MITEL SEMICONDUCTOR

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:

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

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:

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

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

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

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

is the same as that calculated by more exacting methods. This method is a variation of method 1). It has been used to retrospec-

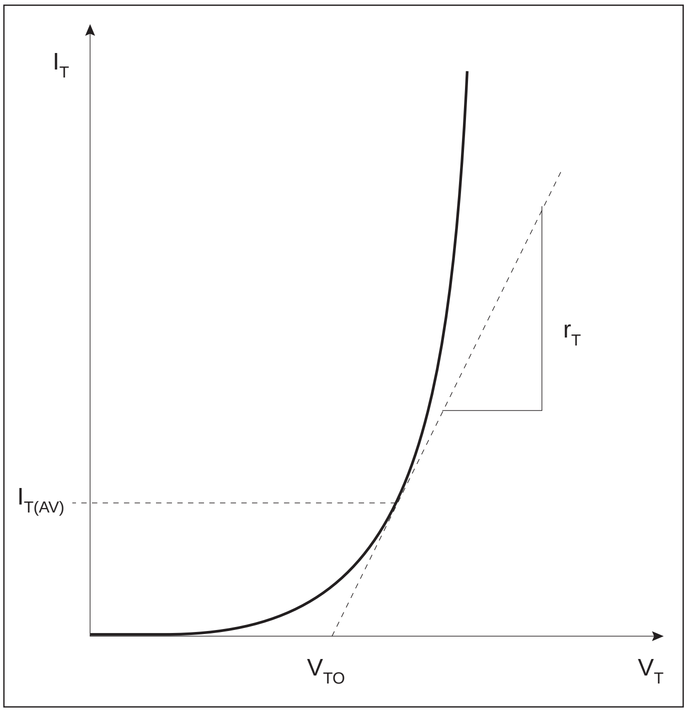

Fig.1

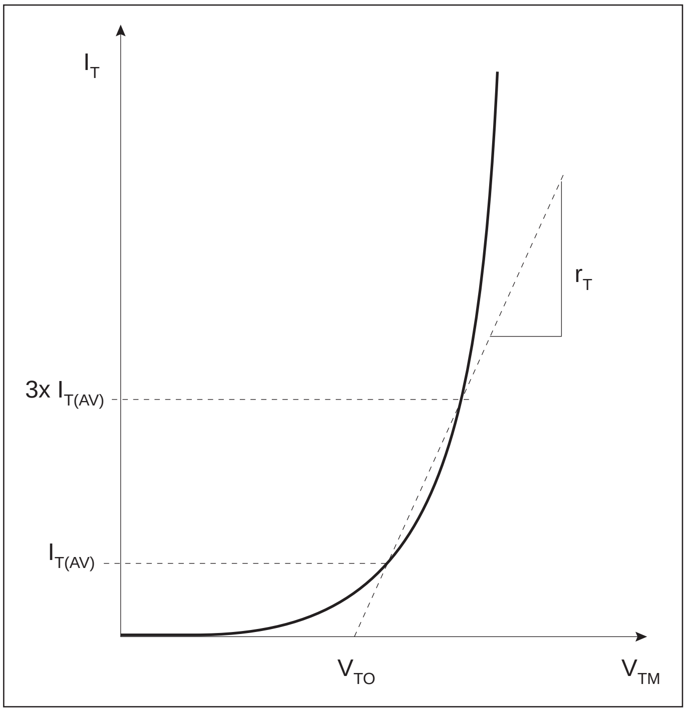

Fig.2

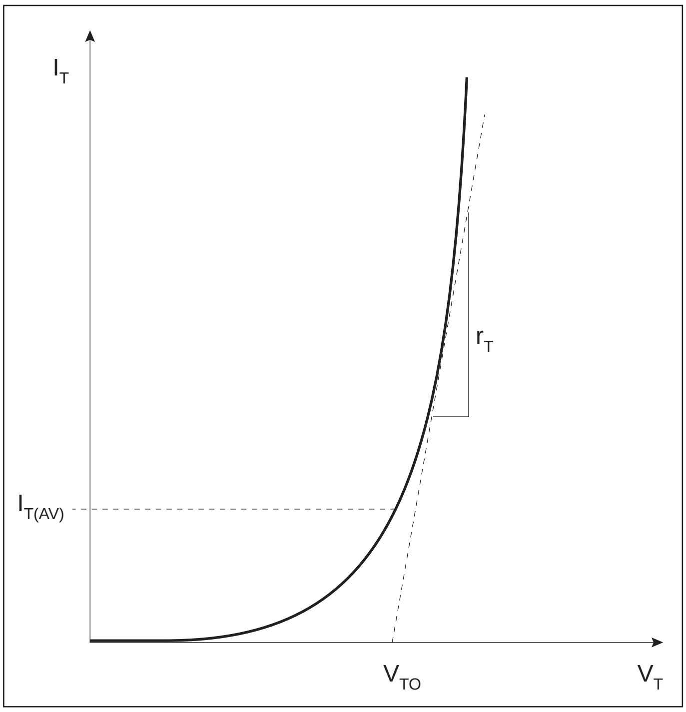

Fig.3

tively 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

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

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.

$$P = [A*(I/E) + B*(I/E)*\ln(I/E)*F + B*(I/E)*G + C*(I/E)^2*H + D*(I/E)^{3/2}*J] \qquad \textbf{[4]}$$

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 :**

$$P = [A + B*\ln(I*360/\theta) + C*(I*360/\theta) + D*\div(I*360/\theta)]*(I*360/\theta)] \qquad \textbf{[5]}$$

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

Mitel 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
DCR803SG	0.6102629	0.08049203	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
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
DCR1275SD	1.255681	–0.14019	7.581403×10^{-5}	0.025833
DCR1277SD	1.712517	–0.201825	0.000256	0.025787
DCR1279SD	1.398966	–0.078055	0.000504	0.011137
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^{-4}
DCR1474SY	0.7635305	8.73036×10^{-3}	8.568357×10^{-5}	1.537158×10^{-3}
DCR1475SY	1.259276	–0.08537149	1.320759×10^{-4}	9.178437×10^{-3}
DCR1476SY	0.8659641	0.03698496	3.245389×10^{-4}	-2.597435×10^{-3}
DCR1478SY	0.8659641	0.03698496	3.245389×10^{-4}	-2.597435×10^{-3}
DCR1574SY	1.328994	0.1381631	3.565973×10^{-6}	0.01786171
DCR1575SY	1.659647	–0.2206499	7.427997×10^{-5}	0.02837417
DCR1576SY	0.06963535	0.1224886	3.310485×10^{-4}	1.619778×10^{-4}
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	0.4769404	0.02958434	3.978298×10^{-5}	6.677479×10^{-3}
DCR1674SZ	0.6844942	–0.0108645	7.203702×10^{-5}	0.01015201
DCR1675SZ	0.8497627	–0.03614853	5.286579×10^{-5}	0.01334724

Table 2 List of thyristor GE V_{TM} coefficients

	Double Side Cooled			Single Side Cooled		
Device Type Number	$I_{T(AV)}$ (A)	$I_{T(RMS)}$ (A)	I_{DC} (A)	$I_{T(AV)}$ (A)	$I_{T(RMS)}$ (A)	I_{DC} (A)
DCR504ST	354	556	497	246	387	320
DCR604SE	551	866	751	372	585	489
DCR803SG	817	1284	1088	506	795	636
DCR806SG	669	1051	928	428	672	552
DCR818SG	420	660	583	269	423	359
DCR820SG	310	487	447	204	321	279
DCR1003SF	1197	1881	1623	831	1305	1065
DCR1006SF	980	1540	1359	690	1083	900
DCR1008SF	828	1300	1164	585	920	774
DCR1020SF	514	807	765	377	592	530
DCR1275SD	1175	1846	1625	798	1255	1045
DCR1277SD	999	1570	1419	691	1086	922
DCR1279SD	859	1349	1217	593	932	787
DCR1374SBA	2102	3301	2773	1503	2361	1888
DCR1375SBA	1562	2453	2142	1139	1790	1501
DCR1376SBA	1319	2072	1851	975	1532	1298
DCR1474SY	2764	4342	3776	1729	2717	2175
DCR1475SY	2224	3494	3149	1431	2248	1877
DCR1476SY	1770	2780	2554	1155	1815	1542
DCR1478SY	1625	2553	2271	1035	1625	1345
DCR1574SY	2704	4247	3670	1682	2642	2144
DCR1575SY	2007	3153	2887	1307	2053	1772
DCR1576SY	1716	2695	2526	1140	1790	1578
DCR1594SW	3036	4769	4128	1894	2975	2407
DCR1595SW	2380	3739	3362	1532	2407	2014
DCR1596SW	2266	3560	3230	1469	2308	1950
DCR1673SZ	3625	5694	4956	2269	3565	2909
DCR1674SZ	3101	4871	4377	1991	3128	2640
DCR1675SZ	3029	4758	4223	1926	3025	2524

Table 3 List of GE calculated currents

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