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Darlington Transistor Modules Ratings and Characteristics

1.0 Transistor Module Construction

The most basic element of a transistor power module is the silicon chip. Because of the high gain of the Darlington configuration, most Powerex bipolar transistor modules contain Darlington transistor chips. Powerex transistor chips are planar structures, as illustrated in Figure 1.1. The surface of a planar chip can be easily treated, simplifying mass production. Powerex transistor chips employ state-of-the-art fine line emitter patterns, resulting in excellent gain and safe operating area performance. High blocking voltages are achieved by using a triple diffusion process and guard rings.

Figure 1.2 illustrates the internal construction of a transistor module. The transistor chip is soldered to a molybdenum base. The molybdenum base alleviates thermal stress on the chip due to the nearly equivalent thermal expansion coefficients of silicon and molybdenum. This assembly is next soldered to a copper collector electrode along with a free-wheeling diode chip. The copper electrode is in turn soldered to a ceramic substrate. The ceramic substrate can withstand 2000 to 2500 volts without adding significantly to the device's thermal resistance. The chips are bonded with aluminum wires and then encapsulated with silicon gel to guard the chip surfaces. Finally, the package is back filled with epoxy resin to increase mechanical and environmental strength.

Figure 1.1 Darlington Transistor Chip Vertical Structure

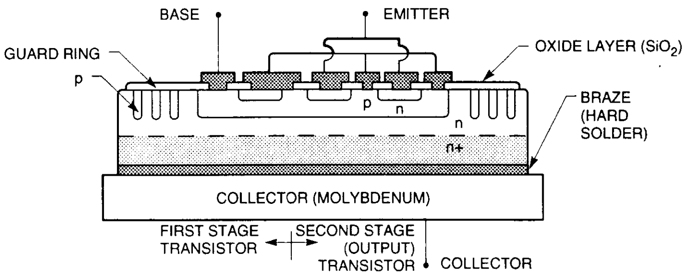


Figure 1.2 Internal Construction of a Power Transistor Module

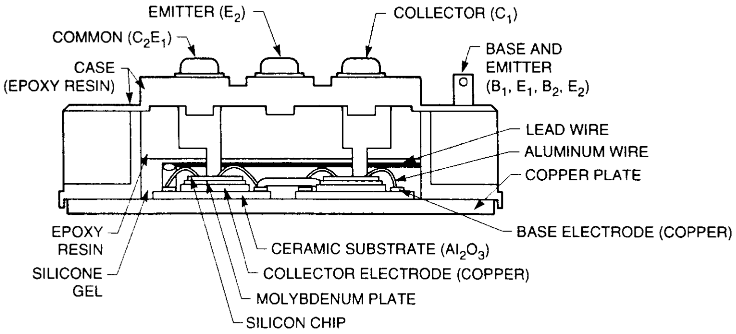
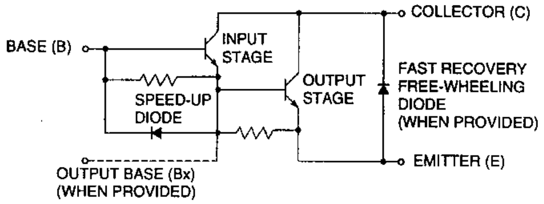
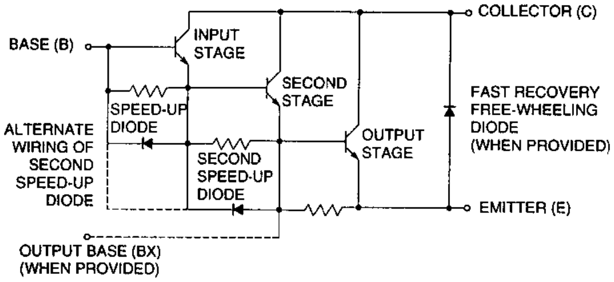


Figure 1.3 Schematic Representation of Darlington Transistor Configurations



(A) DARLINGTON



(B) THEE TRIPLE DARLINGTON

1.1 Darlington Configurations

The basic Darlington configuration is shown schematically in Figure 1.3 (A). The input and output stages, along with their associated base emitter resistors, comprise the transistor chip. Most Powerex modules include discrete fast recovery free-wheeling diodes and speed-up diodes around the input stage as shown in Figure 1.3 (A). Some modules provide a Bx terminal, which is useful when paralleling modules.

At 1000 volts and above, most Powerex modules employ the triple Darlington configuration shown schematically in Figure 1.3 (B). The triple Darlington maintains high gain to allow simple base drive circuits. Both $V_{CE(sat)}$ and $V_{BE(sat)}$ are increased by the triple Darlington configuration. Again, most Powerex modules include discrete fast recovery free-wheeling diodes. Speed-up diodes are provided around both the input and the second stages. The cathode of the second stage speed-up diode may be connected to the input stage emitter, or to the external base connection. Again, some modules provide a Bx terminal.

1.2 The Device Data Sheet

The proper application of power semiconductors requires an understanding of their maximum ratings and electrical characteristics, information which is presented within the device data sheet. Good design practice employs data sheet limits and not information obtained from small sample lots.

A *rating* is a maximum or minimum value that sets a limit on device capability. Operation in excess of a rating can result in irreversible degradation or device failure. Maximum ratings represent extreme capabilities of a device. They are not to be used as design conditions.

A *characteristic* is a measure of device performance under specified operating conditions expressed by minimum, typical, and/or maximum values, or shown graphically.

Table 1.1 illustrates the major ratings and characteristics of a typical Powerex bipolar Darlington transistor module data sheet. Table 1.2 lists the symbols and definitions of the major device parameters.

Darlington Transistor Modules
Ratings and Characteristics

Table 1.1 Typical Bipolar Transistor Data Sheet

Absolute Maximum Ratings, T_j = 25 °C unless otherwise specified

Ratings	Symbol	KS621K30	Units
Junction Temperature	T_j	-40 to 150	°C
Storage Temperature	T_{stg}	-40 to 125	°C
Collector-Emitter Sustaining Voltage, V_{BE} = -2V	$V_{CEV(sus)}$	1000	Volts
Collector-Base Voltage	V_{CBO}	1000	Volts
Emitter-Base Voltage	V_{EBO}	7	Volts
Collector-Emitter Voltage	V_{CEV}	1000	Volts
Continuous Collector Current	I_C	300	Amperes
Diode Forward Current	I_{FM}	300	Amperes
Continuous Base Current	I_B	16	Amperes
Diode Surge Current	I_{FSM}	3000	Amperes
Power Dissipation	P_t	1980	Watts
Max. Mounting Torque M6 Terminal Screws (E, C)	–	26	in.-lb.
Max. Mounting Torque M4 Terminal Screws (B, Bx)	–	12	in.-lb.
Max. Mounting Torque M6 Mounting Screws	–	26	in.-lb.
Modular Weight (Typical)	–	17	oz.
	–	470	Grams
V Isolation	V_{RMS}	2500	Volts

Electrical Characteristics, T_j = 25 °C unless otherwise specified

Characteristics		Symbol	Test Conditions	Min.	Typ.	Max.	Units
Collector Cutoff Current		I_{CEV}	V_{CE} = 1000V, V_{BE} = -2V	–	–	4	mA
			V_{CE} = 1000V, V_{BE} = -2V, T_C = 125°C	–	–	40	mA
Emitter Cutoff Current		I_{EBO}	V_{EB} = 7V	–	–	800	mA
DC Current Gain		h_{FE}	I_C = 300A, V_{CE} = 2.8V	75	–	–	–
			I_C = 300A, V_{CE} = 5.0V	100	–	–	–
Diode Forward Voltage		V_{FM}	I_{FM} = 300A	–	–	1.8	Volts
Collector-Emitter Saturation Voltage		$V_{CE(sat)}$	I_C = 300A, I_B = 6.0A	–	–	2.5	Volts
Base-Emitter Saturation Voltage		$V_{BE(sat)}$	I_C = 300A, I_B = 6.0A	–	–	32.5	Volts
Resistive	Turn-on	t_{on}	V_{CC} = 600V	–	–	3.0	µs
Load	Storage Time	t_s	I_C = 300A	–	–	15	µs
Switch Times	Fall Time	t_f	I_{B1} = 4A, I_{B2} = -6A	–	–	3.0	µs

Thermal and Mechanical Characteristics, T_j = 25 °C unless otherwise specified

Characteristics	Symbol	Test Conditions	Min.	Typ.	Max.	Units
Thermal Resistance, Case-to-Sink	$R_{\theta(c\text{-}s)}$	–	–	–	0.04	°C/W
Thermal Resistance, Junction-to-Case	$R_{\theta(j\text{-}c)}$	Transistor Part	–	–	0.063	°C/W
Thermal Resistance, Junction-to-Case	$R_{\theta(j\text{-}c)}$	Diode Part	–	–	0.3	°C/W

Darlington Transistor Modules
Ratings and Characteristics

Table 1.2 Symbols and Definitions of Major Bipolar Transistor Module Parameters

Symbol	Parameter	Definition/Description
$V_{CEV(sus)}$	Collector-Emitter Sustaining Voltage	With a reverse biased base-emitter, it is the sustained collector-emitter voltage for a specified collector current. (Measurement is made using a clamped inductive load circuit).
V_{CEV}	Collector-Emitter Voltage	With a reverse biased base-emitter, indicates maximum DC voltage between the collector and emitter.
V_{CBO}	Collector-to-Base Voltage	With an open emitter, indicates maximum DC voltage between the collector and base.
V_{EBO}	Emitter-to-Base Voltage	With an open collector, indicates maximum DC voltage between the emitter and base.
I_C	Collector Current	Maximum continuous collector current.
I_B	Base Current	Maximum continuous base current.
P_T	Power Dissipation	Maximum power dissipation at $T_C = 25°C$.
I_{CBO}	Collector Cut Off Current	With an open emitter, indicates the collector current when a specified reverse voltage is applied between the emitter and base.
I_{EBO}	Emitter Cut Off Current	With an open collector, indicates the emitter current when a specified reverse voltage is applied between the emitter and base.
I_{CEV}	Collector Cut Off Current	With a specified reverse voltage between the base and emitter. Indicates collector current when a specified voltage is applied between the collector and emitter.
h_{FE}	DC Forward Current Transfer Ratio	With a specified voltage and current, indicates the ratio between DC output current and DC input current (emitter grounded).
$V_{CE(sat)}$	Collector-Emitter Saturation Voltage	Under specified base and collector current conditions, indicates the DC voltage between the collector and emitter (emitter grounded).
$V_{BE(sat)}$	Base-Emitter Saturation Voltage	Under specified base and collector current condition, indicates the DC voltage between the base and emitter.
t_{on}	Turn-on Time	Indicates the time between the point that the rising edge of a pulse input has risen to 10% of its peak amplitude, and the rising edge of the output pulse has risen to 90% of its peak amplitude.
t_s	Storage Time	Indicates the time between the point where the falling edge of a pulse input has fallen to 90% of its peak amplitude, and the falling edge of the output pulse has fallen to 90% of its peak amplitude.
t_f	Fall Time	Indicates the time taken by a pulse output to fall from 90% to 10% of its peak amplitude.
I_{FSM}	Diode Surge Current	Maximum sinusoidal 60Hz single cycle diode surge current.
I_F	Diode Forward Current	Maximum continuous diode current.
V_{FM}	Diode Forward Voltage	Under specified diode forward current condition, indicates the DC voltage across diode anode-cathode.
V_{RMS}	V Isolation	Maximum AC RMS voltage withstand capability from isolated base plate to all terminals connected together.
$R_{\theta(j-a)}$	Junction-to-Ambient Thermal Resistance	The steady state thermal resistance between the junction and ambient.
$R_{\theta(j-c)}$	Junction-to-Case Thermal Resistance	The steady state thermal resistance between the junction and surface of the case.
$R_{\theta(c-s)}$	Contact Thermal Resistance	The steady state thermal resistance between the surface of the case and the heatsink mounting surface.
$Z_{\theta(j-a)}$	Junction-to-Ambient Transient Thermal Impedance	The transient thermal impedance between the junction and ambient.
$Z_{\theta(j-c)}$	Junction-to-Case Transient Thermal Impedance	The transient thermal impedance between the junction and the surface of the case.

Table 1.2 Symbols and Definitions of Major Bipolar Transistor Module Parameters (continued)

Symbol	Parameter	Definition/Description
$Z_{\theta(j\text{-}s)}$	Junction-to-Sink Transient Thermal Impedance	The transient thermal impedance between the junction and the heatsink mounting surface.
T_A	Ambient Temperature	When used in the natural cooling or forced air cooling it is the temperature of the surrounding atmosphere of a device which is dependent on geographical location and season, and is not influenced by heat dissipation of the device.
T_S	Sink Temperature	The temperature at a specified point on the device heatsink.
T_C	Case Temperature	The temperature at a specified point on the device case.
T_j	Junction Temperature Rating	The device junction temperature rating. Indicates the maximum and minimum allowable operation temperatures.
T_{stg}	Storage Temperature Rating	The device storage temperature (with no electrical connection). Indicates the maximum and minimum allowable temperatures.
—	Mounting Torque Mounting Screw	The maximum allowable torque specification for mounting a device to a heatsink with the specified mounting screw.
—	Mounting Torque Terminal Screw	The maximum allowable torque specification for tightening the specified electrical terminal screws.

1.3 Voltage Ratings

The specified voltages are defined by the maximum rating voltages that can be applied between collector, emitter and base. The transistor ***maximum voltage ratings should never be exceeded.*** Exceeding the maximum voltage ratings can be detrimental to the transistor, resulting in instant failure or a decrease in the life of the device.

1.3.1 Collector-emitter Breakdown Voltages

It is the collector base junction which supports the applied voltage during the off-state of a transistor. Because of the gain of the transistor, the collector-emitter breakdown characteristics are a function of base-emitter bias as shown in Figure 1.4.
The base open condition, V_{CEO}, is the most limiting. At large currents, after breakdown, the voltage drops to a lower sustaining voltage, $V_{CEO(sus)}$. This voltage determines the lowest value of rated collector emitter voltage.

1.3.2 Emitter-base Breakdown Voltage

The emitter base voltage rating, V_{EBO}, is a rating specified at low values of I_{EB} and with the collector open. The V_{EBO} rating is established to prevent avalanching the emitter base junction of the transistor. Repetitive emitter base avalanche may result in degradation of low current h_{FE}.

1.4 Safe Operating Areas

Safe operating areas define the allowable values of collector current and collector-emitter voltage under which a transistor may be safely operated.

1.4.1 Forward Bias Safe Operating Area (FBSOA)

Forward Bias Safe Operating Area (FBSOA) curve defines the ability of a power transistor to dissipate power when its base is forward biased. Figure 1.5 illustrates an FBSOA curve for a 300 amp, 1000 volt Darlington transistor.

Figure 1.4 Collector-emitter Breakdown Voltage Characteristics

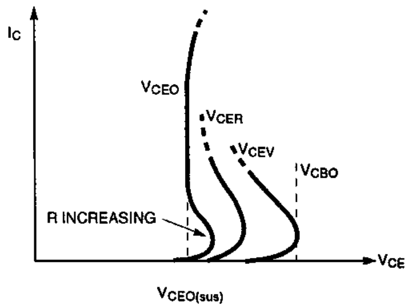
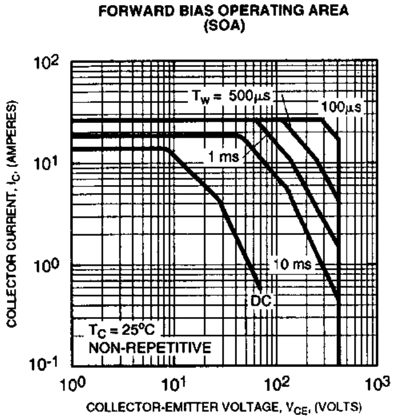


Figure 1.5 Typical Darlington Transistor Forward Bias Safe Operating Area (FBSOA) Curve



The FBSOA curve contains limits for both continuous (DC) and pulsed operating conditions. The upper horizontal line defines the maximum allowable current, regardless of power dissipation, beyond which operation becomes unsafe because of possible damage to bonding wires to the transistor chip and/or to the package. Next, the curve slopes downward in the constant power ($V_{CE} \bullet I_C$) region. This region arises due to the device's thermal limitation defined by the thermal resistance and the maximum junction temperature plotted on a log-log scale, the FBSOA thermal limit is a straight line with a -1 slope.

Power transistors are very sensitive to voltage stress. This is the reason for the second break in the FBSOA curve. The second breakdown ($I_{S/B}$) limit lies below the FBSOA thermal limit and refers to the maximum current allowed prior to occurrence of forward second breakdown. Operation at currents greater than the maximum limit in the $I_{S/B}$ region will cause destruction of the transistor as a result of localized heating. The second breakdown portions of the FBSOA curve is that portion in which allowable power dissipation is decreasing with increased voltage. This is because, as voltage rises current is focused at the edges of the emitter, increasing current density and decreasing the area in which power dissipation occurs.

The limit at the right hand side of the FBSOA curve is $V_{CEO(sus)}$. Operation above $V_{CEO(sus)}$ with forward base current will result in instantaneous destruction of the transistor.

1.4.2 Forward Bias Safe Operating Area Derating

Powerex Darlington Transistor modules are designed for switching applications. They are usually not used in linear applications. In circuits which subject a transistor to both voltage and current simultaneously, leading to high power dissipation, the FBSOA curve must be closely examined. Proper use of the FBSOA curve requires adherence to both thermal and second breakdown limits.

The 25°C FBSOA curves must be derated for actual operating conditions. The derating curves indicate how much to derate the current at a constant voltage in the dissipation limited and forward second breakdown limited portions of the FBSOA curves. The curves do not derate the specified value of $I_{C(max)}$.

The procedure for derating FBSOA is:

1. Determine the maximum allowable power by reading current off the FBSOA curve at the given voltage.
2. Determine the Second Breakdown Derating factor from the Derating curve to derate maximum power at given temperature. Use this derating factor on the maximum power determined in Step 1 to determine the derated maximum allowable power.
3. Determine the derated maximum allowable current by dividing the given voltage into derated maximum allowable power found in Step 2.
4. Check to make sure the thermal limit is not exceeded.

Figure 1.6 illustrates an FBSOA Derating Curve and includes examples of its use.

1.4.3 Reverse Bias Safe Operating Area (RBSOA)

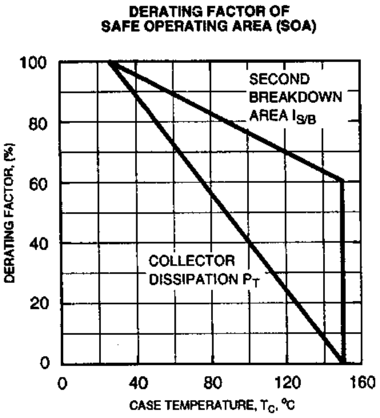
Reverse Bias Safe Operating Area (RBSOA) indicates the ability of a transistor to handle voltage and current stress with its base emitter reverse biased. The RBSOA curve provides the boundary for allowable turn-off load lines. RBSOA is measured in an inductive switching circuit using a collector emitter voltage clamp as shown in Figure 1.7.

Figure 1.8 illustrates a typical RBSOA curve. The curve 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

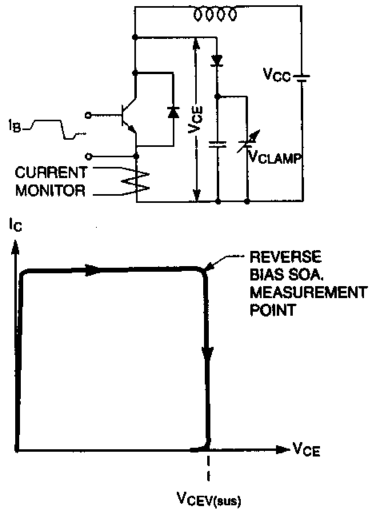


Figure 1.8 Typical Reverse Bias Safe Operating area (SOA) Curve