SGS-THOMSON MICROELECTRONICS

APPLICATION NOTE

MODELLING PARALLEL OPERATION OF POWER RECTIFIERS WITH PSPICE

B. Rivet

I - INTRODUCTION

The behaviour of semiconductor components is always linked with the junction temperature.

This is the case, for example, in current-sharing between diodes connected in parallel. The current in each diode depends on the forward characteristic but also on the junction temperature.

This study describes thermal and electrical modelling of diodes connected in parallel. It allows the variation in current and junction temperature of each diode to be visualized between turn on and the equilibrium state.

II - ELECTRICAL AND THERMAL MODELLING OF A DIODE

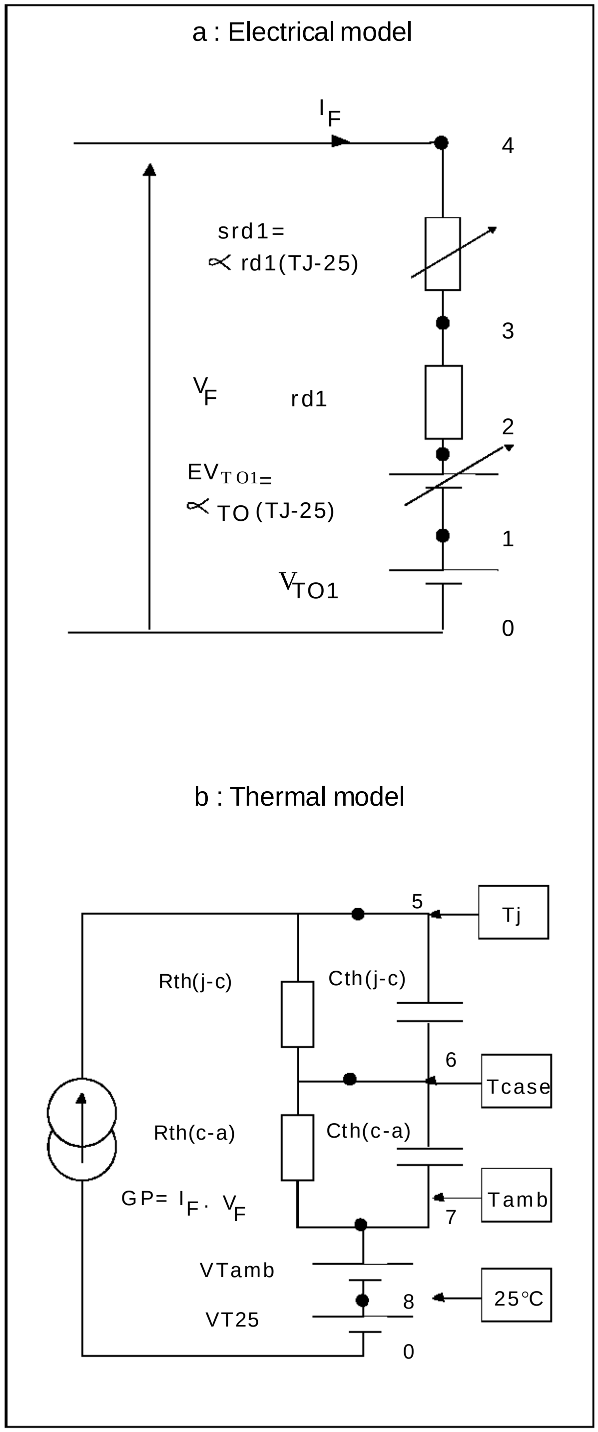
The forward characteristic of a diode is modelled by a threshold voltage V_{TO} in series with a dynamic resistance rd. These two parameters depend on the junction temperature of the diodes. V_{TO} has a negative temperature coefficient $\propto_{TO}$ and rd have a positive temperature coefficent $\propto$ rd.

One way to simulate the operation of such a device is to split the model into 2 different circuits : one "electrical" model and one "thermal" model.

The electrical and thermal models of a diode are shown in fig.1.

The thermal model is represented by electrical components.

Fig.1 : Electrical and thermal models of a diode



THE ELECTRICAL PARAMETERS ARE :

V_{TO1} : Threshold voltage at Tj = 25°C

EV_{T01} : Threshold voltage versus junction temperature

EV_{T01} = $\propto_{TO}$ (Tj-Tamb)
= $\propto_{TO}$ (V(5) - V(8))

rd1 : Dynamic resistance at Tj =25°C

srd1 : Dynamic resistance versus temperature
srd1 = $\propto$ rd1 (Tj - Tamb)
= $\propto$ rd1 (V(5) - V(8))

V_F : Instantaneous forward voltage across the diode

I_F : Instantaneous forward current in the diode

THE THERMAL PARAMETERS ARE :

GP : Generator current representing the instantaneous power dissipated in the diode.
GP = V_F x I_F

Rth(j-c) : Resistor representing the junction to case thermal resistance

Cth(j-c) : Capacitor representing the junction to case thermal capacitance

Rth(c-a) : Resistor representing the case to ambient thermal capacitance

Cth(c-a) : Capacitor representing the case to ambient thermal capacitance

VTamb : Voltage generator representing the ambient temperature
VTamb = Tamb - 25°C

VT25 : Voltage generator representing the 25°C temperature

III - MODELLING OF SEVERAL DIODES IN PARALLEL

See the application note : "Parallel operation of power rectifiers" (B.RIVET) for the qualitative analysis. In this note the acceptable difference between forward voltage drops (ΔV_F) is calculated so that the diodes can be safely connected in parallel.

The modelling will be based on the worst case situation. Suppose D1 has the lowest V_{T0} and rd and the highest Rth(j-c) so that this diode supports the highest current. The diode D2 and D3 have the same characteristics (maximum V_{T0} and rd, minimum Rth(j-c)).

The electrical and thermal models are shown in Fig.2.

Fig.2a : Thermal model of 3 rectifiers in parallel

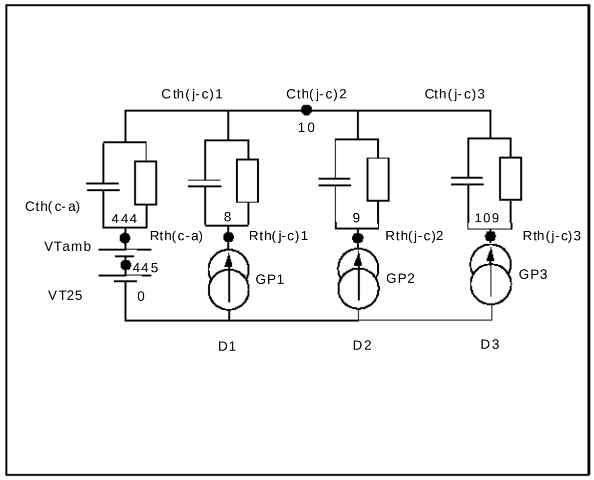
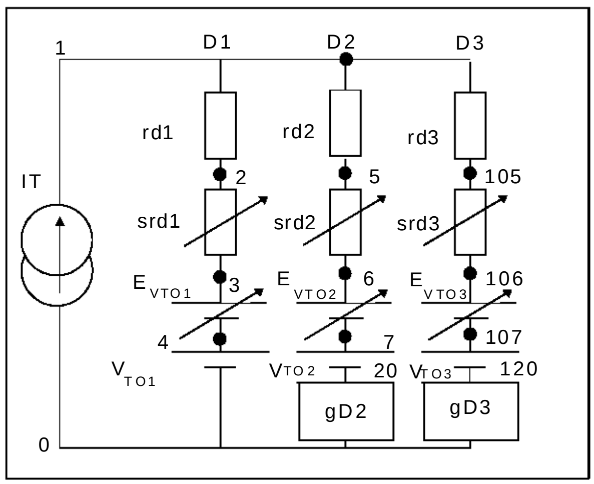


Fig.2b : Electrical model of 3 rectifiers in parallel



The modelling of several diodes in parallel will be treated with an example. Consider three BYV255 in parallel. The total current IT is rectangular with a duty cycle equal to 0.5, a peak current of 300 A and a frequency of 100 HZ.

In this example the following values have been taken.

rd1 = 1.2 mΩ
rd2 = rd3 = 0.9 mΩ

V_{T01} = 0.82 V
$\propto_{T0} = -1.6 \times 10^{-3}$ V/°C
$\propto$ rd = 2.10^{-6} Ω/°C

Rth(j-c)1 = 0.4°C/W
Rth(j-c)2 = Rth(j-c)3 = 0.3°C/W

Their calculation is explained in the previously mentioned application note.

Cth(j-c)1, Cth(j-c)2, Cth(j-c)3, Cth(j-c) are not very important parameters; they influence only the transient behaviour of the circuit and not the equilibrium state.

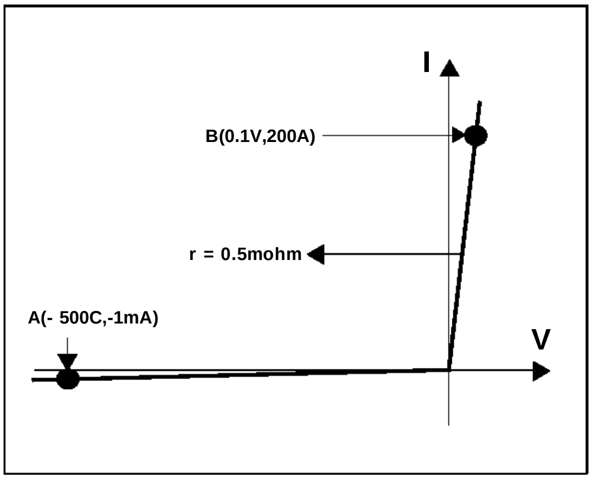
In the example Cth(j-c)1 = Cth(j-c)2 = Cth(j-c)3 = Cth(c-a) = 1 sW/°C has been assumed.

The simulation has been done with ΔV_F = 80 mV

Consider
$\Delta F \approx \Delta V_{T0}$ so $V_{T02} = V_{T03} = V_{T01} + \Delta V_F = 0.9V$

In the electrical modelling of the diode D2 and D3, components gD2, gD3 have been added. Their characteristic is drawn in Fig.3

Fig.3 : Characteristic of gD2 and gD3



These auxiliary components are needed to avoid a current flow in the diodes when the current IT is equal to zero. When the diodes conduct, these components are equivalent to the resistance of 0.5mΩ.

To take these resistances into account, make rd2 = rd3 = 0.4mΩ

The PSPICE description of this circuit is given in the appendix.

Fig.4 and 5 show the results of the simulation.
These curves represent the variations of the current in D1 and D2 (fig.4) and the junction temperatures Tj1 and Tj2 (fig.5)

At t = 0s Tj1 = Tj2 = Tamb = 40°C : the current is higher in D1 than in D2 so Tj1 will increase more quickly than Tj2 and the difference between I_{F1} and I_{F2} will increase also.

When the equilibrium state is reached this difference becomes constant.

If the frequency and the thermal capacitor are high the simulation time needed to reach the equilibrium state is long. So to reduce this time the Cth values can be decreased (This change will affect only the transient behaviour).

IV - CONCLUSION

A very flexible analysis of operation of several rectifiers in parallel can be done easily by using simulation on PSPICE. Because of the importance of the thermal effect on the various parameters of each diode we have design 2 models operating simultaneously. The first circuit calculates the electrical parameters while the second monitors the junction temperature.

One example of calculation with 3 diodes in parallel has shown how the curves of the currents and the junction temperatures can be obtained.

This double model is very powerful. The designer can add other diodes, insert wiring resistance, change the current waveform and also the cooling characteristic of the design.

Fig.4 : Variation of the current in D1 (IRD1) and in D2 (IRD2) versus time

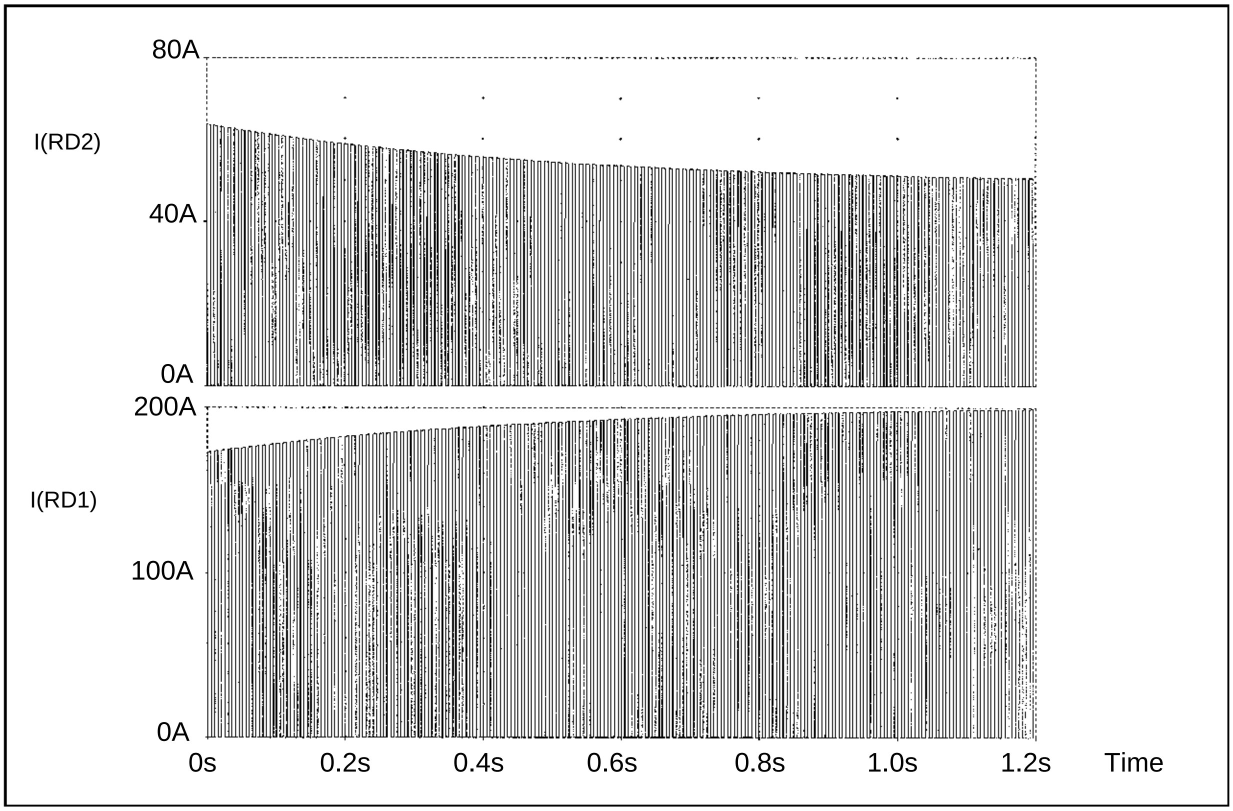
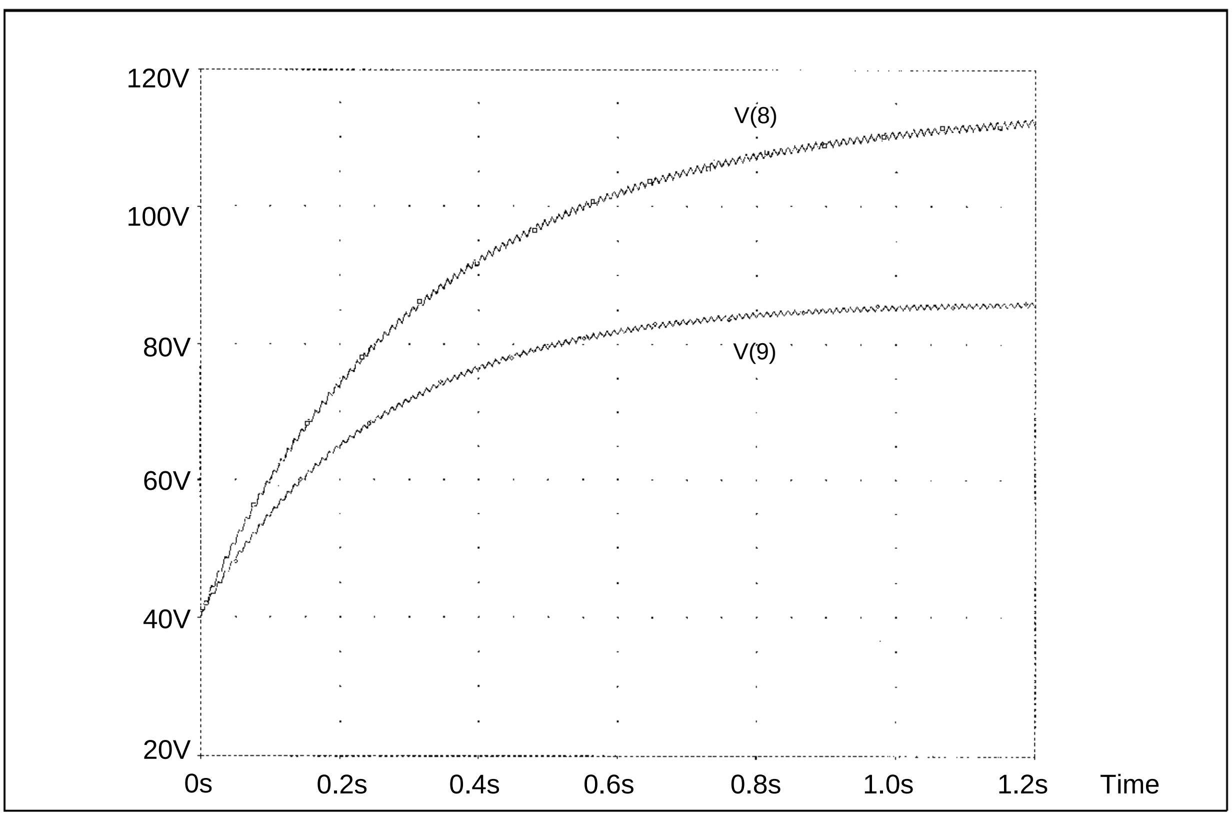


Fig.5 : Variation of the junction temperature of the diode D1 (V(8)) and D2 (V(9)) versus time



APPENDIX

```
DIODES-PARALLEL
I1 1 0 PULSE50 -300 0 0 0 5m 10m)
RD1 1 2 .9m
SRD1 2 3 8 445 SMOD
EVTO1 3 4 VALUE={-0.0016*V(8,445)}
VTO1 4 0 0.82
RD2 1 5 0.7m
SRD2 5 6 9 445 SMOD
EVTO2 6 7 VALUE={-0.0016*V(9,445)}
VTO2 7 20 0.9
GD2 20 0 TABLE {V(20)} =
+ (-500,-0.001)   (0.0)   (0.1,200)
RD3 1 105 0.7m
SRD3 105 106 109 445 SMOD
EVTO3 106 107 VALUE={-0.0016*V(109,445)}
VTO3 107 120 0.9
GR3 120 0 TABLE {V(120)} =
+ (-500,-0.001)   (0,0)   (0.1,200)
GP1 8 0 VALUE={-V(1,0)*V(1,2)*1111.11}
RTHJC1 8 10 .4
CTHJC1 8 10 1
GP2 9 0 VALUE={-V(1,0)*V(1,5)*1428.57}
RTHJC2 9 10 .3
CHTJC2 9 10 1
GP3   109   0   VALUE={-V(1,0)*V(1,105)*1428.57}
RTHJC3 109 10 .3
CTHJC3 109 10 1
RTHCA 10 444 .3
CTHCA 10 444 1
VTAMB 444 445 15
VT25 445 0 25
MODEL SMOD VSWITCH
(RON=0.0006        ROFF=0.00001        VON=250
VOFF=25)
tran    100.000u 1.2    0       0      ; *ipsp*
END
```