AN5001

Use Of The V_{TO}, r_T On-state Characteristic Model

Application Note

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The use of the V_{TO}, r_T on-state characteristic model and a more accurate alternative.

The inclusion of the theoretical terms V_{TO} and r_T in power semiconductor data sheets allows a simple means of calculating power loss, but this can lead to many incorrect assumptions. The terms in question are the two coefficients of a simple straight line model of the device on-state characteristic curve. To calculate the power the following formula is used:

$$P = V_{T0}\, I_{T(AV)} + r_T\, k^2\, I_{T(AV)}^{\ 2} \qquad [1]$$

where k is the current waveform form factor, eg 1.57 for half sine wave.

The use of V_{TO} and r_T to approximate to the forward volt drop curve of a power semiconductor originates from pre-computer days when engineers used slide rules, calculators and, later on, simple computers for their calculations. The use of modern computers means that better approximations to the characteristic can easily be used. The most popular of these is the model proposed by General Electric:

$$V_{TM} = A + B*\ln I + C*I + D*\mathrm{sqrt}(I) \qquad [2]$$

where A, B, C and D are constants with values specific to the device in question.

The use of this model is described below.

V_{T0}, r_T DEFINITIONS

Although the straight line model is basically simple, variations in definition can lead to significant differences in calculated powers.

Different manufacturers of power semiconductors have defined V_{T0} and r_T in different ways. Here are 4 variations:

1) As fig. 1, where the line is the tangent to the V_{TM} vs I_T curve at the average current.

2) As fig. 2, where a chord is drawn through $I_{T(AV)}$ and $3xI_{T(AV)}$. This variation is the one used by Dynex for the calculation of data sheet power losses and current ratings. The definition is commonly used for thyristors. For rectifier diodes a chord through $3xI_{T(AV)}$ and $5xI_{T(AV)}$ sometimes gives a better result.

3) A variation of 2 which uses two straight lines instead of one to approximate to the true curve. In this version the lines

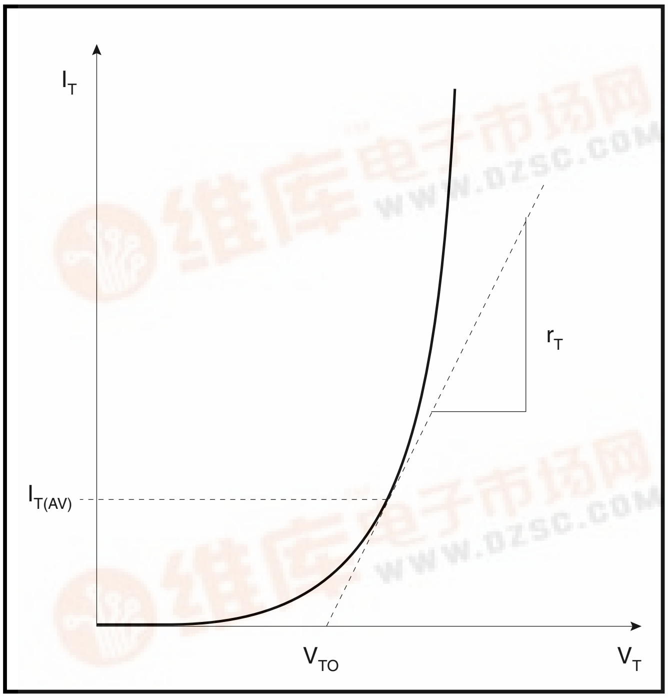

Fig.1

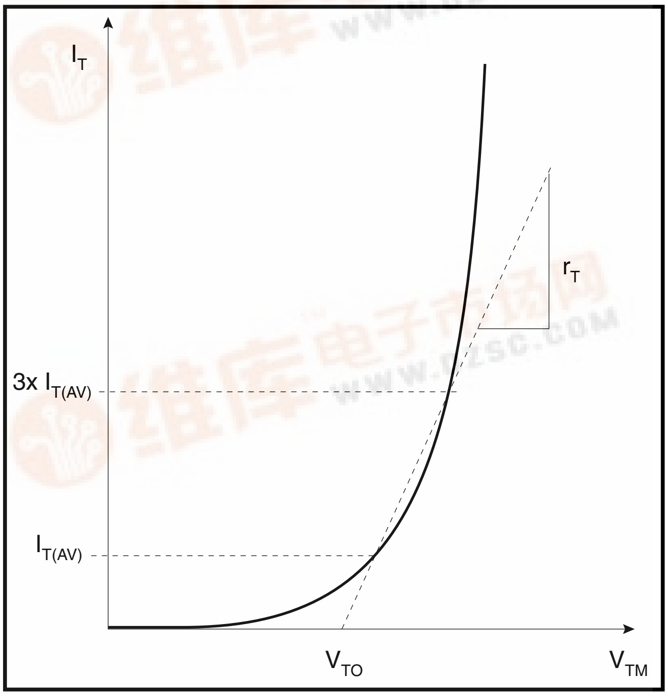

Fig.2

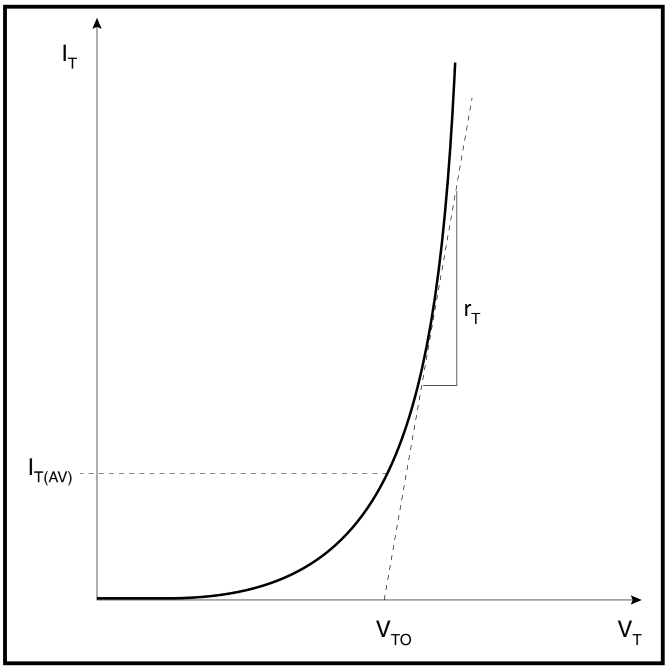

Fig.3

pass through $1/6I_{T(AV)}$ and $\pi I_{T(AV)}$ and also $\pi I_{T(AV)}$ and 20 x $I_{T(AV)}$.

4) As Fig 3. A tangential point constructed such that the value of $I_{T(AV)}$ calculated from:-

$$I_{T(AV)} = (-V_{TO} \pm \div (V_{TO}^2 + 4*k^2*r_T*P)) / 2*k^2*r_T \qquad \textbf{[3]}$$

is the same as that calculated by more exacting methods. This method is a variation of method 1). It has been used to retrospectively calculate meaningful values of V_{T0} and r_T where more accurate current rating data already exists.

LIMITATIONS OF THE V_{T0}, R_T MODEL

Using any one of the four definitions gives the correct value of the conduction losses at one or at most two points on the V_{TM} vs I_T curve, ie where the straight line meets the true curve. It can be seen that depending on where a point is taken on the curve the answers will be optimistic or pessimistic. Definitions 1, 2 and 4 give adequate accuracy up to 3 x $I_{T(AV)}$.

For improved accuracy a mathematical model is needed which approximates better to the true curve.

A FOUR COEFFICIENT MODEL

The GE four term curve-fit equation given above has been shown to be a good isothermal approximation and is being increasingly adopted by several manufacturers of power semiconductors for inclusion in their datasheets. For the user, the one problem with the equation

$$V_{TM} = A + B*\ln I + C*I + D*\mathrm{sqrt}(I) \qquad \textbf{[4]}$$

is that, when multiplied by the equation for the current, it is not easily integratable to give the power loss. However, the equation is solvable by numerical integration, now easily possible with computers.

The following equation **for half sine waves** uses the A, B, C, D coefficients used in the V_{TM} equation above, their numerical values depending on the device type.

$$P = [(A*(I/E) + B*(I/E)*\ln(I/E))*F + B*(I/E)*G + C*(I/E)^2*H + D*(I/E)^{3/2}*J] \qquad \textbf{[5]}$$

where **I is the peak value of the half sine wave current.**

The values of E, F, G, H and J depend on the conduction angle and are given in the table 1, and **for Rectangular waves :**

$$P = [A + B*\ln(I*360/\theta) + C*(I*360/\theta) + D*\div(I*360/\theta)]*(I*360/\theta) \qquad \textbf{[6]}$$

where **I is the average current** *(not the peak current)* and θ is the conduction angle in degrees.

Dynex Semiconductor has determined the values of A, B, C and D and these are given in the attached table 2.

Conduction Angle (degrees)	E	F	G	H	J
180	1	0.31830986	– 0.0976260	0.25	0.27820862
120	1	0.23752350	– 0.0522407	0.02000795	0.21579720
90	0.75	0.15776190	– 0.0488128	0.12361100	0.13771530
60	0.45	0.08077821	– 0.0453849	0.04992036	0.06241130
30	0.25	0.02062772	– 0.0245605	0.00686488	0.01166912
15	0.067	0.00506346	– 0.0095093	0.00084797	0.00203133

Table 1

Device Type Number	A	B	C	D
DCR504ST	0.351374	0.171814	0.000964	– 0.020616
DCR604SE	1.086551	– 0.173031	-3.307461×10^{-5}	0.056345
DCR720E	0.2366	0.1182	0.0005	– 0.0019
DCR803SG	0.464203	0.051516	0.000249	0.005951
DCR806SG	0.6102629	0.08049203	7.189037×10^{-4}	– 0.01028328
DCR818SG	0.650046	– 0.018621	0.000589	0.063601
DCR820SG	– 0.759775	0.639225	0.004376	– 0.092153
DCR840F	6.698580464	– 1.571103736	– 0.001210868	0.239948957
DCR1002SF	– 0.6475	0.3079	0.0002787	– 0.02311
DCR1003SF	– 1.191257	0.4149784	3.623888×10^{-4}	– 0.02991257
DCR1006SF	– 1.456962	0.5361379	6.639949×10^{-4}	– 0.04905585
DCR1008SF	1.458475	– 0.098355	0.000484	0.012565
DCR1020SF	0.25863	0.322589	0.002564	– 0.061059
DCR1021SF	– 0.3126	0.2744	0.001	– 0.0143
DCR1050F	1.458475	– 0.098355	0.000484	0.012565
DCR1374SBA	0.4846543	0.05408984	8.508026×10^{-5}	1.863019×10^{-3}
DCR1375SBA	1.149986	– 0.09990939	7.993598×10^{-5}	0.02290949
DCR1376SBA	1.459103	– 0.07503561	3.442677×10^{-4}	7.82981×10^{-3}
DCR1474SY / DCR1474SV	0.7635305	8.73036×10^{-3}	8.568357×10^{-5}	1.537158×10^{-3}
DCR1475SY / DCR1475SV	0.9905546	– 0.044251168	0.00011976	0.009125351
DCR1476SY / DCR1476SV	0.8659641	0.03698496	3.245389×10^{-4}	-2.597435×10^{-3}
DCR1574SY / DCR1476SV	1.328994	– 0.1381631	3.565973×10^{-6}	0.01786171
DCR1575SY / DCR1476SV	1.659647	– 0.2206499	7.427997×10^{-5}	0.02837417
DCR1576SY / DCR1476SV	0.414672883	0.039124962	0.000288077	0.008514638
DCR5980A	0.4624	0.0275	2.2501×10^{-5}	0.0032
DCR1594SW	1.152158	– 0.08401428	3.351054×10^{-5}	0.01199439
DCR1595SW	0.02866651	0.1590393	1.947584×10^{-4}	-5.23298×10^{-3}
DCR1596SW	– 0.5011559	0.2638417	2.5367114×10^{-4}	– 0.01249303
DCR1673SZ / DCR1673SA	0.6180535	0.007965	4.57×10^{-5}	4.003×10^{-3}
DCR1674SZ / DCR1674SA	0.6844942	– 0.0108645	7.203702×10^{-5}	0.01015201
DCR1675SZ / DCR1675SA	0.8497627	– 0.03614853	5.286579×10^{-5}	0.01334724

Table 2 List of thyristor GE V_{TM} coefficients

Device Type Number	A	B	C	D
DS402ST	− 0.143917755	0.236902917	0.000989976	− 0.026033549
DS502ST	0.50435325	0.056610963	0.000639419	− 0.001101334
DNB61	0.827165759	− 0.035964275	0.000111412	0.007187415
DNB63	0.517184167	0.035582615	4.93781×10^{-5}	− 0.001102222
DNB64	0.50649703	0.070975272	0.000219255	− 0.005527578
DNB65	− 0.369840129	0.292196574	0.000353522	− 0.0311127
DS1104SG	0.782526539	− 0.077708882	0.000120208	0.019499005
DS1107SG	0.616460694	− 0.014521148	0.00034868	0.009951883
DS1109SG	0.788645971	− 0.004501879	0.000591618	0.006984031
DS1112SG	1.249986249	− 0.1764565	0.000523815	0.041024446
DS2002SF	− 0.647732445	0.268580716	0.000160327	− 0.017958086
DS2004SF	− 0.231479628	0.20380136	0.000230067	− 0.01443255
DS2007SF	0.658789195	− 0.017063104	0.00019441	0.01035792
DS2009SF	0.290476453	0.064490173	0.000335017	0.004080104
DS2012SF	0.819644816	− 0.136726285	5.73018×10^{-5}	0.042435146
DS2101SY / DS2101SV	0.081706784	0.100348872	5.71812×10^{-5}	− 0.005290799
DS2102SY / DS2102SV	0.402090735	0.011717664	6.48045×10^{-6}	0.005977122
DS2103SY / DS2103SV	− 0.518264054	0.195880942	6.39322×10^{-5}	− 0.005435085
DS2106SY / DS2106SY	− 0.153571217	0.177571072	0.000178862	− 0.012942108
DS2107SY / DS2107SY	0.671710935	0.011005871	0.000158152	0.000604348
DS2906SZ	− 0.015914444	0.11368224	8.04212×10^{-5}	− 0.002839595

Table 3 List of diode GE V_{FM} coefficients

POWER ASSEMBLY CAPABILITY

The Power Assembly group was set up to provide a support service for those customers requiring more than the basic semiconductor, and has developed a flexible range of heatsink and clamping systems in line with advances in device voltages and current capability of our semiconductors.

We offer an extensive range of air and liquid cooled assemblies covering the full range of circuit designs in general use today. The Assembly group offers high quality engineering support dedicated to designing new units to satisfy the growing needs of our customers.

Using the latest CAD methods our team of design and applications engineers aim to provide the Power Assembly Complete Solution (PACs).

HEATSINKS

The Power Assembly group has its own proprietary range of extruded aluminium heatsinks which have been designed to optimise the performance of Dynex semiconductors. Data with respect to air natural, forced air and liquid cooling (with flow rates) is available on request.

For further information on device clamps, heatsinks and assemblies, please contact your nearest sales representative or Customer Services.

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