Motor Control Consultant Workshop

Scott Roller & Arefeen Mohammed

Digital Control Systems Group

DSP Fest '99

TEXAS INSTRUMENTS

"So attractive is the TI 'C24x DSP family's price, performance and level of integration that it will require every one tasked with controlling motors to take a hard look at the TI DSP solution."

**– George Gulalo,
President, Motion Tech Trends**

TEXAS INSTRUMENTS

Agenda

◆ **TMS320C24x Product Overview**	**(25 min)**
◆ Development Tool Demonstrations	(25 min)
◆ Motor Control Consultant Network	(10 min)
◆ Break	(15 min)
◆ Motor Control Applications Review	(45 min)
◆ Q&A Session	(45 min)
◆ Wrap-Up	(15 min)

TEXAS INSTRUMENTS

TI Leads the
Digital Motor Control Market

FIRST

◆ **First** single-chip DSP motor controller launched (1996)

◆ **First**—and unique—DSP with on-chip Flash memory (1997)

◆ **First**—and unique—DSP with on-chip CAN controller (1998)

BROADEST

◆ DSP motor controller portfolio—7 in production today

◆ Customer base—1000s designing with 'C24x today

◆ Third-party network—10s specialized in motor control

TEXAS INSTRUMENTS

# New TI TMS320C24x DSPs Broaden Digital Motor Control Horizon

◆ **Six new tailored DSP Motor Controllers**

  ■ From low-end cost-conscious appliances to high-end industrial applications

  ■ 50% performance increase

  ■ 2x MIPS/dollar versus the competition

  ■ As low as $2.95 each in 10K units, sub $2 in OEM quantities

  ■ Advanced motor-control-specific peripherals and sectored Flash

  ■ Code compatible with the 7 existing 'C24x devices
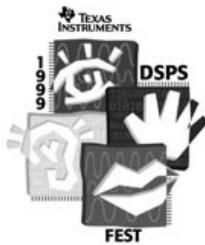
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'C24x Roadmap to the Future

Application Spectrum

◆ **Hi-End Industrial Systems**
  ■ Industrial drives
  ■ Factory automation
  ■ Tape drives
  ■ UPS
  ■ Automotive
  ■ Robotics

◆ **Multi-Function Motor Control**
  ■ HVAC
  ■ Tread mills
  ■ Medical equipment
  ■ Metering
  ■ Vending machines
  ■ Bill/Card readers

◆ **Appliances and Consumer**
  ■ Washing machines
  ■ Refrigerators
  ■ Dishwashers
  ■ Vacuums
  ■ Fan, Blowers
  ■ Printers, Copiers
  ■ Pumps

'LF2407
'F243
'LF2406
'F241
'LC2406
'F240
'C240
'C242
'LC2404
'LF2402
'LC2402

1997   1998   1999   2000   Sample Dates

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TMS320LF2407 : The World's Most Integrated DSP Motor Controller

Data RAM
2.5K words

Boot ROM
256 words

Program Flash
32K words

D(15-0)

Program / Data / I/O Buses

A(15-0)

'C2xx DSP Core

16-bit barrel shifter (L)	16-bit T register
	16 x 16 multiply
	32-bit P register
	Shift L (0,1,4,-6)

32-bit ALU

32-bit accumulator

Shift L (0-7)

8 auxiliary registers

8-level hardware stack

Repeat count

2 status registers

Peripheral Bus

Event Manager

Event Manager

- 2 timers
- 5 compares
- 8 PWM outputs
- Dead band logic
- 3 input captures
- 2 QEP channels

WD Timer

CAN

SCI

SPI

A/D Converter
10 bits, 16 channels

◆ Sectored Flash for field reprogrammability and simplified design

◆ CAN module enables inter-system communication

◆ 16 PWM outputs allow multi-motor/axis control

◆ 500-ns A/D converter enhances system accuracy

◆ 33-ns instruction cycle (30 MIPS) for processing complex motor-control algorithms

◆ More RAM for high-level programming language and high-order system modelization

◆ Code compatible platform provides easy migration path

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TMS320C24x: The Industry's Broadest DSP Motor Controller Portfolio

	'LF2407	'LF2406	'LF2402	'LC2406	'LC2404	'LC2402	'F240	'C240	'F241	'C242	'F243
MIPS	30	30	30	30	30	30	20	20	20	20	20
RAM	2.5Kw	2.5Kw	544w	2.5Kw	1.5Kw	544w	544w	544w	544w	544w	544w
Flash	32Kw	32Kw	8Kw	—	—	—	16Kw	—	8Kw	—	8Kw
ROM	—	—	—	32Kw	16Kw	4Kw	—	16Kw	—	4Kw	—
Boot ROM	256w	256w	256w	—	—	—	—	—	—	—	—
Ext. Memory I/F	Yes	—	—	—	—	—	Yes	Yes	—	—	Yes
Event manager	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
• GP timers	4	4	2	4	4	2	3	3	2	2	2
• CMP/PWM	10/16	10/16	5/8	10/16	10/16	5/8	9/12	9/12	5/8	5/8	5/8
• CAP/QEP	6/4	6/4	3/2	6/4	6/4	3/2	4/2	4/2	3/2	3/2	3/2
Watchdog timer	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
10-bit ADC	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
• Channels	16	16	8	16	16	8	16	16	8	8	8
• Conv. time (min)	500ns	500ns	500ns	500ns	500ns	500ns	6.6μs	6.6μs	850ns	850ns	850ns
SPI	Yes	Yes	—	Yes	Yes	—	Yes	Yes	Yes	—	Yes
SCI	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
CAN	Yes	Yes	—	Yes	—	—	—	—	Yes	—	Yes
Digital I/O pins	37	37	21	37	37	21	28	28	26	26	32
Voltage range	3.3 V	3.3 V	3.3 V	3.3 V	3.3 V	3.3 V	5 V	5 V	5 V	5 V	5 V
Packaging	144 TQFP	100 TQFP	64 PQFP	100 TQFP	100 TQFP	64 PQFP	132 PQFP	132 PQFP	68 PLCC 64 PQFP	68 PLCC 64 PQFP	144 TQFP
Samples	4Q99	4Q99	4Q99	3Q00	2Q00	1Q00	Now	Now	Now	Now	Now
Production	2Q00	2Q00	2Q00	4Q00	3Q00	2Q00	Now	Now	Now	Now	Now
Pricing (10Ku)	$10.45	$9.95	$8.75	$5.95	$5.45	$2.95	$14.28	$9.69	$11.37	$3.96	$12.85

TEXAS INSTRUMENTS
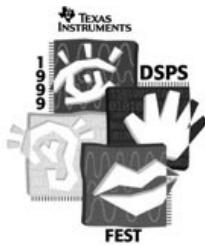
'C24x: Well Ahead of Competition

2x MIPS/$ **1/2 the price** **2x PWMs**

Yes **Yes**

10x Faster **10x App Notes and Software**

Relative Advantage

2

1

0

Performance **Entry Price** **PWMs**

No **No**

Flash **CAN**

10

5

0

A-to-D Sample Rate **Support Infra-structure**
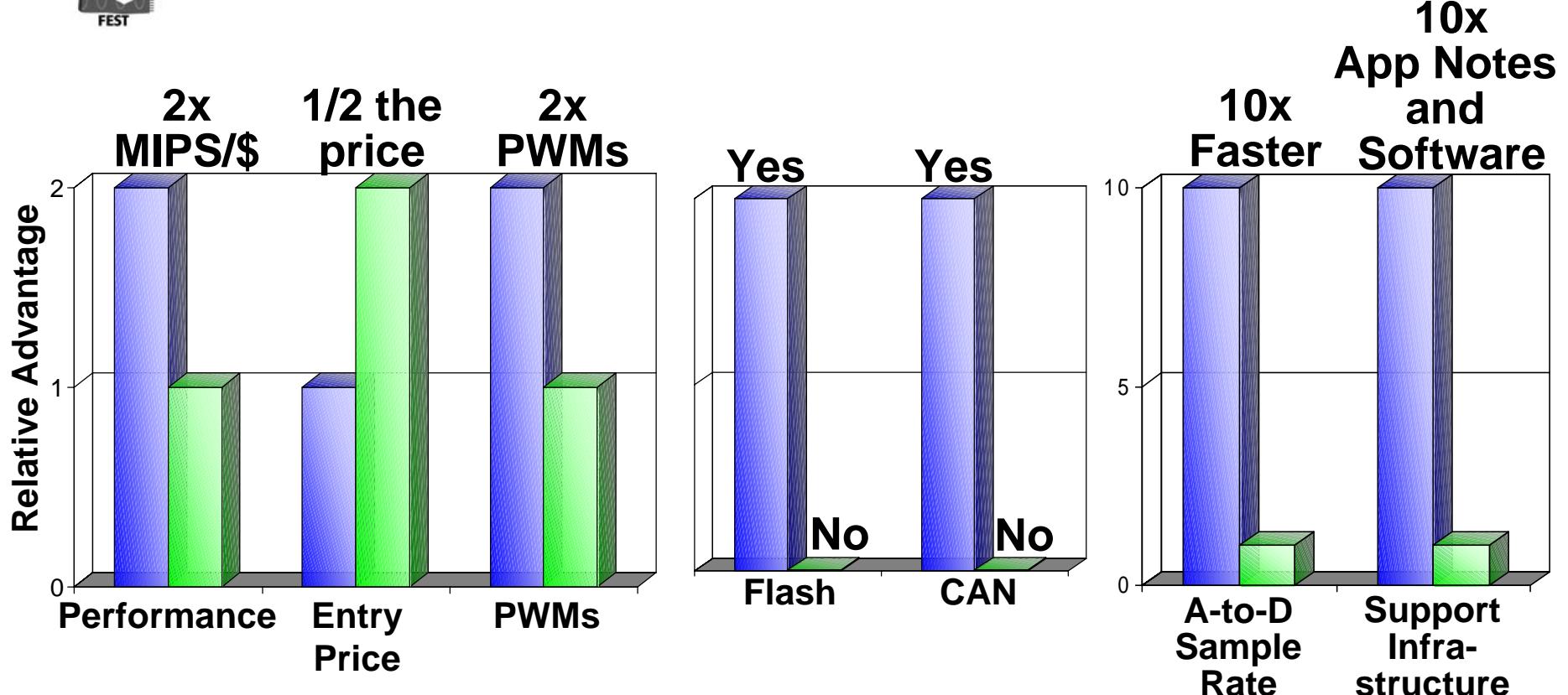
■ **TI TMS320C24x** ■ **ADI ADMC3xx**

Source: ADI press releases, data sheets, and web site

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DSP MIPS Bring *More* for *Less*

Bandwidth usage of a typical 8-bit microcontroller

Basic Motor Control (Open Loop, V/Hz)	Misc.

0%   ~ 90%   100%

Bandwidth usage of a TI 'C24x DSP

PID Control	Sensorless Algorithms	Random PWMs	Ripple Comp. Algorithms	Power Factor Correction	more ...

0%   20%   100%

More precise control

Eliminate costly speed and current sensors

Reduce noise and input filter size

Reduce DC link capacitor size

Eliminates dedicated PFC controller
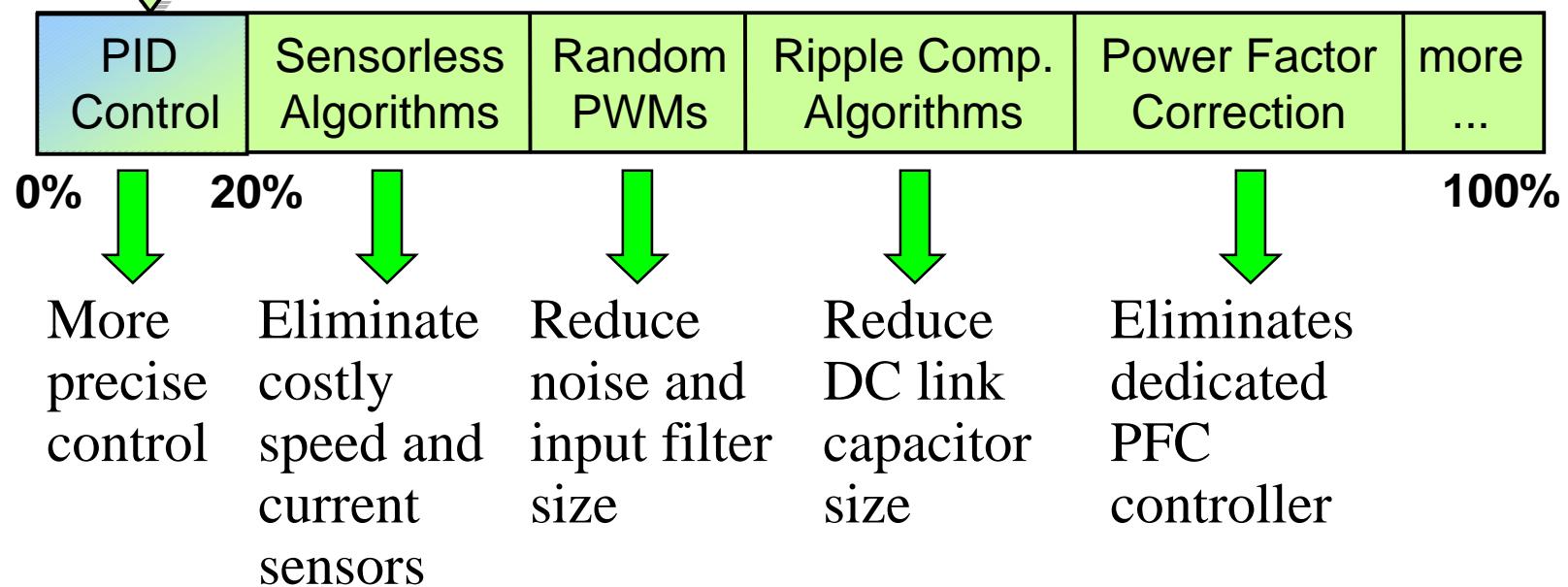
TI 'C24x Enables:

◆ **Energy efficiency**
  - Refrigerators use 25% less electricity
  - HVAC blower power usage is reduced by up to 80%

◆ **System cost reduction**
  - Washing machines motor drive system cost reduced by 35%
  - Fewer moving parts and 40% gear box size reduction
  - 40% board size reduction
  - Refrigerator compressor and coil size reduction
  - $2\times$ UPS reliability increase thanks to board real estate reduction

◆ **Noise reduction**
  - Variable speed control reduces motor acoustic noise
  - Random PWM techniques reduce emission spectrum

TEXAS INSTRUMENTS
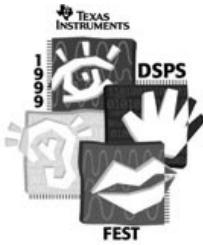
Widely Endorsed Across the Full Spectrum of Applications

"We are using TI DSP motor controllers for our motor control drives because of their excellent performance fully meeting our application requirements and outstanding technical support we have from TI ."
–**Erio Reniero, Product Development Manager, Zeltron S.P.A., Electrolux Group**

"We selected TI for its unique capability to integrate Flash memory and analog functions with the DSP, its in-depth, system-level expertise in embedded control applications and its established track record in working with customers to meet system cost and performance requirements."
–**Mark Ascolese, VP and General Manager, Large Systems Group, Exide Electronics**

TEXAS INSTRUMENTS

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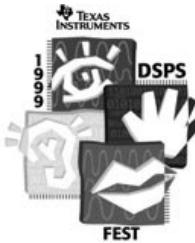
Begin 'Lx240x Development Today

With TI's Digital Motor Control Building Blocks

Turn-Key Solutions from TI Third Parties
(Motion Chip)

DMC Consultant Network
(algorithm development, hardware design, etc.)

Application Notes | **DMC Software Library** | **Reference Designs (ADK)**

Code Gen Tools (Asm/Lnk/C-Comp) | **Code Composer IDE w/ Real-time Monitor**

JTAG-based Emulators (XDS510PP) | **Development Platforms (EVM, DSK, MCK)**

Pin Compatible Flash & ROM
'C24x Devices
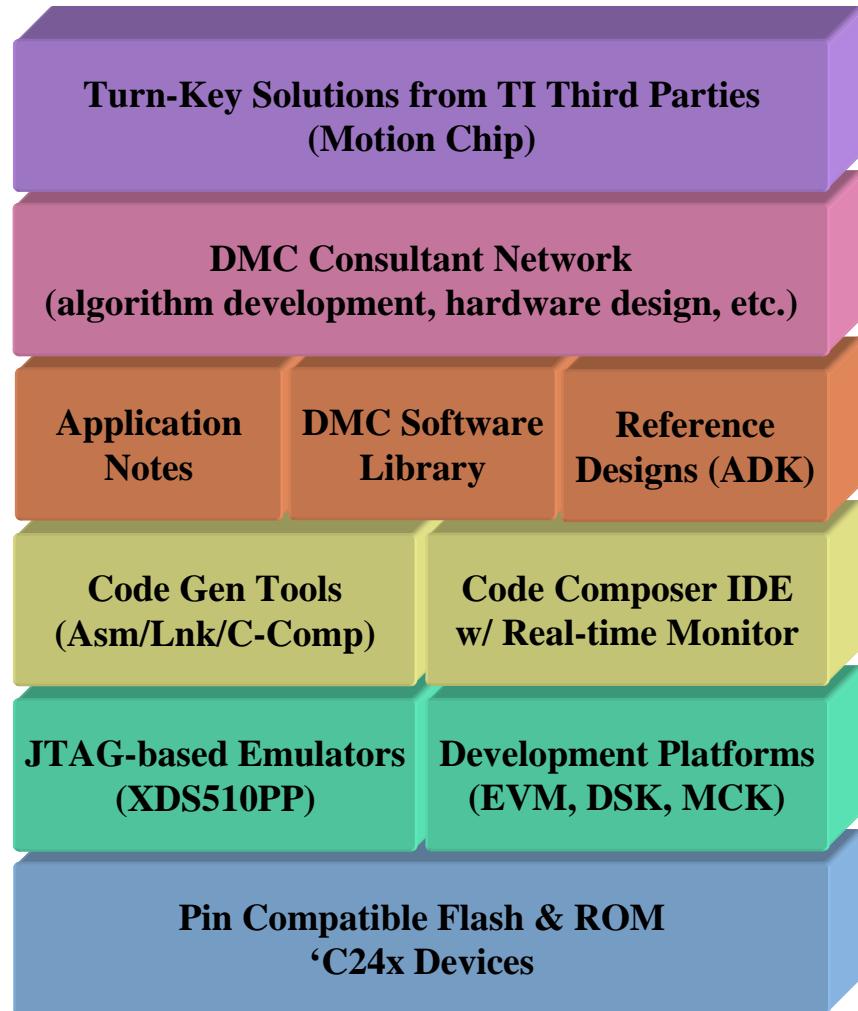
◆ 'Lx240x resources available today
- ■ 'F241/'F243 Silicon—code compatible with 'Lx240x devices
- ■ 'F243 EVM with C-Compiler and Code Composer included
- ■ 'F243-based development boards and turn-key designs from third parties

◆ Design resources now online
- ■ Complete technical documentation
- ■ Over 50 motor control application notes
- ■ DMC algorithms and modular software library
- ■ AC Induction and Brushless DC Application Design Kits
- ■ DMC consultant network

www.ti.com/sc/dmc

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TEXAS INSTRUMENTS
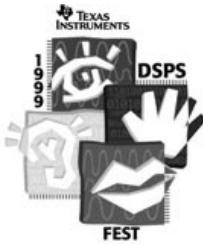
Code Generation & Programming

◆ **Code Generation Tools, v6.60**

- Highly efficient C-Compiler/Assembler/Linker
- ANSI C source code compliant.
- Variety of optimizations for improved code efficiency.
- Includes archiver, hex conversion and cross reference utilities, and absolute lister.
- v7.0, with 52 bug fixes, to be released 11/99

◆ **Flash Programming Utilities**

- Support for JTAG and Serial Port flash programming.
- F240/241/243 utilities available today with free WEB download.
- BP Microsystems Production Flash programmer planned for 4Q99

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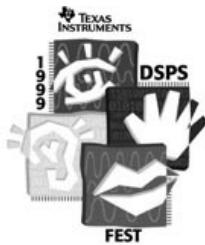
Code Composer 4.1 for DMC

Offers Real-time Monitor and Plug-in Capabilities
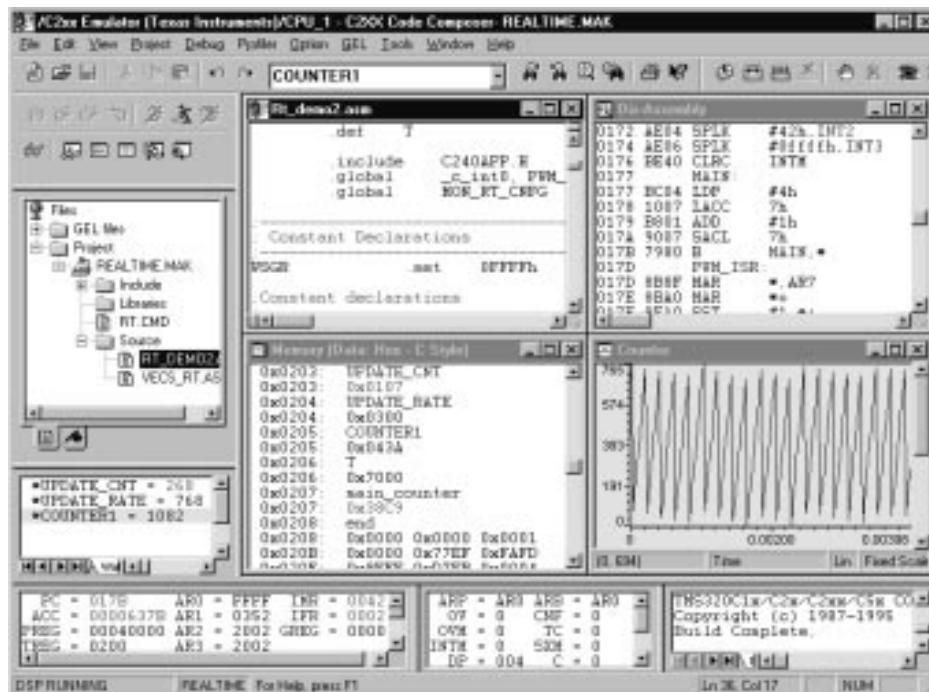
- ◆ Same IDE as C6000/C5000 CCS

- ◆ C2000 Code Gen Tools packaged with CC4.1 release

- ◆ Full Plug-In Capabilities

- ◆ Real-Time Monitor (RTM) integrated into CC4.1 and enables:
  - Interrogation / modification of device memory while application code is running.
  - Single-stepping of background code while ISR's continue to run in real-time.
  - Tuning of system parameters, e.g. PID loops, Motors char, etc..
  - Software switches to control/invoke motor wind-down sequence.

- ◆ Beta test program currently in progress

- ◆ Production release scheduled for 10/99

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'F243 Evaluation Module
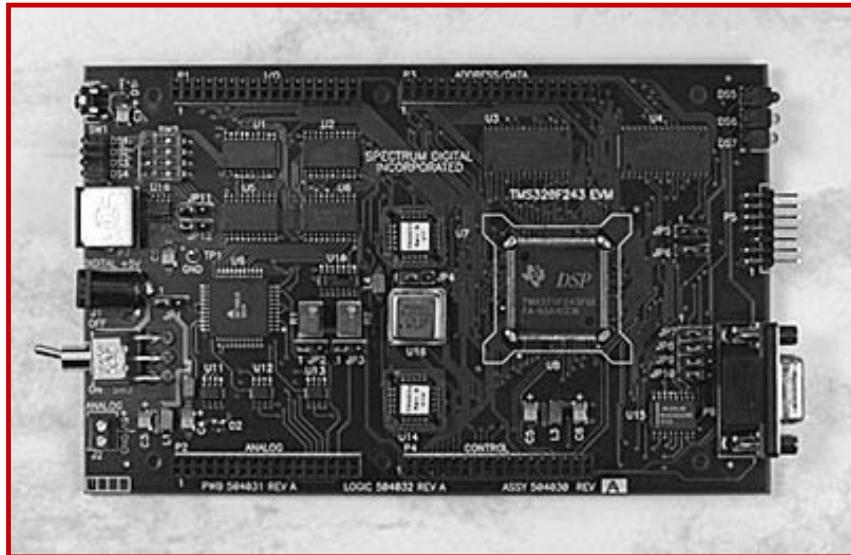
Part Number: TMDS3P604030
Price: $1995

'F243 EVM includes:

- TMS320F243 Evaluation Board with:
  - ◆ 64K of RAM in program & data space
  - ◆ MP7680 DAC (4 channels, 12 bits)
  - ◆ JTAG, UART, and CAN interfaces
  - ◆ Expansion connectors
- C Compiler/Assembler/Linker
- Code Composer IDE, v3.10
- XDS510PP Emulator
- +5VDC universal power supply
- Cables and Technical Documentation

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DMC Software Library

◆ Set of standardized, assembly optimized, software algorithms commonly used in digital motor control applications, available as individual modules and system packages.

◆ Modular format allows modules to be seamlessly integrated with each other in a "plug-n-play" fashion

◆ Enables the building of complete digital motor control algorithms w/o having to dig into assembly language routines

◆ Reduces software development time and complexity

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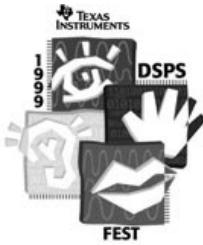
DMC Software Modules & Systems

MODULES:

- Current Measurement
- Speed Measurement
- Tachogenerator Position
- Clarke Transform
- Park Transform
- Inverse Clarke Transform
- Inverse Park Transform
- Space Vector PWM
- PID Controller

- Sin/Cos Function
- Rotor Flux Model
- '24x Initialization
- 3-Phase Sine Generator
- Ramp Generator
- DAC Output Driver
- Random PWM***
- V/Hz Profile***
- Power Factor Correction***
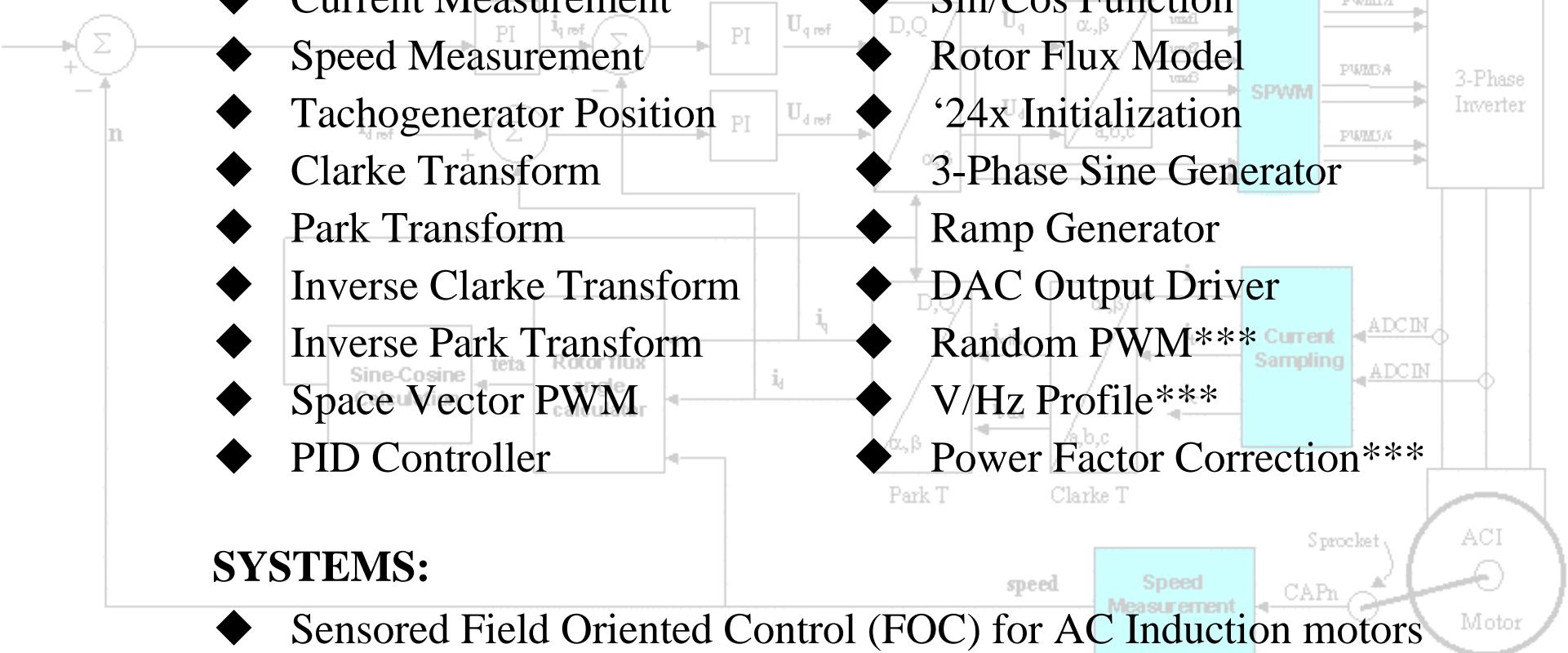
SYSTEMS:

- Sensored Field Oriented Control (FOC) for AC Induction motors
- Open Loop V/Hz Control for AC Induction motors

***These modules coming soon (2H99)

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'F243 DSP Starter Kit

from Spectrum Digital

Part Number: 701024 (Spectrum Digital)

Available 7/99

Price: $199

'F243 DSK includes:

- TMS320F243 Target Board
- RS-232 Communication to host PC
- 16K of RAM in program and data space
- Symbolic assembler
- Code Explorer debugger
- A/C adapter and communication cable
- Direct interface to Spectrum Digital's Digital Motor Controller system
- Standard JTAG interface on board
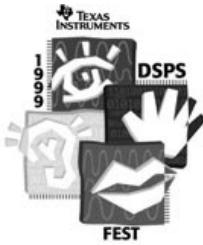
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TEXAS INSTRUMENTS

# Why is the Motor Control Consultant Network Important to TI?

◆ **Reasoning**

■ Customers generally understand the value TI DSP brings to motor control, but often do not have the skills and/or resources to implement a DSP-based design.

◆ **Purpose**

■ To create a network of consultants specializing in the area of 'C24x-based motor control that will become a critical part of the TI Value web by deliberately and systematically designing in TI DSP & Analog products for motor control applications.

Motor Control Consultant Network
Structure & Benefits

◆ **Structure**

- This network is consists of consultants in local markets registered at TI Third Parties.

◆ **Benefits**

- Receive potential customer leads from TI
- Quarterly DSP product updates and training
- Discounted development tool pricing
- Enhanced device sample privileges
- Promoted as a TI certified consultant to potential customers on TI web site

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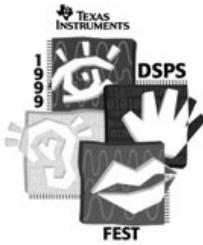
How do I Join the Motor Control Consultant Network?

Requirements

- Interview with one of the following TIers:
  - DCS team member
  - Local Field Sales Rep
  - Third Party Rep
- Qualify as a Motor Control Consultant
- Enroll in TI's Third Party Network
- Participate in local and/or internet-based product update & training opportunities
- Participate in TI/Consultant local opportunity reviews and referrals
- Re-qualify as a TI consultant on an annual basis.
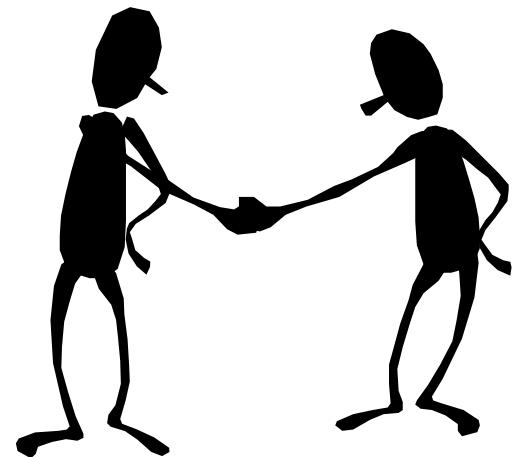
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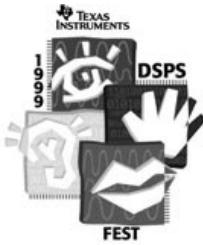
DSP Motor Control Enhances Appliances

◆ Extend the use of inexpensive induction motors for new applications

◆ Introduces new motor types to end equipment

◆ Highest efficiency compressors with low-cost, non-invasive control

◆ Eliminate or reduce gears and pulleys with direct drive applications

◆ Constant torque at all speeds

◆ Increased speed range, both low end and high end

◆ More control options/features

◆ Programmable solution reduces time to market

DSP Motor Control Enhances HVAC

- ◆ True constant air flow rate *without* sensors
- ◆ Highest efficiency
- ◆ Lower audible noise
- ◆ Built in communications for remote sites
- ◆ Diagnostics
- ◆ Power factor correction
- ◆ Multiple motor control simplifies system implementation
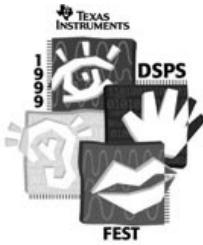
DSP Motor Control
Enhancements for Automotive

◆ Eliminate or reduce hydraulic system with direct drive

◆ Offer reusable programmable steering options across platforms

◆ Reuse of modules EPS across platforms

◆ Greatly reduces torque ripple for smooth operation of motor

◆ Real-time adaptive suspension control

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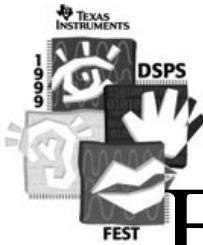
DSP Motor Control
Enhances Industrial Applications

◆ High-resolution PWM drives provide smoother operation and improves efficiency across wide operating speed range.

◆ Supports use of advanced algorithms for sensorless drive designs.

◆ Robust Communications (CAN protocol)

◆ Common Control Platform

◆ Reduced time to market

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Multilevel cost savings

Eliminating sensors

Power factor correction

Reuse and modification of design

Input filter

Power stage

Less glue logic

PCB

Motor

TEXAS INSTRUMENTS
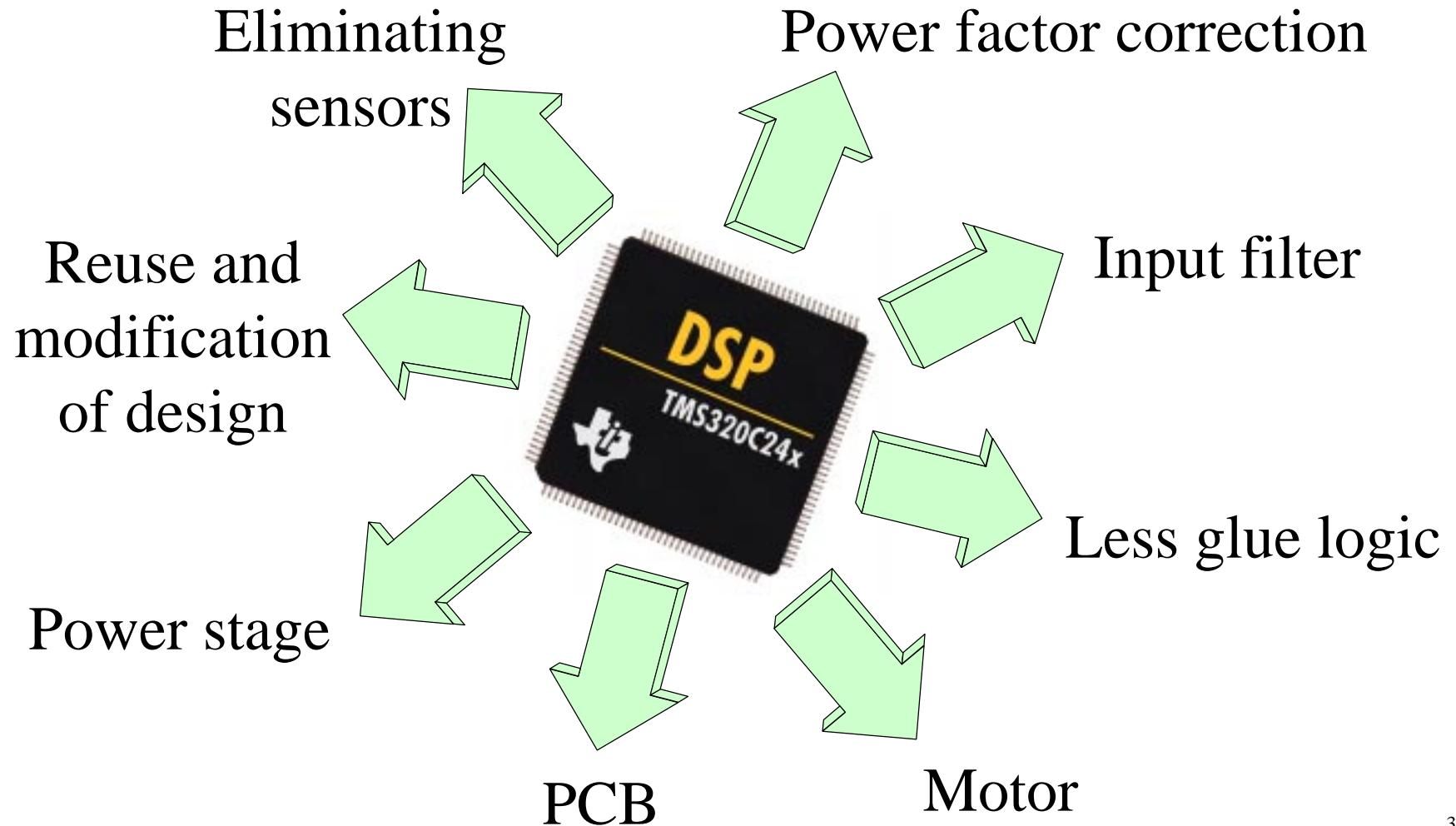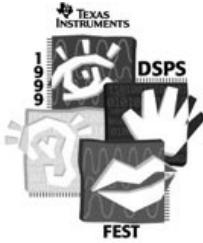
Random PWM Operation

◆ Spreads the carrier energy over the full frequency spectrum.

◆ Lowers the size of input EMI filter.

◆ EMI compliance becomes simpler.

◆ Acoustic noise becomes white instead on tonal

◆ Overall power device switching losses decrease.

◆ DSP enables RPWM with other motor control functions

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RPWM Improves EMI

Fixed PWM carrier frequency

Fundamental frequency (50Hz)

Ch1   2.00 V   M50.0ms Ch1   40mV
Math2   1.00 V   50.0 Hz

Carrier
frequency (15kHz)

Ch1   5.00 V   M 500µs Ch2   2.48 V
Math2   1.00 V   5.00kHz
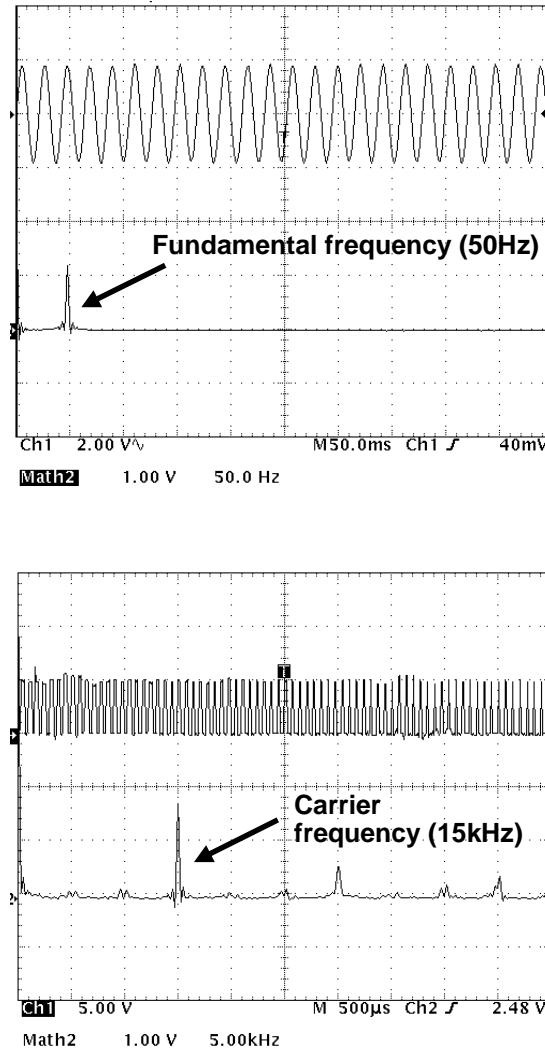
Random PWM carrier frequency

Fundamental frequency (50Hz)

Ch2   2.00 V   M50.0ms Ch2   2.48 V
Math2   1.00 V   50.0 Hz

Ch1   5.00 V   M 500µs Ch2   2.48 V
Math2   1.00 V   5.00kHz

TEXAS INSTRUMENTS
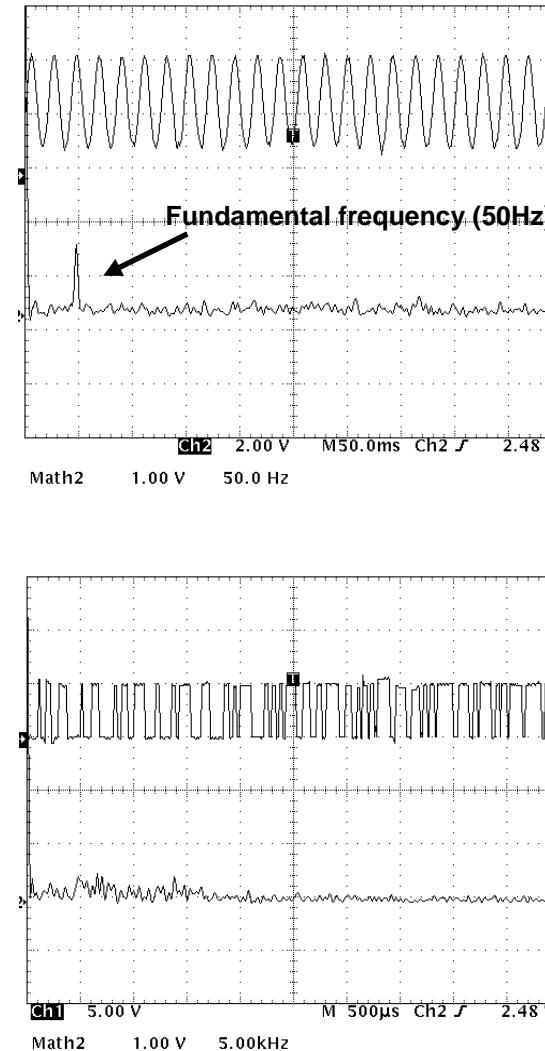
Multiple Motor Control

◆ Independent control of each inverter

◆ Controller(s) will have enough computational bandwidth to implement motor control algorithms

◆ Minimum external circuit components to reduce overall system cost

◆ Two inverter control can also be applied for a system with an inverter and a controlled rectifier

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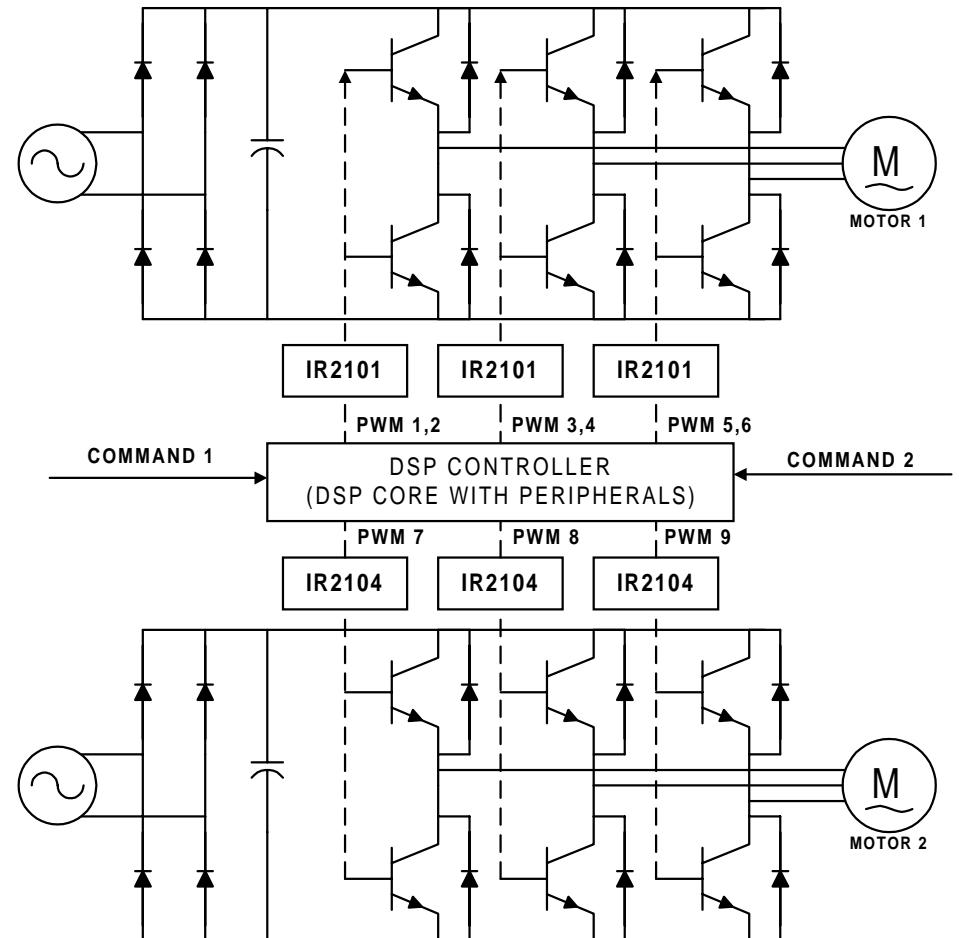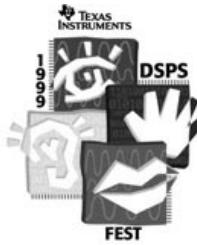
Controller Bandwidth Utilization for Multiple Motor Control

Function	Time (uS)	Bandwidth (%)*
Volts/Hz – 1	1.20	2.4%
SVPWM – 1	4.30	8.6%
Volts/Hz – 2	1.20	2.4%
SVPWM – 2	4.30	8.6%
Random Number	0.10	0.2%
Random Update	4.50	9.0%
Communications	1.40	2.8%
Miscellaneous	2.20	4.4%
Total loading	19.20	38.4%

* at 20 kHz career frequency

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Experimental Results of Multiple Motor Control

◆ Fan/blower (1/3HP) was used as the load for the system

◆ Two independent modulating wave is generated

◆ Distortion free phase current is visible

◆ This particular implementation was in open-loop, however, close loop can be done without significant DSP loading

TEXAS INSTRUMENTS
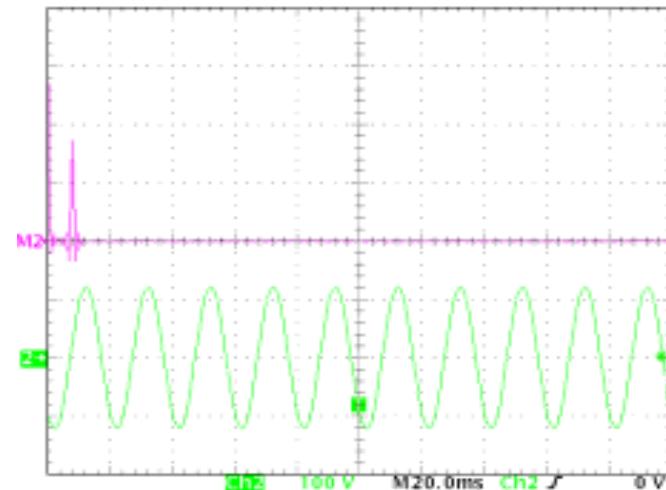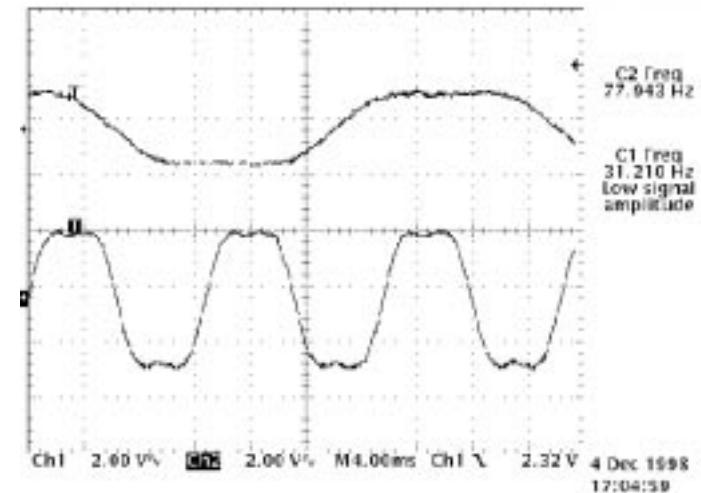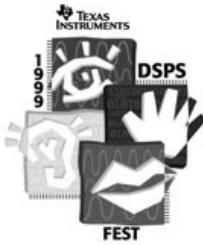
Integrating Multiple Functions Using a DSP

◆ Closed loop speed control of a three phase AC induction motor using Space Vector PWM technique

◆ Input power factor correction using boost topology

◆ Serial communication between the controller and a host.

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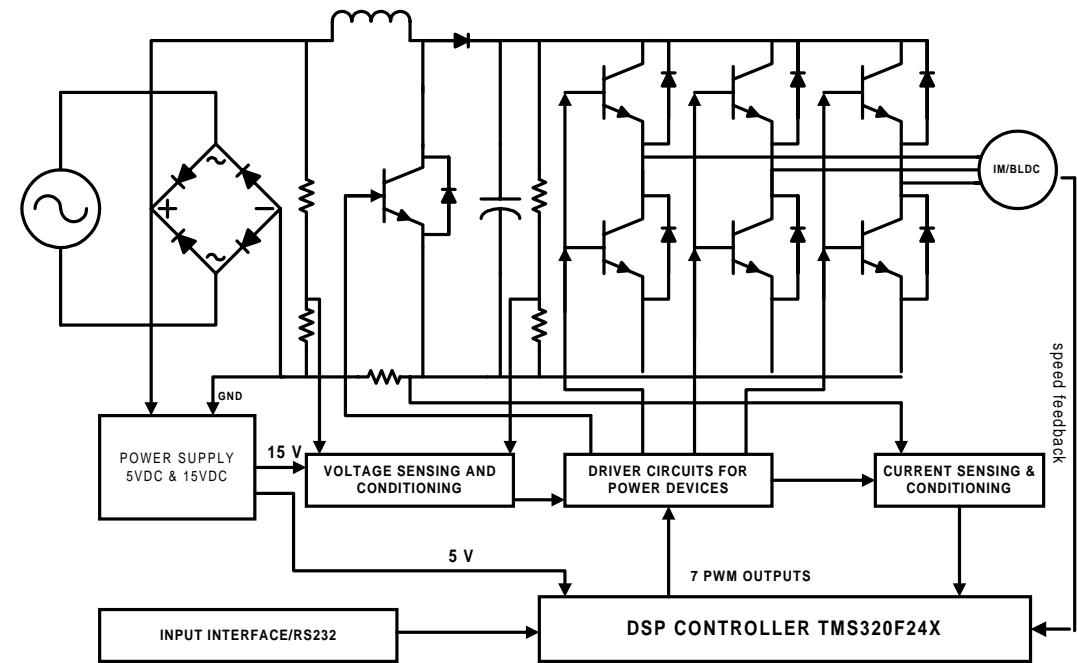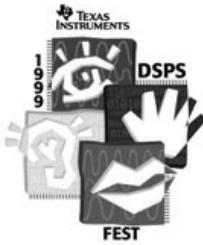
Experimental Results of Multiple Function Integration

◆ A three phase induction motor (1/3HP, 4 pole) with fan blower load was used with test board

◆ The frequency was varied between 0 & 60 Hz

◆ The boost converter regulated the DC bus at 200VDC

◆ The software was written in assembly and was less than 4kW of program space

TEXAS INSTRUMENTS
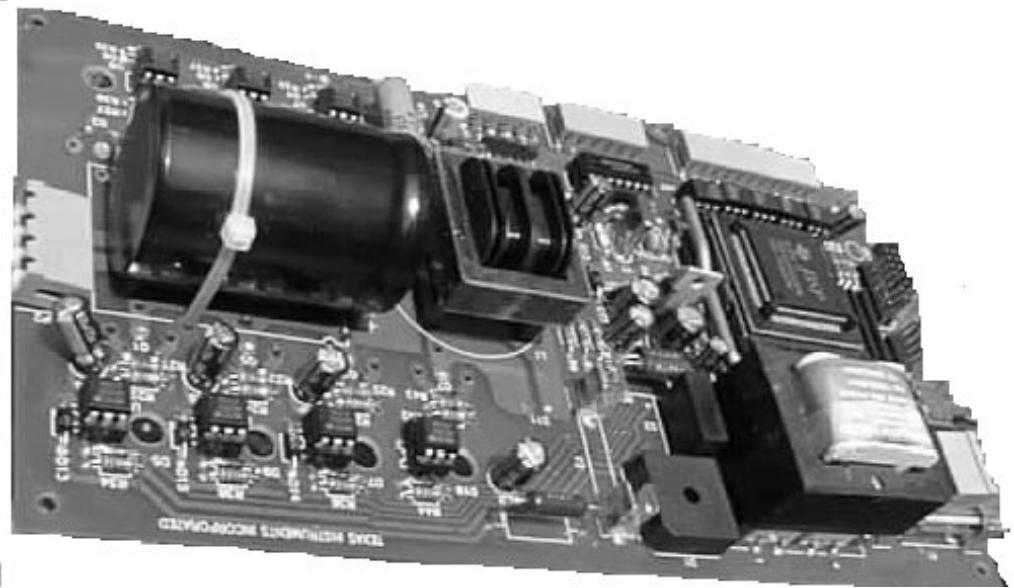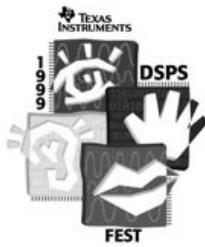
Experimental Results of Multiple Function Integration
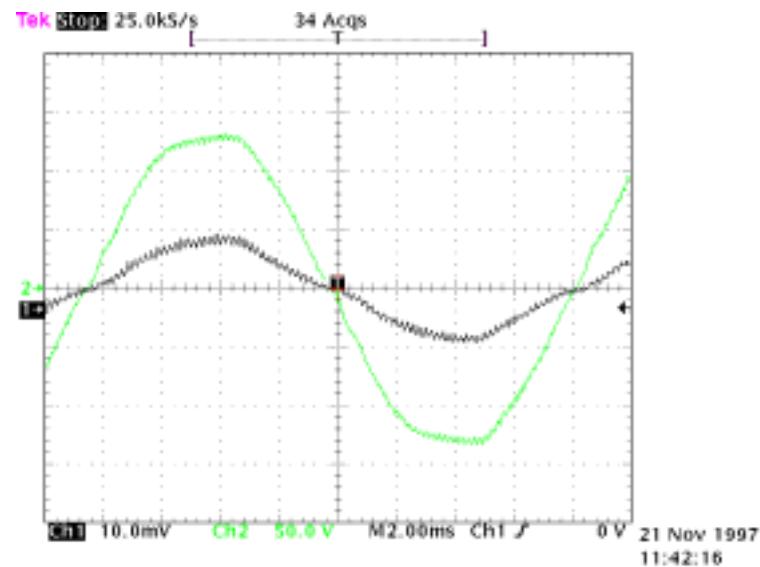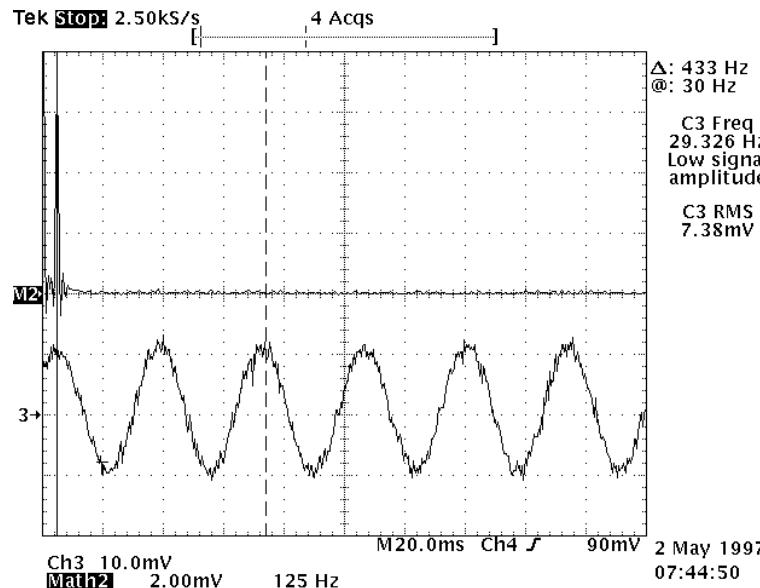
◆ A distortion free motor phase current results from 20kHz SVPWM

◆ Input power factor improves significantly.

◆ The software waits for a certain DC bus value before activating power factor correction circuit.

◆ The speed change goes through software ramp.

TEXAS INSTRUMENTS

DSP Bandwidth Utilization for Multiple Function Integration

Functions	uS	%BW
Volts/Hz	1.20	2.4%
SVPWM	4.30	8.6%
Speed Measurement	5.70	11.4%
Speed PI loop	1.40	2.8%
Power factor correction	4.80	19.2%*
Communication	1.40	2.8%
Miscellaneous	2.20	4.4%
Total software loading	21.00	51.6%

* at 40 kHz

TEXAS INSTRUMENTS

TEXAS INSTRUMENTS
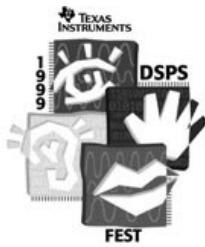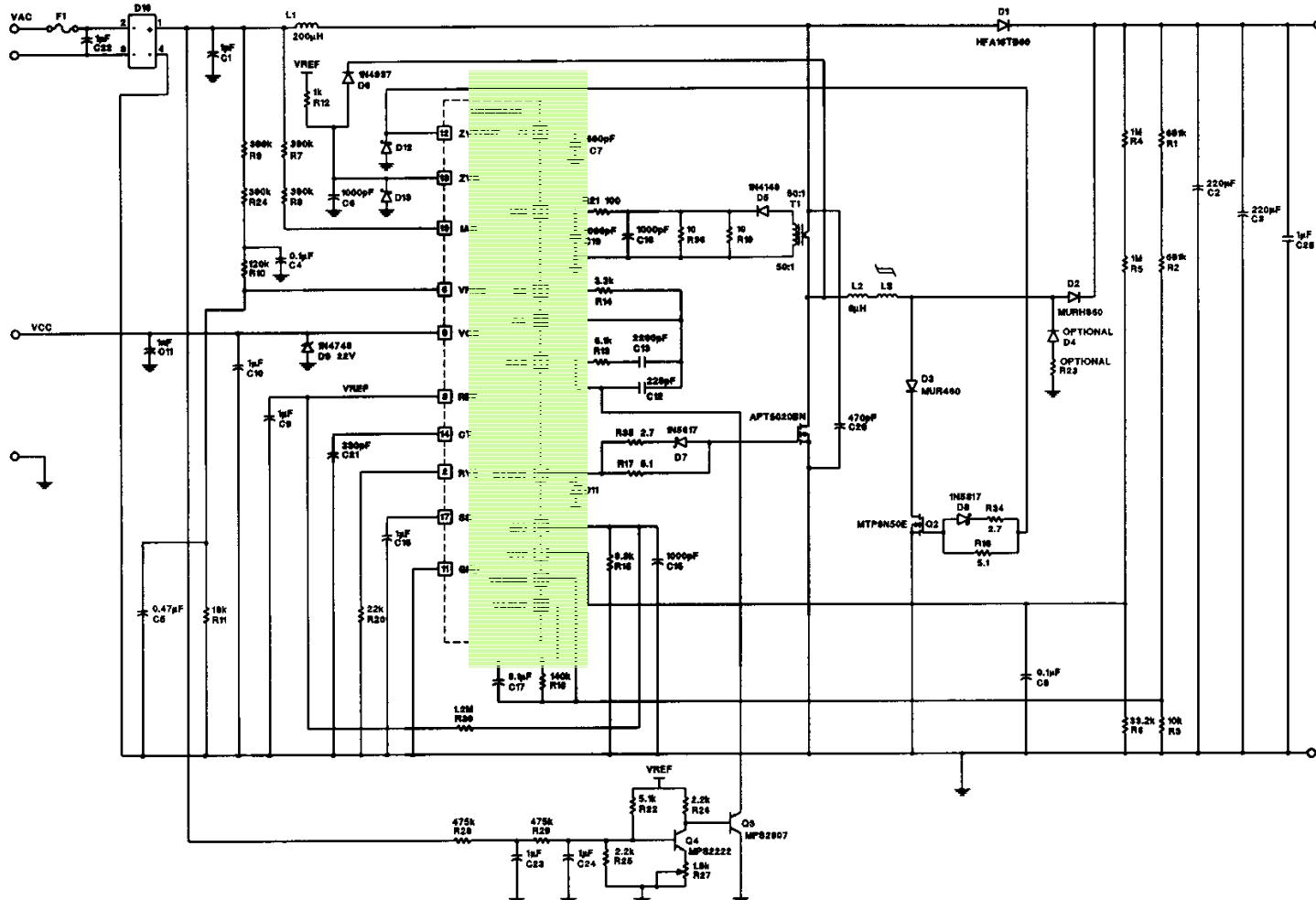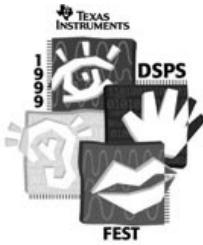
PFC with DSP Simplifies the Overall System

IM/BLDC

POWER SUPPLY
5VDC & 15VDC

GND

15 V

VOLTAGE SENSING AND
CONDITIONING

DRIVER CIRCUITS FOR
POWER DEVICES

CURRENT SENSING &
CONDITIONING

5 V

7 PWM OUTPUTS

INPUT INTERFACE/RS232

DSP CONTROLLER TMS320F24X

TEXAS INSTRUMENTS
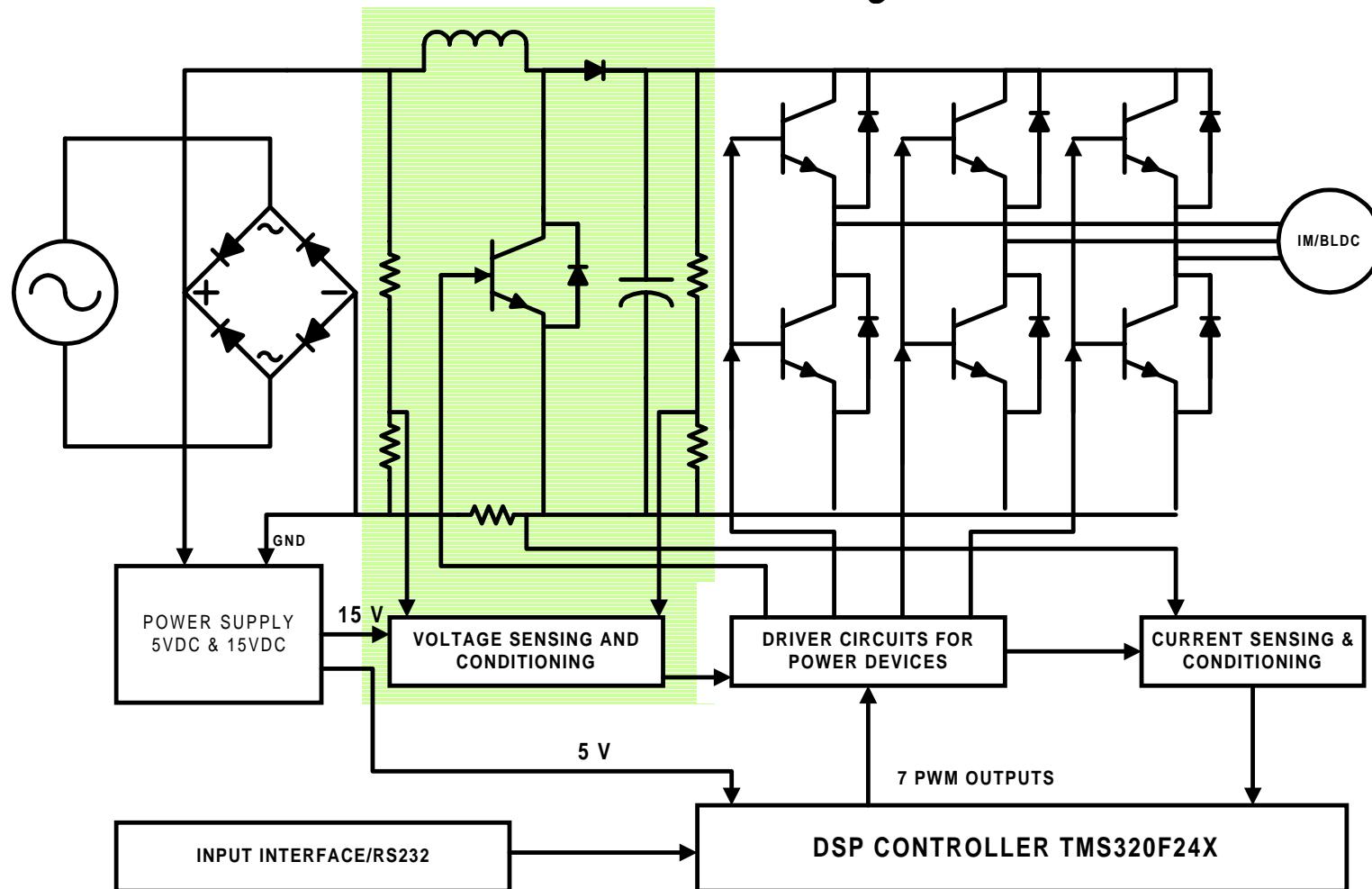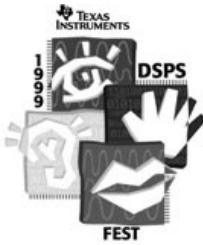
Experimental Results of PFC Implemented with DSP
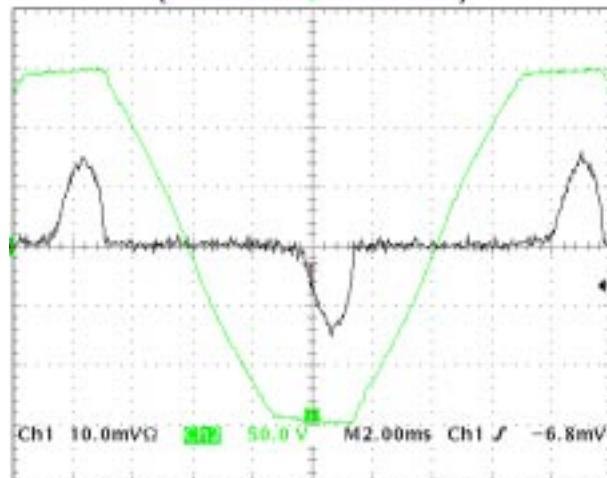
Figure 1 Front end diode bridge rectifier input voltage and current without power factor correction circuit enabled.

Operating frequency	25Hz
Input AC voltage	110 VAC
DC bus voltage	145 VDC
pf	0.62
current	1A/div
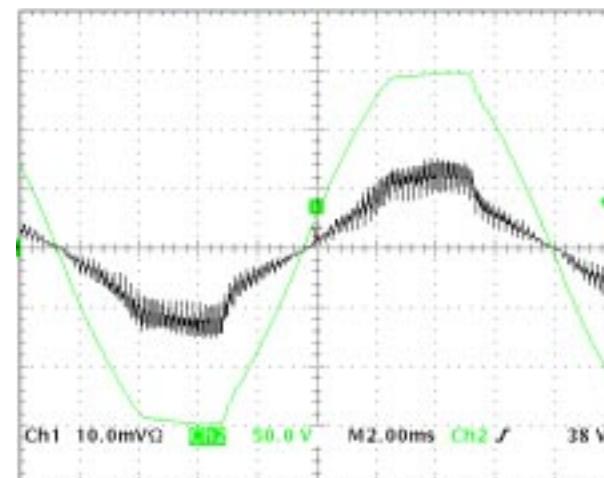
Figure 2 Front end diode bridge rectifier input voltage and current with power factor correction circuit enabled.

Operating frequency	25Hz
Input AC voltage	110 VACDC
DC bus voltage	203 VDC
pf	0.98
Current	500mA/div

DC Bus Ripple Compensation

◆ Inverter output quality depends on the stiffness of the DC bus.

◆ Large DC capacitors ensure stable DC bus, however, increase system cost and lower overall reliability

◆ Smaller DC capacitors reduce system cost but introduce DC bus ripple and distorts inverter output

◆ DC bus ripple compensation enables distortion free inverter output with smaller DC capacitor
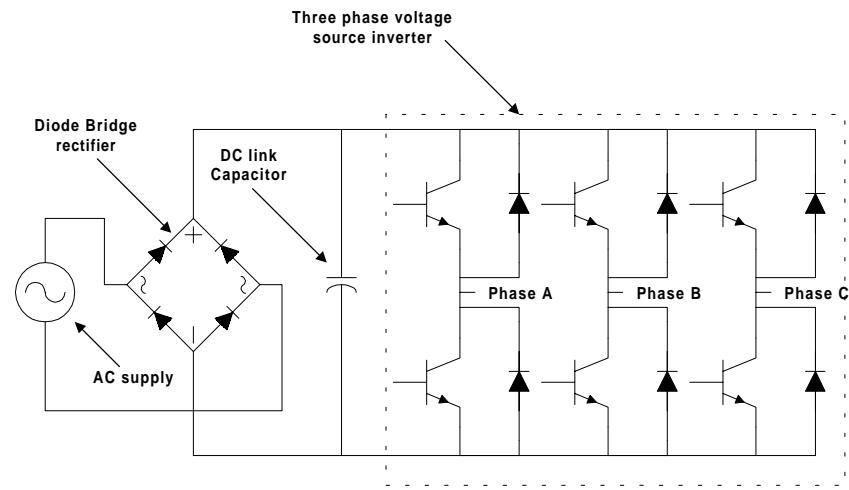
Figure A. Typical three phase voltage source inverter topology

In preliminary system, DC capacitor was reduced from 560uF to 300uF

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# Effect of Smaller DC Bus Capacitor

**Distortion free output**
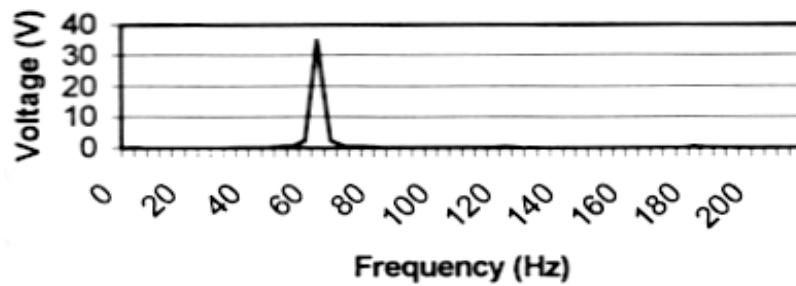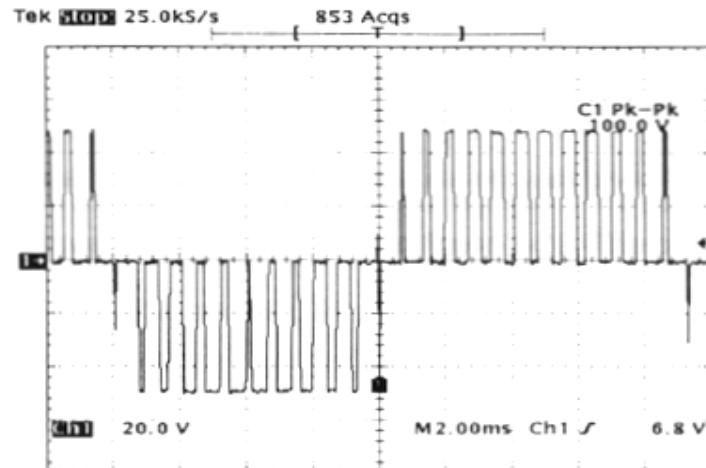
Distorted output without compensation
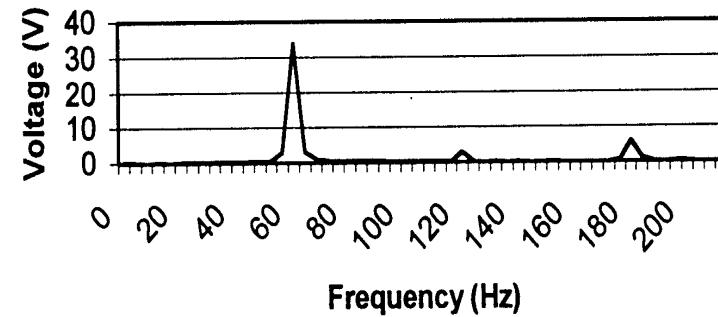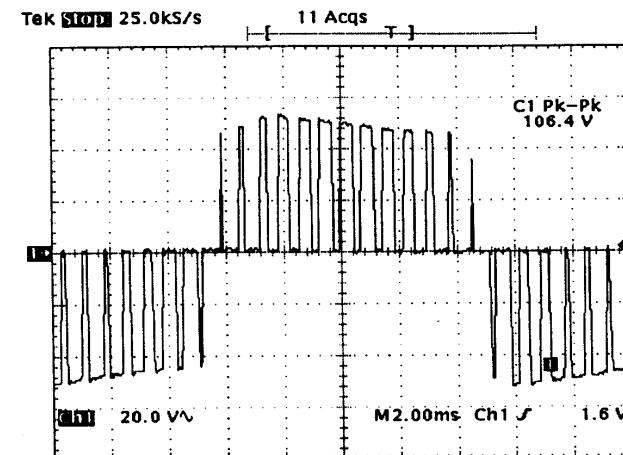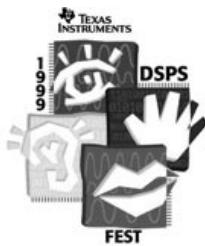
Effect of Smaller DC Bus Capacitor (Cont'd)

Distorted output without compensation
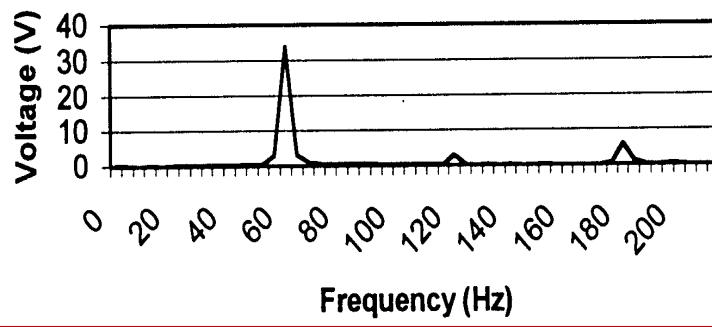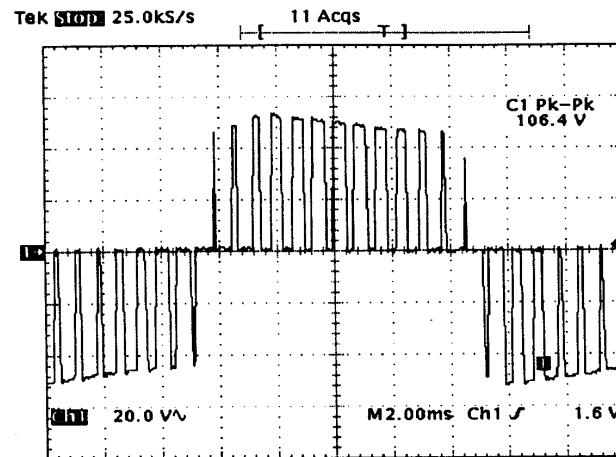
Distortion free output after compensation
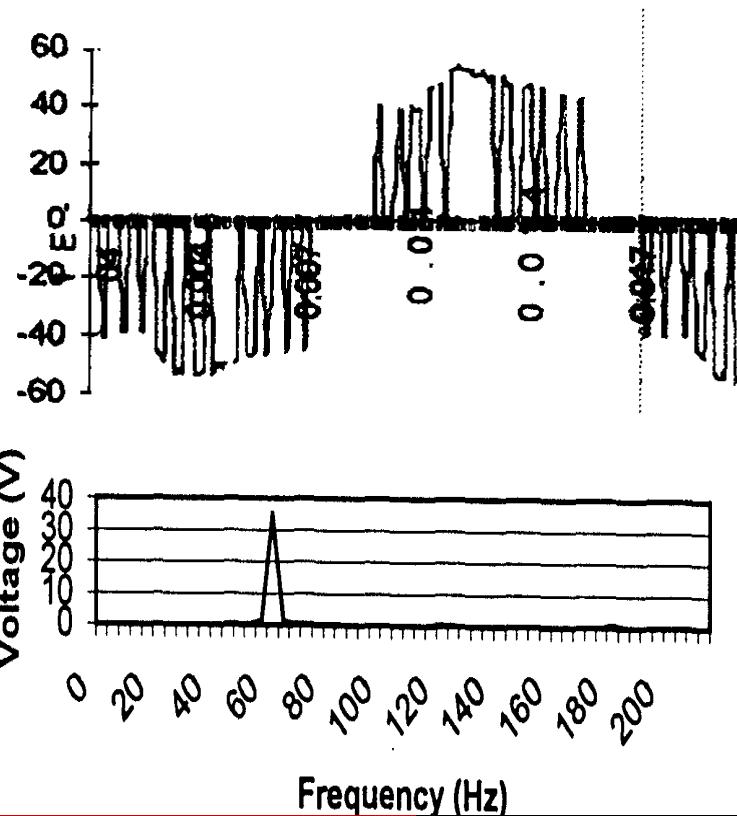
Agenda

◆ TMS320C24x Product Overview   (25 min)

◆ Development Tool Demonstrations   (25 min)

◆ Motor Control Consultant Network   (10 min)

◆ Break   (15 min)

◆ Motor Control Applications Review   (45 min)

◆ **Q&A Session**   **(45 min)**

◆ Wrap-Up   (15 min)

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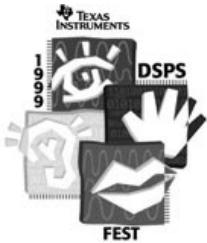
Wrap-Up

Summary

- TI DSPs bring system cost reduction, performance improvements, and additional features to motor control applications at no additional cost.

- With six new 'C24x devices, TI has expanded the broadest portfolio of digital motor controllers.

- TI's industry leading development environment enables consultants to quickly deliver system level solutions to their clients.

Call to Action

- Redeem your coupons for a free F243 DSK and $250 off the 'C24x 4-day workshop

- Qualify as a TI DSP Motor Control Consultant!

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