MSK
M.S.KENNEDY CORP.

30 AMP
600 VOLT IGBT PLUS DIODE HALF BRIDGE POWER HYBRID

4100

8170 Thompson Road Cicero, N.Y. 13039
(315) 699-9201

MIL-STD-1772 CERTIFIED

FEATURES:

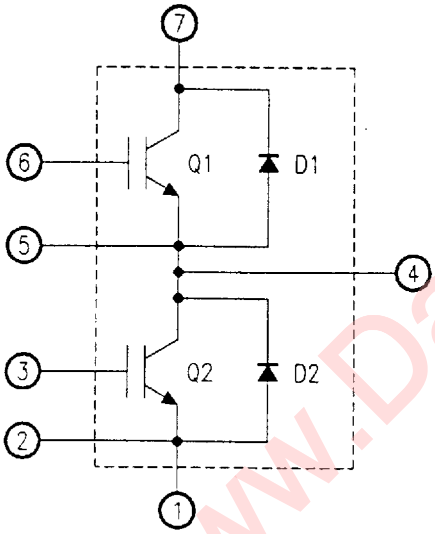
- 600V, 30 Amp Capability
- Ultra Low Thermal Resistance - Junction to Case - 0.5°C/W
- Integral Free Wheeling Fast Recovery Epitaxial Diode (FRED)
- High Power Dissipation Capability - 100 Watts at T_{CASE} = 125°C
- Emitter Kelvin Sense Connections Allow Easy Gate Drive
- Isolated Case Allows Direct Heat Sinking
- Case Bolt-Down Design Allows Superior Heat Dissipation

PRELIMINARY

DESCRIPTION:

The MSK 4100 is a High Power IGBT-Plus-Diode Half Bridge Hybrid. By using the fastest switching IGBT's and fast recovery epitaxial diodes (FRED's) for free-wheeling diodes, an ultra-low switching loss half bridge is now available to use with state-of-the-art motor drive applications. Lower switching losses combined with high thermal conductivity construction techniques make more power available for system needs.

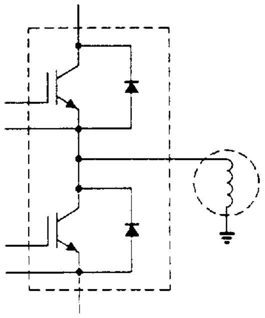
EQUIVALENT SCHEMATIC

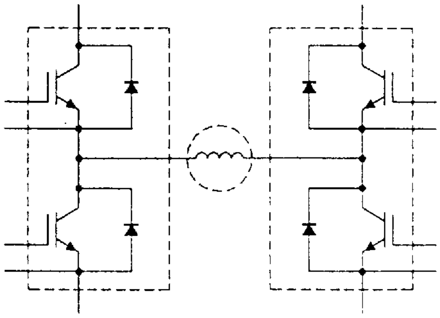


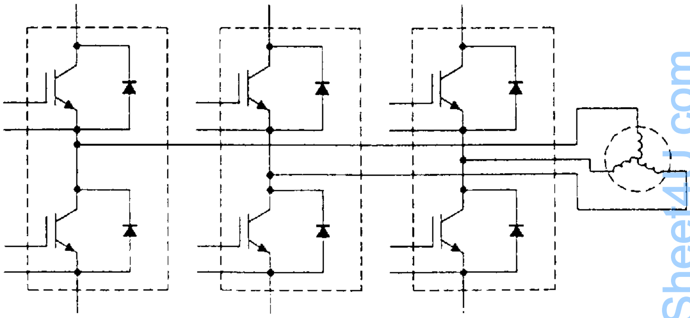
PIN-OUT INFORMATION

1	Emitter Q2
2	Emitter Sense Q2
3	Gate Q2
4	Emitter/Collector Output
5	Emitter Sense Q1
6	Gate Q1
7	Collector Q1

TYPICAL APPLICATIONS


PWM DC
Motor Drive


Single Phase AC
Motor Drive


3 Phase DC
Business Motor Drive

ABSOLUTE MAXIMUM RATINGS

V_{CES}	Collector-Emitter Voltage	600V
V_{GE}	Gate-Emitter Voltage	±20V
I_{C1}	Continuous Collector Current	30A
I_{C2}	Continuous Collector Current @ $T_C=125°C$	20A
I_{CM}	Pulsed Collector Current	70A
I_{LM}	Clamped Inductive Load Current @ $T_C=125°C$	40A
P_D	Power Dissipation @ $T_C=125°C$ (each transistor)	50W

T_L	Lead Temperature for Soldering (10 Seconds)	300°C
T_C	Case Operating Temperature Range (MSK 4100B) (MSK 4100)	 -55°C to +125°C -25°C to +85°C
T_{STG}	Storage Temperature Range	-65°C to +150°C
T_J	Junction Temperature Operating Maximun	+150°C
θ_{JC}	Thermal Resistance, Junction to Case	0.5°C/W

ELECTRICAL SPECIFICATIONS

Parameter	Test Conditions	Group A Subgroup ⑤	MSK 4100B ④ Min.	MSK 4100B ④ Typ.	MSK 4100B ④ Max.	MSK 4100 ③ Min.	MSK 4100 ③ Typ.	MSK 4100 ③ Max.	Units
STATIC									
Collector-Emitter Breakdown Voltage	$V_{GE}=0V$ $I_C=1.0mA$	1	600	-	-	600	-	-	V
		2	600	-	-	-	-	-	
		3	540	-	-	-	-	-	
Gate Threshold Voltage	$V_{CE}=V_{GE}$ $I_C=1.0mA$	1	2.5	-	5.0	2.5	-	5.0	V
		2	2.4	-	5.0	-	-	-	
		3	2.5	-	5.0	-	-	-	
Collector-Emitter On Voltage ②	$V_{GE}=15V$ $I_C=20A$	1	-	1.5	1.65	-	-	1.65	V
		2	-	-	1.65	-	-	-	
		3	-	-	2.25	-	-	-	
Collector Cut-Off Current	$V_{CE}=600V$ $V_{GE}=0V$	1	-	-	1.0	-	-	1.0	mA
		2	-	-	1.0	-	-	-	mA
		3	-	-	1.0	-	-	-	mA
Gate-Emitter Leakage Current	$V_{GE}=\pm 20V$ $V_{CE}=0V$	1	-	-	±100	-	-	±100	nA
		2,3	-	-	±100	-	-	-	nA
G-E Threshold Volt. Temp. Coefficient ②		-	-	-5.8	-	-	-	-	mV/°C
Forward Transconductance ②	$V_{CE}=10V$ $I_C=20A$	-	-	9	-	-	-	-	S
Max. Instantaneous Forward Voltage	$I_F=15A$	1	-	-	1.6	-	-	1.6	V
		2		-	1.3	-	-	-	V
		3	-	-	1.6	-	-	-	V
DYNAMIC CHARACTERISTICS									
Input Capacitance ①②	$V_{GE}=0V$ $V_{CE}=10V$ $F=1MHz$	-	-	1160	1390	-	1160	1390	pF
Output Capacitance ①②		-	-	260	360	-	260	360	pF
Reverse Transfer Capacitance ①②		-	-	90	130	-	90	130	pF
Total Gate Charge ①②	$V_{GE}=10V$ $V_{CC}=300V$ $I_C=20A$	-	-	45	65	-	45	65	nC
Gate-Emitter Charge ①②		-	-	6	9	-	6	9	nC
Gate-Collector (Miller) Charge ①②		-	-	30	45	-	30	45	nC
Turn-On Delay Time ②	(Resistive) $R_G=2\Omega$ $V_{GE}=15V$ $V_{CC}=300V$ $I_C=20A$	-	-	15	-	-	15	-	nS
Rise Time ②		-	-	45	-	-	45	-	nS
Turn-Off Delay Time ②		-	-	330	-	-	330	-	nS
Fall Time ②		-	-	350	-	-	350	-	nS
Turn-On Delay Time ②	Inductive Switching $V_{CLAMP}=300V$ $V_{GE}=15V$ $R_G=2\Omega$ $I_C=20A$ $T_J=125°C$	-	-	15	-	-	15	-	nS
Rise Time ①②		-	-	15	-	-	15	-	nS
Turn-Off Delay Time ②		-	-	180	-	-	180	-	nS
Fall Time ①②		-	-	350	-	-	350	-	nS
Turn-On Switching Energy ②		-	-	0.2	-	-	0.2	-	mJ
Turn-Off Switching Energy ②		-	-	2.0	-	-	2.0	-	mJ
Total Switching Losses ①②		-	-	2.2	2.9	-	2.2	2.9	mJ
Turn-On Delay Time ②	Inductive Switching $V_{CLAMP}=300V$ $V_{GE}=15V$ $R_G=2\Omega$ $I_C=20A$ $T_J=25°C$	-	-	15	-	-	15	-	nS
Rise Time ②		4	-	15	40	-	15	40	nS
Turn-Off Delay Time ②		-	-	75	-	-	75	-	nS
Fall Time ②		4	-	175	300	-	175	300	nS
Total Switching Losses ②		4		1.1	1.5		1.1	1.5	mJ
Reverse Recovery Time ①②	$I_F=15A$ $di/dt=300A/\mu S$ $V_R=300V$	-	-	90	120	-	90	120	nS
Forward Recovery Time ②		-	-	100	-	-	100	-	nS
Reverse Recovery Current ①②		-	-	20	25	-	20	25	A
Recovery Charge ①②		-	-	910	1000	-	910	1000	nC

NOTES:

① Devices shall be capable of meeting the parameter, but need not be tested.
② Typical parameters are for reference only.
③ Industrial grade devices shall be tested to subgroups 1 and 4 unless otherwise requested.
④ Military grade devices ("B" suffix) shall be 100% tested to subgroups 1,2,3 and 4.
⑤ Subgroup 5 and 6 testing available upon request.

Subgroup 1,4 $T_A=T_C=+25°C$
Subgroup 2,5 $T_A=T_C=+125°C$
Subgroup 3,6 $T_A=T_C=-55°C$

IGBT GATE DRIVE REQUIREMENTS

Conventional bipolar transistors are current driven devices. Current is applied to the base to cause current to flow from collector to emitter. MOS-gated devices, including IGBT's, are essentially voltage driven devices, meaning that applying a positive voltage from gate to emitter will cause current to flow from collector to emitter. Theoretically, there is no current flow into the gate, but in reality there is a small leakage current (IGSS specification on the data sheet). This leakage occurs through the gate oxide dielectric. The gate mainly appears as a large capacitor.

Driving the gate of an IGBT on and off is more complex than just driving a simple large capacitive load. Gate-emitter capacitance combine at the gate to form a non-linear relationship based in part on the dynamic gate to collector voltage during switching. This relationship is the "Miller effect". A meaningful number to be used for the gate drive requirement is total gate charge.

Total gate charge is the actual charge in nano-coulombs required to drive the gate to a certain voltage under a set of operating conditions. See Figure 1. All static and dynamic influences that affect actual gate driving conditions are taken into account with this number. By injecting a constant current into the gate and measuring the time to reach a voltage level at the gate during switching, the total gate charge number is derived. A formula for calculating average current for a specific switching frequency is shown in Figure 2.

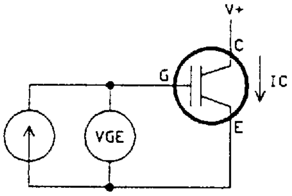


Figure 1A

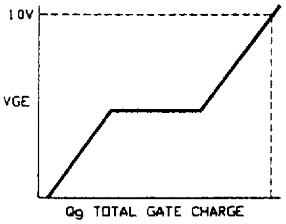


Figure 1B

I_G (AVE) = Q_GTOTAL x F_{PWM} Where
I_G = Average Total Gate Current
Q_GTOTAL = Total Gate Charge
F_{PWM} = Pulse Width Modulating Frequency

Figure 2

GATE DRIVE CIRCUITS

Usually applications require switching the IGBT such that the IGBT doesn't self destruct during worst case operation, or that it doesn't send large switching transients all throughout the system. Data sheet values for switching parameters are obtained under strict control to obtain absolute best performance figures. These figures have to be compromised in most systems to meet overall goals.

Controlling the gate drive impedance will affect the switching speed of the IGBT. See Figure 3. By varying R_G, switching speeds can be controlled. The circuit shown in Figure 4 shows how both turn-on and turn-off can be controlled independently. One effect of IGBT switching that cannot be controlled is the "turn-off tail" due to the recombination of minority carriers in the bipolar portion of the IGBT structure (see Figure 5). This is more important as switching frequencies are increased, as this becomes the major contributor to overall power loss during switching.

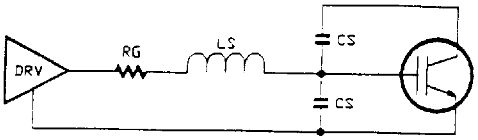


Figure 3A

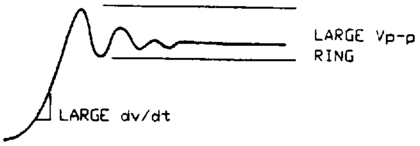


Figure 3B

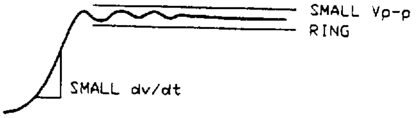
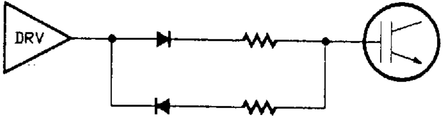


Figure 3C



INDEPENDENT GATE ON/OFF SPEED CONTROL

Figure 4

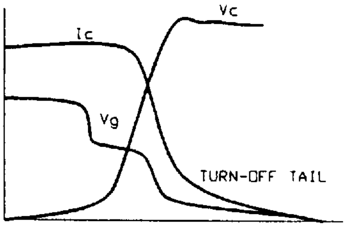


Figure 5

SWITCHING LOSSES

Initially, IGBTs were compared solely by their switching speeds. This has since proven to be less meaningful than switching energy. Switching energy is the average power dissipated in a unit of time multiplied by the time interval. This energy is expressed in millijoules and is a measure of actual lost energy by the IGBT during turn-on or turn-off. By multiplying the voltage waveform times the current waveform, instantaneous power at each point is plotted. The area under the plotted curve is calculated and the resulting number is the switching energy. See Figure 6. Turn-on switching energy can be controlled easily by the driving circuitry, whereas the turn-off switching energy mostly is a function of the turn-off tail (there is a small portion of the turn-off that can be controlled by the circuit). By combining these losses with the conduction losses during the on-time, complete power dissipation of the IGBT can be obtained. See figure 7 for formulas.

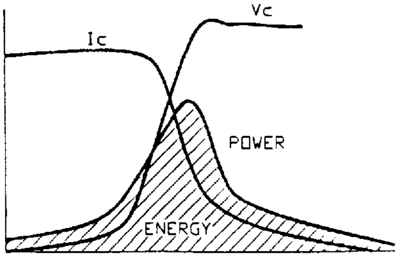


Figure 6

$P_{CL} = I_C \times V_{CE(ON)} \times$ Duty Cycle
$P_{SL} = (E_{ON} + E_{OFF}) \times F$
$P_{TOTAL} = P_{CL} + P_{SL}$
P_{CL} = Power Due to Conduction Loss
P_{SL} = Power Due to Switching Loss
I_C = Average Collector Current
$V_{CE(ON)}$ = Collector-Emitter on Voltage
F = Operating Frequency

Figure 7

DIODE REVERSE RECOVERY

Unlike a MOSFET, an IGBT does not have an intrinsic diode. This offers two advantages. First, for demanding applications, the internal diode in a MOSFET needs to be disabled to allow a better diode to be used (see Figure 8). Secondly, characteristics of the IGBT don't have to be compromised to get good intrinsic diode parameters.

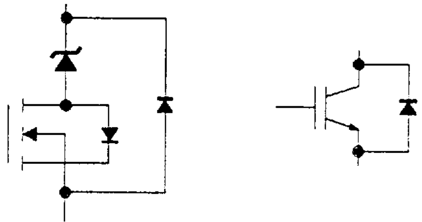


Figure 8

For circuits with inductive loads, diodes are necessary to provide a current path for the decaying magnetic fields. When a half-bridge is driving an inductive load, suddenly the characteristics of the diode become very important. As seen in Figure 9, when Q1 turns on, current flows from the supply through the inductor, building up a magnetic field. Q1 turning off stops the flow of current, causing the inductor's magnetic field to collapse. Because current cannot change instantaneously in an inductor, the current will want to continue to flow in the same direction. In order for this to happen, the voltage on the inductor will reverse instantaneously causing the current to flow back through D2 to the supply.

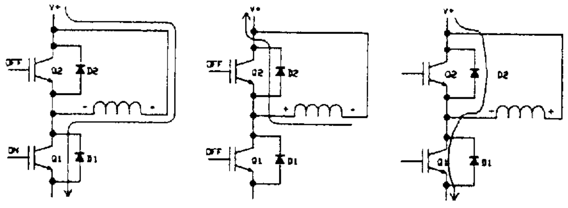


Figure 9

Current will continue to flow in this direction until the magnetic field is collapsed, no longer being able to maintain a proper voltage to keep the current flowing. Normally, as the current continues to flow through the diode, the transistor Q1 will be told to turn on again. The voltage across the conductor will once again be reversed, shutting off the diode current. If the diode continues to conduct current in the reverse direction, the transistor Q1 will be momentarily shorted to the supply. This action of the diode is called reverse recovery; how quickly can the diode shut down when the voltage is reversed (see Figure 10). This is caused by the abundance of minority carriers in the diode being recombined. Once all the minority carriers have been swept out of the junction and recombined, the current will stop. MOSFETs usually have a very long reverse recovery time, making their usefulness limited at high switching frequencies. IGBTs don't have that limitation because they have no diode. The Fast Recovery Epitaxial Diode, or FRED, has very attractive reverse recovery characteristics.

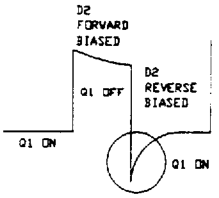


Figure 10A

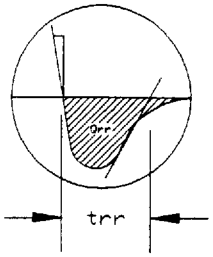


Figure 10B

Many diodes have been optimized to try to minimize recovery time. While the recovery times have been shortened, they exhibit what is now known as snappy recovery, causing transients to be shot through the system, and stressing the transistor (see Figure 11). Intrinsic diodes in MOSFETs have a slow reverse recovery time and ultrafast diodes have snappy recovery. The FRED diode has a very fast, soft recovery characteristic, making them very desirable in today's fast, high frequency switching world. Using this diode allows more power to be delivered to the system, and less power to be dissipated in the transistor. Also, less filtering and snubbing of the transients have to occur, making a very clean switching system.

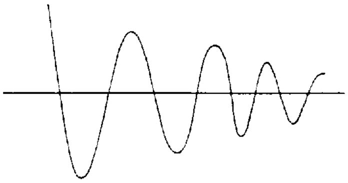


Figure 11A
Snappy Recovery Ultrafast Diode

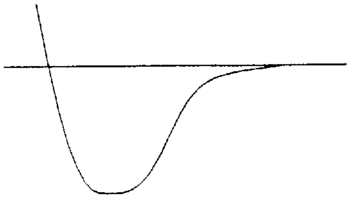


Figure 11B
Soft Recovery Fast Recovery Epitaxial Diode

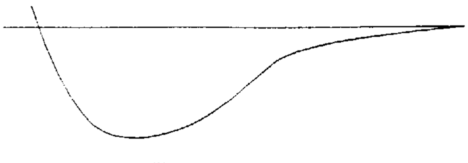
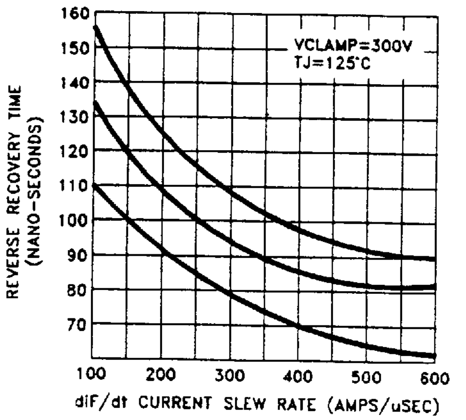


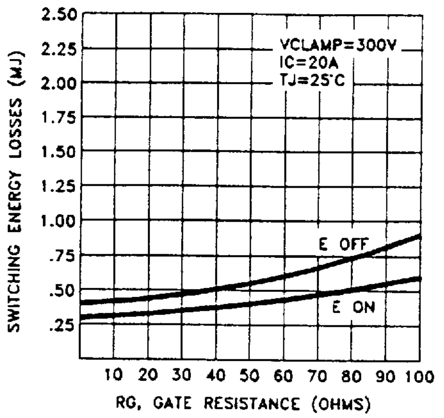
Figure 11C
Slow Recovery MOSFET Intrinsic Diode

TYPICAL PERFORMANCE CURVES

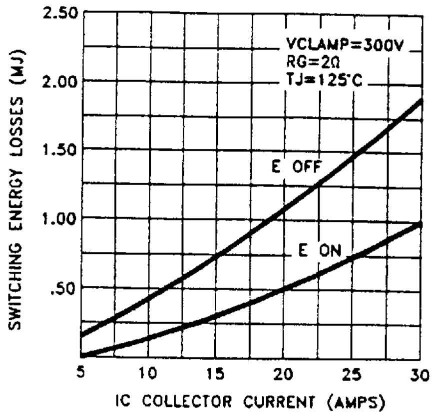
REVERSE RECOVERY TIME vs CURRENT SLEW RATE



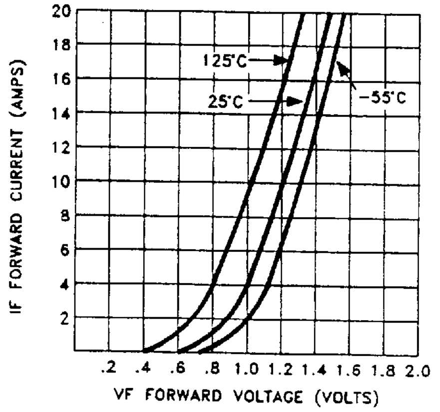
SWITCHING ENERGY LOSSES vs GATE RESISTANCE



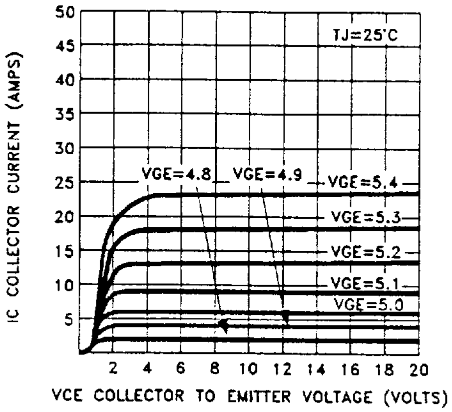
SWITCHING ENERGY LOSSES vs COLLECTOR CURRENT



FORWARD VOLTAGE vs FORWARD CURRENT



ON REGION CHARACTERISTICS



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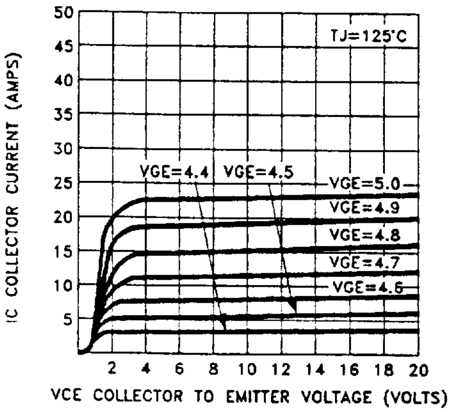
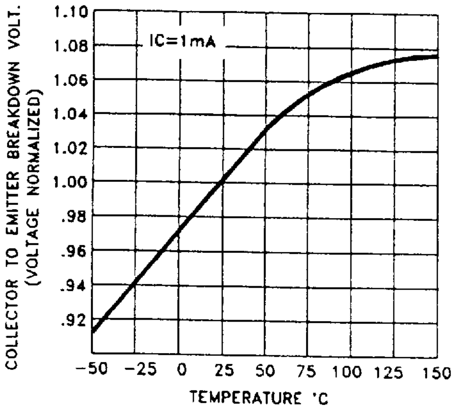
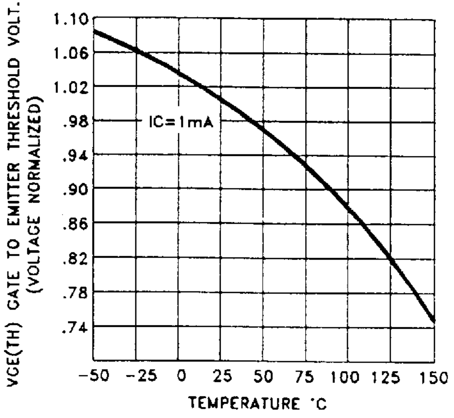


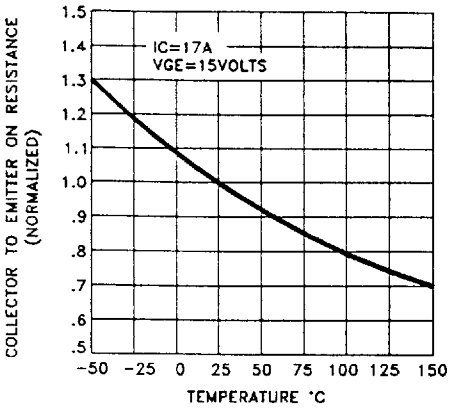
COLLECTOR TO EMITTER BREAKDOWN VOLT. vs TEMP.



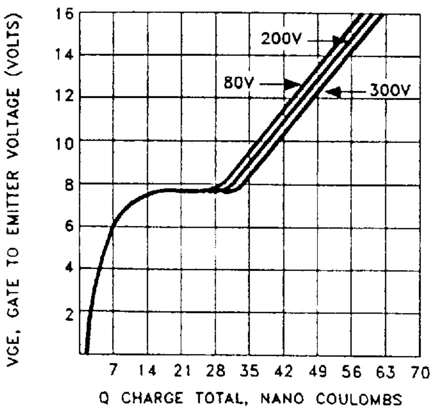
TRANSFER CHARACTERISTICS



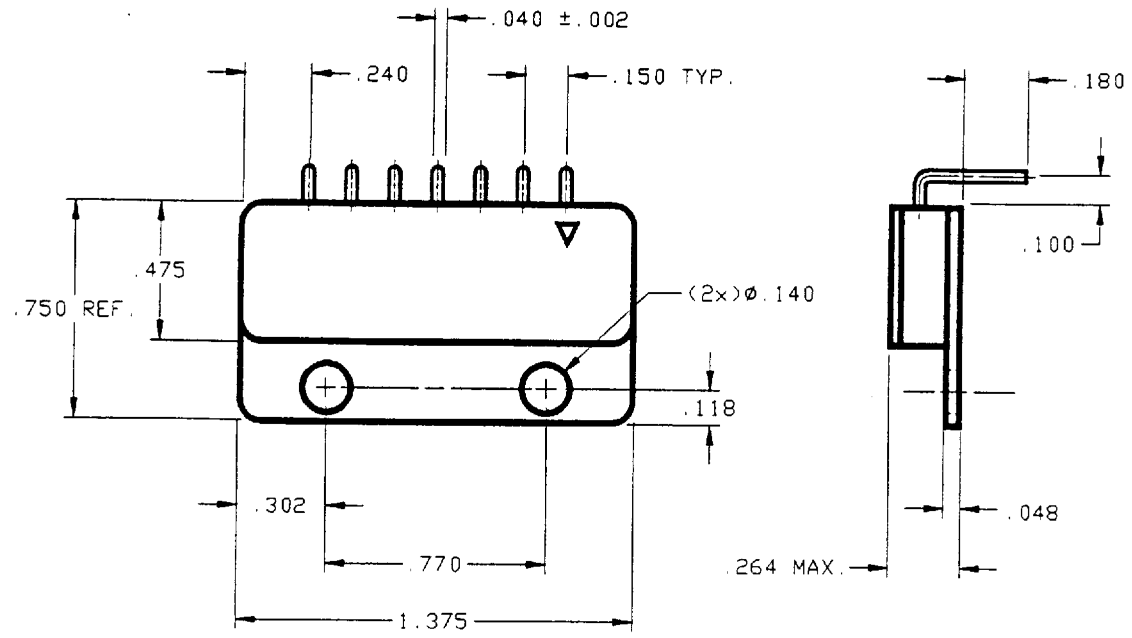
ON RESISTANCE vs TEMPERATURE



GATE CHARGE vs GATE-EMITTER VOLTAGE



MECHANICAL SPECIFICATIONS



NOTE: ESD Triangle indicates Pin 1.

ALL DIMENSIONS ARE ±.005 INCHES UNLESS OTHERWISE LABELED

ORDERING INFORMATION

Part Number	Screening Level
MSK4100	Industrial
MSK4100B	Military-Mil-H-38534

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