White Goods
Part I

Compact MOSFET Inverter Module for Highly Reliable Low-Power Motor Drives

Inverters are integral for energy-savings and high performance in motor drives

Motors consume approximately 20% of all electric energy consumed in the typical household. So, the term "energy-saving" is becoming very commonly used in the world of motor-driven white goods. Since inverter technology is being accepted by a wide range of users in the design of their products, the use of inverters is increasing, but needs careful design.

By Byoung-chul Cho, Dong-keun Jang, and Sung-il Yong, Fairchild Semiconductor, Korea

Inverter motors are used in home appliances such as air conditioners, washing machines, refrigerators, dishwashers and water pumps. Inverter drive applications are increasingly popular because they deliver precise frequency, starting current control and show high efficiency. Compared to a damper or a valve used to control the amount of air or water flow, an inverter can save a substantial amount of energy by controlling the speed. It does this by continuously adjusting the speed to maintain a desired situation under varying system conditions (variable torques like fans and pumps). This makes machinery of all types more productive, improves quality and more flexible with quick change over to run different materials.

Issues when designing the inverter

In order to design a motor drive that runs quietly, the PWM frequency should be higher to simulate a sine wave by adding many full voltage pulses in rapid succession. For this, inverters can output very high switching frequencies and with very rapid changes in voltage. This voltage change begins with a spike of over-voltage, which can burn pin holes in the motor's insulation causing short circuits. Any portion of the waveform that is not a sine wave is converted to heat in the windings. This is more prevalent on the older six step inverters but still can overheat or burn out some motors even on PWM inverters. To minimize these effects, additional external components such as load reactors should be installed to slow down the voltage change. Therefore, setting the right dv/dt helps to reduce the overall system cost.

A high dv/dt can cause electrical problems at the inverter-side. Gate-source voltage induced by Cdv/dt in the half bridge circuit might cause undesired turn-on of the MOSFET and deteriorate overall system efficiency. This is due to induced gate-emitter voltage with the Cgd (miller capacitance) and Cgs (gate-source capacitance), effectively forming a capacitive divider when the high dv/dt is applied to drain-source of MOSFET. Such abnormal operation will increase the inverter turn-on switching loss, which will

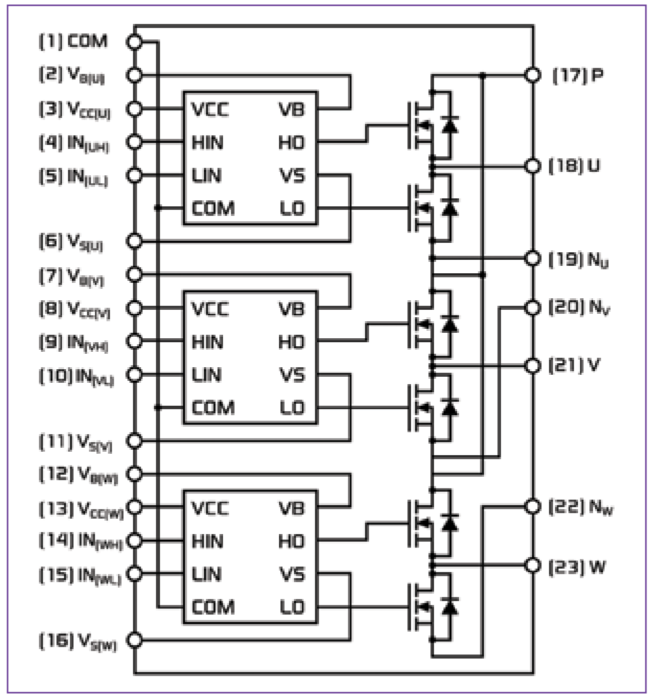

Fig 1: Internal Block diagram of Fairchild's new module.

eventually limit the power rating and stability of the system. The simple remedy for this could a proper gate drive using large turn-on gate resistance and small turn-off gate resistance. However, a large turn-on gate resistance can cause longer turn-on time delay and high turn-on switching loss. This delay is very critical to the current measurement system using external shunt resistor since the ambiguity of the current measurement increases especially at the low speed operation where the modulation index is small.

Furthermore, small turn-off gate resistance accompanies high turn-off dv/dt. Therefore, the above issue cannot be solved completely by merely adjusting the gate resistance. Therefore, in order to get the best performance without instability, it is necessary to optimize C_{GD} / C_{GS}. This methodology involves design changes in the MOSFET devices that are usually not available to power system design engineers.

For lower power appliances such as fans, dishwashers and water pumps, MOSFETs have many advantages over IGBTs. First, one MOSFET can replace both an IGBT and FRD, resulting in cost savings. Second, in view of conduction losses, MOSFETs show better performance under 1A as the turn-on characteristic is ohmic and the conduction losses are proportional to the square of the drain current; unlike an IGBT where the current flows through the PN junction. Second, switching losses of MOSFETs are lower than that of IGBTs because of the lower threshold voltage and smaller current tail at the off period. Especially when switched off, the IGBT has a long tail current. This is because it is a minority carrier recombination device in which the gate of the device has very little effect in driving the device off. Third, MOSFETs have attractive ruggedness characteristics, such as longer short-circuit withstanding time and superior UIS (Unclamped Inductive Switching) performance. Fourth, lower temperature coefficient of threshold voltage will make MOSFETs less susceptible to transient conditions with high dv/dt.

The traditional approach for driving low-power inverter systems has been to use a discrete solution. However, system designers face a number of challenges when designing these devices in a non-integrated fashion; namely design flexibility, packaging and reliability. Traditional solutions using MOSFETs and gate drive ICs are not designed specifically for the gate drive ICs, making board design more complex and time consuming. Furthermore, there are increasing demands for compactness, built-in control, and lower overall-cost. A power module can fix this problem.

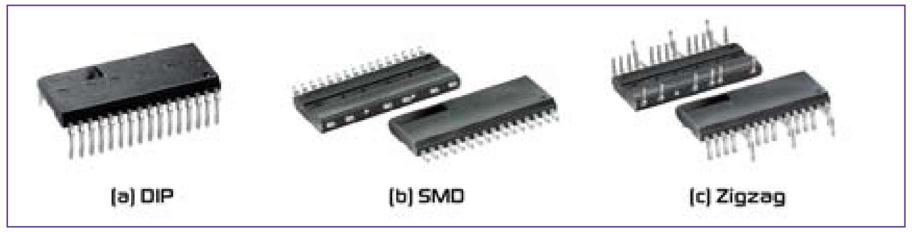

Fig 2: Range of package options for Fairchild's new module.

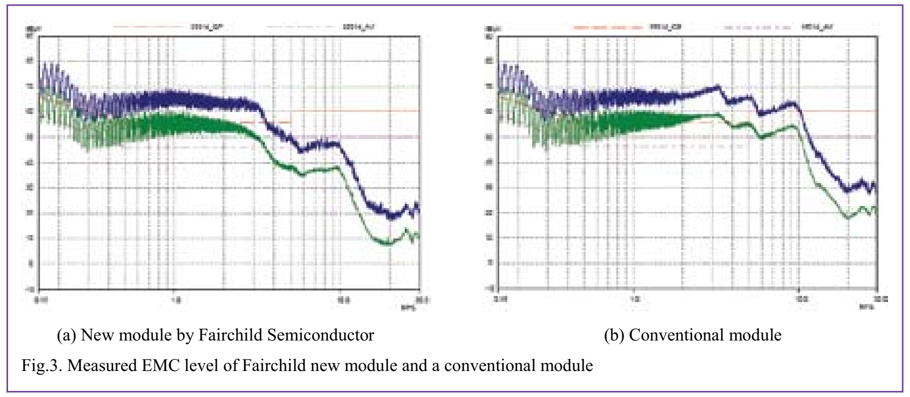

Fig 3: Measured EMC level of Fairchild new module and a conventional module.

Integrated Approach to Inverter Design

Fairchild Semiconductor has developed a new MOSFET inverter module for driving small brushless DC motors. This module implements a 3-phase inverter circuit including HVIC (High-Voltage IC) with UVLO (Under-Voltage Lock-Out) protection function in a transfer-molded full-pack package that measures 29 x 12mm as seen in Figure 1. With a specially designed MOSFET and dedicated HVIC, it provides optimized loss and EMC (EMI & EMS) characteristics to maximize the power density with a high reliability when in the field. In addition to the EMC, ruggedness there is another key factor determining field reliability. A MOSFET inverter also can provide a wider safe operating area (SOA) compared to other devices with the same rating. Package form is another extremely important consideration for designing a compact system because packaging requirements vary according to individual system design requirements. Fairchild provides a range of compact package options, including DIP (Dual-In-Line), Zigzag, and SMD (Surface Mounted Device), giving the designer freedom and flexibility as seen in Fig.2.

As stated previously, the inherent switching mode operation of power inverters used in industrial and domestic appliances, leads to many problems caused by unwanted harmonics. To minimize this problem, the dv/dt should be controlled under certain level. Fairchild Semiconductor has developed the new, more efficient module with a significantly lower EMC level by optimizing the internal MOSFET and drive IC design.

Finally, an experiment was carried out to test and verify this performance without taking any of the usual measures to reduce EMC, such as by the use of reactors or snubber capacitors. The prime goal was to see the difference just within the device itself. The results as displayed in Figure3 demonstrate that although both devices do not meet the EMC regulation without the normal snubber techniques, the peak and average EMC level of the new module is significantly lower in value than of that found in the conventional type.

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WHITE GOODS

Capacitive Sensors in White Goods

Improved capacitive-sensing technology expands the realm of potential applications

With all the excitement about capacitive sensing in the portable media player, laptop PC and mobile handset markets, it is easy to forget that such interface technologies have been actively designed into White Goods applications for years.

By Ryan Seguine, Product Engineer, PSoC CapSense, Cypress Semiconductor, San Jose, Calif

Significant improvements in sensing algorithms and control circuitry have expanded the suite of applications in which the technology can be implemented. Designers are seeing the value of capacitive sensing as a mechanical button and membrane switch replacement as well as discovering new, exciting applications such as touchscreens and proximity sensors.

Sensing Capacitance

A capacitive sensor is constructed of a conductive pad, the surrounding ground, and its connection to a controller. In most applications, the conductive pad is a large copper footprint and the surrounding ground is a poured fill. A native (parasitic) capacitance, C_P, exists between these two objects. When a third conductive object, such as a human finger, is brought into proximity with the sensor, the capacitance of the system is increased by the capacitance of that object, C_F.

There are several methods for detecting the increase in capacitance caused by the addition of C_F. Field Effect measurement uses a AC voltage divider between a sensor capacitor and a local reference capacitor. Finger detection is achieved by monitoring the change in voltage on this divider). Charge transfer uses a switched capacitor circuit and a reference bus capacitance with repeated charge transfer steps from the smaller sensor capacitor to the larger bus capacitor. The voltage on the bus capacitor is proportional to the sensor capacitance. The capacitance can be determined by measuring the voltage after a fixed number of steps or by counting the number of steps necessary to reach a threshold voltage. A relaxation oscillator is a charge time measurement where the charging ramp is determined by the current source (usually fixed) and the sensor capacitance value. Larger sensor capacitors yield longer ramp times, usually measured with a PWM and a timer. Successive Approximation is a capacitance charging time measurement where start voltage is determined by successive approximation.

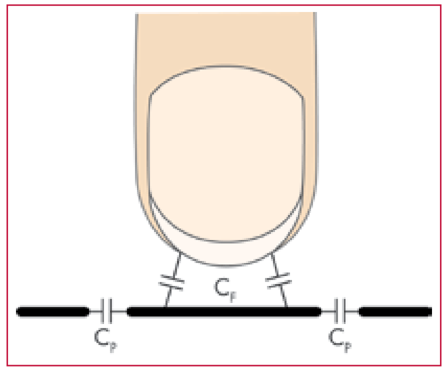

Figure 1: Illustration of capacitive sensing system.

The successive approximation method (patents applied for by Cypress Semiconductor) implemented with the PSoC device uses a capacitance to voltage converter and single slope ADC. The capacitance measurement is achieved by converting the capacitance to a voltage, storing this voltage on a capacitor, and then by measuring the stored voltage using an adjustable current source.

The capacitance to voltage converter is implemented with switched capacitor technology. The circuitry brings the sensor capacitor to a voltage relative to the capacitance of the sensor. The switched capacitor is clocked by the PSoC's internal main oscillator.

The sensor capacitor is connected to the analog mux bus and is charged via a programmable current output digital-to-analog converter (iDAC) also connected to the bus. The charge on each bus is given by q=CV. SW2 is opened and SW1 closed to bring the potential across CX to zero and reducing the charge on the bus by a value proportional to capacitance of the sensor capacitor. This (charge-discharge) is repeated so that the sensor capacitor is a current load on the bus.

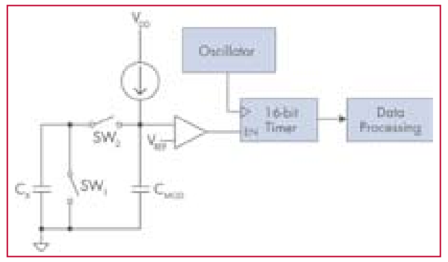

Figure 2: Schematic of capacitance sensing system.

With the switched capacitor circuit running, the iDAC uses a binary search to determine the value at which the voltage on the bus remains constant. This voltage is a factor of the switching frequency, the sensor capacitance and the iDAC value (current). The bus also functions as a bypass capacitor, stabilizing the resulting voltage. Additional capacitors can be added to the bus and affect performance and timing of the circuit.

$$V_X = \frac{1}{f_{OSC} C_X} I_{DAC}$$

$$V_{BUS} = V_{REF} - V_X$$

The calculated iDAC value is then used to charge the bus again and the time required to take the bus from an initial voltage to the comparator threshold is measured. The initial voltage with no finger present and therefore the charge time is known. A finger on the sensor increases the value of CX, decreasing the initial voltage and increasing the charge time measurement.

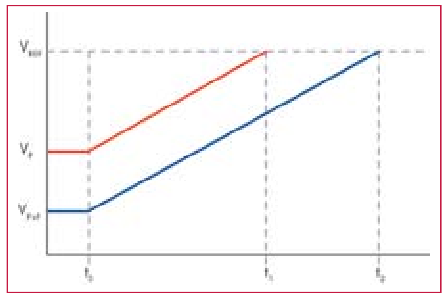

Figure 3: A finger on the sensor increases charge time measurement.

Building a Sensor

Capacitive sensors have diverse form and function. They can use a variety of media. Their implementation ranges from simple to complex. Application requirements determine sensor construction and implementation details.

Buttons and sliders are most common. Buttons are large conductive pads connected to the controller. Capacitance is measured and compared against a series of thresholds. Decisions can be made as digital outputs or with more analog characteristics for activation pressure or finger size. Sliders are linear or radial arrays of conductive pads. Center of mass algorithms determine the position of activation to a resolution far greater than the number of pins used to sense. Most often simple capacitive sensors like buttons and sliders deposited onto a printed circuit board using copper. Other substrates and deposition media such as silver ink can be used, however.

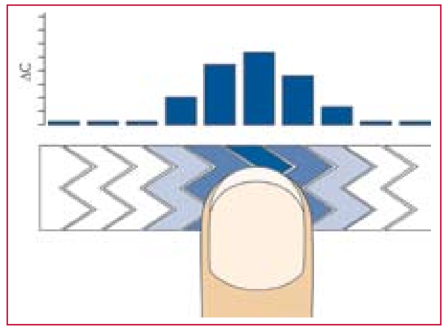

Figure 4: Center of mass algorithms determine the position of activation.

Dynamic user interfaces use buttons or activation regions that reconfigure in response to the display itself. These displays are moving the user experience forward by promoting more seamless and intuitive interaction. The construction of these systems is somewhat more complex that simple buttons or sliders. Projected capacitance touchscreens use transparent conductive materials over a display. The conductive surface is deposited onto a substrate such as glass or PET film and connected to the control circuitry. The substrate is then adhered to the overlay between the overlay and the display. The position of the activation is determined in the same way as a slider. Two sliders, one for each axis are intertwined to provide complete coverage of the display area. Activation is detected on both axes and the position exported as x- and y-data except on two axes. Because a projected capacitance touchscreen is behind an overlay, it is protected from impact, flexion, and environmental factors that plague traditional resistive touchscreens.

Proximity Sensors are essentially large buttons. The object of a proximity sensor is not to detect the exact position of a conductive object, rather the presence. Since the device does not need to know exact position, the response time may be slower (3-4ms vs. 250us). The sensitivity of a proximity sensor is much greater; 30cm can be achieved in a well constructed design. Since proximity sensors do not need to be associated with any display graphic, their placement on the device is more flexible. A copper ring around the outside of the control circuit board or a wire behind the overlay allows very basic, cost-effective construction of a proximity sensor.

Using a Capacitive Sensor

Usage of capacitive sensors is expanding. The described sensors have created new opportunities for designers to work with such flexible, durable and elegant design elements. Buttons are still used for basic menu navigation and

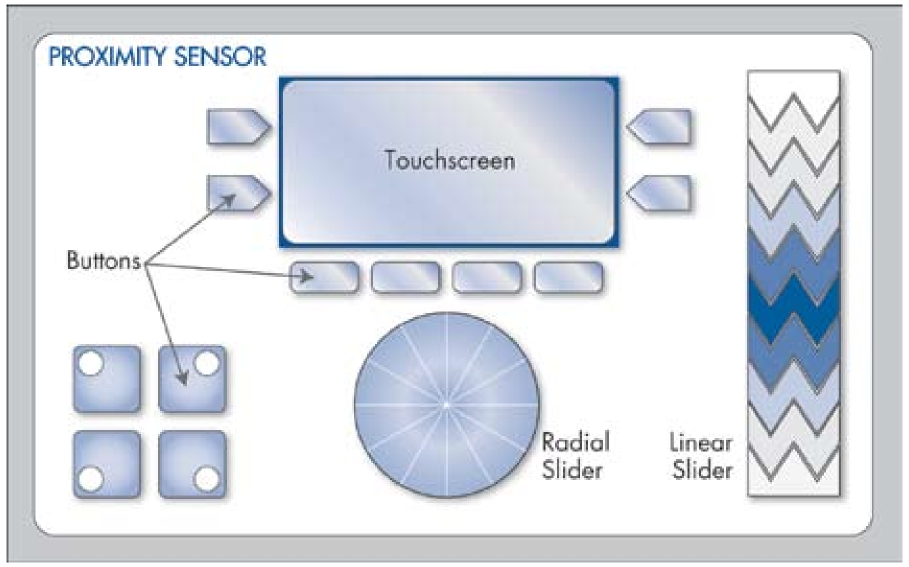

Figure 5: Illustration of proximity sensor arrangements.

Figure 6: The LG LA-N131DR air cleaner, developed by LG Electronics, uses five capacitive sensors for front panel display menu navigation buttons. Photo: LG Electronics.

activation. However, analog characteristics of buttons that are not expensive potentiometers are allowing easier and less expensive implementation of increased functionality and safety features.

The LG LA-N131DR Air Cleaner uses five capacitive sensors for front panel display menu navigation buttons. These buttons have allowed the designers to implement a seamless chassis design while still realizing the user interface. The capacitive buttons detect the presence of a human finger through four millimeters of glass. The control circuitry is located on the non-sensor side of a two-layer printed circuit board. LG uses the PSoC Mixed-Signal Array to control the sensors and output status to the main device processor.

Proximity sensors allow for reactive backlighting for night-time operation or for safety features requiring a larger activating element such as an adult hand or metal pot to engage the range-top controls. Proximity sensors, buttons, sliders and even touchscreens can be controlled by a single processor using PSoC. Firmware routines allow changes in state based on user inputs or host commands.

Create You Capacitive Sensing Application

The PSoC Mixed Signal Array is a configurable array of digital and analog resources, flash memory and RAM, an 8-bit microcontroller, and several other features. These features allow PSoC to implement innovative capacitive sensing techniques in its CapSense portfolio. Use PSoC's intuitive development environment to configure and reconfigure the device to meet design specifications and specification changes. New sensing technologies exhibit improved sensitivity and noise immunity, reduced power consumption, and increased update rate. For more information on PSoC, go to www.cypress.com. For more information on PSoC CapSense, visit www.cypress.com/capsense.

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Motor Control Designs for White Goods Demand Innovation

Plug-and-play modules reduce parts count and production costs

We are seeing more motor control designers turning to the power of the DSP. This is for good reason. It saves time and designs have lower component-count. Production runs can be scaled up easily, using very similar designs for differing applications.

By Jeffrey Reichard, CEO, Tier Electronics LLC and Andrew Soukup, Worldwide TMS320C2000™ Marketing Manager, Texas Instruments

Today's engineers must learn to prosper in an environment that emphasizes a plug-and-play design strategy. Most major white goods manufacturers, for example, have adopted the practice of considering even critical electronic subsystems (such as a motor controller) simply as a component.

This strategy keeps costs under control. It also allows the OEM to focus its internal design team's attention on value-added features instead of spending time designing various functions that can be outsourced to the OEM's suppliers.

Plug-and-play designs can place additional burdens on suppliers. For the circuit designer, it means creating flexible designs that are frequently a combination of subsystems.Typically, a main circuit assembly implements the basic functionality with one or more smaller assemblies providing the customization for optional interfaces, capabilities and even applications.

In motor control applications, the choice of processor is a vital step to ensure sufficient flexibility together with the ability to deliver a high level of performance at a low cost. Digital signal processors (DSPs) are increasingly being utilized in white goods for precisely this reason.

At the same time, the designer must use the kind of flexibility that DSPs provide, to achieve low manufacturing costs over a wide range of scenarios. Designs are most cost effective in terms of engineering time expended if they can ramp from initial trial production runs to 250,000 units or more with basically the same design.

Motor control a la carte

Here, we discuss a motor control design that takes flexibility to the next level. The same architecture can be used for a variety of motor control applications. It can also be adapted to different applications such as Uninterruptible Power Supplies (UPS), frequency converters and variable power sources.

For this particular white goods motor control application, the cost target was about €11 for a 1 horsepower motor (washing machine application) when the production run was ramped to over 250,000 units. The design needed to be flexible enough so that variations of the basic design could handle the requirements of a 5 hp motor (for a home air conditioner) or a half-horsepower (waste disposal) motor.

Module requirements

The absolutely key component choices at the design stage are the DSP and the IPM (Intelligent Power Module). Together, they deliver almost all the design's functionality. IPM requirements include voltage and current options in the range of 3 to 50 A and 600 VDC to 1200 VDC. Cost targets dictate DIP or SIP packaging.

A more subtle requirement for the IPM is that its drivers match directly to the IGBT to be used in the design. This simplifies the design effort by reducing component count, switching losses, and improving reliability, in comparison to designs that require external driver circuits.

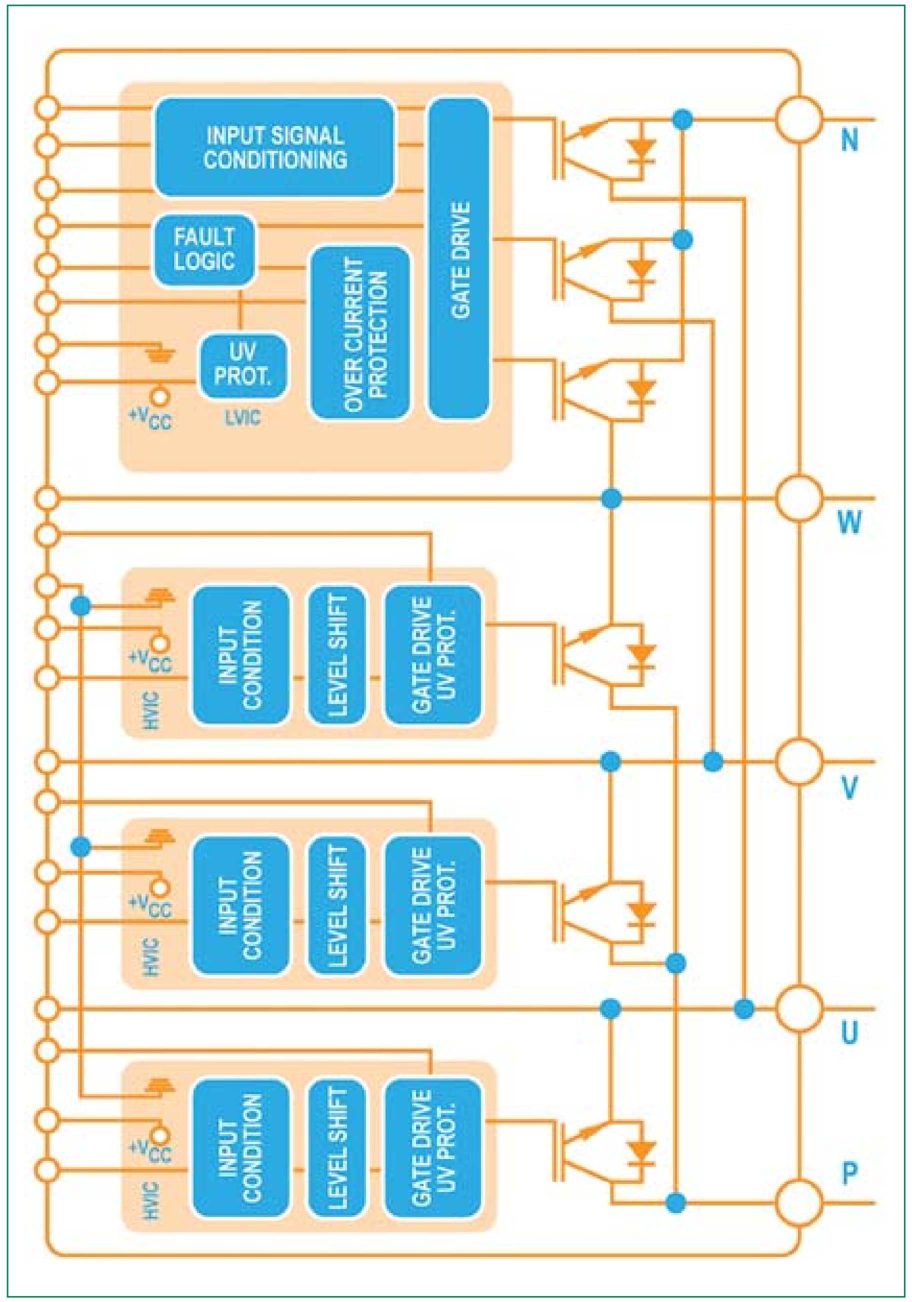

Figure 1: IPM for flexible motor control design with built-in protection circuits.

Some IPMs available today offer an array of built-in protection modes including under voltage, over voltage, over current, over temperature and shoot through. Choosing one of these IPMs reduces part count, engineering design time, and therefore final product cost. A diagram of a typical IPM is shown in Figure 1.

Processor requirements

The processor has stringent requirements. To handle field-oriented control (FOC) of brushless DC motors, it requires the signal processing capabilities of a DSP, cope with the normal level of function integration of an MCU and be inexpensive enough to be used with an induction motor. Digital signal controllers, such as those found in Texas Instruments (TI) TMS320C2000 platform, are designed for these applications. The choice of controller is determined by cost, performance, and manufacturing requirements.

The control optimized high speed DSP-based devices are capable of reading current and voltage signals during predetermined PWM patterns. This allows for simple sensors to be used to calculate individual phase leg currents and voltages by coordinating the internal A/Ds and PWM forced states. Functionality that is created by the DSP's speed allows a design team to use less expensive non-isolated sensors to replace their costly isolated counterparts.

Integrated features such as fast A/Ds, multiple communication channels, PWM modulators, and high speed operation are key to adding value. The DSP that has these features can be used to reduce design time, unit cost and manufacturing time. For example, one of the communication channels, CAN (Controlled Area Network), could be used for test and calibration data exchange during manufacturing to automate this phase of the product.

An RS-232 interface offers unsuspected value in contactless control. Safety regulations prefer contactless (which primarily means infrared) connections between the appliance's internal parts and its customer interface medium. RS-232 is a prime candidate for this type of communications due to its wide range of speed and control options. Contactless control also mitigates EMI concerns since the coupling capacitance is essentially eliminated.

Topology and packaging

A three-phase design with a single low-side current sensing resistor, an NTC temperature sensor, IPM power device, and DSP controller is the basic topology. This can be modified for two-phase and one-phase motors by simple re-programming of the DSP or through multiple resident programs.

The fast A/D converters make it unnecessary to use a differential amplifier for voltage feedback measurements. The accuracy and speed of the ADCs and the DSP allow the channels to be read sequentially without a differential amplifier. The signal error caused by the DSP can be extremely low since samples can be as close as 500ns.

Careful system partitioning is just as important in packaging. When white goods manufacturers view power controllers as plug-and-play components, there is usually little consistency

TYPICAL COMPONENT COUNT		
COMPONENT	**DISCRETE/ MCU**	**IPM/ DSP**
IGBT/MOSFET	8	2
RESISTOR	101	38
CAPACITOR	84	50
ELECTROLYTIC CAPACITOR	4	1
DIODE	29	17
IC/PROCESSOR	19	6
OPTO	6	0
IPM	0	1
TRANSFORMER/ INDUCTOR	7	1
CRYSTAL	1	1
TOTAL	**259**	**117**

Figure 2: Comparative parts count.

FEATURES COMPARISON		
FEATURE	**DISCRETE/ MCU**	**IPM/DSP**
Component Count	259	117
Hardware	9 Sets	3 Sets
Protection	OC/OT/OV	OC/OT/OV/ UV/De - Sat/ Shoot Through
Sensors	3 x IFBK/1 x Res Div/Diff Amp/NTC	1 x IFBK/4 x Res Div/NTC
Uses	PWM Controller for Motor/UPS/ BLDC Motor/ Active Rectifier	PWM Controller for Motor/UPS/ Sensor Less BLDC Motor/ Active Rectifier /Harmonic Compensator

Figure 3: Fewer parts enhance reliability.

between their specifications. In particular, different applications and OEMs specify quite different frame sizes for the PCB. But to be cost effective one design should accommodate all of them with a minimum of design changes.

By treating the DSP and its support components as a single component and assembling these functions on a mini PCB and the IPM module with its related power components on a main PCB, a design that achieves a great deal of flexibility is accomplished. The main PCB which contains the IPM and other devices that change according to manufacturer, voltage, and power level make it a straightforward design that uses through-hole components along with the DSP component and can be changed easily without complicating the manufacturing processes.

Since each converter application uses the same DSP PCB assembly, it can be manufactured easily in large volume. It is then simply installed into any of the different forms of the main PCB, configured with the appropriate type of IPM.

Parts count and reliability

Figure 2 illustrates a comparison of the conventional MCU/discrete design approach versus the new methodology. The DSP/IPM design can cut the total parts count by 50%.

MTBF metrics are also improved by reducing the number of components. Additionally, mechanical stresses on the main PCB are reduced by using the DSP PCB assembly approach because the thermal stresses, normally associated with greatly dissimilar components on a common PCB, are eliminated. Circuit protection is enhanced by the utilization of specific IPMs and three sensors are replaced by one as compared to the MCU/discrete-based design. The differential amplifier can also be eliminated by using the fast A/Ds of the DSP. Figure 3 shows a few metrics related to reliability.

Lower cost, more functionality

By opting for more powerful and highly integrated components, the number of parts, manufacturing costs, and engineering costs can all be reduced. The plug-and-play approach of the motor controller with the two-board system produces manufacturing flexibility that keeps unit costs low.

This approach also allows production scaling from low volume to hundreds of thousands of units while maintaining a design that is highly cost effective. On the performance side, using advanced DSP and IPM components provides up to 30% better efficiency compared to conventional designs based on MCUs and discrete components. Finally, the reduction in parts count improves reliability.

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WHITE GOODS

Resettable Circuit Protection for Appliance Motors and Transformers

Better than fuses…and reduce warranty returns

These devices, with their low resistance, fast time-to-trip, low profile, and resettable functionality help circuit designers provide a safe and dependable product, comply with regulatory agency requirements, and reduce warranty repair costs.

By Faraz Hasan, Global Industrial & Appliance Marketing Manager,
Raychem Circuit Protection products, Tyco Electronics

The latest generation of PPTC (polymeric positive temperature coefficient) devices includes components that are rated for line voltages of 120 VAC and 240 VAC and can be used in parallel for increased current capacity. Their low cost, resettable functionality and latching attributes make them a reliable, cost-effective circuit protection solution for the small and medium-sized electric motors used in home and professional-grade appliances.

In many electric motor and transformer applications, single-use fuses are used to help protect electronic circuits from damage caused by excessive current or heat. However, PPTC devices are rapidly gaining popularity, due to their resettable functionality and their ability to help provide protection for two fault conditions – overcurrent and overtemperature.

PPTC Principle of Operation

Although often referred to as "resettable fuses", PPTC devices are non-linear thermistors used to limit current. PPTC circuit protection devices are

made from a composite of semi-crystalline polymer and conductive particles. At normal temperature, the conductive particles form low-resistance networks in the polymer (Figure 1). However, if the temperature rises above the device's switching temperature (T_{Sw}) either from high current flowing through the part or from an increase in the ambient temperature, the crystallites in the polymer melt and become amorphous. The increase in volume during melting of the crystalline phase separates the conductive particles resulting in a large non-linear increase in the resistance of the device.

The resistance typically increases by three or more orders of magnitude. This increased resistance helps protect the equipment in the circuit by reducing the amount of current that can flow under the fault condition to a low, steady state level. The device remains in its latched (high resistance) position until the fault is cleared and power to the circuit is cycled – at which time the conductive composite cools and re-crystallizes, restoring the PPTC to a lo w resistance state in the circuit and the affected equipment to normal operating conditions.

PPTC devices are employed as series elements in a circuit. Their small form factor helps conserve valuable board space, and, in contrast to traditional fuses that require user-accessibility, their resettable functionality allows for placement in inaccessible locations. Because they are solid-state devices, they are also able to withstand mechanical shock and vibration.

Performance Comparison: Thermal fuse vs. PPTC device

Tyco Electronics recently conducted

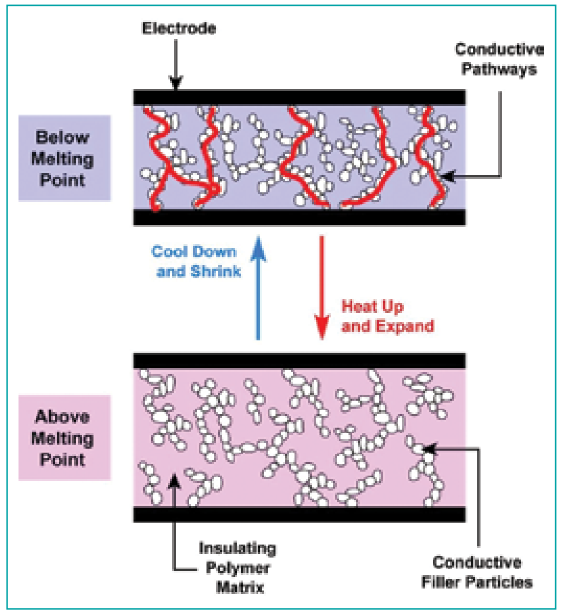

Figure 1: PPTC devices protect the circuit by going from a low-resistance state to a high-resistance state in response to an overcurrent or overtemperature condition.

comparison tests of their PolySwitch™ LVR series of PPTC devices as primary protection elements on a variety of transformers. The performance characteristics of the PPTC devices were compared to those of thermal fuses and ceramic PTC devices.

Many transformer designs utilize a single-use thermal fuse as a primary protection solution. In this test, a short on the secondary side resulted in coil temperatures increasing to over 200ºC. The thermal fuse – rated at 115ºC and mounted near the center of the core – failed to open, and the insulation on the windings melted, destroying the transformer.

Figure 2 illustrates the results of a test in which a transformer was tested with the PPTC device installed as a primary protection element. A primary input voltage of $253V_{AC}$ was applied and a secondary short was simulated. Surface temperatures of the primary and secondary windings as well as that of the PPTC device were measured. The PPTC device started to trip when its external temperature reached approximately 95ºC, at which time the primary coil temperature was about 95ºC. Once the PPTC device tripped and limited the current, the coils began to cool.

The performance characteristics of the PPTC devices and the thermal fuses studied in similar tests on a $120V_{AC}$ transformer with a short on the secondary side are shown in the following table (Figure 3). These data demonstrate the advantages of the PPTC device's faster time-to-trip and its ability to limit the maximum coil temperature, thereby helping to provide some improved protection for the transformer windings, as well as the secondary circuitry.

Because PPTC devices transition to their high impedance state based on the influence of temperature, they help provide protection for two fault conditions – overcurrent and overtemperature. Overcurrent protection is provided when the PPTC device is heated internally due to I^2R power dissipated within the device. High current levels through the PPTC device heat it internally to its switching temperature causing it to "trip" and go into a high impedance state.

The PPTC device can also be caused to trip thermally by linking it to a component or equipment that needs to be protected against overtemperature conditions – such as a motor. If the equipment temperature reaches the PPTC device's switching temperature, the PPTC device will transition to its high impedance state, regardless of the current flowing through it. In this way, the PPTC device can be used either to reduce the current to the equipment to very low levels, or as an indicator to the control system that the equipment is overheating.

Motor Protection Strategy

Although generally reliable, electric motors are subjected to mechanical overloads, overheating, stalls, lost

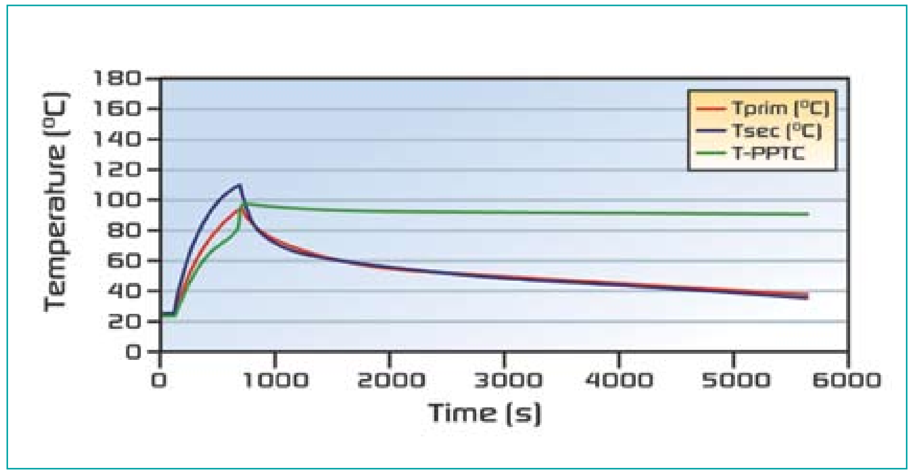

Figure 2: Effect of secondary short on $240V_{AC}$ transformer utilizing a PPTC device as the primary protection element.

Device	Time-to-Trip/Open	**Max Coil Temp (°C)**	Max Current (mA)
Thermal Fuse	>100 min	147	90
Thermal Fuse	51 min	157	89
Thermal Fuse	66 min	147	90
PPTC Device	11 min	107	87
PPTC Device	13 min	112	86
PPTC Device	11 min	103	88

Figure 3: Comparison of performance characteristics of thermal fuses and PPTC devices used as primary protection elements on $120V_{AC}$ transformer with a short on the secondary.

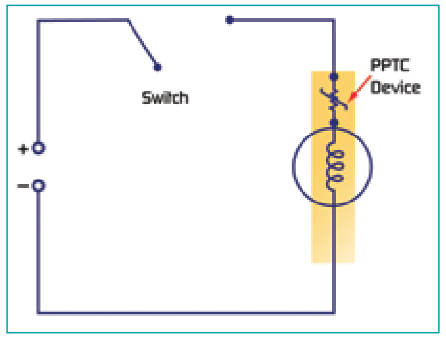

Figure 3: Comparison of performance characteristics of thermal fuses and PPTC devices used as primary protection elements on 120V_{AC} transformer with a short on the secondary.

neutral, severe overvoltage conditions, humidity and other damaging factors. Intermittent operation motors, such as those used in blenders and food processors, are usually designed to operate for a limited time. In general, operating these products for longer than the designed maximum limit, usually results in stalling, overheating and ultimately, failure. Fault conditions arise when the power is held on, either because of contact failure or customer misuse.

To prevent overheating, the circuit protection device used must “trip” quickly, but not sooner than intended, to avoid creating a nuisance condition for the user. The design challenge is to create a protection scheme that effectively protects the motor without nuisance tripping.

Nuisance tripping is often caused by inrush currents associated with certain electrical components found on motorized equipment. The major advantage of the PPTC device is that it can be specified with a trip current substantially below the normal operating current of the motor, but with a time-to-trip that is several times longer than a full system operating cycle, to avoid nuisance tripping.

Figure 4 shows how a PPTC device can be installed in a motor circuit to help protect against damage from overcurrent or overtemperature events. When the device is enclosed within the motor housing it reacts to the current flowing in the motor, as well as any temperature rise that may occur during a fault condition.

Summary

Resettable PPTC devices help protect electronic circuits from damage caused by electrical short, overloaded circuit or customer misuse. They are qualified for and widely used in appliance designs, compliant with the UL 1434 standard, and are compatible with lead-free solders and high-volume assembly processes. Their low resistance, fast time-to-trip, low profile, and resettable functionality help circuit designers provide a safe and dependable product, comply with regulatory agency requirements, and reduce warranty repair costs.

www.tycoelectronics.com

Sensorless Field Oriented Motor Control for Consumer and Industrial Goods

FOC provides higher efficiency, better dynamic response and less torque ripple

Sensorless FOC execution on Infineon’s 8-bit microcontrollers XC886 and XC888 with 15 kHz PWM frequency and 133 μs current control response time only requires 58% of the CPU’s performance…plenty of headroom for application specific functionality.

By Arno Rabenstein, Senior Staff Engineer Application Engineering, Microcontrollers, Infineon Technologies AG

Field Oriented Control (FOC) is increasingly being used in consumer and industrial motor control. The highly efficient programming of the 8-Bit Microcontroller with sensorless FOC algorithm in 16-bit arithmetics can only be realized by a nested utilization of the co-processors MDU and CORDIC – called vector computer – and the 8051 compatible CPU itself. The MDU is a 16-bit multiply and divide unit, the CORDIC is a 16-bit co-processor dedicated for vector rotation and angular calculations.

Sensorless Field Oriented Control

A sensorless field oriented control (FOC) offers the full benefits of sinusoidal commutation at a minimum system cost.

There is just one shunt in the DC link necessary to acquire the phase currents. Figure 1 shows the block diagram of the sensorless FOC with speed control of a permanent magnet synchronous motor (PMSM). From a control point of view, the FOC is comparable with that of a DC motor. The basic concept is a cascade control with the important difference that the electrical variables (V_d, I_d, V_q and I_q) are turning with the rotor. Thus the currents measured at the stator (I and I) have to be transformed in the rotor coordinates (I_d and I_q). The controller for the currents is realized in the rotating system as PI-controller, whereas the field exciting d-component and the torque exciting q-component is controlled separately. The speed controller adjusts - as for a DC motor - the reference value for the torque exciting current I_q. Due to the permanent magnets at the rotor, the reference value for the field exciting current I_d is set to zero.

The output of the current controllers represents the reference voltages (V_d and V_q) in the rotor coordinates. These values are transformed into the stator coordinates (V and V) in order to calculate the polar coordinates (norm and angle). Using space vector pulse with modulation, the norm and angle values are converted in three phase currents by modulating the high-side and low-side switches of the power inverter accordingly.

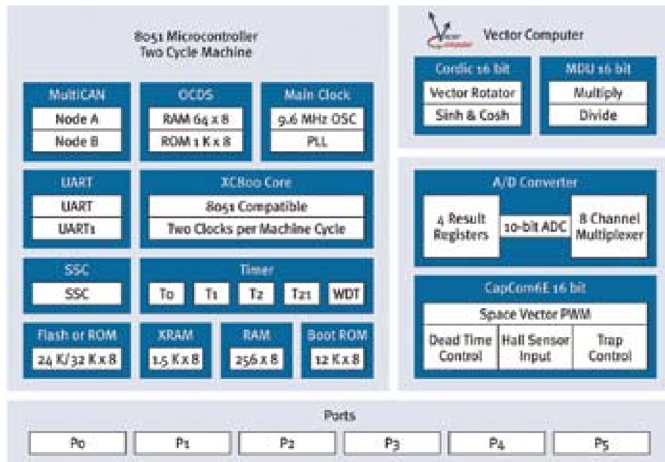

Figure 1: Block Diagram of 8-bit Microcontroller XC886/888 with vector computer.

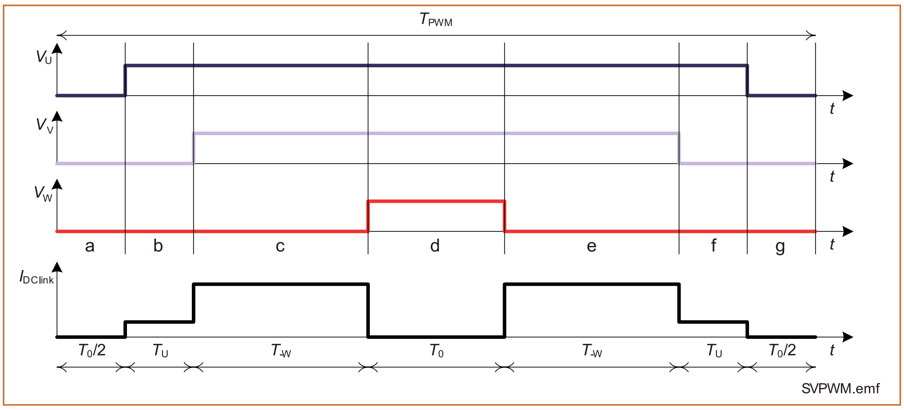

Figure 2: Space Vector Pulse Width Modulation: Three-phase inverter output signal and DC-link current I_Dclink.

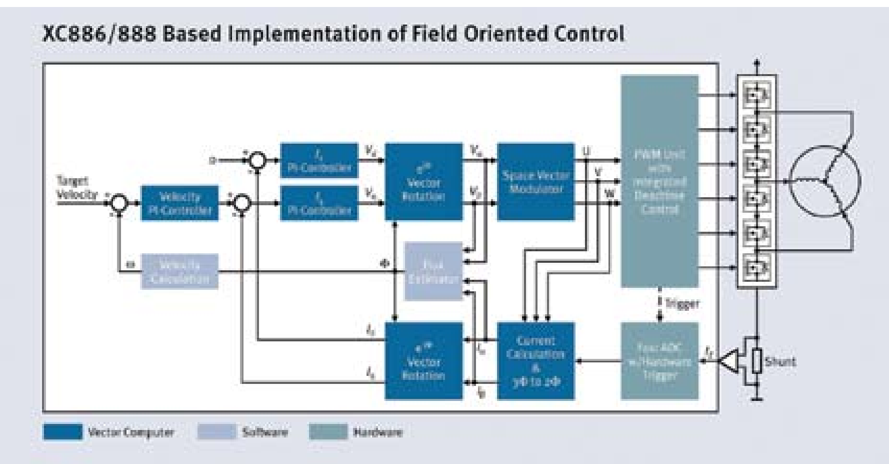

Figure 3: Sensorless Field Oriented Control of PMSM motor.

A space vector is a sinusoid whose center is able to "float" in space. The inactive states are used as an off time during the switching period when creating the space vector. A three-phase space vector is represented by a hexagon which can be divided in six sectors. Any desired voltage-space vector will consist of a "real" voltage from one of the phases and an "imaginary" right-angle voltage created from the other two phases.

The space-vector algorithm will determine the time required at a first active state, a second active state, and an inactive state to produce the desired magnitude and angle of the space vector. See figure 2 as an example. The first active state (b&f) is TU, the second active state (c&e) is T_{-W}, the inactive state is T_0 which appears twice, first as (000) vecor (a&f), second as (111) vector (d).

If we translate the voltage waveform to the phasor diagram, we can see that the space-vector-modulation technique has a maximum predictable voltage of V_Dclink * sqrt(3). A space-vector-modulation system does not constrain the phasor center, yielding a 15 percent increase in available motor voltage. For a smooth rotation, it is the control of the sinusoidal current, not the shape of the voltage waveform that generates the magnetomotive force.

Acquisition of Actual Values

In order to estimate the rotor position by a single shunt measurement, the PWM pattern generation and the triggering of the ADC for current measurement must be very fast and accurate. Any jitter in the trigger point will influence the actual rotor's angle estimation. As a result, the total harmonic distortion of the sinusoidal current signals will increase.

The XC886/888C(L)M microcontrollers implement the above requirement using an event-based hardware trigger from the PWM unit CapCom6E towards the ADC. The event based trigger eliminates any interrupt latency and enables fast and accurate current measurement The ADC provides in total four result registers, from which two are used to hold the appropriate DC-link current values I_{DClink}. The ADC sample time is as low as 250 ns. As the current is measured in time slot (b) and (e) of figure 3, there is always enough time for conversion available.

The voltage model is a simple model for rotating field motors which is based on dedicated differential equations. In order to determine the actual angle of the rotor, the flux vector >Psi< can be calculated by integrating the voltages.

$$\vec{\Psi} = \int(\vec{v}_s - \vec{i}_s \cdot R)dt - (\vec{i}_s \cdot L)$$

The integration is simplified by replacing it by a lowpass filter with a very low cut-off frequency.

FOC Drive Application Kit: CANmotion

Infineon plans to launch an evaluation platform for FOC at PCIM Europe 2007. This CANmotion platform is featuring the XC886CM (TQFO-48 package), a 24V BLDC motor, a plug-in power supply and a CDROM providing the complete sensorless FOC source code, a free development environment for compiling and debugging and a comprehensive documentation. A CAN to USB bridge, built by using the XC886CM, is available for hexcode download and parameter adjustment.

For further details on Infineon's Sensorless FOC algorithm and the FOC Drive Application Kit, please refer to www.infineon.com/XC800-FOC.

Summary

Unlike most competitive FOC implementations that are hard-coded, XC886/8 microcontroller based solutions offer the added benefit of software re-programmability to give you more versatile application options.

Sensorless Field Oriented Control implemented on the 8-bit microcontroller families XC886 and XC888 of Infineon is the perfect answer to energy related regulations and pricing pressure for appliance manufacturers.

www.infineon.com/XC800-FOC