871420e-06 *| 3.303597e-06 |
   |    285 | 2.850000e-06 | 1.871420e-06 | 1.871420e-06 *| 3.303597e-06 |
   |    290 | 2.900000e-06 | 1.871420e-06 | 1.871420e-06 *| 3.303597e-06 |
   |    295 | 2.950000e-06 | 1.871420e-06 | 1.871420e-06 *| 3.303597e-06 |
   |    300 | 3.000000e-06 | 1.871420e-06 | 1.871420e-06 *| 3.303597e-06 |
   |    305 | 3.050000e-06 | 1.871420e-06 | 1.871420e-06 *| 3.303597e-06 |
   |    310 | 3.100000e-06 | 3.202763e-06 | 3.219358e-06  | 3.303597e-06 |
   |    315 | 3.150000e-06 | 5.684368e-14 | 5.007632e-09  | 3.303597e-06 |
   |    320 | 3.200000e-06 | 4.924549e-07 | 5.627812e-07 *| 3.303597e-06 |
   |    325 | 3.250000e-06 | 4.924256e-07 | 4.924262e-07 *| 3.303597e-06 |
   |    330 | 3.300000e-06 | 4.924256e-07 | 4.924256e-07 *| 3.303597e-06 |
   |    335 | 3.350000e-06 | 4.924256e-07 | 4.924256e-07 *| 3.303597e-06 |
   |    340 | 3.400000e-06 | 4.924256e-07 | 4.924256e-07 *| 3.303597e-06 |
   |    345 | 3.450000e-06 | 4.924256e-07 | 4.924256e-07 *| 3.303597e-06 |
   |    350 | 3.500000e-06 | 4.924256e-07 | 4.924256e-07 *| 3.303597e-06 |
   |    355 | 3.550000e-06 | 4.924256e-07 | 4.924256e-07 *| 3.303597e-06 |
   |    360 | 3.600000e-06 | 4.924256e-07 | 4.924256e-07 *| 3.303597e-06 |
   |    365 | 3.650000e-06 | 4.924256e-07 | 4.924256e-07 *| 3.303597e-06 |
   |    370 | 3.700000e-06 | 4.924256e-07 | 4.924256e-07 *| 3.303597e-06 |
   |    375 | 3.750000e-06 | 4.924256e-07 | 4.924256e-07 *| 3.303597e-06 |
   |    380 | 3.800000e-06 | 4.924256e-07 | 4.924256e-07 *| 3.303597e-06 |
   |    385 | 3.850000e-06 | 4.924256e-07 | 4.924256e-07 *| 3.303597e-06 |
   |    390 | 3.900000e-06 | 4.924256e-07 | 4.924256e-07 *| 3.303597e-06 |
   |    395 | 3.950000e-06 | 4.924256e-07 | 4.924256e-07 *| 3.303597e-06 |
   |    400 | 4.000000e-06 | 4.924256e-07 | 4.924256e-07 *| 3.303597e-06 |
   --- Maximum Residual: 3.3036e-06
-------------------------------------------------------------------------------

 Plotting output file: trans_res.out.
 Plotting output file: trans_temp.out.


************** fREEDA 1.3 stopping on Thu Apr 17 22:25:28 2008  ***********
```

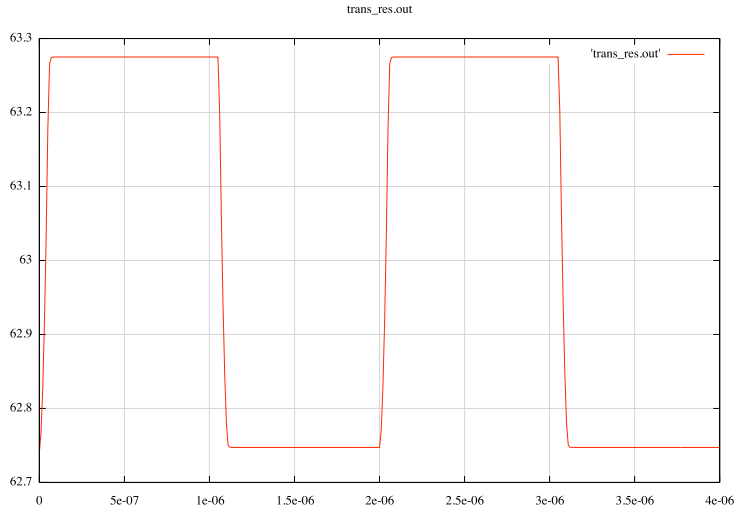


Figure 2: Transient Analysis - Resistance variation of thermal interconnect

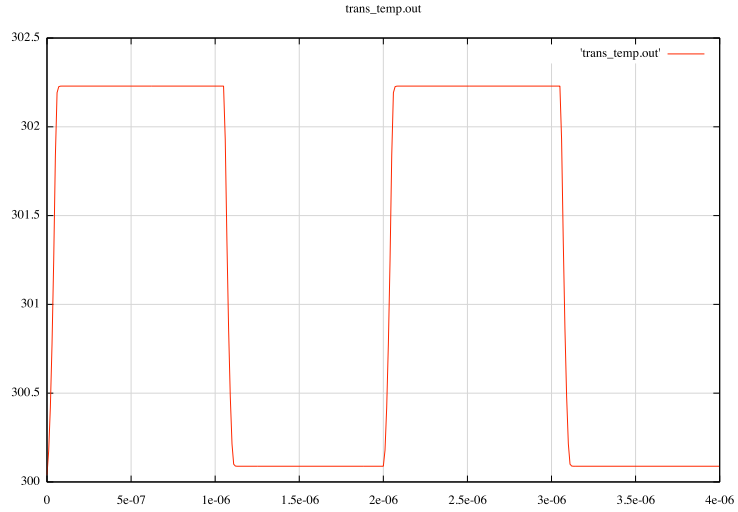


Figure 3: Transient Analysis - Temperature variation of interconnect line

*Version:*
2008.04.21 (2008 April 21)

*Credits:*

| Name | Affiliation | Date | Links |
|---|---|---|---|
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