Email: powersolutions@dynexsemi.com
Main switchboard: +44 (0)1522 500 500
Website: www.dynexsemi.com

AN5001

Use of V_{T0}, r_T, On-state Characteristic Model

Application Note

Replaces AN5001-8 AN5001-9 October 2022 (LN42106)

The use of the V_{T0}, r_T on-state model and a more accurate alternative

The inclusion of the theoretical terms V_{T0} and r_T in power semiconductor datasheets 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 straight-line model of the device on-state characteristics 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, e.g. 1.57 for half sine wave.

The use of V_0 and r_T to approximate the forward volt drop curve of a power semiconductor originates from pre-computer days when engineers used slide rules, calculators or even log tables for their calculations. The use of modern computers and spreadsheets means that better approximations to the characteristics can easily be used. The most popular of these models is that proposed by General Electric:

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

Where A, B, C and D are constants with values specific to the device in question. The use of this model is described later.

V_{T0}, r_T definitions

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

Different manufacturers of power semiconductors have defined V_0 and r_T in different ways. Here are 4 variations:

1. As fig. 1, where the line is a tangent to the V_{TM} vs I_T curve at the average current rating.
2. As fig. 2, where a chord is drawn through $I_{T(AV)}$ and 3x $I_{T(AV)}$. For rectifier diodes, a chord through 3x $I_{T(AV)}$ and 5x $I_{T(AV)}$ sometimes gives a better result.

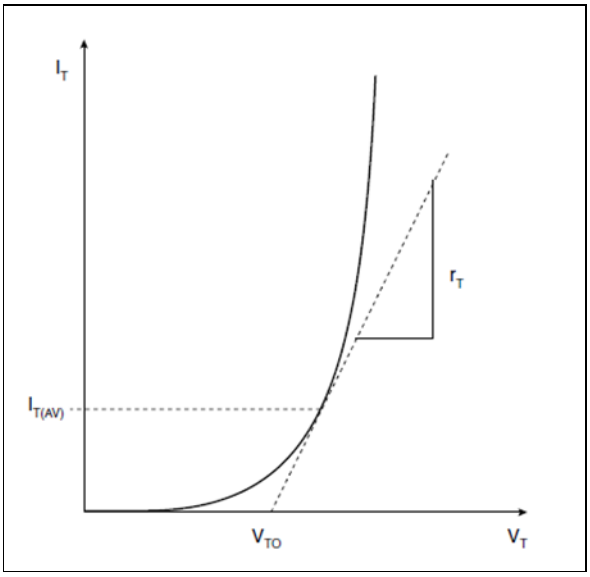

Fig. 1

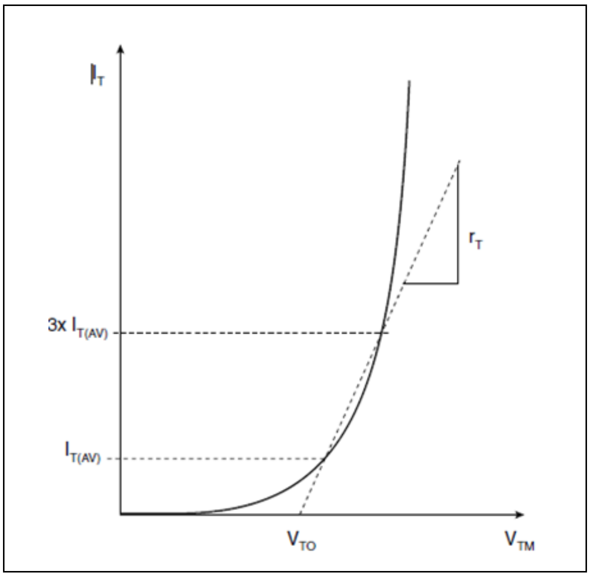

Fig. 2

Similarly, if the thermal resistance, junction to heat-sink, is used then the corresponding de-rate curve of junction temperature against heat-sink temperature is calculated.

As previously indicated, a more rigorous derivation can be performed numerically using the ABCD coefficients to define the forward voltage drop curve: $V_{TM} = A + B.\ln(I_T) + C.I_T + D.\sqrt{I_T}$

3. A variant of 2 which uses two straight lines instead of one to approximate the true curve. In this version the lines pass through $1/6.I_{T(AV)}$ and $I_{T(AV)}$ and also $I_{T(AV)}$ and $20.I_{T(AV)}$.

4. As fig. 4, a tangential point constructed such that the value of $I_{T(AV)}$ calculated from:

$$I_{T(AV)} = (-V_{T0} \pm \sqrt{(V_{T0}^2 + 4*k^2*r_T*P)})/2*k^2*r_T \qquad [3]$$

is the same as that calculated by more exacting methods. This method is a variation of method 1.

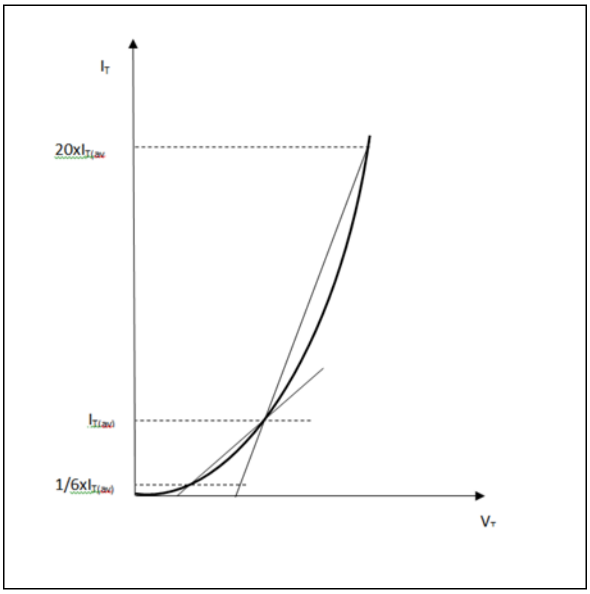

Fig. 3

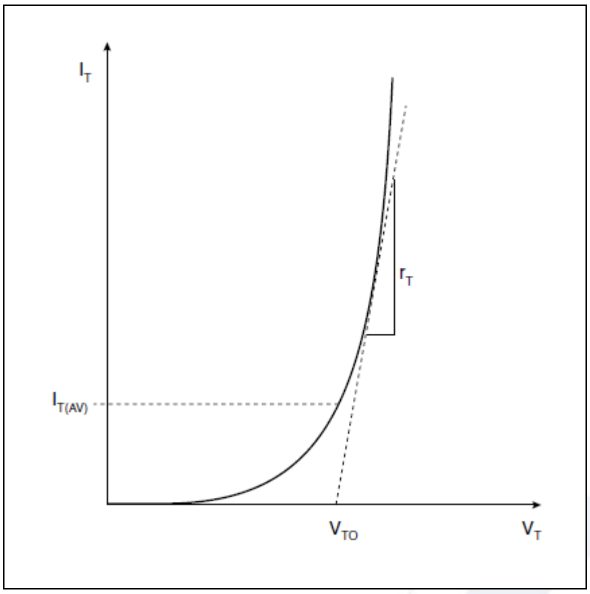

Fig. 4

Limitations of the V_{T0}, r_T model

Using any one of the four definitions gives the correct losses at one or at most two points on the V_{TM} vs I_T curve. It can be seen that depending on where a point is taken on the curve the answer will be either optimistic or pessimistic. Definitions 1, 2 and 4 give adequate accuracy up to 3x $I_{T(AV)}$. For improved accuracy a mathematical model is needed which is a better fit to the true curve.

A Four Coefficient Model

The GE four term curve-fit equation, given above in equation 2, has been shown to be a good isothermal approximation and is being increasingly adopted by manufacturers of power semiconductors for inclusion in their datasheets. A word of warning here, not all manufacturers quote the formula with the coefficients in the same order, for instance GE, Dynex, Powerex and Westcode all use $V_{TM} = A + B*\ln(I) + C*I + D*\sqrt{I}$, whilst ABB use $A + B*I + C*\sqrt{I} + D*\ln(I+1)$, and Infineon use $A + B*I + C*\ln(I+1) + D*\sqrt{I}$, so great care must be taken if using a spreadsheet to compare the forward voltage characteristics of devices from different manufacturers.

For the user, the one problem with the equation,

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

is that, when multiplied by the equation for current, it is not easy to integrate to give the power loss. However, the equation is easily solvable by numerical integration. The following equation for **half sine waves** uses the ABCD coefficients as in equation 2, their values depending upon the device being considered.

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

Where **I is the peak value of the half sine wave of current**. The values E, F, G, H, and J depend on the conduction angle and are given in table 1.

For Rectangular waves, $P = [A + B*\ln(I*360/\Theta) + C*(I*360/\Theta) + D*\sqrt{(I*360/\Theta)}]*I \qquad [5]$

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

Dynex Semiconductor has calculated the values of A, B, C & D and these are given in the datasheets for High Voltage Phase Control Thyristors and Rectifier Diodes.

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

IMPORTANT INFORMATION:

This publication is provided for information only and not for resale.

The products and information in this publication are intended for use by appropriately trained technical personnel.

Due to the diversity of product applications, the information contained herein is provided as a general guide only and does not constitute any guarantee of suitability for use in a specific application. The user must evaluate the suitability of the product and the completeness of the product data for the application. The user is responsible for product selection and ensuring all safety and any warning requirements are met. Should additional product information be needed please contact Customer Service.

Although we have endeavoured to carefully compile the information in this publication it may contain inaccuracies or typographical errors. The information is provided without any warranty or guarantee of any kind.

This publication is an uncontrolled document and is subject to change without notice. When referring to it please ensure that it is the most up to date version and has not been superseded.

The products are not intended for use in applications where a failure or malfunction may cause loss of life, injury or damage to property. The user must ensure that appropriate safety precautions are taken to prevent or mitigate the consequences of a product failure or malfunction.

The products must not be touched when operating because there is a danger of electrocution or severe burning. Always use protective safety equipment such as appropriate shields for the product and wear safety glasses. Even when disconnected any electric charge remaining in the product must be discharged and allowed to cool before safe handling using protective gloves.

Extended exposure to conditions outside the product ratings may affect reliability leading to premature product failure. Use outside the product ratings is likely to cause permanent damage to the product. In extreme conditions, as with all semiconductors, this may include potentially hazardous rupture, a large current to flow or high voltage arcing, resulting in fire or explosion. Appropriate application design and safety precautions should always be followed to protect persons and property.

Product Status & Product Ordering:
We annotate datasheets in the top right-hand corner of the front page, to indicate product status if it is not yet fully approved for production. The annotations are as follows: -

Target Information:	This is the most tentative form of information and represents a very preliminary specification. No actual design work on the product has been started.
Preliminary Information:	The product design is complete and final characterisation for volume production is in progress. The datasheet represents the product as it is now understood but details may change.
No Annotation:	The product has been approved for production and unless otherwise notified by Dynex any product ordered will be supplied to the **current version of the data sheet prevailing at the time of our order acknowledgement.**

All products and materials are sold and services provided subject to Dynex's conditions of sale, which are available on request.

Any brand names and product names used in this publication are trademarks, registered trademarks or trade names of their respective owners.

HEADQUARTERS OPERATIONS
DYNEX SEMICONDUCTOR LIMITED
Doddington Road, Lincoln, Lincolnshire, LN6 3LF
United Kingdom.
Phone: +44 (0) 1522 500500

Web: http://www.dynexsemi.com

CUSTOMER SERVICE
Phone: +44 (0) 1522 502753 / 502901

e-mail: powersolutions@dynexsemi.com