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High Performance AC Drive by Single Chip Motion Control Engine IC

Introduction of new breed of digital motion control IC :IRMCK201 and IRMCK203

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Abstract

The IRMCK201 and IRMCK203 are new integrated circuit devices designed as a one-chip solution for complete closed loop current control and velocity control for high performance AC drive systems. Unlike traditional microcontrollers or DSPs, the IRMCK201 and IRMCK203 do not require any programming effort to complete complex AC servo algorithm development. Combined with International Rectifier's high voltage gate drive and current sensing IC, the user can implement a complete AC servo and Sensorless control with minimum component count and design effort. Although all control algorithm in the IRMCK201 and IRMCK203 are implemented by, Motion Control Engine™ (MCE) dedicated hardware logic, to perform the closed loop control of AC current and velocity, they have a wide range of application coverage through flexible configuration ability Their dedicated hardware approach for time critical motion control computation results in closed loop control performance to attain unparalleled bandwidth. When used with the IRMCK201, the drive can be easily configured as an induction machine closed loop vector control or permanent magnet motor servo drive. Sensorless control of a permanent magnet AC motor can be also simply configured by the IRMCK203 IC. Rich motion peripherals, analog and digital I/O can also be configured in both ICs. Host communication logic contains Asynchronous Communication Interface for RS232C or RS422 or RS485 communication interface, a fast slave SPI interface and an 8 bit universal Parallel Interface. The IC comes with a compact 100pin and 80pin plastic QFP package and enables easy assembly of the user printed circuit board.

Review of today's motion control design process

Designing high performance servo control systems is a complex task. It normally involves multiple talents and disciplines in different technology fields. Therefore, many design engineers are typically involved in the design process which involves a deep understanding of power electronics technology, hardware integration, advanced control algorithm, flexible user interface, network communication, and so on.

Among those design factors are control algorithms, which critically influence the final system performance. Control algorithm includes various elements interface to sensors, which are closely coupled with power electronics circuit and elements. Position, speed, current are essential variables that need to be fed back from appropriate sensors.

Controlling three-phase AC motors requires Field Orientation Control (FOC). The objective of the FOC is to establish linear control of torque by transforming three-phase AC current and voltage.

The FOC senses 3-phase motor current and transforms into two variables, torque current and field current, so that it simplifies torque control. Therefore, closed loop current control actually contains two separate current control loops. One is for torque current and the other is for field current. Each loop is identical and consists of several control elements. Vector rotator, Clark transformation, Proportional plus integral, PWM, and current sensing are these essential control elements in each closed loop current control.

Besides the PWM and current sensing functions, all control elements are traditionally implemented by software code in a motion control DSP or microcontroller. In a real-time control environment with a DSP and a microcontroller, these current control loops are implemented in high priority tasks. It requires intensive knowledge of real-time control to make sequential execution of each control element to complete computation within a specified time frame.

These tasks, often driven by specific hardware events/interrupts, require precise execution timing of software, requiring sequencing of instruction coding to manipulate hardware at specific time in order to control a motor.

In particular, the FOC for servo application and sensorless control is usually written in the assembly language rather than a high level language. This is due to the fact that these applications often demand fast computation and update rate in order to satisfy growing demand for higher dynamic performance. Sometimes special coding technique, (i.e. use of shift instruction to achieve fast multiply/divide function are used to achieve fast computation to overcome classic computation power sluggishness.

Regardless of high level language (i.e. C, C++, etc) or low level assembly language, and regardless of a DSP or a microcontroller, programming requires the specific skill of writing motion action into all sequential computational description consisting of thousand of lines of instructions. Then all of the pieces of source code of software modules (i.e. software is normally modularized) are compiled and linked together Finally, it becomes one big executable object code which contains all functions including closed loop control, user interface sequencing, network communication, etc. If errors or mistakes exist, then they must be discovered and fixed at source code level, and recompiled and linked again to produce the revised version of the executable object code. This process is usually repeated a number of times to reach the final product.

Another trade-off is code maintenance. The code maintenance cost is usually a hidden cost and does not show up at a start of development phase.

Therefore, quick motion control algorithm development while achieving high performance is still a challenging job for high performance servo system and sensorless AC motor drive system development.

Motion Control Engine™ – The heart of IRMCK201 and IRMCK203

International Rectifier recently introduced new digital motion control ICs, namely the IRMCK201 and IRMCK203, aimed at high performance servo application and sensorless control application. Implemented on a cost effective 100-pin QFP package (Figure 1) for IRMCK201 and an 80-pin QFP package for the IRMCK203, these ICs simply require an inexpensive crystal resonator to feed the 33MHz clock. The IRMCK201 is designed to simplify the task of servo drive system design and quickly enable high performance servo drive, while the IRMCK203 is designed to achieve high performance sinusoidal sensorless control of permanent magnet AC motor. Once hardware is realized with the IRMCK201 IC or IRMCK203 IC, motor tuning, for example, becomes readily available without spending the time and effort of programming. All functions are implemented in the hardware. Unlike a traditional motion DSP, the IRMCK201 contains not only motion peripheral functions (i.e. PWM, encoder counter circuit, current sensing interface, etc) but also complete field orientation control algorithm and speed control algorithm in the hardware form – so called Motion Control Engine™ (MCE).

Figure 1 IRMCK201

The MCE consists of control elements (i.e. Proportional plus integral, Vector rotator, Clark transformation, etc) necessary to perform closed loop controls, motion hardware peripherals (i.e. Space Vector PWM, motor current feedback interface, encoder feedback), and flow control logic, which enable parallel multi-loop control. Therefore, no multi-tasking is required. Synchronous execution mechanism of closed loop velocity control and closed loop current control is included in the logic hardware.

Internal Structure – Fixed hardware yet highly flexible and configurable

The IRMCK201 is a digital integrated circuit that implements all necessary functions of the encoder based servo control in hardwired logics. Therefore, the structure is pre-configured as shown in Figure 2, yet it allows different structure of control algorithm. A Vector controlled induction motor is one example. The internal control structure has a feed forward slip gain path to the vector angle generation. Closing the associated switch

No programming and easy diagnostic

The IRMCK201 does not require any programming and/or coding. Therefore, it can be easily converted to a

fixed function and hardwired logic IC, as a stand-alone servo controller, without requiring any PC interfaces at all. The configuration process to adapt a new motor and tuning is very simple. It provides host registers that can be read or written by either a PC or a mating microprocessor through RS232C serial interface or SPI serial interface or parallel interface. Writing specific

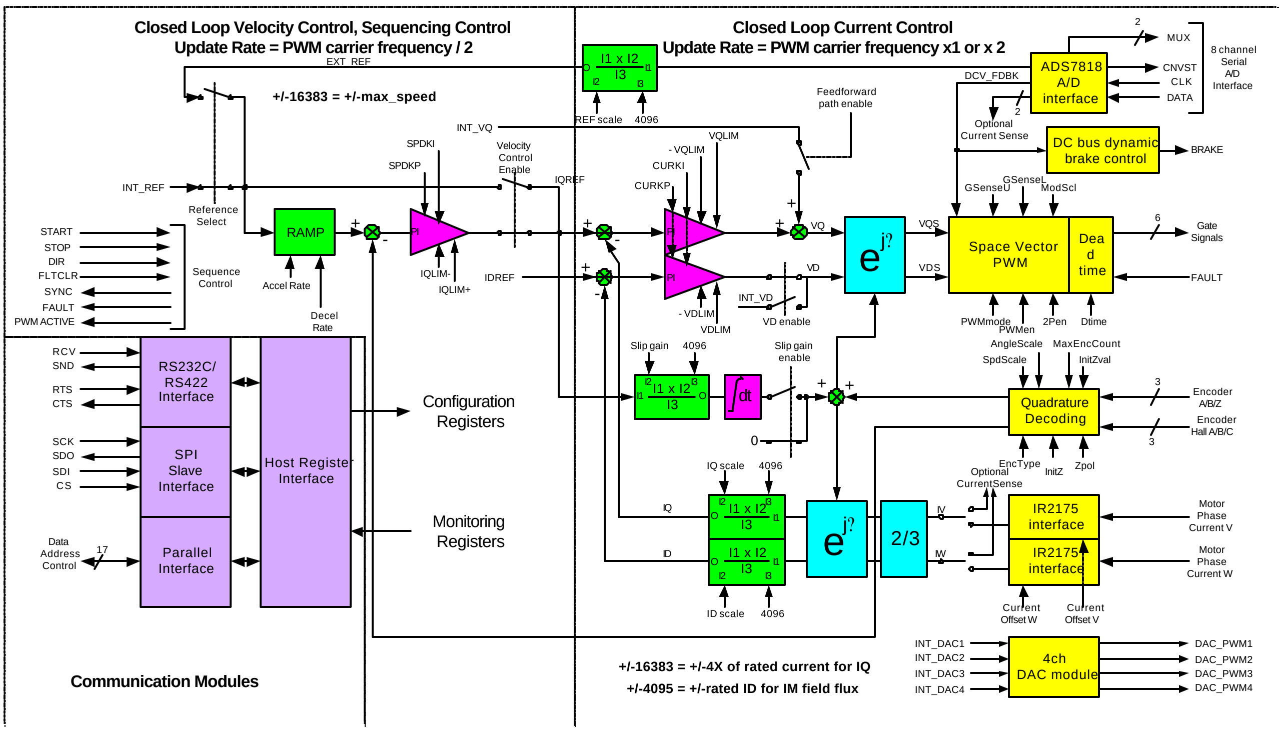

Figure 2 Detailed Block Diagram of IRMCK201

on the path can enable this control configuration. Therefore, enabling and disabling induction motor control can be done by simply closing or opening the switch, more precisely by writing a “1” or “0” value to the associated write register by the PC. The IRMCK201 supports other structural changes such as interfacing with a different type of current sensors rather than IR2175 current sensing IC, enabling/disabling feed forward gain path in the current control, enabling/disabling velocity closed loop control, and selecting source of velocity command.

values into the associate registers configures a servo drive very quickly with the desired performance and functions. For example, if a 10kHz PWM switching frequency for inverter power electronic is chosen, then the user simply writes a corresponding value to the associated register. The user does not have to write codes to implement PWM algorithm. Once the drive is configured through writing host registers, no additional step is required. (No software compilation and assembly of the final object code).

Fast computation and unparalleled dynamic performance

One significant advantage of Motion Control Engine is a very short computation time to complete closed loop control algorithm with deterministic timing. Fast computation directly influences the dynamic performance of torque and speed of a servo system. The faster the update rate of closed loop current control is, the higher the bandwidth of torque control. This will in turn affect system turn around time or cycle time of the machine. For example, a surface mount component insertion machine requires fast pick-and-place time to shorten the total cycle time to complete component assembly.

A digital servo drive, although very flexible, has not yet come close to analog servo drive when it deals with high bandwidth performance, especially high bandwidth torque control. This has mainly been due to DSP and microcontroller throughput limit stemmed from sequential computation mechanism of executing tons of instructions one-by-one.

The IRMCK201 equipped with the Motion Control Engine removes this barrier. The IRMCK201 can run at even 40kHz PWM update rate or greater frequency update rate that is similar to an analog servo drive counterpart.

Figure 3 shows step response of torque control loop. Two traces are torque current reference ("Iq reference" in the blue color trace) and torque current feedback ("Iq feedback" in the red color trace). The data was taken at a stalled rotor with 40kHz PWM frequency and 40kHz current control loop update configuration. The reference amplitude is 50% of the rated motor current. As shown, it only takes approximately 350 microseconds for torque current to reach the reference.

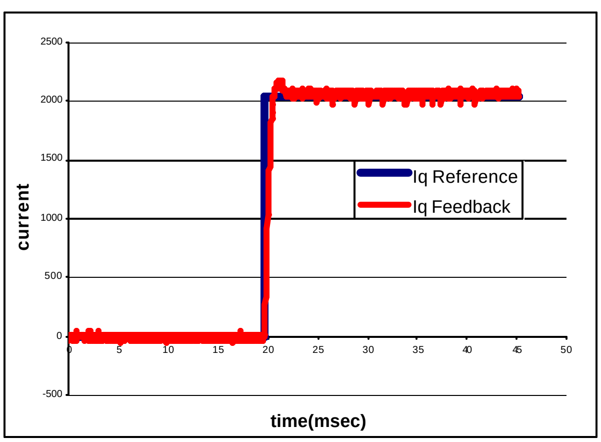

Figure 3 Step Response of Torque control loop

When used with the IRMCK203, the computation time of sensorless closed loop current control can be significantly shortened. This will benefit application, which requires sinusoidal sensorless control such as compressor motor drive of home air conditioner system. A 32-bit high performance RISC microprocessor, for example, is used in the latest home-use air conditioner system [1]. With this microprocessor, computation power reaches 50MIPS, however, it still takes sixty microseconds to calculate the sensorless control algorithm. Since air conditioner application requires not only a single motor control by sensorless algorithm but also additional sensorless motor control for cooling fan and control for PFC (Power Factor Control) function, the total sum of computation time still needs to be shortened to satisfy power hungry needs for microprocessor. Accordingly memory usage is also increased since instruction set is based on 32 bit. According to application referenced in [1], it requires 128kB of instruction memory.

When used with the IRMCK203, computation time will be reduced to 11 microseconds instead of 60 microseconds. This will create more room for faster update rate with higher PWM carrier frequency. Ultra high-speed application using permanent magnet motor will benefit from the IRMCK203 simply by adjusting PWM carrier frequency running at even 40kHz or higher. High-speed spindle and dental drill application are examples of using such a high carrier frequency PWM with IRMCK203.

Low loss and low EMI Space Vector PWM reduce heatsink size and EMI filter

The IRMCK203 employs a low loss and low EMI Space Vector PWM method for switching output to the IGBT power devices. When compared to traditional 3-phase PWM, it reduces approximately 20% or more in power loss and EMI noise. Typical voltage switching waveform and motor current waveform are shown in Figure 4.

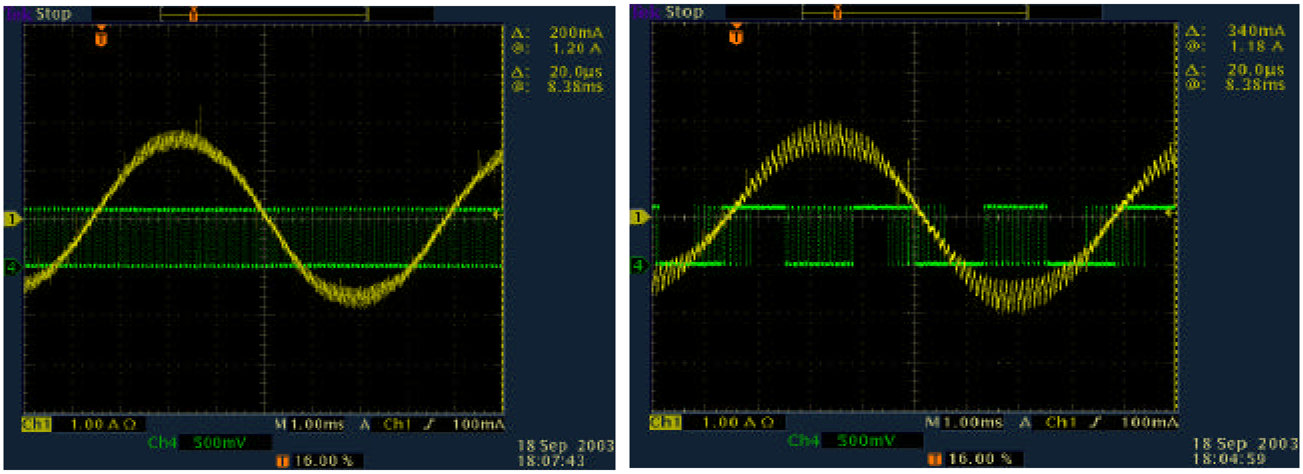

Figure 4 Traditional 3-phase PWM (left) and Low loss/EMI PWM (right)

Ideal solution for upgrading high performance analog "Torque drive"

The IRMCK201 can operate in a "stand-alone" mode without the host controller. A serial EEPROM can be utilized to load motor-specific parameters into the IC. The IC also provides direct interface to an inexpensive serial 12-bit A/D converter so that the system solution using IRMCK201 accepts industry standard +/-10V input for speed or torque reference. A 100-pin QFP small IC package together with the SO-8 packaged IR2175 current sensing IC enables significant size reduction of the final servo amplifier for cost sensitive application.

Application and support tools

Designing the IRMCK201 into the real life circuit is still a challenging job. International Rectifier understands the effort necessary to take the process from prototyping to product release of the complete servo drive system. Design of power electronics circuit, analog signal conditioning, switch mode power supply circuit, sensor interface circuit are examples of circuit designs and essential elements of the complete servo amplifier system. In particular, the design of power electronics circuit combined with thermal management requires specific technical talent and experience and most frequently hinders users from completing hardware design.

IRMCS2011/IRMCS2031 Complete1kW design platform

In order to assist the user's design-in effort in a more comprehensive fashion, International Rectifier introduced the IRMCS2011 design platform (Figure 5 and Figure 6) together with the IRMCK201 IC. Unlike previous l design kits, the IRMCS2011 is a complete design system for 1kW servo applications. It contains all the necessary hardware including the heatsink and connectors. This hardware platform is actually extremely close to the real life product since its design incorporates many industry standards. For example, the PCB layout follows the UL508C, which /allows for the high voltage creepage distance requirement between high voltage potential traces. The cover and faceplate are the only missing elements in the IRMCS2011.

The user can immediately evaluate the system performance of the IRMCK201 without adding or modifying the circuit.

IRMCS2031 reference design kit will also be available based on IRMCK203 IC.

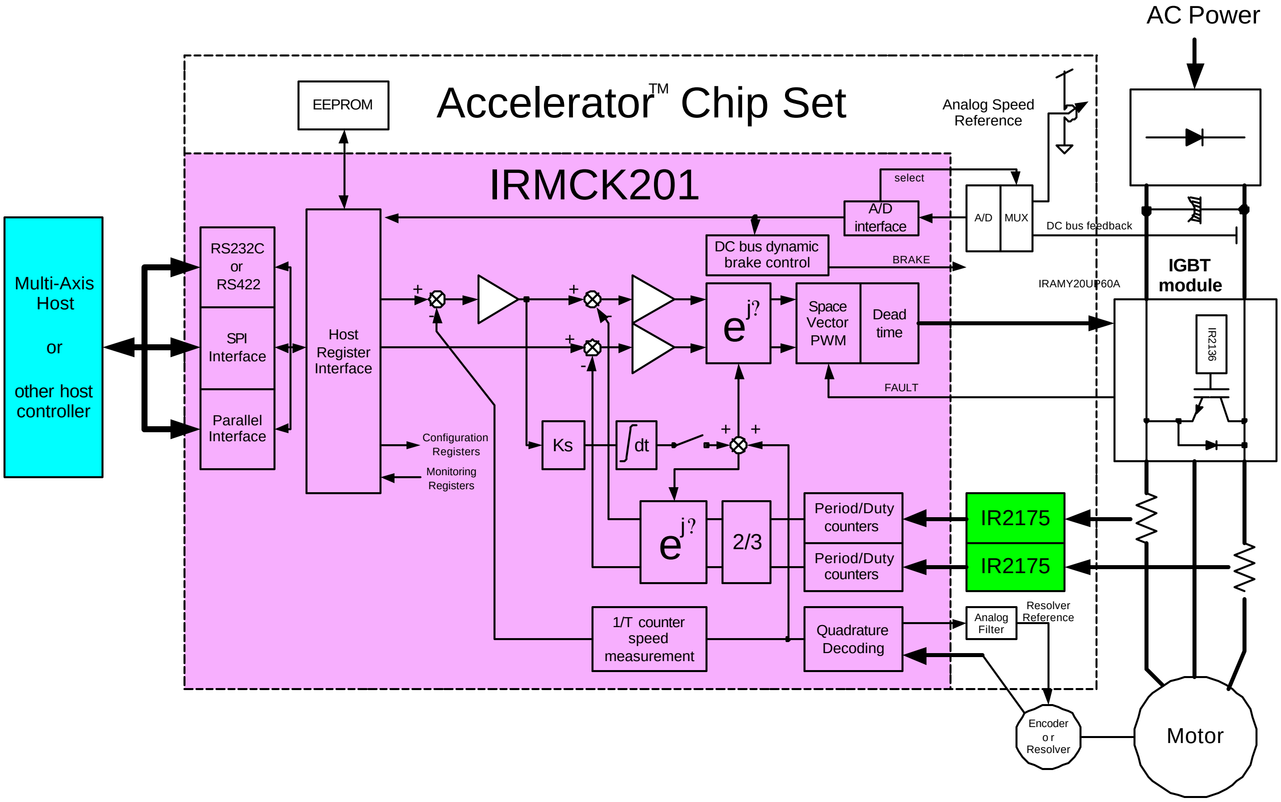

Figure 5 Simple Digital Servo Amplifier using IRMCK201

Both the IRMCS2011 and IRMCS2031 hardware use the company's most advanced IGBT intelligent modules, IRAMY20U60A, rated at 20amps and 600V for the IRMCS2011 and IRAMY16U60A, rated at 16amps and 600V for IRMCS2031. The module, based on advanced IMS technology, integrates with the IR2136 3-phase high voltage gate drive IC inside. The IR2175 monolithic high voltage IC implements motor current sensing. This IC is able to directly interface to the IRMCK201 IC and comes in the small SO-8 package to enable a very compact and simple motor current sensing function for sophisticated closed loop motor control application. A 3-leg low side shunt resistor based current sensing is also available as an option for the IRMCS2031 system.

The IRMCK201 and IRMCK203 motion control IC combined with the company's intelligent IGBT module and IR2175 current sensing IC significantly simplify the user's power electronics design and reduce component count and board space. The IRMCS2011/IRMCS2031 is constructed by the compact single 3" x 5" sized PCB as shown in Figure 6.

Figure 6 IRMCS2011 Hardware Design Platform

The IRMCS2011 also contain overcurrent/short circuit protection circuit to protect against any mode of overcurrent drive fault. Multiple output switched mode power supply and all necessary sensor interface circuits are also equipped on the board.

ServoDesigner™ PC tool:

Although configuring the host registers is a simple process and does not require any programming or coding effort, it still requires writing specific values into each associated registers. ServoDesigner™ is a window based PC tool to facilitate writing and reading the host registers without any other tools or preparation. This tool will work with any hardware platform so long as it uses the IRMCK201 IC. Therefore, this tool can also be used as a tool at user's factory parameter setting.

The tool is very flexible. The user can define which registers to be accessed, change the register names, customize reading and writing registers group into subgroups.

Defining and adding new functions enables powerful motion expansion and specific performance verification. For example, the user can easily create the sequence of moving motion consisting of multiple start-and-stop speed profile with different acceleration/deceleration. This interactive motion profile generation provides a quick verification tool for the desired performance, simplifies and minimizes time for the application development process.

The ServoDesigner™ facilitates the diagnostic feature. Drive fault and status, indicating either the drive is running or at stop mode or faulted, is always displayed on the screen without any configuration effort.

ServoDesigner™ also includes an interactive HELP menu and description of each host registers to provide an effective configuration guiding tool for the user.

Configuring registers can be further simplified by using an Excel™ spreadsheet. ServoDesigner™ provides a supplemental Excel™ spreadsheet as a template for adapting and configuring a new motor. All the user has to do is to write the motor nameplate data such as motor amps, speed, encoder line count into the spreadsheet. Then this spreadsheet calculates and generates the values to be written to each specific host registers. Then the user can "import" this spreadsheet data to ServoDesigner™ registers.

The tool contains EEPROM read/write utility so that the user can store tuned parameters and eliminate repetitive configuration.

After completion of configuration, the user can still choose either to use ServoDesigner™ to initiate the motion action or to use the stand-alone mode of operation without ServoDesigner™ tool.

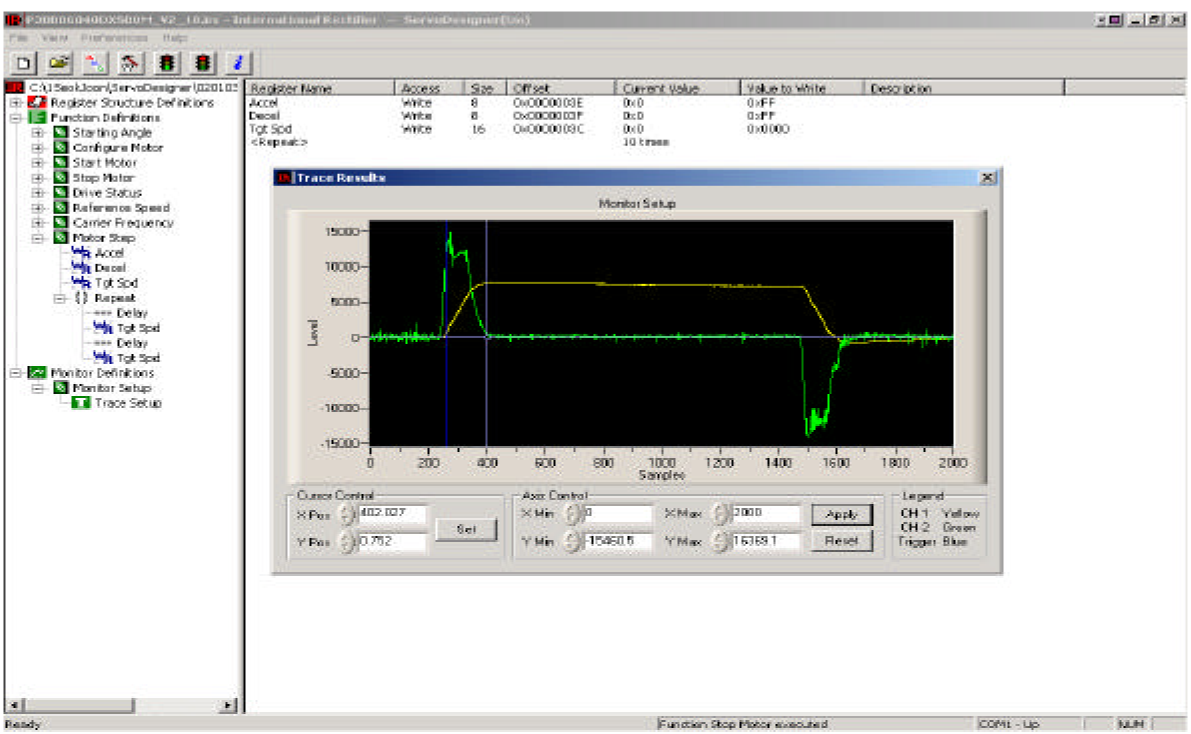

Figure 4 ServoDesigner™ tool

Future Roadmap

IRMCK201 and IRMCK203 are just beginning the process of simplifying motion control design and enabling high performance motion control solutions. International Rectifier is committed to continuing and providing advancement of motion control solutions. The Motion Control Engine continues to be the core computation hardware engine for future digital motion control IC.

Other motion control ICs are on the horizon. The development of the IRMCK202 resolver based complete servo control IC is well underway. This IC, positioned to be a sister IC of the IRMCK201 serving the high performance servo drive application market, integrates 12-bit resolver interface to achieve high resolution of position and speed feedback.

In addition, a low cost appliance motion control IC will be released in the near future. This IC will be targeted at appliance specific motion control including home air conditioner and washing machine applications.

In order to facilitate design-in effort by users, International Rectifier will also release an associated Hardware design platform and supporting application PC software tool at the same time each IC is introduced. With these design kits, the user can shorten time to market their product development cycle.

Reference

[1] A.Hiruma,H.Kanazawa,T.Uchida,Y.Yamanashi, "Inverter Air Conditioner in Japan", Proceedings, PCIM China 2003, March 2003.