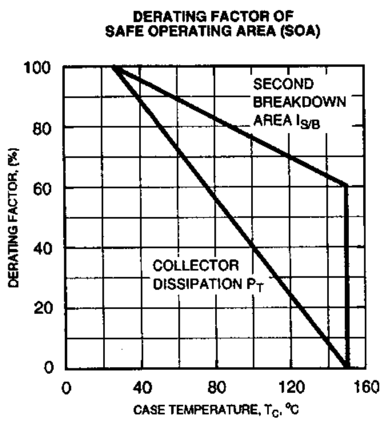
represents the peak collector emitter voltage and collector current limits for the device. These are instantaneous limits. The turn-off load line should not go outside the RBSOA curve. The amount of reverse base current used has a strong effect upon RBSOA performance. Higher reverse base current reduces the RBSOA capability because the higher base current creates an internal voltage that causes current crowding under the center of the emitter fingers.

1.5 On Characteristics

Powerex data sheets provide a number of characteristic curves that apply to the transistor in the on or saturated condition.

Figure 1.6 Forward Bias Safe Operating Area Derating Curve and Examples of its use



$I_{S/B}$ Derating Factor = -0.32 T + 108
P_T Derating Factor = -0.8 T + 120
T = Case Temperature in °C.
Equations valid over 25°C to 150°C range.

Thermal Limitations Example

Assume it is desired to operate the KS621K30 at 20 volts with a case temperature of 90°C.

1. Current from the FBSOA curve at 20 volts = 99 amps, yielding 1980 watt maximum power.
2. From Second Breakdown Derating Curve, $I_{S/B}$ derating at 90°C = 78%. Thus derated maximum power = 1980 • 0.78 = 1544 watts.
3. Maximum allowable current at 90°C case temperature = 1544/20 = 77 amps.
4. From Collector Dissipation Curve, thermal derating = 48% at 90°C. Thus maximum power = 1980 • 0.48 = 950 watts and maximum current = 950/20 = 47.5 amps. In this example the thermal derating is the limiting factor on device current.

Second Breakdown Limitation Example

Assume it is desired to operate the KS621K30 at 150 volts with a case temperature of 90°C.

1. Current from the FBSOA curve at 150 volts = 4.3 amps, yielding 645 watts maximum power.
2. From Second Breakdown Derating Curve, $I_{S/B}$ derating at 90°C = 78%. Thus derated maximum power = 645 • 0.78 = 503 watts.
3. Maximum allowable current at 90°C case temperature = 503/150 = 3.4 amps.
4. From Collector Dissipation Curve, thermal derating = 0.48% at 90°C. Thus maximum power = 1980 • 0.48 = 950 watts and maximum current = 950/150 = 6.3 amps. In this example the second breakdown derating is the limiting factor on device current.

Figure 1.7 $V_{CE(sus)}$, Reverse Bias Safe Operating Area (SOA) Measurement Circuit and Waveform

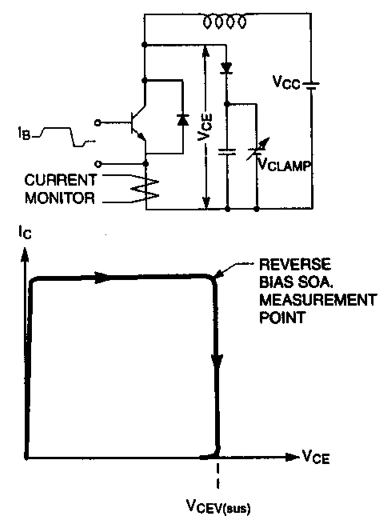


Figure 1.8 Typical Reverse Bias Safe Operating area (SOA) Curve

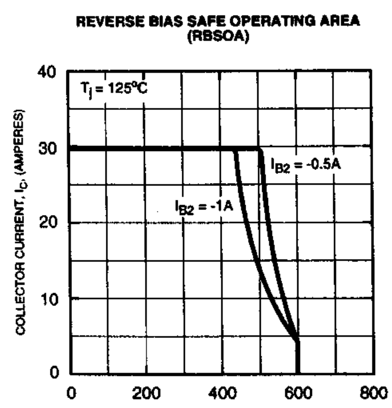


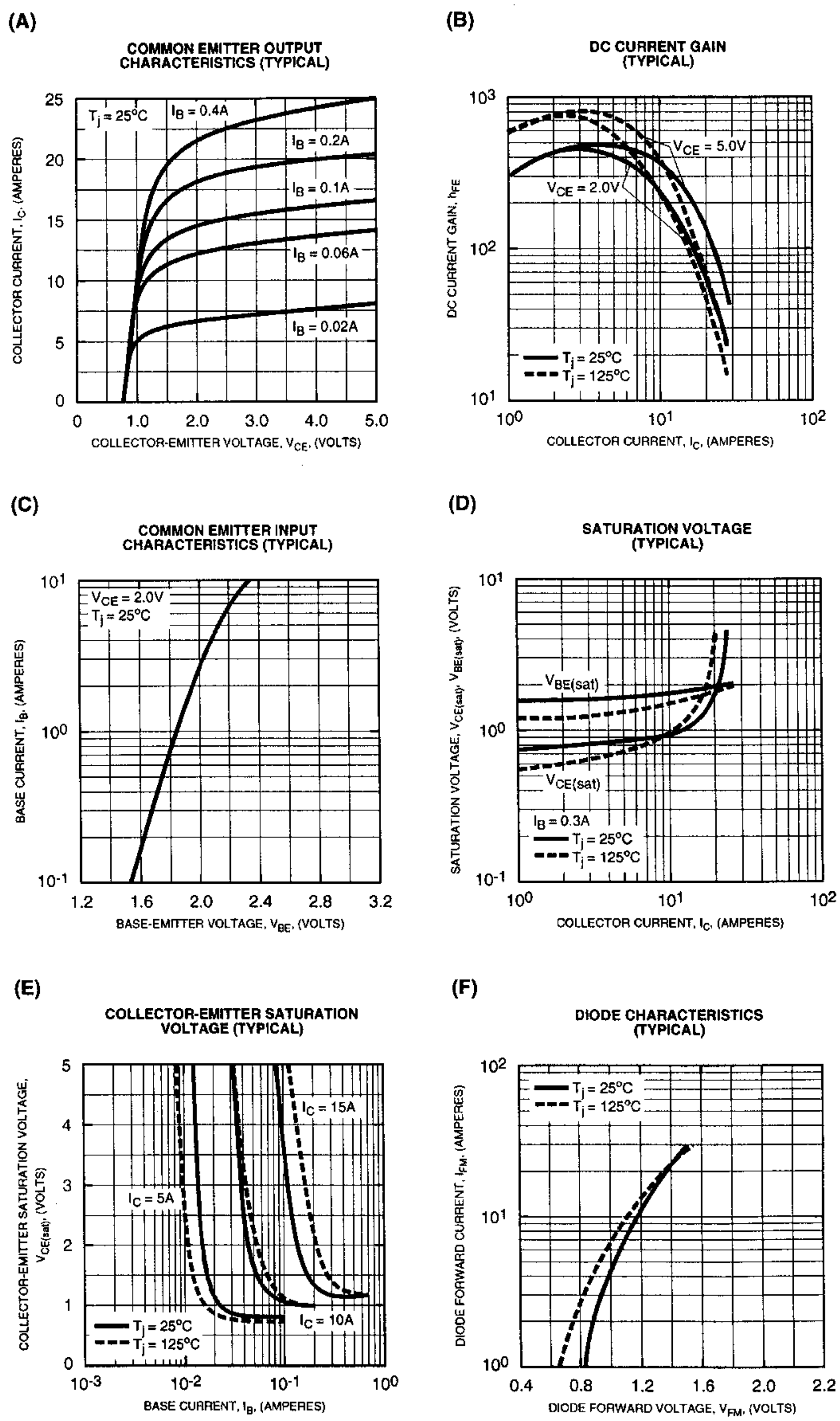
Figure 1.9 (A) illustrates an output characteristic curve which plots the collector emitter voltage vs. collector current for different values of base current. The region in which the curves converge into a single vertical line represents hard saturation of the transistor. Hard saturation provides the lowest achievable $V_{CE(sat)}$, as further increases in base current will not decrease $V_{CE(sat)}$.

To the right of the hard saturation region, the transistor operates in the quasi-saturation region. In quasi-saturation, for a fixed base current, the collector current decreases as collector emitter voltage decreased, which means the gain decreases. At higher collector emitter voltages, the curves become horizontal with little change in collector current for a fixed base current as collector emitter voltage changes. This linear region of the output characteristic is not shown on the data sheet curves.

For efficiency, it is desirable to control large collector currents with small values of base current. The common emitter current gain, h_{FE}, is the ratio of collector current to base current at a fixed V_{CE}.

Figure 1.9 (B) shows a typical data sheet curve for Gain vs. Collector Current as a function of V_{CE} and temperature. Gain increases with voltage and increases with temperature at low currents. At high currents, gain decreases with temperature. Gain hold-up is defined as the change in h_{FE} as a function of collector current. Powerex Darlington Transistors have excellent gain hold-up to

Figure 1.9 Typical On-state Transistor Characteristics



rated current allowing low values of $V_{CE(sat)}$ with reasonable forced gains.

Figure 1.9 (C) illustrates an input characteristic curve which plots base emitter voltage, V_{BE}, as a function of base current, I_B, at a fixed collector emitter voltage, V_{CE}. This curve is used when designing base drive circuits. Darlington transistors, especially triple Darlingtons, have significant base emitter voltages which must be allowed for when choosing drive circuit source voltage.

Figure 1.9 (D) and (E) illustrate saturation voltage curves. The saturation voltages are specified as a function of base current, collector current, and temperature. Saturation voltages are important in calculating device power dissipation.
For transistor modules which include integral fast recovery free-wheeling diode(s) a forward voltage vs. forward current curve such as Figure 1.9 (F) is provided.

1.6 Switching Characteristics

The switching times of power transistors are measured with respect to the collector current. This is because in power switching the load is generally inductive and the collector emitter voltage waveform is circuit dependent.

Figure 1.10 shows the switching time curves provided on Powerex data sheets and shows the switching time test circuit. Switching time measurements are made using a resistive load to insure test repeatability. For inductive switching, the switching times are shorter than those for resistive switching. Note the reduction in storage and turn-off time obtained by increasing the reverse base current I_{B2}.

For transistor modules which include integral fast recovery free-wheeling diode(s), the diode surge current ratings and reverse recovery characteristics are provided on curves such as illustrated in Figure 1.11. The diode reverse recovery is characterized in an inductive switching circuit as shown in Figure 1.11.

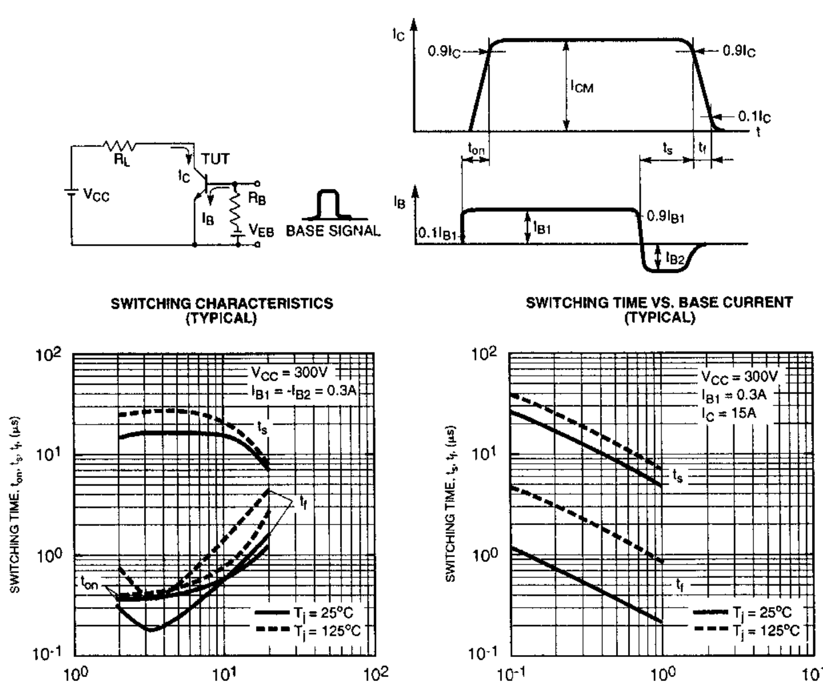
1.7 Power Dissipation and Thermal Ratings

Successful application of power transistors requires adherence to power dissipation and thermal ratings. Transistor failure rate is directly proportional to junction temperature. Derating junction temperature below data sheet maximum is recommended to enhance reliability.

1.7.1 Power Dissipation vs. Temperature

The maximum power dissipation in Watts is specified at a case temperature of 25°C. If the case temperature is higher than 25°C, the derating curve shown in Figure 1.12 must be used. Total power dissipation, or losses, dissipated in a transistor consist of off-state, conduction, and drive power dissipation.

Figure 1.10 Switching Characteristics



1.7.2 Thermal Resistance

Temperature calculations are simplified by using thermal resistance concepts. The flow of heat through a thermal path as a result of power dissipation is analogous to the flow of current through a conductive path as a result of a voltage source. Hence, knowing the power being dissipated in a device, and the ambient temperature, the resulting junction temperature can be calculated using the total thermal resistance and the following equation:

$$T_j = T_A + P_T \bullet R_{\theta(j\text{-}s)}$$

where:

$R_{\theta(j\text{-}a)}$ = Total thermal resistance junction-to-ambient (°C/Watt)

P_T = Total power dissipation (Watts)

T_j, T_A = Junction, ambient temperature (°C)

The total thermal resistance is given by:

$$R_{\theta(j\text{-}a)} = R_{\theta(j\text{-}c)} + R_{\theta(c\text{-}s)} + R_{\theta(s\text{-}a)}$$

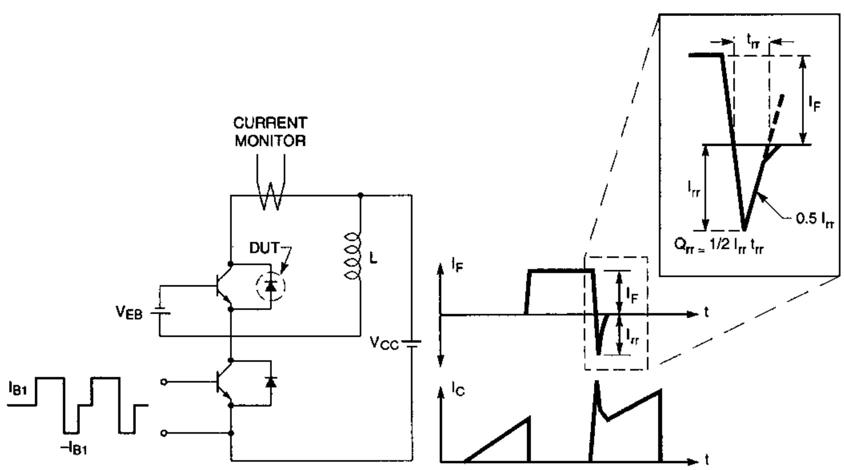
where:

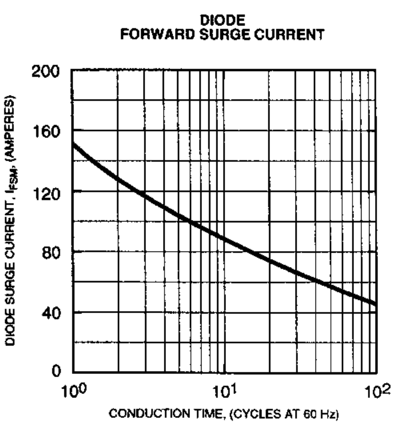
$R_{\theta(j\text{-}c)}$ = Junction-to-case thermal resistance specified on data sheet (°C/Watt)

$R_{\theta(c\text{-}s)}$ = Lubricated case-to-sink thermal resistance specified on data sheet (°C/Watt)

$R_{\theta(s\text{-}a)}$ = Sink-to-ambient thermal resistance (°C/Watt)

Figure 1.11 Diode Surge and Reverse Recovery Characteristics and Test Circuit





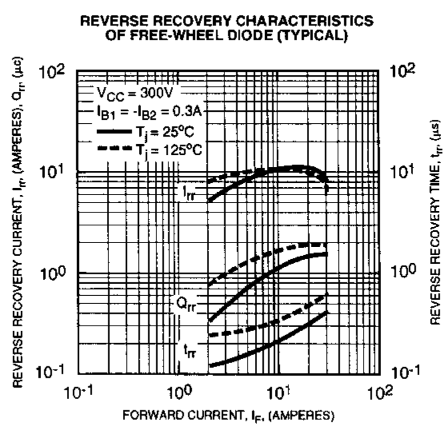
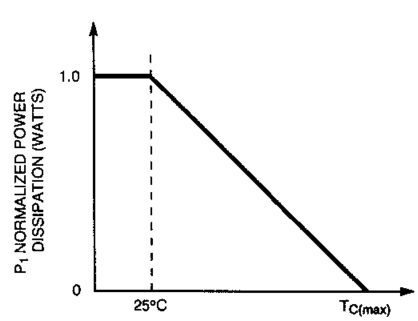


Figure 1.12 Power Dissipation Thermal Derating Curve.



The thermal resistance ($R_{\theta(j\text{-}c)}$) specified for a transistor is always a maximum value, with a safety margin included to allow for production variations from lot to lot. The interface case-to-sink thermal resistance ($R_{\theta(c\text{-}s)}$) can be significant and the data sheet value specified is for a baseplate properly lubricated with thermal compound.

Figure 1.13 provides the thermal resistance models for both single and dual Darlington modules with free-wheeling diodes. Note that $R_{\theta(c\text{-}s)}$ value specified on the device data sheet for a dual Darlington module is applied per half module.

1.7.3 Transient Thermal Impedance

For short or low duty power pulses, using the steady state thermal resistance will give conservative junction temperatures. In addition, using the average value of power dissipation will underestimate the peak junction temperature. The solution is use of the transient thermal impedance curves (Figure 1.14 illustrates typical transient thermal impedance curves). For a power device subjected to single or very low duty cycle, short duration power pulses, the maximum allowable power dissipation during the transient period can be substantially greater than the steady state dissipation capability.

Figure 1.13 Transistor Module Thermal Resistance Models

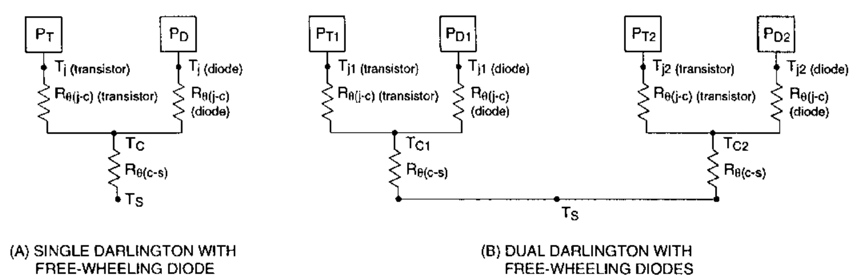


Figure 1.14 Transient Thermal Impedance Curves