Intelligent Power Management Peripheral for Motor Control

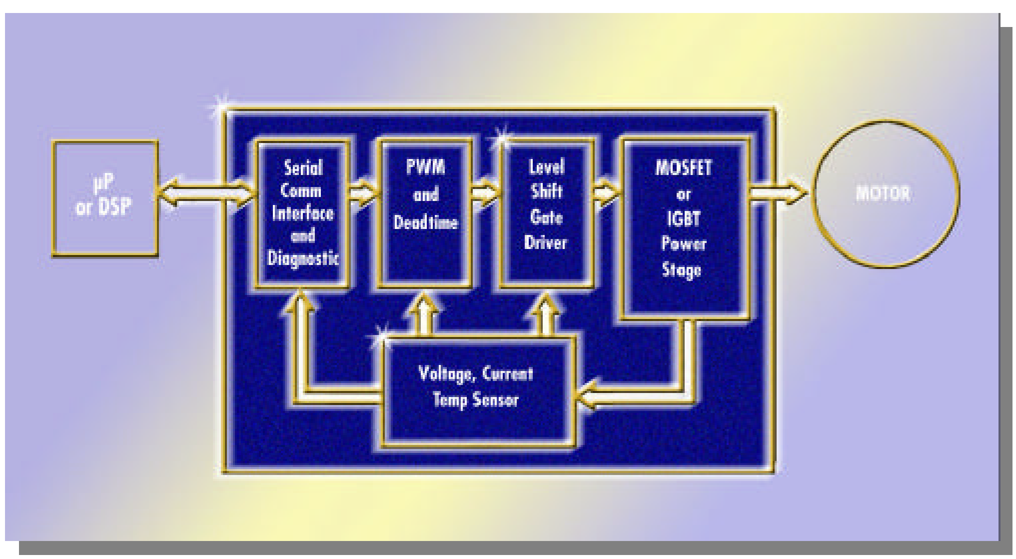
The new International Rectifier* Accelerator™ *sets the architectural standard for motor control system design by partitioning the inverter function as an intelligent power management peripheral to the motion system controller.

The design of modern motor control systems is quite complex and requires a deep understanding of control system algorithms, micro-controller and digital signal processors, sensor signal measurement and analog-to-digital converters, high voltage interface and gate drivers, and the output inverter power stage. Traditional methodologies do not efficiently partition the design tasks into well-defined architectural elements with standardized interface protocols. This results in complex and customized designs, high initial product cost, as well as high lifetime ownership cost.

International Rectifier is introducing *Accelerator* ™ a new architecture for the power management of the motor drive inverter to better define interface protocol elements. This very flexible, versatile and yet performance oriented power management architecture uses a new chipset positioned between the micro- or DSP controller and the motor.

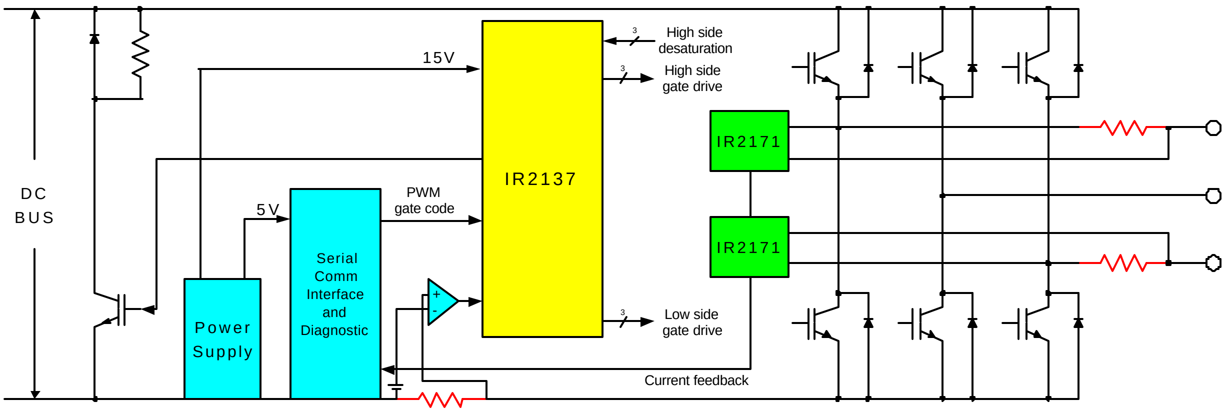
The guiding principles behind this new design are intelligent partitioning, standardized interface protocol and performance enhancement of the power management functions. The most fundamental concept is treating the inverter as an "intelligent power management peripheral" for the micro-controller or DSP. With the new *Accelerator* ™ architecture, control system software can be written at a higher hierarchical level (for example in C language) without the need to program at the bit level for the motor control power management functions such as pulse width modulation (PWM), dead time generation and compensation, diagnostic and protection, voltage and current measurement interface. High voltage analog and power circuits required to turn the software algorithms into commanding power transfer are integrated within the chipset in concert with the other power management functions.

A suite of technologies is used to implement the chipset, including mixed signal 0.5µm CMOS and high voltage integrated circuits (HVIC) with ratings from 600V to 1200V. The intelligent power management peripheral can be applied to a variety of applications such as driving AC or brushless DC motors for industrial AC drives, industrial servo drives, appliance drives (air-conditioner, washing machine, refrigerator compressor), robotics, electronic power steering (12V, 42V), integrated starter alternator (42V), and high reliability drives (aviation, space). Below is simplified block diagram for the *Accelerator*™ intelligent power management peripheral:



Intelligent Power Management Peripheral

Accelerator™ is configured as an intelligent power management peripheral to the micro-controller or DSP. Individual chips in the set are designed to work in an integrated manner. A simplified circuit schematic for the first series in the chipset family is shown below:

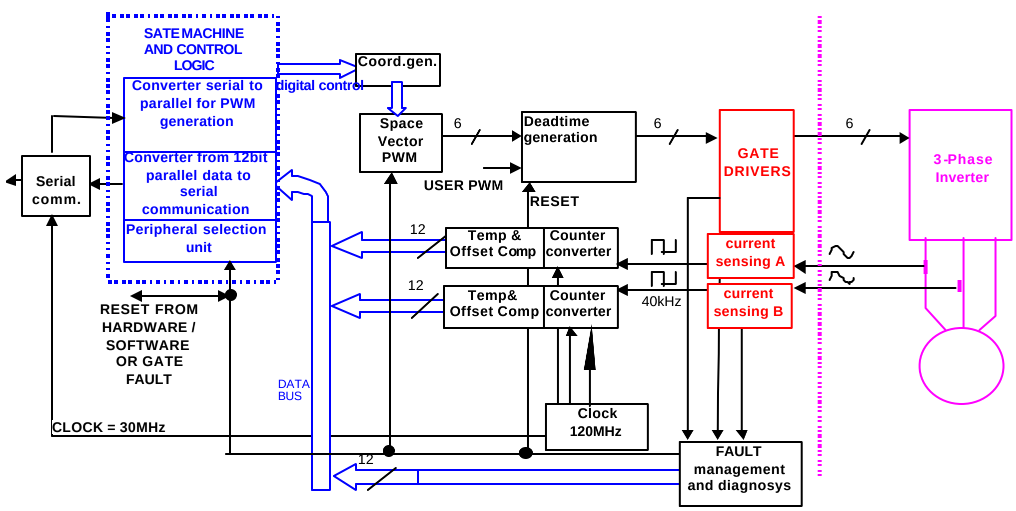


The chipset user can choose between its built-in, optional space vector pulse width modulator (SVPWM) or an external modulation technique. Programming of the modulator can be accomplished through different input coordinates introduced through a serial interface:

- auto-generation based on (V,f) information;
- bi-phase (v_x,v_y);
- two phase of a three-phase system (v_a,v_b);
- polar co-ordinates input.

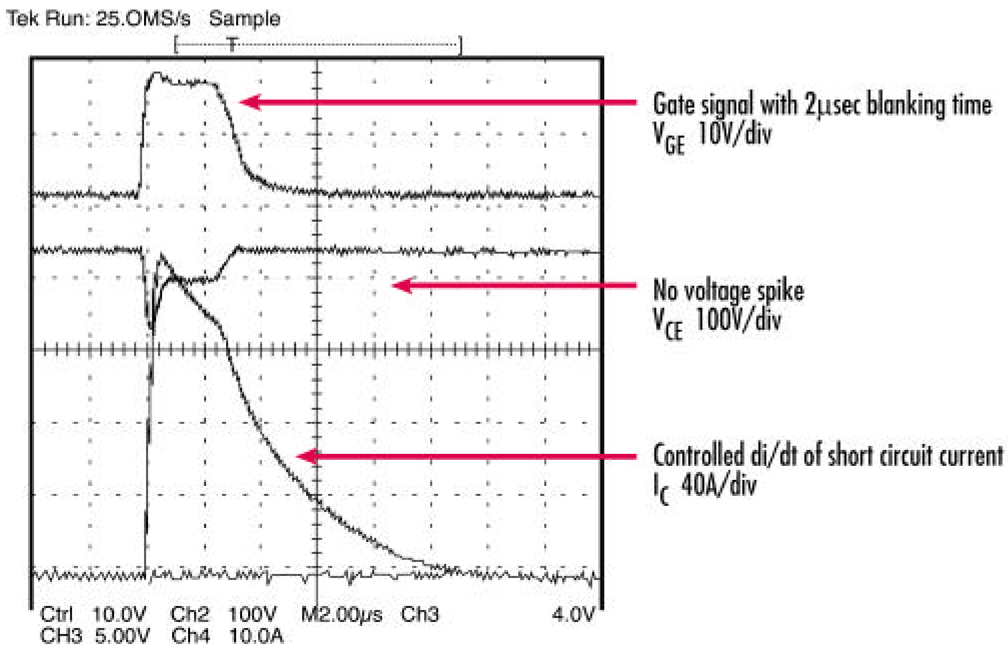
Sampling frequencies, including high frequencies able to replace analog PWM generators, are ranging between 3.6kHz and 29.2kHz. A special arrangement of the main timer maintains the same pulse resolution at all sampling frequencies to allow the same resolution in the digital control system. A special selection of the zero vector is used to reduce switching loss in the inverter power stage when two switching events occur at a same instance. The dead time generator resolution is 16.66ns and the maximum dead time is about 8.4µs. A minimal value of 100ns is introduced to avoid delays in signal propagation when no dead time is programmed.

Programming of the space vector modulator, dead time generator and current sensing interface are made through a dual-port memory. This is periodically read and/or written by the upper hierarchical level through a well-defined serial interface. The overall block diagram is shown below:



High Voltage Gate Drive

The 3-phase inverter power stage usually consists of three high-side and three low-side IGBTs or MOSFETs operating from a high voltage DC bus. The bus voltage varies depending on applications, but can range from 12V for automotive to 600V for 230VAC and 1200V for 460VAC industrial drives. Previous methods use discrete opto-couplers to provide the high voltage gate drives to the IGBTs or MOSFETs. High voltage IC technology enables the integration of a 3-phase gate driver in a single chip such as the industry standard 600V IR213x and 1200V IR223x product families. The first series of the International Rectifier motor control chipsets integrates the 600V IR2137 or 1200V IR2237 in the gate driver function. Added features include IGBT de-saturation protection and synchronized soft shutdown. The robust protection against short circuit conditions, such as line-to-line short, ground fault and shoot through, results in controlled di/dt and no voltage spike across the IGBT during short circuit turn-off as shown:

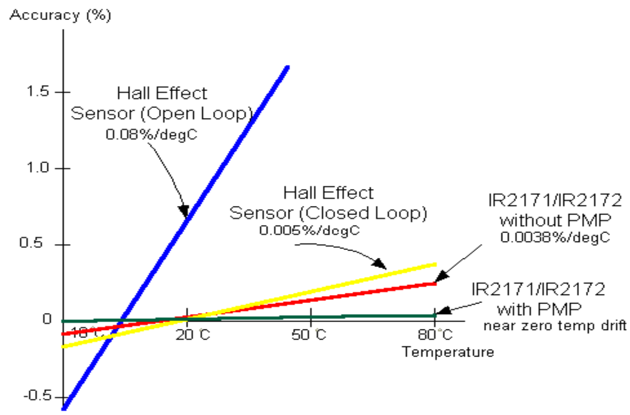


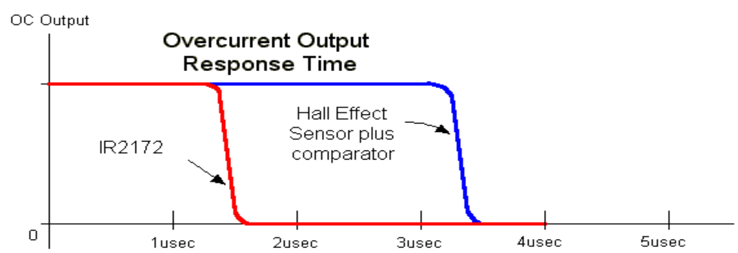
Phase Current Measurement

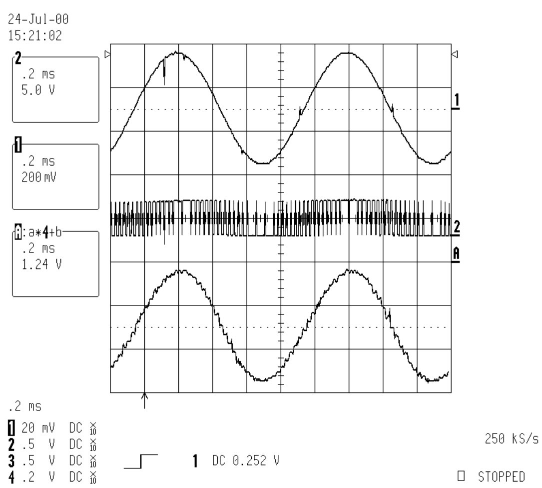
Motor phase current is difficult to measure accurately or with precise linearity over wide current and temperature ranges. Hall effect sensors can be used but are inherently bulky and costly. Alternatively, current sense resistors are used to measure the differential voltage drop across each output phase. An opto-coupler or high voltage IC is then used to translate the differential voltage to a usable level. Linear opto-couplers suffer from linearity drift over temperature range and operating life due to current transfer ratio (CTR) degradation over the years. The International Rectifier motor control chipset uses high voltage ICs such as the 600V IR217x and 1200V IR227x product family. Differential voltage in the range of +/-200mV, that sits on top of fast switching common mode voltage up to 600V or 1200V, is converted to a ground-based PWM output from the IR217x chip. Then the PWM signal is processed using a 12-bit counter having a clock frequency of 120MHz. The function also contains auto-offset cancellation with initial offset calibration capability. A fast 13-bit hardware division block calculates the duty ratio of the incoming PWM signal, withdrawing any temperature dependence of the slope and canceling the temperature drift to enable temperature-independent data acquisition.

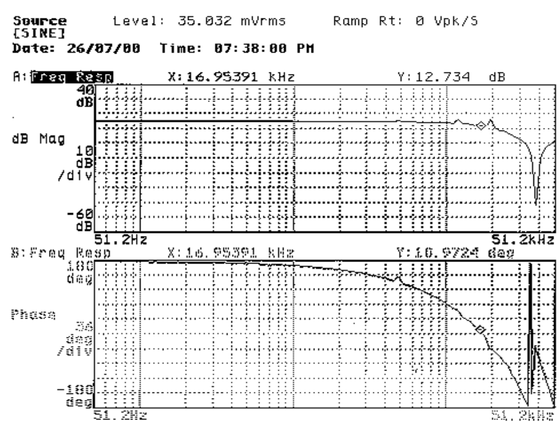
Overall, the motor current sensing interface provides a high speed/resolution measurement system, which cannot be attained by the conventional capture/compare unit found in the motion control DSP or micro-controller. Shown below is a linearity plot of the direct and compensated current measurement outputs from the

IR2171 or IR2172 as compared to open loop and closed loop Hall effect sensors over the temperature range. The 1kHz sinusoidal current waveform is also shown in the top trace while showing the processed waveform (after hardware divide to eliminate temperature drift) in the bottom trace to indicate resulting minimal phase shift (less than 10° phase shift). The middle trace shows the direct output from the IR2171. The Bode plot data is also shown to support the 10° phase shift at 1kHz which implies that any closed current control with the IR2171 can achieve a total bandwidth of 1kHz without any performance degradation.









Versatile Power Diagnostics

The drive system often requires a centralized diagnostics information handling system, particularly established in the factory automation system. This is because the cost of the system down time is prohibitive and fast problem resolution is mandatory to reach the root cause of the problem. Traditionally, the conventional micro-controller, or DSP, only provided scalar information of whether or not the fault condition occurred, without providing any further intelligent information. International Rectifier's new power management system addresses this issue and provides versatile diagnostic capability. In the event of any fault condition in the power circuit (including IGBT line-to-line short condition, IGBT ground fault condition, over-current condition off the IR2172 OC (over-current) pin, and over-temperature of the IGBT module), the system latches the last moment of PWM pattern as a complete switching state and reports back to the host system through the fast serial interface communication. This snapshot of IGBT switching state, along with OC status of the motor current allows motor drive engineers to easily analyze the failure of the event to diagnose the inverter system to reach the root cause of the problem. When used with the IR2172, the drive engineer can also implement the fast current limit control through the OC status bit to improve a trip-free characteristic of the inverter drive system.

International Rectifier Motor Control Roadmap

The concept of the International Rectifier *Accelerator*™ motor control architecture is rooted in the idea of considering the inverter as an intelligent power management peripheral to the micro-controller or DSP control. It is not just a replacement of the motion control peripheral function, but a new definition of power intelligence between switching events. All the detailed power management functions are performed within the chipset and the results are presented in memory locations that are updated periodically in a very transparent way. The upper level control software is greatly simplified by requiring only the look up of the data updates to and from the chipset.

The intelligent power management peripheral roadmap is evolutionary, allowing performance enhancement functions to be added in each new generation of product development while maintaining the standard interface protocol to the system control. The first series in the chipset family includes robust power stage protection, linear current measurement, SVPWM, dead time generation and system monitoring functions.

System performance will be enhanced due to the temperature-compensated current measurement technique such that the torque precision can reach +/-1% vs. the +/-2 to 3% in existing motor drive. Another benefit of the intelligent power management peripheral is its relatively small size, since it uses integrated technologies in mixed-mode CMOS and HVIC. Typical reduction in PCB size can reach up to 55% and component count reduction can reach 25% when comparing the intelligent power management peripheral approach vs. the older and bulkier method using discrete opto-couplers, Hall effect sensors and additional glue circuit components. Thus the mechanical integration of the power management peripheral with the power stage is greatly simplified. The entire chipset and its support components fit easily within the dimensions of an industry standard outline Econo2 package. This allows the other standard interface protocol to be set up between the power management chipset and the power stage. Further developments will couple the new functions in the chipset with additional integration of sensor components inside the power module while having a well defined pin-out standard for the interface protocol.

The second stage of development will focus on the advanced dead time compensation, ripple free motor current sensing, IGBT temperature sensing, trip free overcurrent limit control and histogram based power diagnostics. Performance enhancement includes up to a 10X improvement in usable speed range due to accurate dead time compensation using voltage feedback. The additional intelligence in the power management peripheral feature set will allow applications to be extended to sensorless vector control of industrial drive and precision control of brushless DC servo drive.

Voltage feedback-based dead time compensation itself is not unique, with many attempts recorded in the industry over the years. However, due to the implementation limit, they did not succeed. The traditional approach of sensing the motor phase voltage was based on either optically-isolated coupling devices or a high resistor divider network. However, both methods suffer from inaccurate measurement due to a large time constant and accuracy limit associated with the hybrid component structure of opto-coupling devices. Using HVIC technology will enable the accurate voltage feedback to solve the traditional problem.

The new motor current sensing IC will have a unique feature to alleviate erroneous sampling due to motor ripple current caused by the fast PWM switching. The current sensing IC is able to synchronize the sampling event relative to the motor PWM switching. Therefore the effect of motor current ripple, which varies depending on the motor inductance, will be eliminated to achieve the stable current feedback system to the closed loop motor control.

IGBT module temperature feedback and DC bus voltage feedback will be added to the next generation of the power management peripheral IC to facilitate the torque foldback control and current limit control which achieve the new level of trip free operation.

New power diagnostics will have FIFO memory to store all IGBT switching states of the last ten consecutive PWM switching periods in the event of the drive fault condition (i.e., overcurrent, overtemperature). This will help to more effectively guide the application user to the root cause of the motor drive system fault and shorten the down time of the factory automation floor.

Other applications will also benefit from the development of the Intelligent Power Management Peripheral Roadmap. Appliance drives will become lower cost and easier to design with application specific feature sets for compressors and for direct drive washers. Automotive drives for electric power steering (EPS) and for integrated starter alternators (ISA) will have higher performance in torque and speed performance. High-Reliability drives for space applications will have robust protection and complete diagnostics.