MSK 50 AMP, 600 VOLT IGBT PLUS DIODE HALF BRIDGE POWER HYBRID 4101

M.S. KENNEDY CORP.

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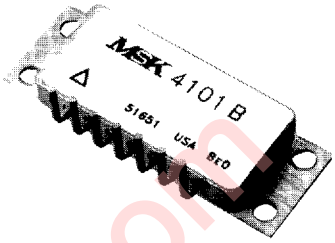
FEATURES:

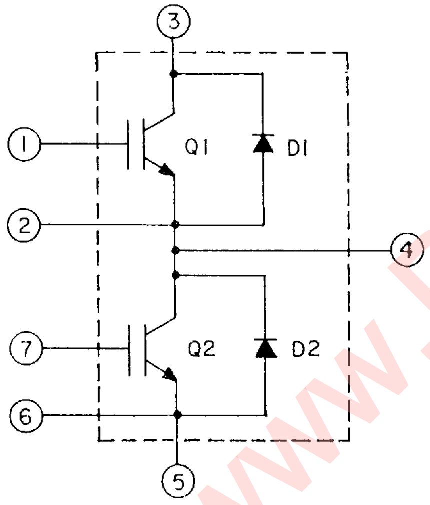
- 600V, 50 Amp Capability
- Ultra Low Thermal Resistance – Junction to Case – 0.21°C/W
- Integral Free Wheeling Fast Recovery Epitaxial Diode (FRED)
- High Power Dissipation Capability – 238 Watts at T_{CASE} = 125°C
- Emitter Kelvin Sense Connections Allow Easy Gate Drive
- Isolated Case Allows Direct Heat Sinking
- Case Bolt-Down Design Allows Superior Heat Dissipation



DESCRIPTION:

The MSK 4101 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.

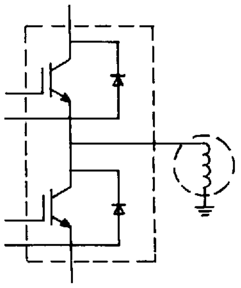
EQUIVALENT SCHEMATIC



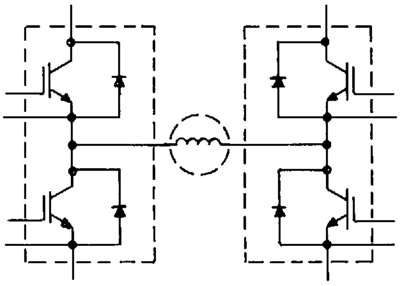
PIN-OUT INFORMATION

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

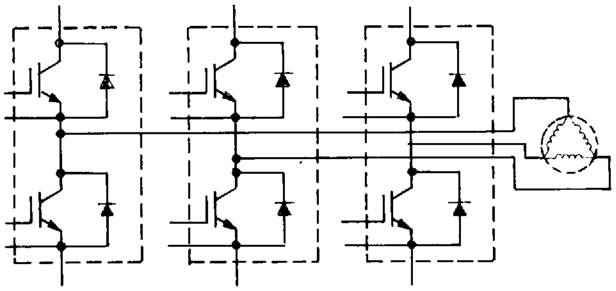
TYPICAL APPLICATIONS



PWM DC
Motor Drive



Single Phase AC
Motor Drive



3 Phase DC
Brushless Motor Drive

ABSOLUTE MAXIMUM RATINGS

V_{CES}	Collector-Emitter Voltage	600V
V_{GE}	Gate-Emitter Voltage	±20V
I_{C1}	Continuous Collector Current	50A
I_{C2}	Continuous Collector Current @ T_C=125°C	29A
I_{CM}	Pulsed Collector Current	100A
I_{LM}	Clamped Inductive Load Current @ T_C=125°C	58A
P_D	Power Dissipation @ T_C = 125°C (each transistor)	119W
T_L	Lead Temperature for Soldering (10 Seconds)	300°C
T_C	Case Operating Temperature Range (MSK 4101B) (MSK 4101)	 -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 Maximum	+150°C
θ_{JC}	Thermal Resistance, Junction to Case	0.21°C/W

ELECTRICAL SPECIFICATIONS

Parameter	Test Conditions	Group A Subgroup	MSK 4101B Min.	MSK 4101B Typ.	MSK 4101B Max.	MSK 4101 Min.	MSK 4101 Typ.	MSK 4101 Max.	Units
STATIC									
Collector-Emitter Breakdown Voltage	V_{GE} = 0V I_C = 4.5mA	1	600	–	–	600	–	–	V
	V_{GE} = 0V I_C = 5.0mA	2	600	–	–	–	–	–	
	V_{GE} = 0V I_C = 4.5mA	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 = 29A	1	–	3.0	3.4	–	–	3.4	V
		2, 3	–	–	3.4	–	–	–	
Collector Cut-Off Current	V_{CE} = 600V V_{GE} = 0V	1	–	–	4.5	–	–	250	mA
	V_{CE} = 600V V_{GE} = 0V	2	–	–	5.0	–	–	–	mA
	V_{CE} = 540V V_{GE} = 0V	3	–	–	4.5	–	–	–	mA
Gate-Emitter Leakage Current	V_{GE} = ±20V V_{CE} = 0V	1	–	–	±100	–	–	±100	nA
		2, 3	–	–	±100	–	–	–	
G-E Threshold Volt. Temp. Coefficient ②		–	–	-5.8	–	–	-5.8	–	mV/°C
Forward Transconductance ②	V_{CE} = 10V I_C = 29A	–	–	9	–	–	9	–	S
Max. Instantaneous Forward Voltage	I_F = 29A	1	–	–	1.7	–	–	1.7	V
		2	–	–	1.5	–	–	–	V
		3	–	–	1.9	–	–	–	V
DYNAMIC CHARACTERISTICS									
Input Capacitance ①②	V_{GE} = 0V V_{CE} = 25V F = 1MHz	–	–	2100	2550	–	2100	2550	pF
Output Capacitance ①②		–	–	435	600	–	435	600	pF
Reverse Transfer Capacitance ①②		–	–	130	200	–	130	200	pF
Total Gate Charge ①②	V_{GE} = 10V V_{CC} = 300V I_C = 29A	–	–	75	110	–	75	110	nC
Gate-Emitter Charge ①②		–	–	10	15	–	10	15	nC
Gate-Collector (Miller) Charge ①②		–	–	40	60	–	40	60	nC
Turn-On Delay Time ②	(Resistive) R_G = 2Ω V_{GE} = 15V V_{CC} = 300V I_C = 29A	–	–	15	–	–	15	–	nS
Rise Time ②		–	–	45	–	–	45	–	nS
Turn-Off Delay Time ②		–	–	55	–	–	55	–	nS
Fall Time ②		–	–	350	–	–	350	–	nS
Turn-On Delay Time ②	Inductive Switching V_{CLAMP} = 300V V_{GE} = 15V R_G = 2Ω I_C = 29A T_J = 125°C	–	–	15	–	–	150	–	nS
Rise Time ①②		–	–	30	60	–	30	60	nS
Turn-Off Delay Time ②		–	–	200	–	–	200	–	nS
Fall Time ①②		–	–	350	400	–	350	400	nS
Turn-On Switching Energy ②		–	–	0.3	–	–	0.3	–	mJ
Turn-Off Switching Energy ②		–	–	3.1	–	–	3.1	–	mJ
Total Switching Losses ①②		–	–	3.4	3.9	–	3.4	3.9	mJ
Turn-On Delay Time ②	Inductive Switching V_{CLAMP} = 300V V_{GE} = 15V R_G = 2Ω I_C = 29A T_J = 25°C	–	–	10	–	–	10	–	nS
Rise Time ②		4	–	20	40	–	20	40	nS
Turn-Off Delay Time ②		–	–	120	–	–	120	–	nS
Fall Time ②		4	–	220	300	–	220	300	nS
Total Switching Losses ②		4	–	1.7	2.2	–	1.7	2.2	mJ
Reverse Recovery Time ①②	I_F = 30A di/dt = 240A/µS V_R = 350V	–	–	50	65	–	50	65	nS
Forward Recovery Time ②		–	–	155	–	–	165	–	nS
Reverse Recovery Current ①②		–	–	4	10	–	4	10	A
Recovery Charge ①②		–	–	100	325	–	100	325	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 IGBTs, 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 capacitances 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.

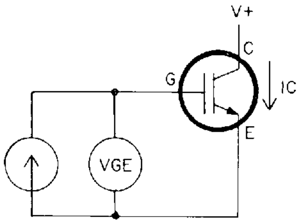


Figure 1A

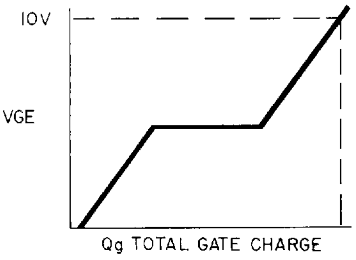


Figure 1B

$I_g\,(AVE) = Q_gTOTAL \times F_{PWM}$ 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 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.

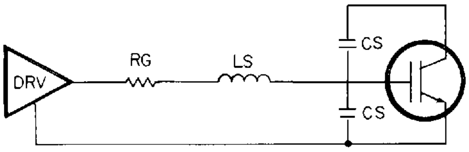


Figure 3A

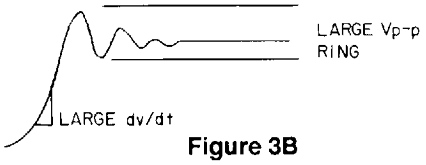


Figure 3B

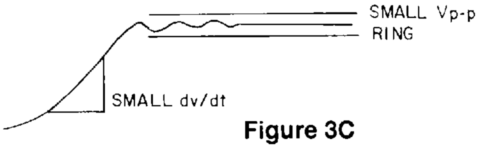
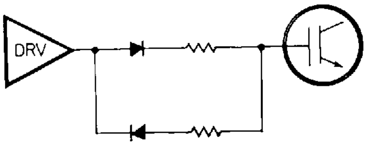


Figure 3C



INDEPENDENT GATE ON/OFF SPEED CONTROL

Figure 4

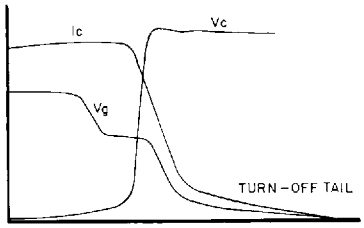


Figure 5

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 by 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.

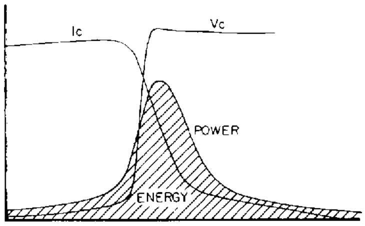


Figure 6

$P_{CL} = I_C \times V_{CE(ON)} \times \text{Duty Cycle}$

$P_{SL} = (E_{ON} + E_{OFF}) \times F$

$P_{TOTAL} = P_{CL} + P_{SL}$

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.

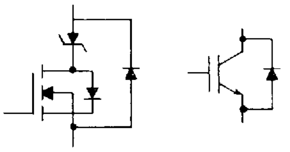


Figure 8

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, the characteristics of the diode suddenly 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.

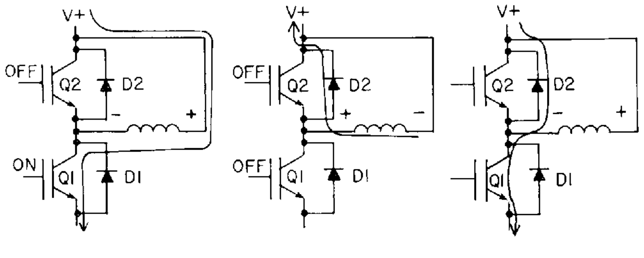


Figure 9

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 inductor 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 lack a diode. The Fast Recovery Epitaxial Diode, or FRED, has very attractive reverse recovery characteristics.

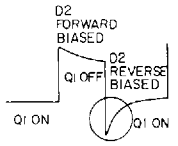


Figure 10A

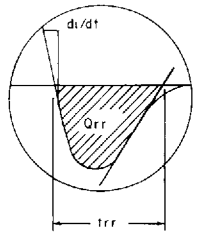


Figure 10B

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 propagated throughout 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 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.

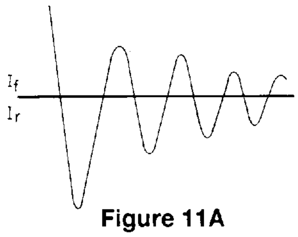


Figure 11A
Snappy Recovery Ultrafast Diode

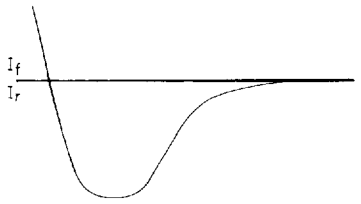


Figure 11B
Soft Recovery Fast Recovery Epitaxial Diode

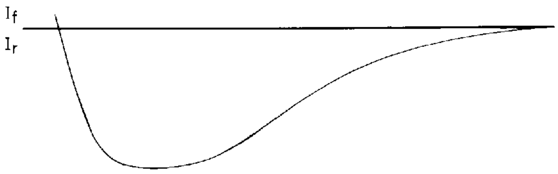
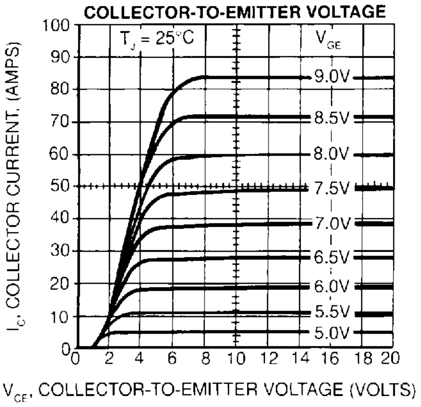


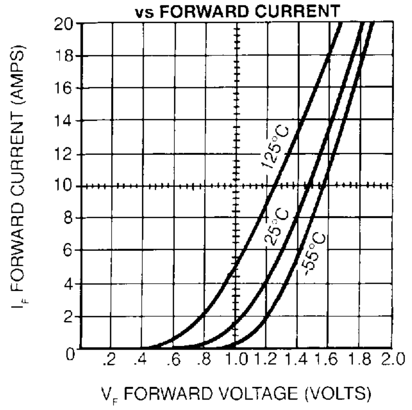
Figure 11C
Slow Recovery MOSFET Intrinsic Diode

TYPICAL PERFORMANCE CURVES

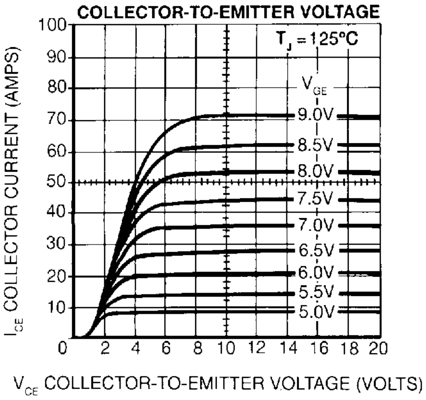
COLLECTOR CURRENT vs COLLECTOR-TO-EMITTER VOLTAGE



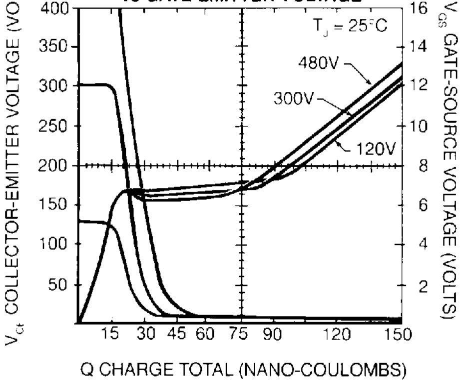
FORWARD VOLTAGE vs FORWARD CURRENT



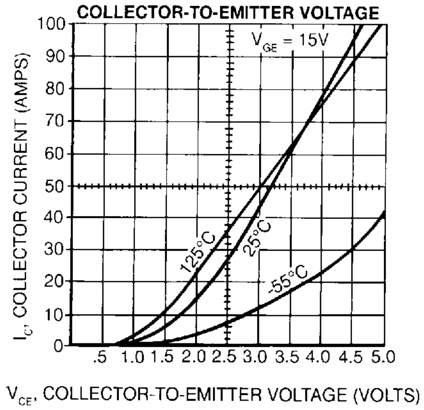
COLLECTOR CURRENT vs COLLECTOR-TO-EMITTER VOLTAGE



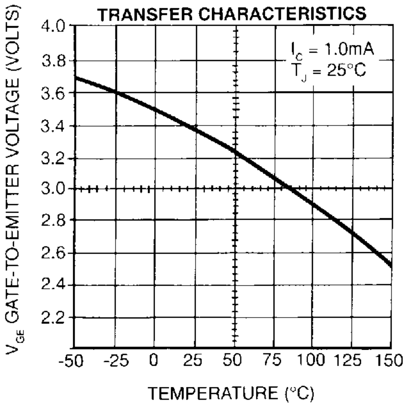
GATE CHARGE vs GATE EMITTER VOLTAGE



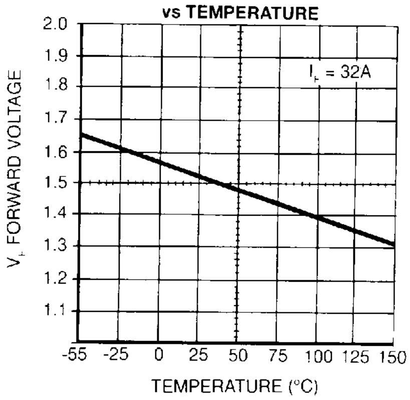
COLLECTOR CURRENT vs COLLECTOR-TO-EMITTER VOLTAGE



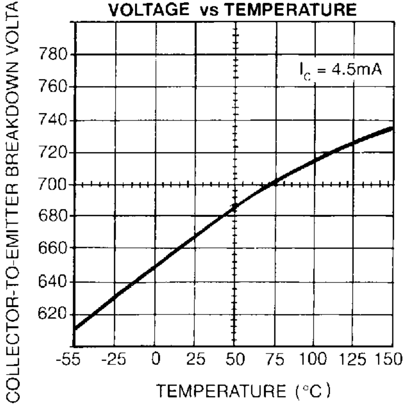
TRANSFER CHARACTERISTICS



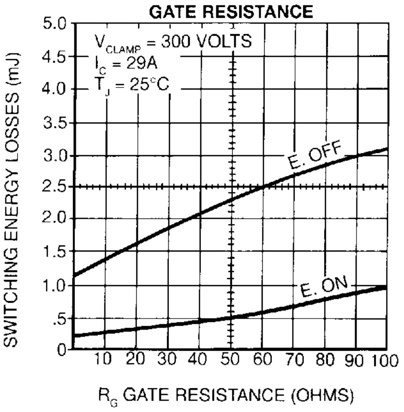
FORWARD VOLTAGE vs TEMPERATURE



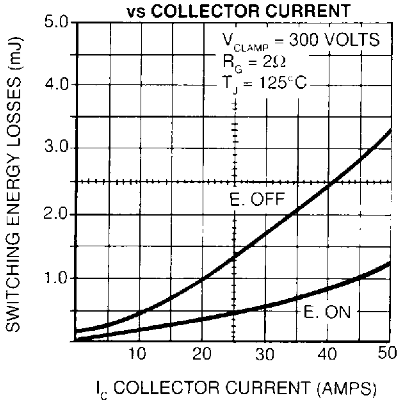
COLLECTOR-TO-EMITTER BREAKDOWN VOLTAGE vs TEMPERATURE



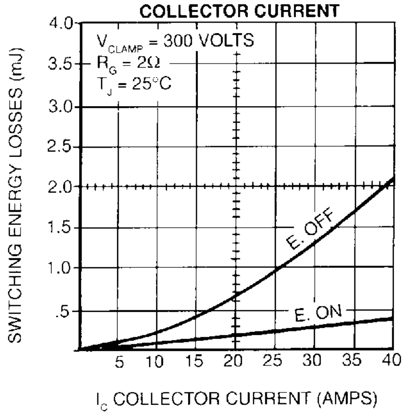
SWITCHING ENERGY LOSSES vs GATE RESISTANCE



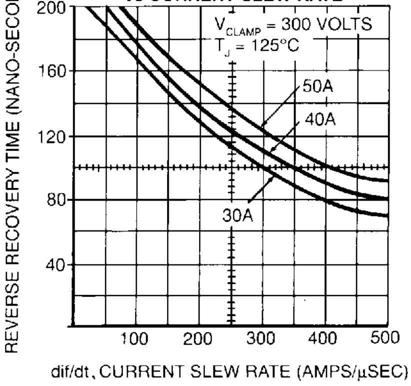
SWITCHING ENERGY LOSSES vs COLLECTOR CURRENT



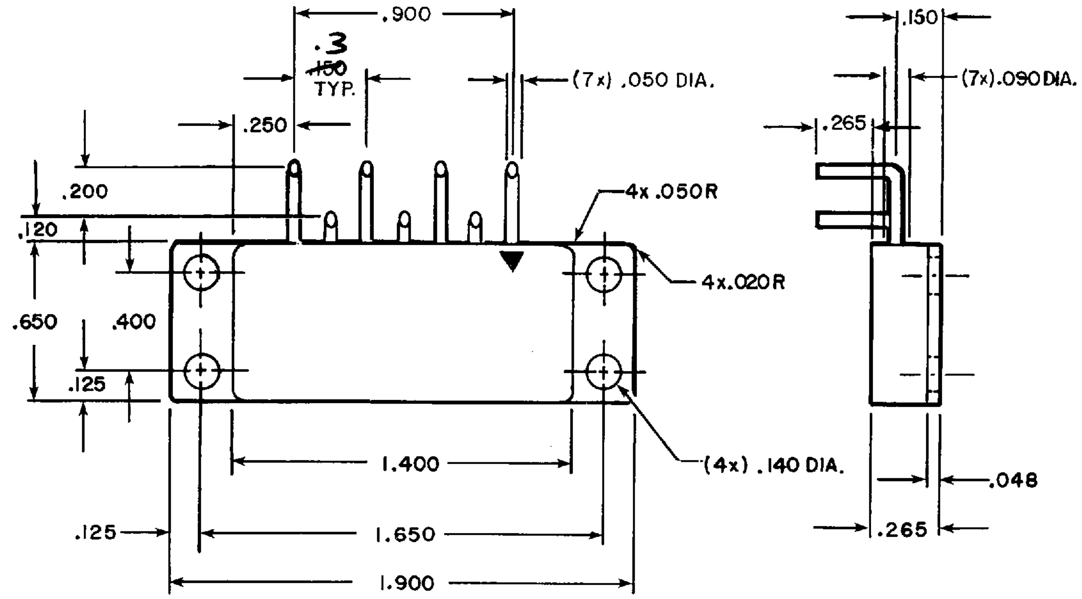
SWITCHING ENERGY LOSSES vs COLLECTOR CURRENT



REVERSE RECOVERY TIME vs CURRENT SLEW RATE



MECHANICAL SPECIFICATIONS



NOTE: ESD triangle identifies Pin 1.

ORDERING INFORMATION

Part Number	Screening Level
MSK 4101	Industrial
MSK 4101B	Military - Mil-H-38534

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