White Goods Motor Controller Improves The Environment And The Bottom Line

Green design is a natural result of designing a more capable and reliable motor controller

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An enduring myth about green design is that it tends to increase component count and manufacturing costs and, as result, make the end product more expensive.

While many design engineers have seen first-hand the fallacy of this argument, a surprisingly significant proportion of the design community still believes that green inevitably means more expensive and less competitive.

When Tier Electronics set out to design a better motor control module for white goods that could also be used in other cost-sensitive consumer products, green was not uppermost in the design team's collective mind. The primary goals were to create a flexible design that minimized component count and was suitable for high volume, cost-effective manufacturing.

Not surprisingly the end result was a more power efficient design, which made the subsystem all the more attractive to OEMs.

To achieve its design goals, Tier's design team followed the familiar path of higher integration and sought out the most technologically advanced components: DSPs capable of handling the compute-intensive algorithms that produce highly-efficient motor control and intelligent-power modules (IPM) that integrate functionality and use less energy.

Together, DSPs and IPMs deliver most of the Tier design's functionality and flexibility. The design also cuts parts count more than in half, as shown in Table 1.

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

Fig. 1: Comparative Parts Count

Fewer parts do more than just reduce component and manufacturing costs. High levels of integration are almost guaranteed to produce a design that consumes less power and is more reliable.

Moreover, the green attributes of DSP-based Field-Oriented Control (FOC) are well documented [see *Digital Signal Processors Usher in Green Motors*, by Kedar Godbole, Texas Instruments, July 28, 2003. http://www.analogZONE.com/grnt0728.pdf]

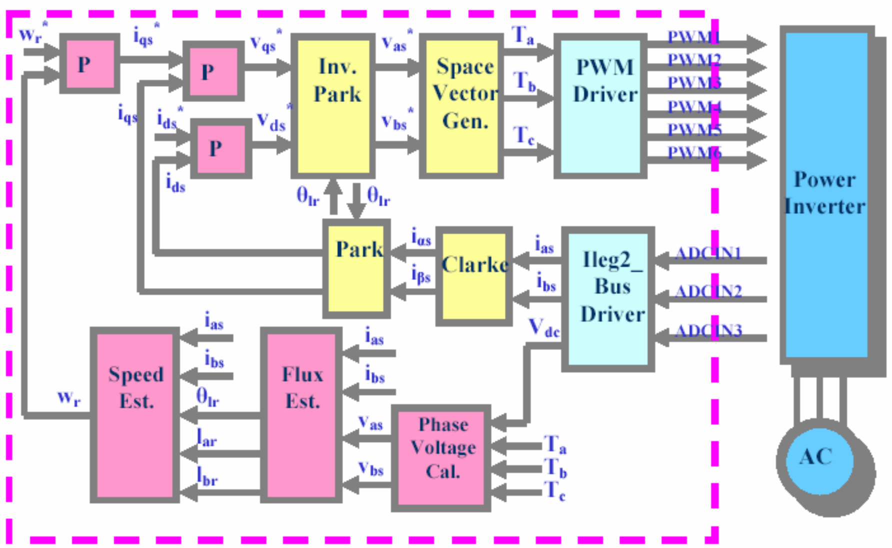

Fig. 2: Typical Field Oriented Control (FOC) Block Diagram For Electric Motor

From a green perspective, when used to control white goods motors, the design produces up to 30% better efficiency compared to conventional designs based on microcontrollers (MCUs) and discrete components.

In Europe, where energy and power factor are design goals themselves, the design is even more competitive. Even in the US, with consumers and industry alike collapsing under the weight of crude oil at over $70 per barrel, the design is also winning friends.

The Design Challenge

Tier's design was in response to an important trend in the white goods industry that calls for reducing in-house design efforts. Over the past few years, OEMs have increasingly treated even major subsystems such as the motor controller as components that can be plugged into an overall system without much tweaking or configuration. This approach allows the OEM's designers to concentrate on value-added features; tends to keep reliability higher; and moderates manufacturing costs.

To achieve plug-and-play status for a motor control module, a simple, flexible architecture capable of addressing numerous applications is the most productive design choice. This type of architecture allows Tier's design team to produce cost-effective designs for low volume production (<10,000 units), medium volume production (10,000 to 100,000 units) and high volume production (>100,000 units).

The design is flexible enough, however, to accommodate motors between ¼ hp (garbage disposal) and 5 hp (large home air conditioner) without significant design changes to the circuit boards or any change at all in the DSP controller. One key to accomplishing this goal is to support as large a number of communications interfaces as possible because different applications use different communications protocols.

For a white goods motor control application the cost target was about $18 for a 1 hp motor (washing machine application) when production was ramped to 250,000 units or more.

It should be noted that the requirements for this design methodology extend beyond motor control. They include, for example, uninterruptible power supplies (UPS), frequency converters, and bi-directional variable power sources. In some instances these applications impose additional performance requirements that can be accommodated with this topology.

DSP Requirements

The processor has stringent requirements. To handle FOC of brushless DC motors, the processor requires the signal processing capabilities of a DSP, but must also have some of the characteristics of an MCU. The processor must be able to execute control functions usually associated with an MCU because a dual-processor architecture is cost prohibitive.

The processor must also have a high level of peripheral integration -- another feature typically associated with MCUs. We will discuss peripheral integration at greater length later in this TechNote.

Several semiconductor companies have fielded products to address these requirements. As a group the products can be designated as DSP-MCU hybrids, or digital signal *controllers*. For each application the choice of controller is determined by cost, performance, and manufacturing requirements.

Among the most important features that the team required of the controller was that it offers a variety of peripheral options so that it could be used for both entry level and for very high-end appliances. Code compatibility with other members of the microcontroller family was also desired because, sooner or later, a transition to a more powerful chip would in in order. Flexibility is another important part of the design criteria because other applications for the controller board may have slightly different characteristics.

Manufacturing requirements included wave soldering that could be performed in virtually any PCB facility in the world. This required that the controller's lead spacing was wide enough to provide a high yield of the finished PCBs.

With these criteria in mind, Tier's design team searched for a controller that met all the performance and manufacturing requirements but still cost less that $2 per unit in volume pricing. The team chose the Texas Instruments TMS320LF2401A, the least expensive part in the F240x family.

A block diagram of the TMS320LF2407A controller series is shown in Fig. 2. Note the number of peripheral options, which are the most in the 240x family.

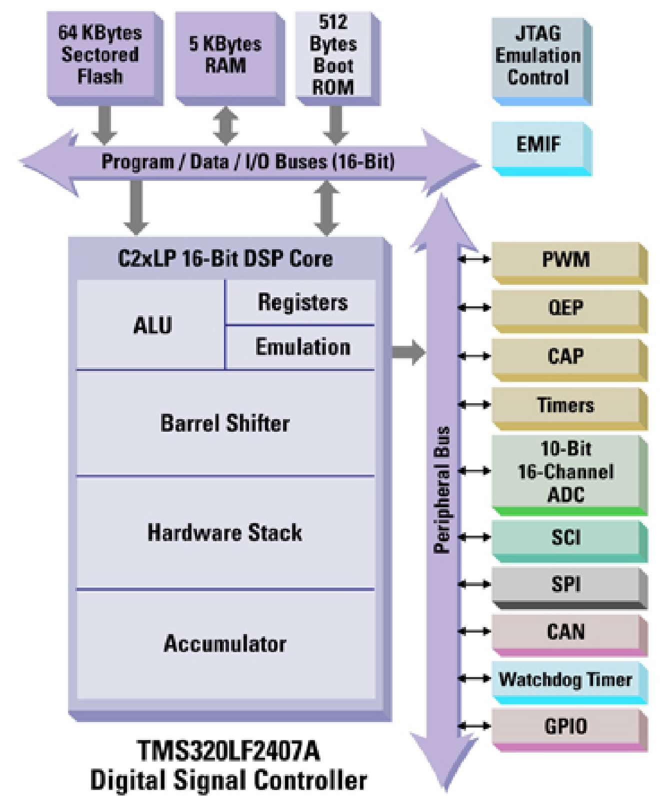

Fig. 3: Block Diagram Of TMS320LF2407A Controller

Peripheral Integration

As previously mentioned feature integration is a key determinant in IC selection. Most important for this application is integrated PWM and numerous I/O options.

The controller has to be fast enough to take in a PWM waveform, force it to hold its state long enough to acquire a measurement from a sensor, and still be capable of correcting for any dc offset. The primary advantage of this aspect of processing speed is lower sensor costs.

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 analog-to-digital and PWM forced states. The digital signal controller's speed enables functionality and allows the Tier design team to use less expensive, non-isolated sensors to replace costly isolated sensors.

The processor's speed and the integration of fast ADCs also eliminates the need for the differential amplifiers that were required in MCU-based designs.

Having a broad range of communications options can have more advantages than just the ability to provide the appropriate I/O port required by a specific application. Cost savings can also be achieved during the manufacturing process and during testing. A controller area network (CAN) bus interface, for example, is attractive because it can speed manufacturing by reducing test time.

In the field the motor receives control information from a wide variety of sensors, including temperature and pressure, which must all be accommodated. Internal communication is frequently implemented with RS-232 bus interface and this interface can also be used during production test as the module comes off the line.

The preferred communication protocol is RS-232 for control and monitoring. Also, the European Union has mandated the necessity for high levels of isolation between the controller and the cabinet control buttons. To achieve this Tier Electronics developed a contactless form of communications using IR technology. This form of communications allows for the high isolation needed, two-way communications, and low cost.

IPM Requirements

IPMs offer several advantages compared with the simple combination of conventional IGBT modules and drive circuits.

Built-in drive circuits: allow the IGBT gate drives to operate under optimal conditions. Since the wiring length between the internal drive circuit and IGBT is short, and the impedance of the drive circuit is low, no reverse-bias dc source is required.

Built-in protection circuits: overcurrent, short-circuit, overtemperature, shoot-through protection that prevents turning on both switches at the same time; and also undervoltage protection for control power source.

Built-in brake circuit: for motor control inverter applications, a brake circuit can be built to protect bus overvoltage with the simple addition of a power dissipating resistor.

Ceramic substrates: enable direct mounting of the IPM with very little hardware which allows for more efficient cooling and lower manufacturing costs.

For this application, the IPM chosen has multiple voltage and current options in the range of 3 A to 50 A and up to 1200 V. The IPM must be able to handle multiple voltage and current options so the design can be used in many different applications. DIP or SIP lead frame devices are used to meet cost targets and simplify manufacturing.

Matching the IPM drivers directly to the IGBTs yields four important advantages: it simplifies and speeds the design, significantly reduces component count, reduces switching losses compared to subsequent designs that require modifications to the driver circuits and improves reliability.

To maintain design flexibility, the family of IPMs chosen also had the advantage that the total control plus driver power was kept under 10 mA. This again lowers costs by simplifying the power supply requirements.

As mentioned earlier, integration is important to achieving the goals of higher reliability, reduced cost, and creating a design that needs very little design tweaking from application to application.

The cost of an IPM with the features just described is under $5 per unit when purchased in high volume quantities. A diagram of a typical IPM is shown in Fig. 4.

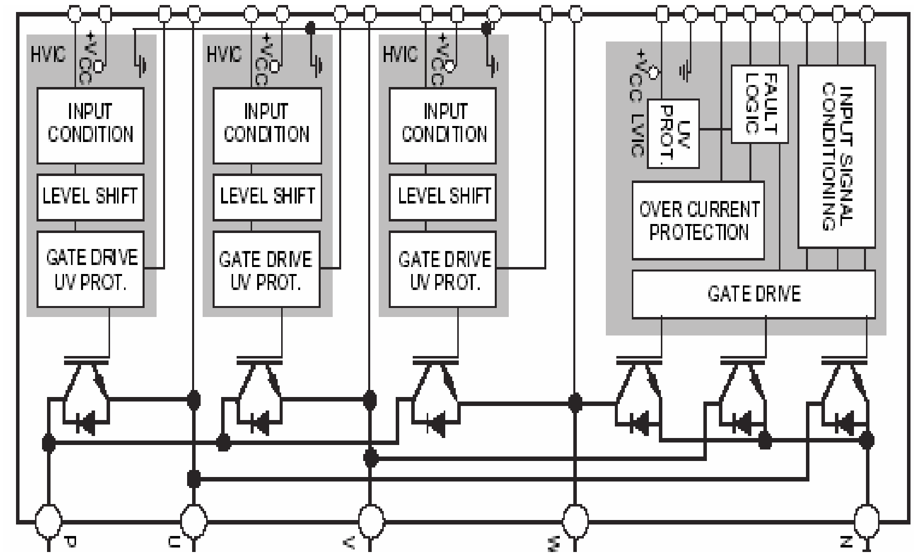

Fig. 4: Typical IPM

Circuit Topology

Viewed from a subsystem level, the controller is a basic three-phase design with low-side current sensing and motor-phase voltage feedback. The design (see Fig. 5) for controlling a three-phase motor can be modified for two-phase and one-phase motors. Current sensing of the IGBT current through a resistor is used to reduce costs.

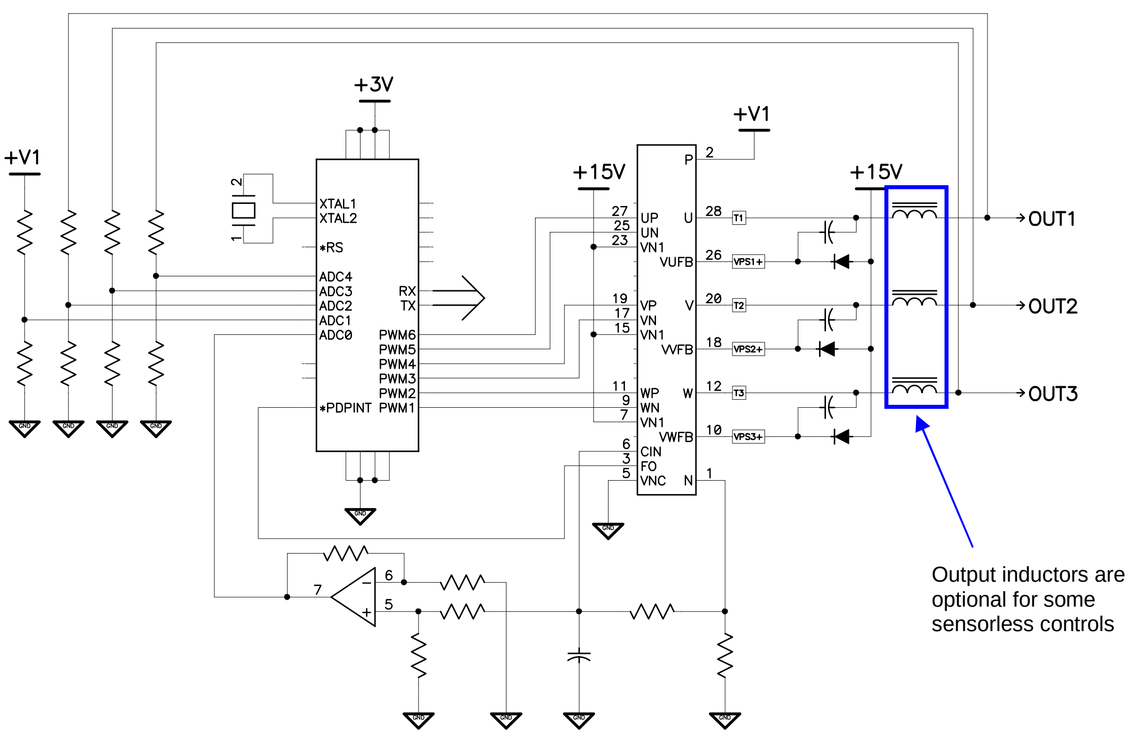

Fig. 5: Subsystem Topology

A differential amplifier is not required for voltage-feedback measurements. Once again the elimination of a discrete part is due to the digital signal controller's capabilities with the fast on-board ADCs accuracy and speed allowing it to read channels sequentially and compare them without the help of a differential amplifier.

In addition to reducing part count it also reduces circuit complexity and provides a power saving.

Packaging

Designers of power control modules intended for use as subsystem-level components by several white goods manufacturers are faced with the fact that different OEMs often specify quite different frame sizes for the PCB as well as different specifications related to power output.

Since the C2000 digital signal controller is both programmable and quite small, however, all of the adjustments that must be accommodated by changing hardwired parts of the subsystem involve the IPM and its associated components.

The Tier design team chose to address the customization problem by partitioning the complex circuits that include the LF24x device onto a mini board. A connector on the board makes it easy to plug into, or be soldered into the main board -- which contains the IPM and other devices that change according to OEM needs and application requirements. The main PCB is manufactured with relatively low-end equipment. Through-hole component placement was chosen to simplify manufacturing requirements.

As a result of this partitioning each converter application uses the same DSP board but has a different number of power modules. The DSP board can be manufactured in large volume and simply plugged into the main board, which has been configured with the appropriate sized IPM.

Reliability

White goods experience a good deal of vibration and this means that reliability is another critical part of the design.

Tier's design team took a straightforward approach to achieving the MTBF metrics specified by the white goods OEMs. MTBF scores can be improved simply by reducing the number of components, so reducing part count by about 50% made for a more reliable system.

In addition, using a mini board for the controller provided reliability benefits as well.

Having the power module on the same board as the controller would mean that two fairly dissimilar components would be integrated onto the same board and this tends to increase thermal stress. Using the mini board for the DSP-based controller, however, eliminated this problem.

Reliability is further improved by the advanced circuit protection obtained when using IPMs. Other parts are eliminated simply by the sophistication of the basic components -- the digital signal controller and IPM -- and the design. Whereas the MCU/discrete-based design has three sensors, this digital signal controller-based design has only one. Remember too that the differential amplifier was eliminated by the fast ADCs of the controller. Fig. 6 shows a few metrics related to reliability.

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

Fig. 6: Fewer Parts Enhance Reliability

Lower Cost, More Functionality

By opting for more powerful and highly-integrated components, the number of parts, manufacturing costs, engineering costs, and power consumption 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 keeping a design that is highly cost effective.

On the performance side, using advanced digital signal controller 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.

Further Information:

- 3.3-V DSP for digital motor control http://focus.ti.com/dsp/docs/dspsupporttechdocsc.tsp?sectionId=3&tabId=409&abstractName=spra550
- C2000 Controller discussion groups http://tigroups.ti.com/WebX?14@@.eed327d
- Sensorless Speed Controlled Brushless D Drive Using TMS320C242 DSP Controller http://focus.ti.com/dsp/docs/dspsupporttechdocsc.tsp?sectionId=3&tabId=409&abstractName=spra498

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