NEW COMPACT IGBT MODULES WITH INTEGRATED CURRENT AND TEMPERATURE SENSORS

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Abstract – A new family of compact IGBT modules has been developed to bridge the gap between fully integrated IPM devices and basic IGBT modules. The idea of this new family was to give the designer the dynamic control offered by conventional IGBT modules while maintaining the reliability provided by integrated current and temperature sensing. The result is a new family of dual (half-bridge) modules with ratings ranging from 200A to 800A at 600V and 1200V.

Introduction

Intelligent power modules (IPMs) containing power semiconductors along with low voltage ICs to provide gate drive and protection functions have been widely accepted for general purpose and high performance industrial motor drive applications ranging from 200W to more than 150kW [5][8]. The success of these modules is the direct result of advantages gained through increased integration. Some of these advantages include the following: (1) Reduced design time and improved reliability offered by the factory tested, built-in gate drive and protection functions, (2) Lower losses resulting from simultaneous optimization of power chips and protection functions, (3) Smaller size resulting from the use of bare power die and control chips, and (4) Improved manufacturability resulting from lower external component count and isolated heat sink mounting surface.

Unfortunately, in spite of these advantages, sometimes IPMs are not suitable for certain applications having unique requirements or operating conditions. The main reason for this is that the designer looses the capability to optimize the gate drive conditions and protection circuit operating points. In these situations, the IPM’s built-in protection and gate drive circuits may either be ineffective or interfere with the desired operation of the system. As a result the designer is forced to use conventional IGBT modules containing only the power semiconductor devices.

With properly designed gate drive and supporting circuits conventional IGBT modules can be reliably implemented in most industrial applications. However, some features of the IPM provide a level of performance that can not be easily duplicated using conventional IGBT
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modules. In particular, the IPM’s use of temperature sensing that is closely coupled to the power devices and IGBT chips with current mirror features enables very effective protection against excessive temperatures and currents. These features are useful in almost all applications as long as the designer is given the ability to decide how the output of these sensors will be used in a given design. This is the basic concept behind the newly developed IGBT modules presented here.

Temperature Sensing

The most basic of the IPM’s features that is needed in virtually all power electronics applications is temperature sensing. In systems using conventional IGBT modules the temperature is typically monitored using a sensor mounted on the heat sink. The fundamental problem with this approach is that from the thermal point of view the temperature sensor is relatively far from the power semiconductor chips. In order to set the over temperature protection trip point accurately the designer needs perfect knowledge of the worst case losses in the device and the effective thermal impedance between the measurement point and the power semiconductor chips. The worst case losses are influenced by the system operating modes and normal device to device variations in a complex way. In addition, the effective thermal impedance will vary depending on the module mounting conditions and the distance between the sensor and each individual semiconductor element. If the design does not take all these potential variations into consideration the power semiconductor chip may overheat and fail before the heatsink sensor indicates a problem. If all the worst case variations are considered when setting the protection trip point the protection will work effectively. However, if the typical losses and effective thermal impedance are considerably lower than the worst case then the device will be

Figure 1: Compact IGBT Large Package
under utilized in most situations. In some cases it may even be necessary to use a larger rated device which will significantly increase system cost.

A better method for handling the temperature measurement is to have the sensor integrated within the module. An integrated sensor eliminates many of the possible variations discussed above so that the device can be protected effectively without the need for large design margins. The new compact IGBT modules presented in this paper implement temperature sensing in two different ways.

The large package Compact IGBT has an integrated NTC thermistor with external access to its terminals. A photograph and equivalent internal circuit diagram for this module is shown in Figure 1. Access to the internal thermistor allows not only accurate over temperature protection but also continuous temperature monitoring that can be used for system control purposes. Figure 2 shows the temperature versus resistance characteristic of the integrated thermistor. The large package compact IGBT also uses an RTC (Real Time Control) circuit for maintaining robust short circuit withstanding capability. The RTC circuit monitors the current through the IGBT module and actively reduces the gate voltage if the current exceeds the device’s safe operating area. The reduced gate voltage limits the short circuit current to provide increased short circuit withstanding time. The operation of the RTC is described in detail in reference [2].

The medium package Compact IGBT also provides an integrated temperature sensor. However, in order to help simplify the external circuit design the sensor’s output is buffered with a comparator circuit to provide an active low fault signal when the baseplate reaches the data sheet specified over temperature trip point. The typical baseplate temperature trip point is set at about 110°C. A photograph and equivalent internal circuit for the medium package Compact IGBT is shown in Figure 3. A typical user supplied interface circuit for the medium package compact IGBT is shown in Figure 4. The internal over temperature fault detection circuit is
powered by connecting the positive gate drive power supply \( (V_{G2^+}) \) to the modules \( V_D \) terminal as shown in Figure 4. When the temperature of the baseplate exceeds the over temperature trip point the FO line pulls low. In the typical interface the active low FO line is used to initiate current flow from the positive gate drive power supply through an opto-isolator and 1.5\( \Omega \) current limiting resistor. The opto-isolator is used to provide an isolated feedback signal for the system controller. The over temperature fault is only implemented on the C2E2 side of the device. The fault output on the C1E1 side of the device will not operate on over temperature conditions. When an over temperature is detected the gate drive is not inhibited in any way. The user must program the system controller to take the appropriate action. The fault signal stays low until the temperature falls back below the trip level.

**Current Sensing**

The medium package Compact IGBT also provides a fault signal if the current through the device exceeds the data sheet specified over current trip level. Like conventional IPM devices the main current through the IGBT is monitored using a special current mirror feature fabricated on the IGBT chip. The current mirror produces a current that is a small fraction of the main emitter current. The current from the current mirror is supplied to a comparator circuit that monitors the current through the device. If the current exceeds the over current trip point the comparator circuit pulls the fault line low. The over current fault signal feature is implemented on both the C1E1 and C2E2 sides of the dual Compact IGBT module and two separate fault output signal pins are provided as shown in Figure 3. Unlike conventional IPM devices the over current condition will not inhibit the gate drive. Normal switching operation will continue unless the user programs the system controller to take the appropriate action. The fault signal is
maintained as long as the current stays above the OC trip level and the IGBT gate is being driven on. If the current falls below the trip level or the gate drive signal is removed the fault signal becomes inactive. The Compact IGBT does not provide a minimum fixed lock-out time like a conventional IPM. Like the large package Compact IGBT the medium package uses an RTC current limiting circuit to maintain robust short circuit performance. In the case of a low impedance short circuit the IGBT is guaranteed to survive for a minimum of 6µs after the fault signal becomes active provided that the DC bus voltage, gate drive voltage, and series gate resistance are within the limits specified in Table 1. The maximum internal propagation delay of the fault signal line is 8µs so the actual short circuit withstanding capability of the IGBT chips is 14µs.

As was noted above both the medium and large package Compact IGBTs utilize a built in RTC circuit to limit the current in the event of a low impedance short circuit. The RTC circuit responds to the output of the current mirror emitter on the IGBT chip. The operating point of the RTC is set low enough to provide increased short circuit withstanding time and high enough so

<table>
<thead>
<tr>
<th>Type Number</th>
<th>P-N Terminal DC Bus Voltage (V)</th>
<th>Gate Voltage $V_{GE}$ (V)</th>
<th>Gate Resistor $R_G$ (Ω)</th>
<th>Starting Junction Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>MG400J2YS61A</td>
<td>$V_Cc \leq 375V$</td>
<td>$13.8V \leq V_{GE} \leq 16V$</td>
<td>$R_G \geq 7.5Ω$</td>
<td>Tj $\leq 125C$</td>
</tr>
<tr>
<td>MG600J2YS61A</td>
<td></td>
<td></td>
<td>$R_G \geq 5.1Ω$</td>
<td></td>
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<tr>
<td>MG200Q2YS60A</td>
<td>$V_Cc \leq 750V$</td>
<td>$14.8V \leq V_{GE} \leq 17V$</td>
<td>$R_G \geq 10Ω$</td>
<td></td>
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<tr>
<td>MG300Q2YS60A</td>
<td></td>
<td></td>
<td>$R_G \geq 6.6Ω$</td>
<td></td>
</tr>
<tr>
<td>MG400Q2YS60A</td>
<td></td>
<td></td>
<td>$R_G \geq 5.1Ω$</td>
<td></td>
</tr>
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</table>
that it will not activate under normal operating conditions. As a result, the actual operation point of the RTC may be higher or lower than desirable for some applications. In these cases, it is advantageous to have access to the current feedback signal from the IGBT chip so that external circuits can be designed to respond appropriately based on the magnitude of the current.

The C² IGBT (Current Control) shown in Figure 5 has been proposed as way to provide user access to the current mirror signal. The current mirror output is a very low level signal so the C² IGBT provides a built-in buffer to amplify the output and improve its noise immunity. A typical application circuit for the C² IGBT is shown in Figure 6. The SEN output terminal is pulled high using a 330Ω resistor to provide a voltage that is inversely proportional to the main current through the IGBT. Figure 7 shows a typical voltage versus collector current characteristic using the circuit shown in Figure 6. Recognizing that the current mirror signal is generally not accurate enough for fine control its level was selected with the intention of using it for over current and short circuit detection. Table 2 shows the proposed line up for the C² IGBT. The first devices to be developed are all in a single switch configuration with a low inductance package that has been optimized for parallel applications. A photograph of the new module package is shown in Figure 5.

**Table 2**

<table>
<thead>
<tr>
<th>Type</th>
<th>Current</th>
<th>Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>MG800J1US52A</td>
<td>800A</td>
<td>600V</td>
</tr>
<tr>
<td>MG600Q1US59A</td>
<td>600A</td>
<td>1200V</td>
</tr>
<tr>
<td>MQ400V1US51A</td>
<td>400A</td>
<td>1700V</td>
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</tbody>
</table>
Conclusion

This paper has presented new compact IGBT modules with integrated temperature and current sensing features. These new modules provide added design flexibility compared to conventional IPMs that have a fixed gate drive design and protection circuit trip points. Compared to conventional IGBT modules the new Compact IGBTs permit the user to develop efficient cost effective protection circuits tailored to the specific requirements of the application.

References